Stratigraphy of the upper Hazelton Group and the Jurassic evolution of the Stikine terrane, British Columbia[1]

J.-F. Gagnon, T. Barresi, John W.F. Waldron, J.L. Nelson, T.P. Poulton, and F. Cordey

Abstract: The Lower to Middle Jurassic Hazelton Group represents the final stage of magmatic arc activity in the intraoceanic Stikine terrane, which was followed by accretion within the Cordilleran terrane collage. The Hazelton Group is exposed in the following areas: (*i*) on the periphery of the Bowser Basin, where arc and back-arc strata are overlain by mainly sedimentary strata of the upper Hazelton Group and then by the clastic basin fill of the Bowser Lake Group; and (*ii*) within a 300 km long rift system, the Eskay rift, west of the Bowser basin, where a predominantly bimodal volcanic succession contains significant mineral deposits. Examination of representative stratigraphic sections throughout the regional extent of the upper Hazelton Group has suggested significant revisions and clarification of its stratigraphy and include the following: (*i*) informal division of the Hazelton Group into upper and lower parts and recognition of a diachronous unconformity or unconformities at the boundary between them; (*ii*) establishment of a type section for the sandstone-dominated Smithers Formation; (*iii*) establishment of separate Quock and revised Spatsizi formations in the north and extension of the Quock Formation to include all lithostratigraphically equivalent units of blocky, thinly bedded siliceous mudstone and tuff around the periphery of the Bowser basin; and (*iv*) introduction of the Iskut River Formation for rift-related and volcanic facies in the Eskay rift area. Two independent rifting events occurred during deposition of the Hazelton Group: a Late Sinemurian to Early Pliensbachian phase in the northwest-trending Hazelton trough and a more restricted Aalenian to Bajocian extensional event in the Eskay rift.

Résumé : Le Groupe de Hazelton (Jurassique inférieur à moyen) représente l'étape finale d'activité d'arc magmatique dans le terrane intra-océanique Stikine, laquelle fût suivie par son accrétion dans le collage de terranes de la Cordillère. Le Groupe de Hazelton affleure : (*i*) à la périphérie du bassin Bowser, où des strates d'arc et d'arrière-arc sont recouvertes par des strates surtout sédimentaires du Groupe de Hazelton supérieur et ensuite par le remplissage clastique de bassin du Groupe de Bowser Lake et (*ii*) dans un système de rifts d'une longueur de 300 km, le rift Eskay, à l'ouest du bassin Bowser, où une succession volcanique principalement bimodale contient des gîtes minéraux significatifs. Un examen de sections stratigraphiques représentatives à travers l'étendue régionale du Groupe de Hazelton supérieur suggère d'importantes révisions et précisions de sa stratigraphie dont : (*i*) une division informelle du Groupe de Hazelton en parties inférieure et supérieure et la reconnaissance d'une ou de plusieurs discordances diachroniques à la limite entre les parties; (*ii*) l'établissement d'une section-type pour la Formation de Smithers, dominée par des grès; (*iii*) l'établissement, au nord, d'une Formation de Quock distincte ainsi qu'une révision de la Formation de Spatsizi et l'extension de la Formation de Quock pour inclure toutes les unités à équivalence lithostratigraphique de mudstone et de tufs siliceux, à blocs et à lits minces, autour du bassin Bowser et (*iv*) l'introduction de la Formation d'Iskut River pour les faciès volcaniques et ceux reliés au rift dans la région du rift Eskay. Deux événements indépendants de distension ont eu lieu durant la déposition du Groupe de Hazelton : une phase (Sinémurien tardif à Pliensbachien précoce) à tendance nord-ouest dans la fosse Hazelton et un événement d'extension plus restreint (Aalénien à Bajocien) dans le rift Eskay.

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Introduction

The Jurassic Period marks a key transition in the tectonics of the Canadian Cordillera. During this time, the western margin of North America was changing rapidly from a complex of island arcs, marginal basins, and offshore crustal fragments, analogous to tectonic elements in the modern southwest Pacific, to an accretionary orogen. The Stikine terrane, or Stikinia, is the largest arc terrane within the Canadian Cordillera (Fig. 1). Within Stikinia, the Lower to Middle Jurassic Hazelton Group is a widespread assemblage of volcanic and associated sedimentary strata that records the last volcanic phase of the long-lived Stikine volcanic arc and also its demise. The Hazelton Group represents a time of critical change in the history of the Stikine terrane, as it evolved from an independent arc towards incorporation into the Cordilleran tectonic collage. Its lower part comprises voluminous, predominantly andesitic to dacitic arc-related volcanic accumulations with an intervening sedimentary basin, the Nilkitkwa trough (Marsden and Thorkelson 1992). Its upper part, the main focus of this paper, comprises generally thinner sedimentary strata and localized bimodal volcanic units, which record processes of arc extinction, rifting, and subsidence. The detailed regional analysis of the stratigraphic record of the upper part of the Hazelton Group, presented here, sheds light on a profound mid-Jurassic reconfiguration in the Cordilleran orogen.

The upper Hazelton Group is also of great economic interest in that it contains mid-Jurassic polymetallic massive sulphide deposits (Alldrick 1993; Barrett and Sherlock 1996; Macdonald et al. 1996; Roth et al. 1999; Sherlock et al. 1999; Barresi and Dostal 2005) and potential petroleum source units (Evenchick et al. 2003, 2005; Ferri et al. 2004; Ferri and Boddy 2005; Osadetz et al. 2007).

Tectonic setting of the Hazelton Group

The Hazelton Group unconformably overlies arc-related strata of the Middle to Upper Triassic Stuhini and Takla groups (e.g., Tipper and Richards 1976; Monger and Church 1977; Grove 1986; MacIntyre et al. 1989; Alldrick et al. 1989) and the Lower Devonian to Upper Permian Stikine assemblage (e.g., Monger 1977; Stevens and Rycerski 1989; Brown et al. 1991; McClelland 1992). All three successions contain volcanic arc rocks characterized by juvenile Sr and Nd isotopic signatures (Gabrielse et al. 1980; Armstrong 1988; Samson et al. 1989, 1991); together they represent a multistage arc terrane that developed in an intraoceanic setting isolated from the North American margin.

The Lower to Middle Jurassic Hazelton Group is an extensive assemblage of volcanic and sedimentary strata. The unusual width of the Hazelton volcanic field (450 km predeformation), combined with the lack of chemical variability in major and trace element profiles, led Marsden and Thorkelson (1992) to propose that volcanism was generated by concurrent subduction of two opposing oceanic plates beneath the Stikine terrane. One involved east-facing subduction of the Cache Creek oceanic basin on the east side of the Stikine terrane; the other, west-facing subduction of oceanic lithosphere on the west side (directions in present-day coordinates). In this model, the Hazelton Group evolved on a Philippine-style microplate as a pair of coeval volcanic arcs separated by a northwest-trending interarc basin, the Hazelton trough.

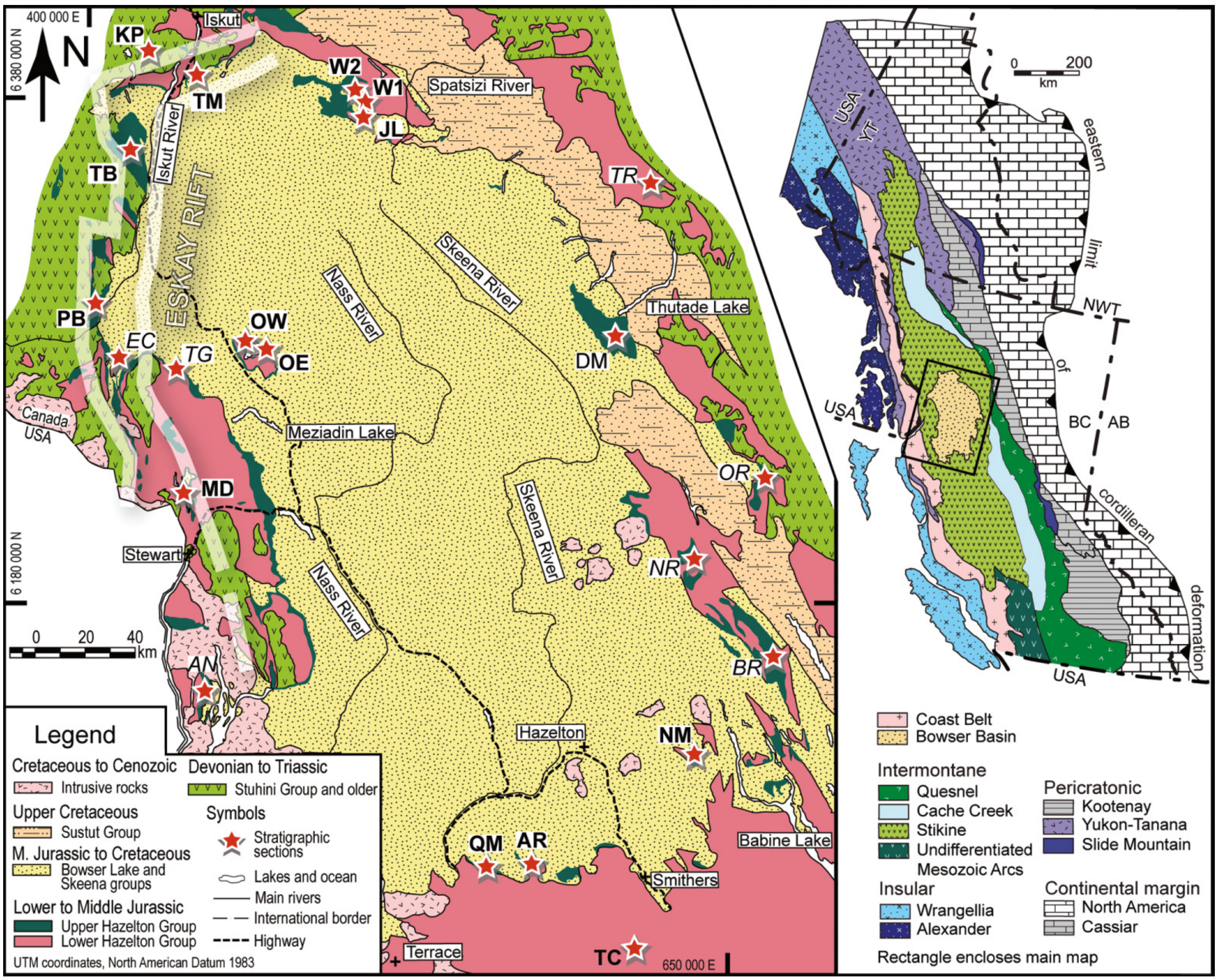
The Hazelton Group is overlain by coarse clastic strata of the Middle to Upper Jurassic Bowser Lake Group, which were deposited in a large, deep, subsiding sedimentary basin that developed as Stikinia, and the terranes inboard underwent a series of collisions that led to their accretion to the North American margin (e.g., Eisbacher 1985; Ricketts et al. 1992; Evenchick et al. 2007*a*, 2010; Gagnon et al. 2009). The Cache Creek ocean closed in the Middle Jurassic, and west-vergent shortening structures developed in rocks of the North American margin (Omineca belt), coeval with the southwest-vergent thrust faults that emplaced Cache Creek oceanic assemblages on top of the accreting Stikine arc terrane, or Stikinia (Fig. 1; Evenchick et al. 2007*a*). The western side of Stikinia was also affected by collision with outboard terranes (van der Heyden 1992), including the Alexander terrane (Gehrels 2001).

Hazelton Group stratigraphy: previous work

The upper parts of the Hazelton Group include a wide variety of sedimentary and volcanic rock types, discontinuously exposed around the periphery of the Bowser Basin (Fig. 1). These rocks have been described in detail by authors working in different areas, leading to significant advances in understanding but leaving overlaps and inconsistencies in stratigraphic nomenclature in the absence of a larger regional framework. This paper attempts to correlate and simplify mappable lithostratigraphic units at a regional scale by comparing multiple sections measured in the field and available in the literature. Existing nomenclature is reviewed first, to demonstrate the need for simplification and to highlight inconsistencies (Fig. 2). New paleontological data and measured sections are then presented. Where appropriate, ambiguous units are revised or recommended for abandonment and new formal stratigraphic names are proposed, to highlight the main depositional themes and to facilitate understanding of this economically and tectonically important unit.

The Hazelton Group was first introduced by Leach (1910) to describe a Jurassic assemblage of volcanic and sedimentary rocks exposed in north-central British Columbia. It replaced in part the broader term “Porphyrite Group” previously proposed by Dawson (1877). The Hazelton Group was subject to minor modifications later (e.g., Hanson 1925; Armstrong 1944; Duffell and Souther 1964) but remained imprecise owing to the lack of age control in the included units. Tipper and Richards (1976) completely revised the Jurassic stratigraphic nomenclature of north-central British Columbia. They established the first regional subdivision and interpretation of the Hazelton Group in the area between Terrace and McConnell Creek (Figs. 1, 2). They identified a thick, volcanic-dominated Early Jurassic lower unit, the mainly Sinemurian Telkwa Formation to the west and east. Between these exposures, Pliensbachian to Toarcian marine sediments and basalts of the Nilkitkwa Formation were deposited in the “Nilkitkwa trough”. The uppermost unit, the Middle Jurassic Smithers Formation, is mainly clastic, with cherts and very fine tuffs in the Yuen Member (Fig. 2). The nomenclature of Tipper and Richards (1976) was subsequently

Fig. 1. Simplified geologic map showing the distribution of the Hazelton Group rocks on the periphery of the Bowser Basin and the locations of stratigraphic sections. Inset shows location in Cordillera. BC: British Columbia; AB: Alberta; YT: Yukon; NWT: Northwest Territories. Section names (**bold**: sections described in this study; *italic*: sections compiled from cited literature): *AN*: Anyox; **AR**: Ashman Ridge; *BR*: Bait Range; *DM*: Diagonal Mountain; *EC*: Eskay Creek; **JL**: Joan Lake; **KP**: Klastine Plateau; **MD**: Mount Dilworth; **NM**: Netalzul Mountain; *NR*: Nilkitkwa Range; **OE**: Oweegee East; *OR*: Omineca Range; **OW**: Oweegee West; **PB**: Pillow Basalt Ridge; **QM**: Quinlan Mountain; **TB**: Table Mountain; **TC**: Tenas Creek; *TG*: Treaty Glacier; **TM**: Todagin Mountain; *TR*: Toodoggone River; **W1**: Mount Will 1; **W2**: Mount Will 2. Modified from Evenchick et al. (2009) and Alldrick et al. (2006). Approximate outline of Eskay rift after Alldrick et al. (2004*b*). Coordinates are Universal Transverse Mercator (UTM) grid zone 9, North American datum 1983 (NAD83).

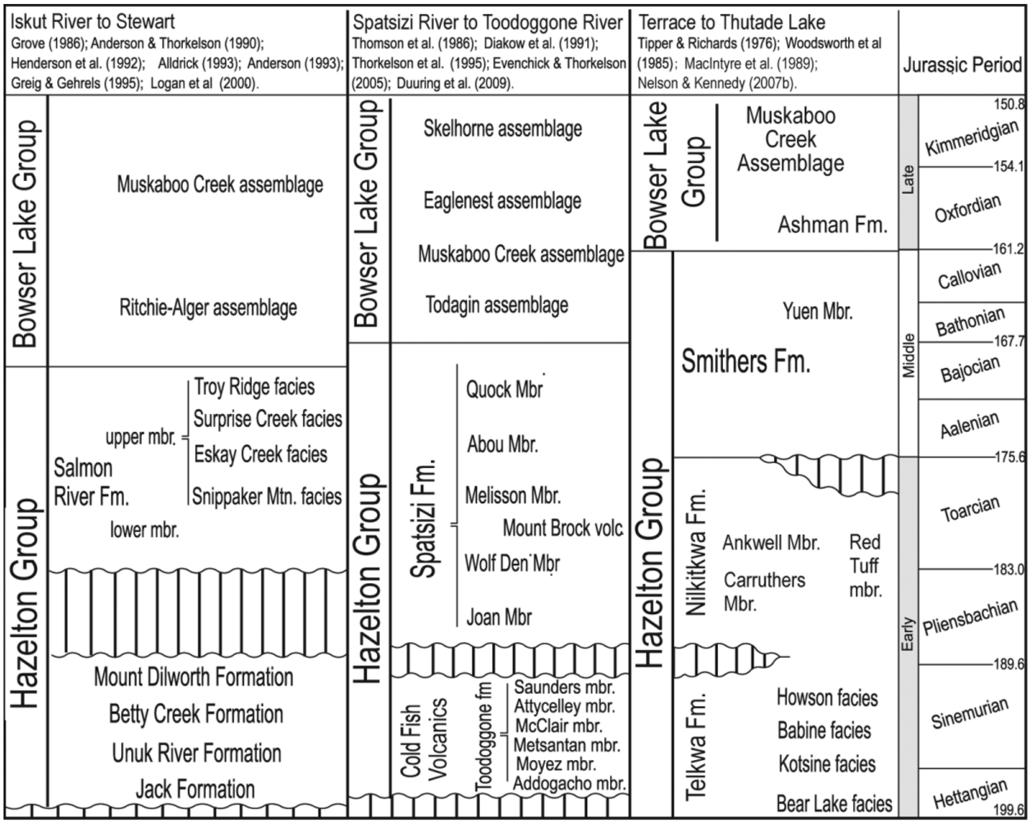


extended to other areas around the margin of the Bowser Basin (Woodsworth et al. 1985; Diakow and Mihalynuk 1987; MacIntyre et al. 1989, 1997).

Northwest of McConnell Creek, in the Spatsizi River and Toodoggone River areas (Fig. 1), lower volcanic units of the Hazelton Group were assigned different formation names (Marsden and Thorkelson 1992; Thorkelson 1992; Thorkelson et al. 1995; Diakow et al. 1991) (Fig. 2). Above this volcanic succession, a distinct Pliensbachian to Bajocian mainly sedimentary succession, 700 m thick, was named the Spatsizi Group by Thomson et al. (1986). However, other authors (Marsden and Thorkelson 1992; Evenchick and Thorkelson 2005) pointed out that this contradicted Tipper and Richards' (1976) widely accepted definition of the Hazelton Group and made regional correlations more difficult, as other clastic-dominated successions at similar stratigraphic levels were included within the Hazelton Group. These arguments led Evenchick and Thorkelson (2005) to demote the Spatsizi Group to the Spatsizi Formation and, consequently, its five formations to members.

In the Iskut River area (Fig. 1), the Hazelton Group has been divided into five formations, shown in Fig. 2 (e.g., Grove 1986; Alldrick et al. 1989; Anderson and Thorkelson 1990; Henderson et al. 1992; Anderson 1993; Greig and Gehrels 1995). A recently enlarged geochronological and biostratigraphic database in this area has provided improved age constraints on these units (e.g., Lewis et al. 1993; Macdonald et al. 1996; Logan et al. 2000). A Pliensbachian to Toarcian hiatus apparently separates the four lower, predominantly volcanic units from the overlying Salmon River Formation

Fig. 2. Summary of previous stratigraphic nomenclature for the Hazelton Group in north-central British Columbia. Time scale modified from Ogg (2004). The new stratigraphic scheme proposed in this paper is shown in Fig. 15.



(Anderson 1993; Greig and Gehrels 1995). The latter includes, in its upper member, a unit of thinly interbedded and laminated dark cherty mudstone and light-coloured ash tuff termed the Troy Ridge facies. These rocks became known informally but widely as "pyjama beds", a term coined by Howard Tipper in the late 1980s to describe their pinstriped appearance, and subsequently applied to similar facies throughout the upper Hazelton Group. We propose in the following text that this distinctive, mappable facies be recognized throughout the region as the Quock Formation, a name defined by Thomson et al. (1986).

In the Iskut River area, a zone of thicker mid-Jurassic volcanic and coarse to fine clastic rocks occupies a narrow, elongate N–S belt, characterized as the Eskay rift (e.g., Evenchick and McNicoll 2002, Alldrick et al. 2005). These rocks are laterally equivalent to the upper parts of the Hazelton Group elsewhere, but they display distinct facies and occupy a unique tectonic setting; we propose the new Iskut River Formation to include these rocks.

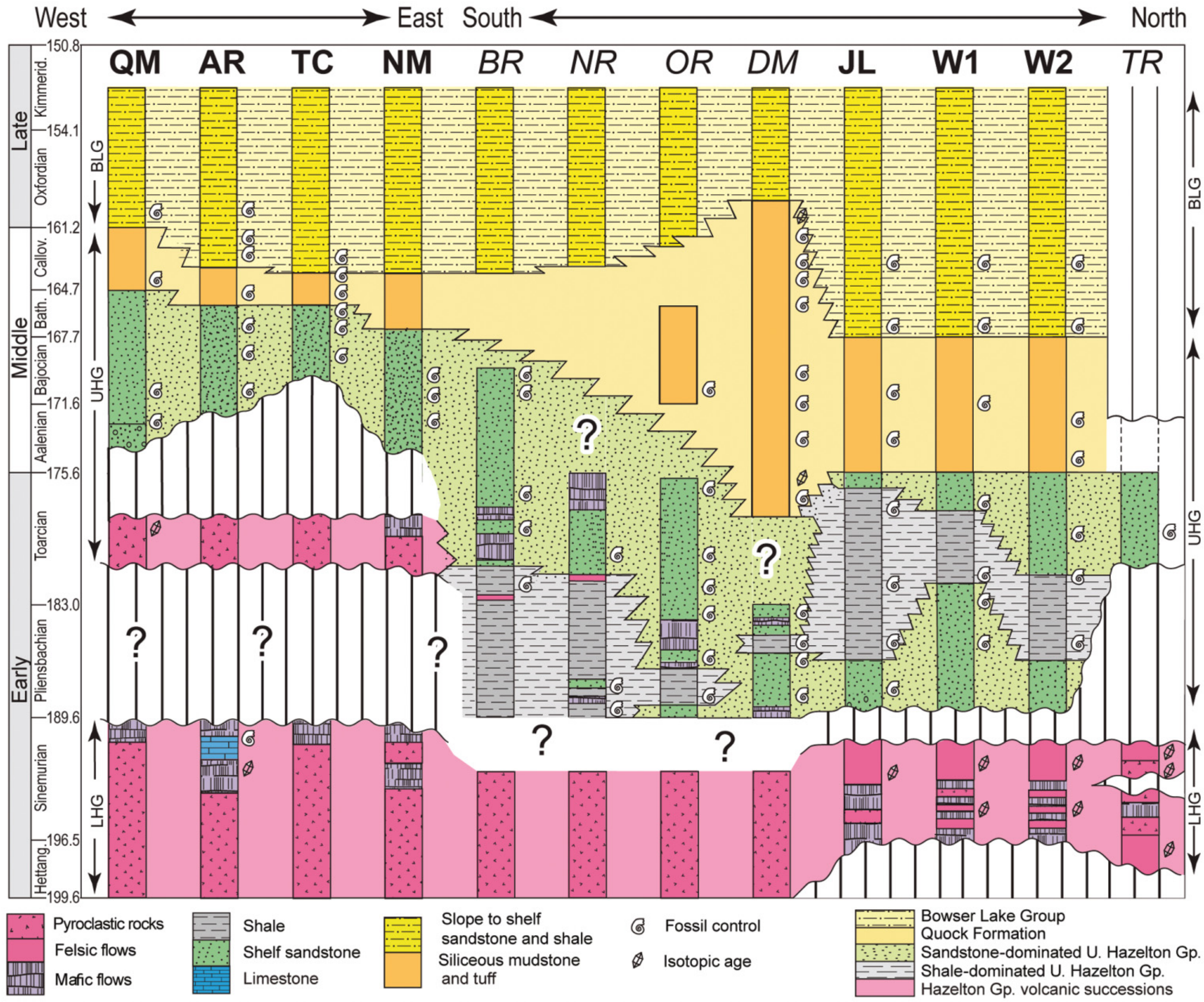
In all these areas, the Hazelton Group is conformably overlain by an assemblage of mudstone, siltstone, sandstone, and chert-pebble conglomerate of the Bowser Lake Group (Fig. 2). In the Smithers area, Tipper and Richards (1976) originally assigned Upper Bajocian to Middle Oxfordian clastic rocks, including "pyjama beds", to the Ashman Formation, and therefore to the Bowser Lake Group, largely based on their age. However, Evenchick et al. (2007*b*, 2008*a*, 2008*b*, 2010) and Gagnon and Waldron (2008) showed that the Ashman Formation comprises facies elsewhere divided between the Hazelton Group and the Bowser Lake Group. Consequently, the term Ashman Formation has been abandoned; beds previously assigned to the latter were reassigned to either the upper Hazelton Group or the Bowser Lake Group based on the presence or absence of tuffs, respectively (Evenchick et al. 2007*b*, 2008*a*, 2008*b*, 2010).

Stratigraphic sections

New lithostratigraphic sections were measured at locations around the margin of the Bowser Basin and within the Eskay rift (Fig. 1), using 50 m tapes on the ground, correcting trigonometrically for the orientation of the tape and the dip of strata. Locally, in rugged sections, individual beds were measured directly with a tape measure held perpendicular to bedding. These sections, and others compiled from previous publications, are identified by two-letter codes in two profiles, running roughly S–N and W–E across the basin, shown, respectively, in Figs. 3 and 4. In addition to lithologies and sedimentary structures, our observations include numerous trace fossils not recorded by previous authors. New collections of macrofossils and microfossils provide additional biostratigraphic constraints.[2]

[2]Supplementary data are available with the article through the journal Web site at http://nrcresearchpress.com/doi/suppl/10.1139/e2012-042.

Fig. 3. Regional lithostratigraphic subdivisions of the Hazelton Group. Line of cross-section is oriented W–E across the southern Hazelton trough, then SE–NW along the eastern part of the trough. Section locations shown in Fig. 1 (**bold**: sections described in this study; *italic*: section information compiled from Tipper and Richards 1976; Diakow et al. 1991; Jakobs 1993; Evenchick et al. 2007*b*; Duuring et al. 2009). Vertical axis shows time scale modified from Ogg (2004); thicknesses are not proportionate because rates of sedimentation varied. BLG: Bowser Lake Group. UHG: upper Hazelton Group. LHG: lower Hazelton Group. Refer to Fig. 1 for abbreviations of section names. Full names of abbreviated Jurassic stages are shown in Fig. 2.



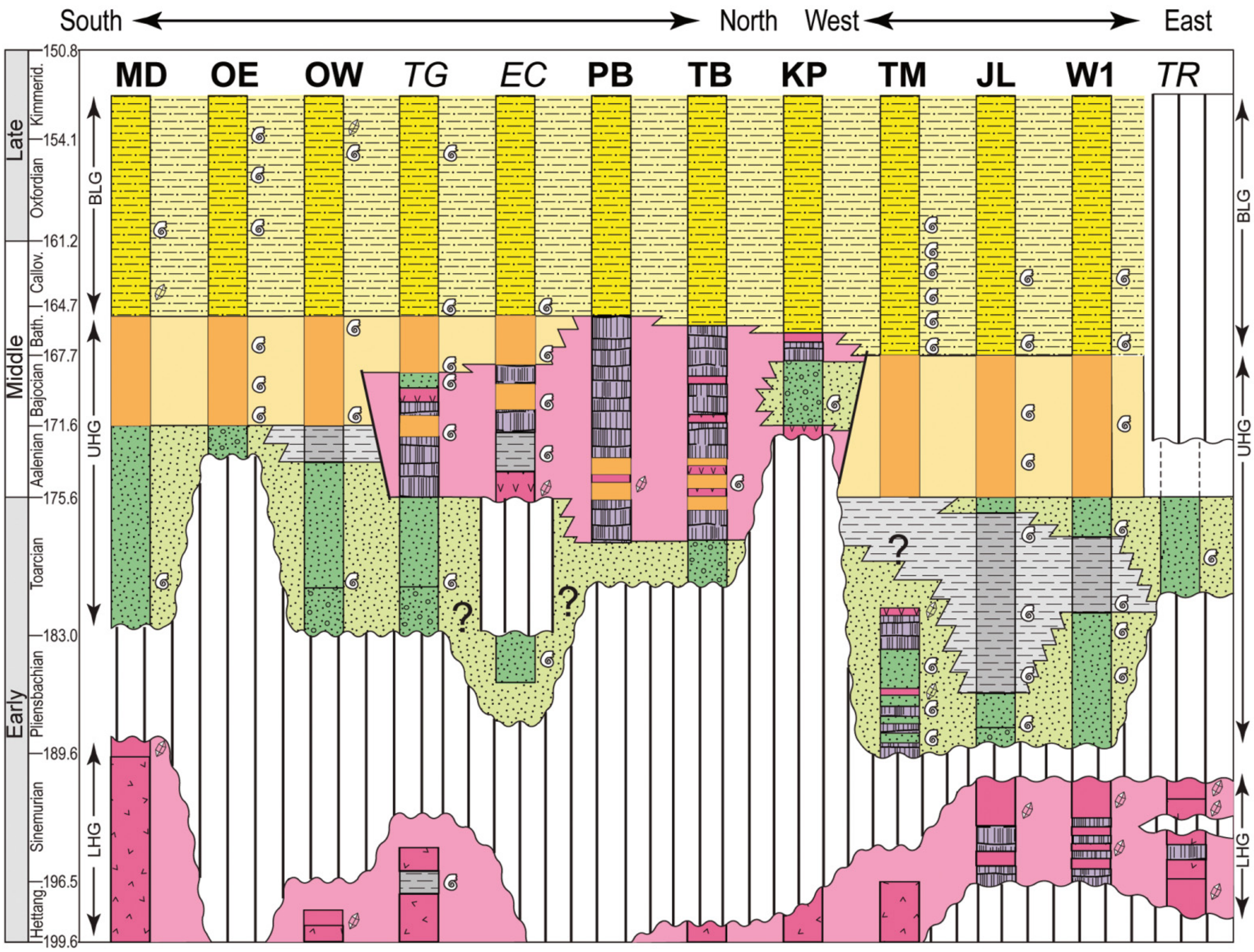
McConnell to Terrace area

Ashman Ridge (AR)

Section AR, ~45 km west of Smithers (Fig. 1), was originally described by Tipper and Richards (1976) as the type section of their Ashman Formation (since abandoned). Lower units of the Hazelton Group are also well exposed and provide a record of the changing Early to Middle Jurassic environment. Figure 5 shows the lithostratigraphic units identified in this study and the stratigraphic positions of fossil localities (Tipper and Richards 1976; Pálfy and Schmidt 1994; Johnston 2002).

The lowest units are amygdaloidal andesitic to dacitic flows and associated pyroclastic rocks (Fig. 5), assigned to the Howson subaerial facies of the Telkwa Formation by Tipper and Richards (1976). The volcanic flows are typically 5–15 m thick and autobrecciated near their tops. Most flows are aphanitic, with lesser feldspar-phyric andesite. Highly indurated ignimbrite containing flattened pumice suggests subaerial deposition. Pálfy et al. (2000) obtained a minimum U–Pb age of 192 Ma on discordant zircon fractions collected from andesitic tuff at 295 m in the section. Consistent with this isotopic age (according to the time scale of Ogg 2004), overlying bioclastic sandstone at 325 m contains Upper Sinemurian ammonites (Tipper and Richards 1976; Pálfy and Schmidt 1994). The asteroceratid-bearing layer immediately overlies 10 m of thick light grey fossiliferous packstone containing well-preserved silicified burrows, algal oncoids, and ooids indicating deposition in a warm-water subtidal environment (Figs. 6A, 6B). These marine sedimentary rocks are capped by a 40 m thick rusty-weathered vesicular basalt flow with epidote-bearing quartz veins.

Fig. 4. Lithostratigraphic subdivisions of the Hazelton Group in the vicinity of the Iskut River area, S–N across the Eskay rift, then W–E across northern Hazelton trough. In the Iskut River area, deposition of siliceous siltstone beds of the Quock Formation was contemporaneous with accumulation in the Eskay rift of thick bimodal volcanic rocks of the Iskut River Formation. Section locations shown in Fig. 1 (**bold**: sections described in this study; *italic*: section information compiled from Lewis et al. 1993; Roth 2002; Diakow et al. 1991; Duuring et al. 2009). For abbreviations of section names, refer to Fig. 1; for legend, see Fig. 3. Vertical axis shows time scale modified from Ogg (2004); thicknesses are not proportionate because rates of sedimentation varied. BLG: Bowser Lake Group. UHG: upper Hazelton Group. LHG: lower Hazelton Group. Full names of abbreviated Jurassic stages are shown in Fig. 2.

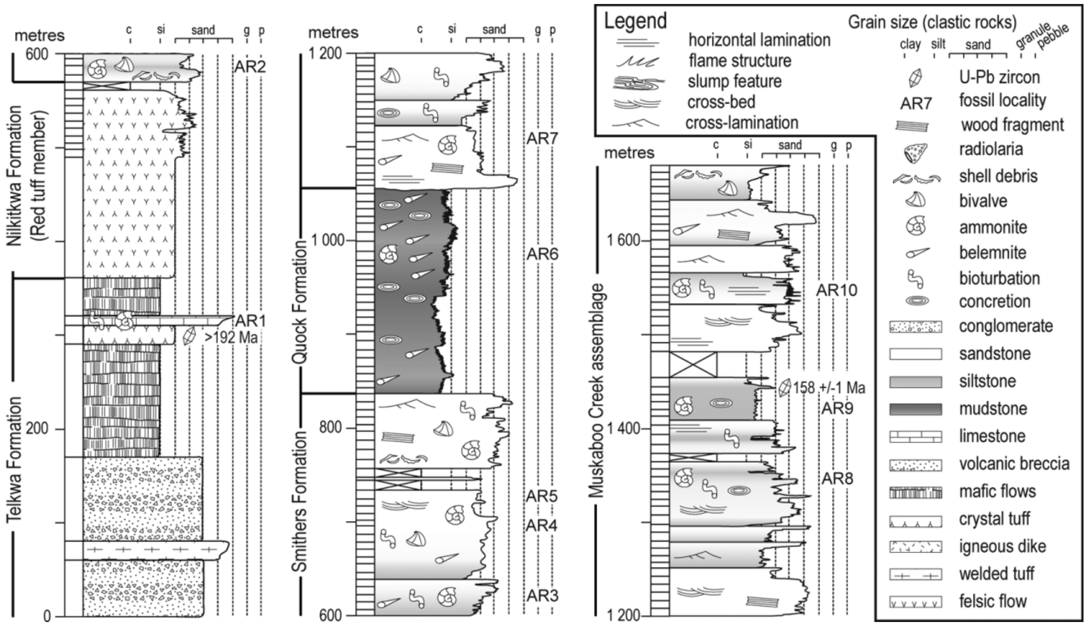


The uppermost volcanogenic unit of the section consists of ~200 m of well-bedded maroon to bright-red fine-grained crystal-lithic non-welded ash flow tuff, poorly sorted rubbly lapilli tuff, and lahar. Rounded bombs up to 30 cm in diameter are common and suggest a return to predominantly subaerial deposition. Tipper and Richards (1976) assigned this unit to the Red Tuff Member of the Nilkitkwa Formation. Regionally the Red Tuff Member is of mid-Toarcian age and in some areas overlies Pliensbachian to Lower Toarcian clastic and tuffaceous strata (Tipper and Richards 1976). Here, it occurs in apparent continuity with the underlying andesitic volcanics, across a cryptic hiatus. Essentially the red tuff represents the last pulse of arc-related volcanism at this locality.

The Red Tuff Member is disconformably overlain by tuffaceous sandstone and siltstone of the Smithers Formation (Figs. 5, 6C). A high concentration of volcanic-derived clasts in the formation suggests recycling of the older pyroclastic rocks from adjacent highlands. The Smithers Formation mostly comprises medium- to fine-grained greenish-brown sandstone with locally abundant and varied marine fauna, including ammonoids, belemnites, gastropods, solitary scleratinian corals, and a wide variety of ornate bivalves such as *Myophorella* (Fig. 6D). At Ashman Ridge, the Smithers Formation ranges from Lower Bajocian to Bathonian. Bioturbation is pervasive and is well displayed in beds of green chlorite-rich sandstone. Common ichnogenera include *Teichichnus*, *Cylindrichnus*, *Rosselia*, *Planolites*, and *Chondrites*. The prolific faunal assemblages, *Cruziana* ichnofacies traces, and common wave-generated sedimentary structures suggest deposition in a lower shoreface environment.

The Smithers Formation is conformably overlain by 220 m of thinly bedded blocky-weathering dark grey siliceous mudstone with recessive laminations and very thin (<3 cm) beds of pale orange-weathered ash tuff. This unit was originally included in the Ashman Formation by Tipper and Richards (1976) but is assigned here to the revised Quock Formation.

Fig. 5. Detailed measured section at Ashman Ridge (AR in Fig. 1) showing the lithological units and grain size variation. Descriptions of fossil localities (AR1–AR10) are given in the supplementary data.[2]



These beds are distinguished from the underlying sandstones of the Smithers Formation by their finer grain size, fewer bivalves, and sparse bioturbation. The contact between the two units is easily mappable on the ridge. Belemnites and calcareous concretions are abundant in the upper half of this unit. Well-preserved Late Bathonian ammonites, including *Kepplerites* sp. aff. *K. mclearni* Imlay, were collected ~66.5 m below the top (AR6 in Fig. 5). The fine grain size, laterally continuous bedding, and lack of current-generated structures indicate deposition mostly from suspension, below wave base.

The siliceous fine-grained succession is conformably overlain with a sharp boundary by brown- and white-weathering arkosic sandstone and finely laminated siltstone of the Bowser Lake Group. Hummocky cross-stratification, trough cross-bedding, and climbing-ripple cross-lamination are common, and these allow the unit to be assigned to the Muskaboo Creek assemblage of the Bowser Lake Group (Evenchick et al. 2001). The abundant ammonite faunas are Middle Callovian to Lower Oxfordian (Tipper and Richards 1976; Evenchick et al. 2010). We measured 615 m of Middle to Upper Jurassic strata without significant overall lithological change.

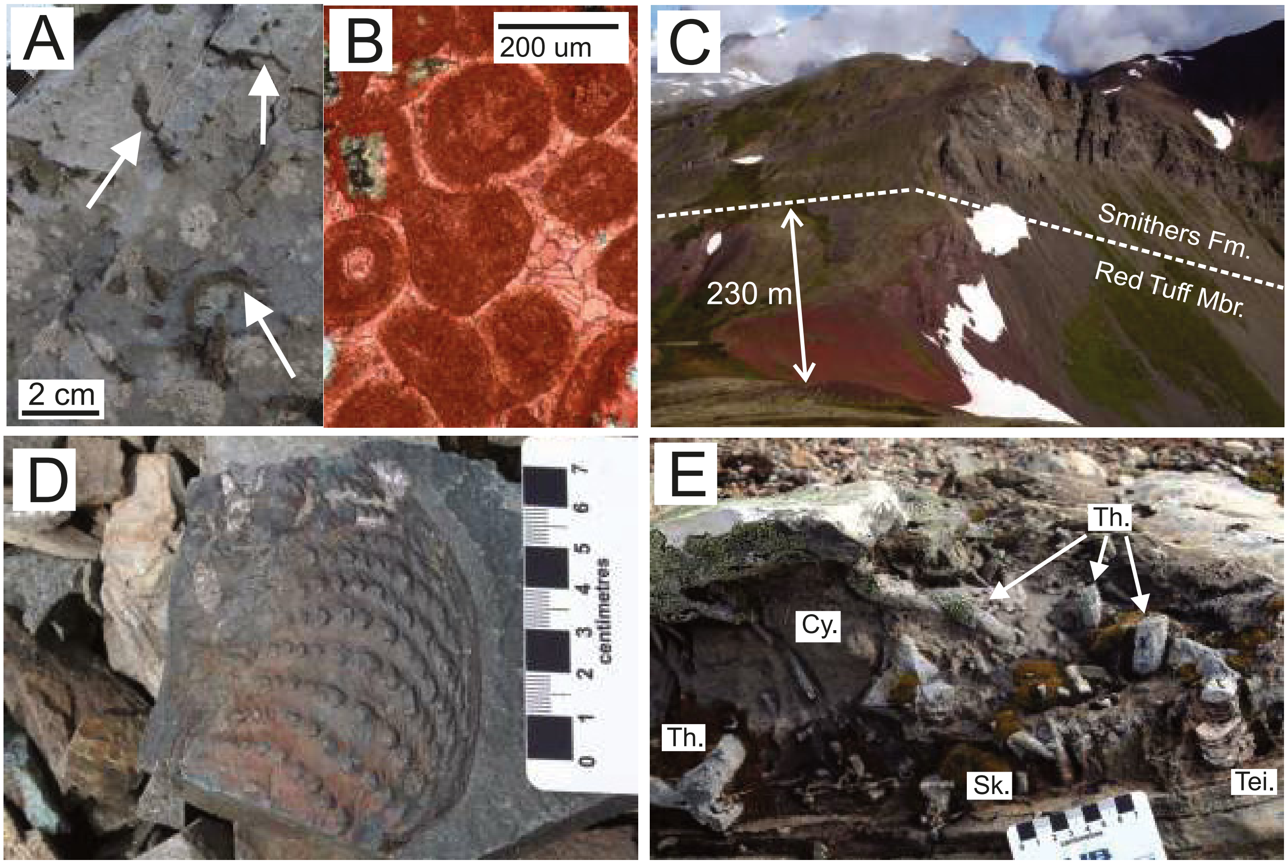
Quinlan Mountain (QM)

Stratigraphy similar to section AR, with minor differences, is observed at Quinlan Mountain, 50 km NE of Terrace (Figs. 1, 7). The lowermost unit in this section is non-welded maroon to brick-red dacitic crystal-lithic ash tuff equivalent to the Red Tuff Member of the Nilkitkwa Formation described at Ashman Ridge (Fig. 7A). Euhedral white plagioclase crystals are conspicuous in the very fine-grained matrix. Abundant pyroclastic bombs 30–50 cm in diameter occasionally display distorted concentric layering, probably related to rapid compaction when the material was still in a partly molten state. At ~1 km south of this section, the bomb-bearing tuff paraconformably or disconformably(?) overlies red dacite and andesite tuffs assigned to the Telkwa Formation (Nelson and Kennedy 2007*a*, 2007*b*). This distinctive unit is recognized over 35 km of strike length in the Terrace area, constituting the uppermost volcanic unit in the Hazelton Group (Nelson and Kennedy 2007*b*). As at Ashman Ridge, it is assumed to be of mid-Toarcian age based on regional correlation (Tipper and Richards 1976).

The Red Tuff Member is overlain with apparent disconformity by 265 m of siliciclastic sedimentary rocks of the Smithers Formation (Fig. 7A). In contrast with the Ashman Ridge section, there is a 10 m basal clast-supported conglomerate. The clasts are generally well sorted, are moderately to well rounded, and consist of white, silicified crystal-lithic-dust tuff. Their rhyolitic composition differs drastically from the underlying bright red andesitic to dacitic pyroclastics, which suggests that they were not locally derived. The conglomerate fines rapidly upward into interbedded limy sandstone and tuffaceous siltstone, similar to that at section AR, with abundant marine fossils. Well-preserved ammonoids and bivalves collected immediately above the conglomerate unit are mid-Aalenian; Early Bajocian fauna occur higher in the section. Bioturbation is also common in the finer-grained sedimentary strata and includes a high-diversity assemblage of *Teichichnus*, *Planolites*, *Cylindrichnus*, *Ophiomorpha*, *Palaeophycos*, *Skolithos*, *Rosselia*, *Thalassinoides*, and *Chondrites* (Fig. 6E). The Smithers Formation gradually fines upward into grey siltstone and mudstone near the top, where shallow water fauna become less abundant.

The Smithers Formation is conformably overlain by 120 m of thinly bedded dark siliceous mudstones and pale orange ash tuff, previously mapped as undivided upper Hazelton Group (Evenchick et al. 2008*a*) and assigned here to the revised Quock Formation (Fig. 7A). A collection located near the base of the unit yielded Early Callovian ammonites (QM7 in Fig. 7A). Isolated very fine-grained limestone beds suggest environmental conditions above the carbonate com-

Fig. 6. Photographs of distinctive lithological characteristics of units exposed at Ashman Ridge and Quinlan Mountain. (A) Outcrop view of silicified burrows (arrows) in a fine-grained oolitic limestone of the Telkwa Formation (located at 320 m in Fig. 5). (B) Stained photomicrograph of the same limestone in cross-polarized light showing concentric layers of coated grains (oolites) and the recrystallized calcite cement (sparite). (C) Stratigraphic contact between the subaerial crystal-lithic tuff of the Nilkitkwa Formation and the thickly bedded fossiliferous siltstone and sandstone of the Smithers Formation at Ashman Ridge. (D) Bivalve (*Myophorella* sp.) in the Smithers Formation (located at 575 m in Fig. 3). These thick-shelled bivalves are interpreted to represent a shallow marine depositional environment. (E) Bioturbated fine-grained tuffaceous sandstone of the Smithers Formation showing a high diversity assemblage of trace fossils, including *Skolithos* (Sk.), *Teichichnus* (Tei.), *Cylindrichnus* (Cy.), and *Thalassinoides* (Th.). Scale bar in centimetres.



pensation depth. Local monospecific assemblages of *Chondrites* traces may indicate bottom-water conditions with reduced oxygen (Bromley and Ekdale 1984).

The uppermost unit at Quinlan Mountain is laminated bluish-grey, medium- to very fine-grained sandstone and siltstone (Fig. 7A) mapped as Bowser Lake Group by Evenchick et al. (2008*a*). The dark grey siltstone beds are fissile and show a strong fabric, significantly different from the blocky habit of the underlying beds of the Quock Formation. Individual layers are normally graded and show partial Bouma sequences with abundant biogenic reworking in the hemipelagic "T_E" subdivision, consistent with the Richie-Alger assemblage of the Bowser Lake Group, and suggesting deeper-water conditions than at Ashman Ridge. The turbidite deposit contains traces such as *Asterosoma*, *Chondrites*, *Planolites*, *Zoophycos*, *Teichichnus*, *Phycosiphon*, and *Cosmorathes*, consistent with a distal *Cruziana* ichnofacies. Lower Oxfordian bivalves were recovered ~300 m above the base of the Bowser Lake Group.

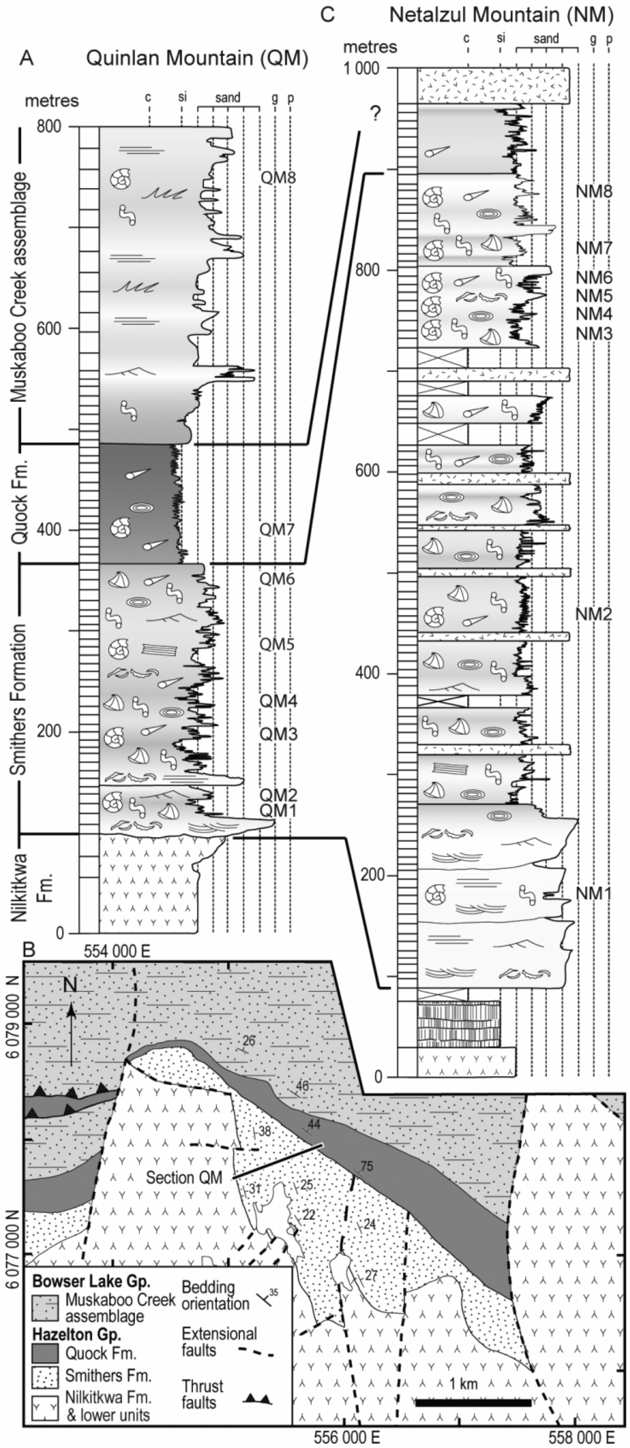
Section QM is closely comparable to two additional measured sections at Tenas Creek (TC) and Netalzul Mountain (NM: Figs. 3, 7C), although the sections are variable in thickness. (Gagnon 2010).

Spatsizi River to Toodoggone River area

Joan Lake (JL)

The Spatsizi Formation type section JL, previously measured by Thomson et al. (1986), was revisited during this study (Figs. 1, 8A). The most significant lithological break is the unconformable contact between the Cold Fish Volcanics and the overlying sedimentary rocks assigned by Thomson et al. (1986) to the Spatsizi Group (Spatsizi Formation of Evenchick and Thorkelson 2005). A rusty-weathering pyroclastic ash-flow unit at the top of the Cold Fish Volcanics is disconformably overlain by 2 m of monomictic, clast-supported conglomerate of the Joan Member (Fig. 8A). The whitish grey volcanic pebbles are well-rounded and poorly sorted, and they include occasional cobble- and boulder-size clasts (Fig. 9A). The conglomerate rapidly fines upward into medium to thick beds of very fine- to fine-grained sandstone. New collections of fossils (see supplementary data[2]) include

Fig. 7. Detailed measured sections in the Terrace to Smithers area south of the Bowser Basin. (A) Section QM (stratotype of the Smithers Formation). (B) Location map for section QM, modified from Nelson et al. (2007). (C) Section NM. See Fig. 5 for legend details and Fig. 1 for geographic locations. Coordinates are UTM zone 9, datum NAD83.



the Early Pliensbachian ammonite *Dubariceras freboldi* Dommergues, the bivalve *Weyla bodenbenderi* (Behrendsen), and the bivalve *Weyla bodenbenderi* (JL1 in Fig. 8A). Fossils are mainly concentrated in distinctive brown-weathering calcareous sandstone beds (Fig. 9B). Moderately inclined to vertical biogenic traces, such as *Skolithos* and *Cylindrichnus*, are abundant in the fine-grained sandstone intervals.

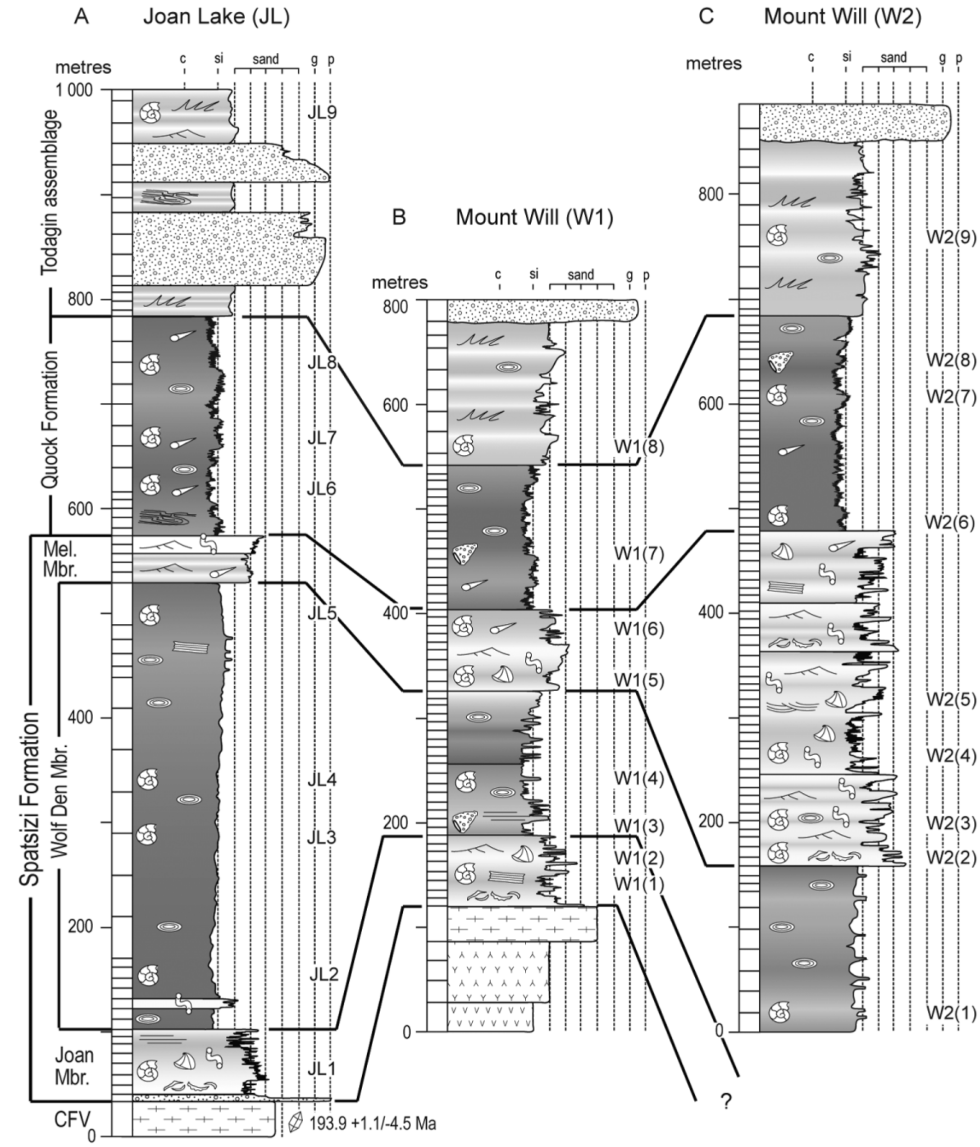
At 100 m in the section, fossil-rich fine-grained sandstone of the Joan Member is overlain by dark grey calcareous siltstone and mudstone of the Wolf Den Member, 427 m thick (Fig. 8A). The sudden decrease in grain size suggests a flooding surface, consistent with deepening as proposed by Thomson et al. (1986). Ammonites throughout the Wolf Den Member are Upper Pliensbachian to Middle Toarcian (Thomson et al. 1986; Thomson and Smith 1992; Jakobs 1997). Pale-beige ash tuffs and rare wood fragments occur near the top of the unit. The monotonous shale succession grades upward into well-sorted, thin to medium fine-grained sandstone beds (Figs. 8A, 9C) of the Melisson Member (Thomson et al. 1986). The basal 20 m are characterized by greyish-beige calcareous sandstones interbedded with very thin mudstone intervals. Up-section, the sandstone beds become amalgamated, and current-generated structures such as asymmetric ripples and cross-laminations are common. The uppermost layer of the Melisson Member is a tuffaceous sandstone bed with abundant trace fossils, including *Teichichnus*, *Cylindrichnus*, *Palaeophycos*, *Rhizocorallium*, *Ophiomorpha*, *Granularia*, and pervasive *Chondrites*. These observations are consistent with the shoaling interpretation of Thomson et al. (1986) and further suggest a fully marine environment throughout. No fossils were recovered from the Melisson Member at section JL, but fossils in both the underlying and overlying units suggest the unit is Middle to Upper Toarcian (Thomson et al. 1986).

The upper boundary of the Melisson Member is at the top of the uppermost bioturbated tuffaceous sandstone (575 m on Fig. 8A). The overlying Quock Formation (Thomson et al. 1986) consists of alternating thinly bedded dark siliceous mudstone and light beige rusty tuffaceous siltstone with rare limestone intervals (Fig. 9D). According to Thomson et al. (1986), the Quock Formation was deposited in a deep-water environment of relatively slow sedimentation interrupted by frequent ash falls. Ammonites indicate an Early Bajocian age (Thomson et al. 1986). The formation is ~200 m thick and is overlain gradationally by chert-pebble-rich conglomerate and turbiditic siltstone of the Todagin assemblage of the Bowser Lake Group (Evenchick et al. 2010). The Bowser Lake Group is at least 1500 m thick in the vicinity of Joan Lake and ranges from Bathonian to Callovian (Evenchick and Thorkelson 2005).

Mount Will (W1, W2)

Sections W1 and W2, respectively 5 and 10 km north of JL, were measured to document lateral variation in the Spatsizi River area. All three sections lie in the hanging wall of the SW-dipping Mount Will thrust, which cuts the NE margin of the Bowser Basin. The succession is similar to JL, but the unit thicknesses vary (Figs. 8B, 8C). Indurated ash flow tuff at the top of the Cold Fish Volcanics is overlain by medium-grained calcareous sandstone of the Joan Member, as at JL. Near the base of the overlying Wolf Den Member (230 m in the section), well-preserved Toarcian radiolaria recovered from a dark siliceous mudstone include *Helvetocapsa minoensis* (Matsuoka) and *Parvicingula spinifera* (Takemura) (Fig. 10). Their age is consistent with Lower Toarcian ammonites *Hildaites murleyi* (Moxon) and *Harpoceras* sp. cf.

Fig. 8. Detailed measured sections in the Spatsizi River area north of the Bowser Basin. (A) Joan Lake (unit stratotype of the Spatsizi and Quock formations). (B) Mount Will 1. (C) Mount Will 2. The revised Spatsizi Formation includes three formally defined members: fossiliferous coarse-grained sandstone of the Joan Member, dark mudstone of the Wolf Den Member, and the bioturbated sandstone and siltstone of the Melisson Member. See Fig. 5 for legend details and Fig. 1 for geographic locations. CFV: Cold Fish Volcanics; Mel. Mbr.: Melisson Member.



H. subplanatum (Oppel) collected 30 m up-section. Finely laminated very fine-grained sandstone and mudstone of the Wolf Den Member coarsen upward into bioturbated sandstone of the Melisson Member. The Middle Toarcian ammonites *Peronoceras* sp. aff. *P. verticosum* (Buckman) and *Denckmannia* sp. cf. *D. tumefacta* (Buckman) of the Planulata regional zone (Jakobs 1997) were collected both at the base and near the top of this unit. Ichnofossils of the Melisson Member are dominantly suspension feeder traces such as *Skolithos*, *Diplocraterion*, and *Cylindrichnus*. As in section JL, the base of the Quock Formation is immediately above the uppermost bioturbated sandstone (405 m in Fig. 8B). Despite its lithological similarity, section W1 is much thinner than section JL, largely because the Wolf Den Member at W1 is reduced to one third of its thickness at JL. This suggests that the basin floor at W1 never reached deep-water conditions and that the accommodation space was filled relatively rapidly in the Middle Toarcian.

Mapped northward thickening of the Spatsizi Formation in this region (Evenchick and Thorkelson 2004; Loogman 2008) is in part attributable to the NE-verging Mount Will thrust fault, which duplicates a significant portion of the Spatsizi Formation. However, both sections W1 and W2 were measured entirely in the hanging wall of the thrust. Section W2, closest to the thrust, included locally folded strata of the uppermost 160 m of the Wolf Den Member up to the base of the Bowser Lake Group (Fig. 8C). The structural thickening due to these folds was taken into account during measurement by tracing beds around fold hinges and identifying overturned sections. Even after this correction of apparent thickening due to thrust-related folding, the Melisson Member in section W2 is significantly thicker than at W1, 5 km

Fig. 9. Photographs of distinctive lithostratigraphic units exposed at the Joan Lake section. (A) Basal clast-supported conglomerate of the Joan Member (revised Spatsizi Formation). The clasts range in size from pebbles to boulders and mostly consist of recycled volcanic material from the underlying Cold Fish Volcanics. (B) Thickly bedded tuffaceous sandstone of the Joan Member with distinctive brown-weathering calcareous beds (arrows) containing abundant marine fossils. (C) Stratigraphic contact between the recessive dark mudstone of the Wolf Den Member and the overlying more competent bioturbated sandstone of the Melisson Member. (D) Thinly bedded dark siliceous mudstone and beigeweathering ash tuff ("pyjama beds") of the revised Quock Formation. Hammer: 30 cm.

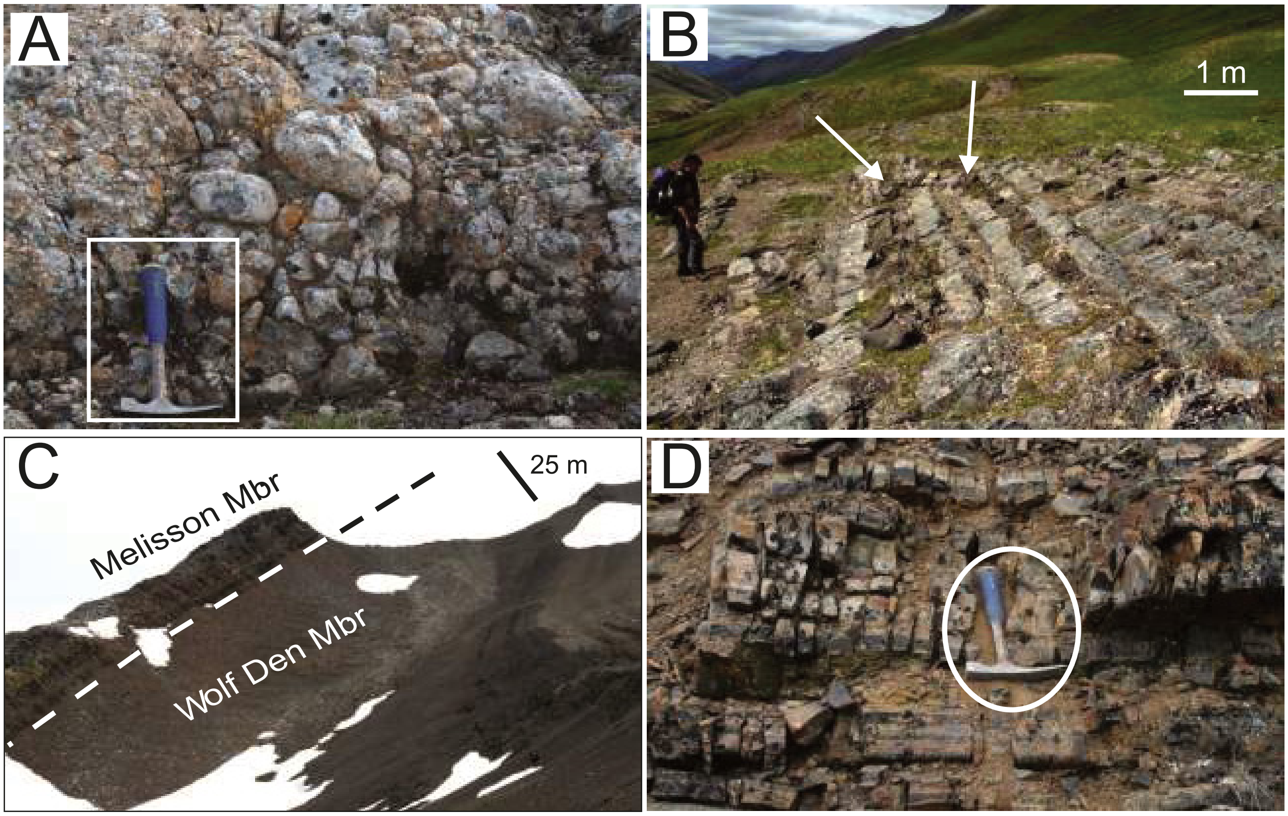
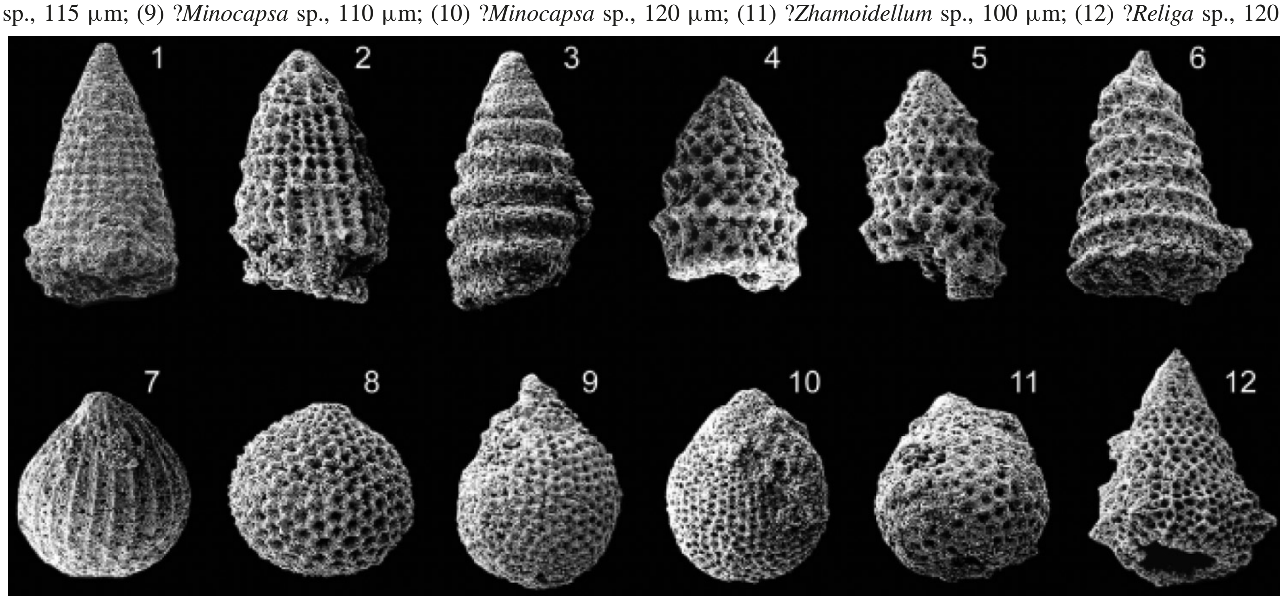


Fig. 10. Jurassic radiolarians from the Quock Formation of the Hazelton Group (scanning electron microscope). Numbers 1–5 and 7–10 correspond to fossil location W1(3) of Fig. 8B. Numbers 6, 11, and 12 correspond to fossil location OE(1) of Fig. 13B. Scales vary; maximum widths as stated. (1) *Parahsuum* sp., 80 µm; (2) *Canutus* sp., 120 µm; (3) *Canoptum* sp., 90 µm; (4, 5) *Praeparvicingula spinifera* (Takemura), 80 µm; (6) *Praeparvicingula* sp. C (Pessagno & Whalen), 120 µm; (7) *Helvetocapsa minoensis* (Matsuoka), 75 µm; (8) *Zhamoidellum* sp., 115 µm; (9) ?*Minocapsa* sp., 110 µm; (10) ?*Minocapsa* sp., 120 µm; (11) ?*Zhamoidellum* sp., 100 µm; (12) ?*Religa* sp., 120 µm.



to the south. Hummocky cross-stratification, sparse bioturbation, and ammonites of the Middle Toarcian Planulata regional zone occur throughout the 322 m of section assigned to the Melisson Member (Fig. 8C). The remainder of the section includes ash tuffs and siliceous radiolarian-bearing mudstones of the revised Quock Formation overlain by fissile silty shale and chert-pebble conglomerate of the Bowser Lake Group.

The units established by Thomson et al. (1986) can be correlated throughout the Spatsizi River area, except for calcareous to siliceous dark organic shale of the Abou Member, which is present only west of the Joan Lake anticline. It probably accumulated in a restricted sub-basin where anaerobic conditions initially developed prior to more widespread anoxia during deposition of the Quock Formation.

Iskut River area

The Hazelton Group shows much greater lateral variation in the Iskut River area, beneath the NW extremity of the Bowser Basin, than in the areas to the east and south. Thick volcanic sections of Middle Jurassic age host significant mineral deposits, contemporaneous with condensed successions deposited elsewhere. The thick volcanic strata occupy a N–S belt, the Eskay rift (e.g., Alldrick et al. 2005). The sections described here illustrate the contrast between the volcanic-dominated rift-fill assigned to the new Iskut River Formation and flanking successions assigned to the revised Spatsizi and Quock formations.

Table Mountain (TB)

Table Mountain (informal name) is a highland ~40 km SW of Iskut (Fig. 1). Section TB is compiled from our observations supplemented by reports and maps of Alldrick et al. (2004*a*, 2004*b*, 2006) and Simpson and Nelson (2004). The lowest unit exposed along the western slope consists mainly of maroon and green plagioclase-phyric andesite flows and dacite breccias (Fig. 11A), with sparse black mudstone and greyish-blue ash tuff. Minor diorite intrusions with pegmatitic pods cut the section. This unit is at least 720 m thick, but only the uppermost 100 m are shown in Fig. 11B. Despite the absence of age control, rock-types identified in this unit suggest correlation with the lower Hazelton Group, but lower parts of the section could include Stuhini Group.

These intermediate volcanic rocks are unconformably overlain by volcanic and sedimentary rocks mapped as part of the informal "Willow Ridge Complex" by Alldrick et al. (2006); in this paper, these rocks are assigned to the new Iskut River Formation. The unconformity at the base of the Iskut River Formation dips steeply east and is onlapped by varied lithologies along strike, including polymictic conglomerate, basalt, and rhyolite (Fig. 11A). Its best-exposed locality (Fig. 11A) is at UTM (Universal Transverse Mercator) zone 9 coordinates 415200 E, 6352500 N, NAD83 (North American datum 1983), where the unconformity is overlain by a heavily altered rhyolite unit ~70 m thick. Hematite and limonite give the regolithic groundmass a distinctive red to orange colour. In the few unaltered outcrops, the rhyolite consists of 1–7 mm pale white spherulites in a semi-translucent pale blue-green siliceous groundmass.

The rhyolite is overlain by 1770 m of dark to olive green basalt (lower basalt unit of Alldrick et al. 2004*b*), typically aphanitic or feldspar-phyric, which forms eruptive units of pillowed flows and pillow breccias typically 5–20 m thick (Fig. 12A). Simpson and Nelson (2004) listed three basalt facies in this unit: aphyric, massive, and coherent pillow basalt; monomictic, blocky basalt breccia; and fluidal-clast breccia. Common devitrification variolites, 3–5 mm in diameter, appear on weathered surfaces as overlapping pale yellow spots (Fig. 12B). The uppermost 5 m are highly altered and contain up to 40% sulphides by volume; the hyaloclastite groundmass of the basalt breccia is partly to completely replaced by very fine-grained pyrite (Fig. 12C). This mineralization is bounded by the contact with the overlying mudstone at the base of the middle sedimentary unit of Alldrick et al. (2004*b*), where fluids responsible for the replacement mineralization were apparently capped (1940 m on Fig. 11B). Laminated beds of pyrite (up to 5 cm thick) immediately above the contact suggest that exhalative vents were still active during sedimentation.

The 10 m unit of thinly bedded black mudstone and grey siltstone is overlain by 50 m of poorly sorted, matrix- to clast-supported polymictic conglomerate with a matrix of coarse to very coarse sandstone. The sub-angular to sub-rounded clasts are basalt, mudstone, rhyolite, massive fine-grained pyrite, and limestone. This unit directly onlaps the basal unconformity in some places. Where it does, polymictic conglomerates grade into coarser fan-conglomerate with clasts that are identical to the underlying plagioclase-phyric andesites and dacites of the lower Hazelton Group. These relationships suggest that the Iskut River Formation was deposited unconformably against a surface with significant topographic relief, here interpreted to represent the floor and a bounding fault of the rift system.

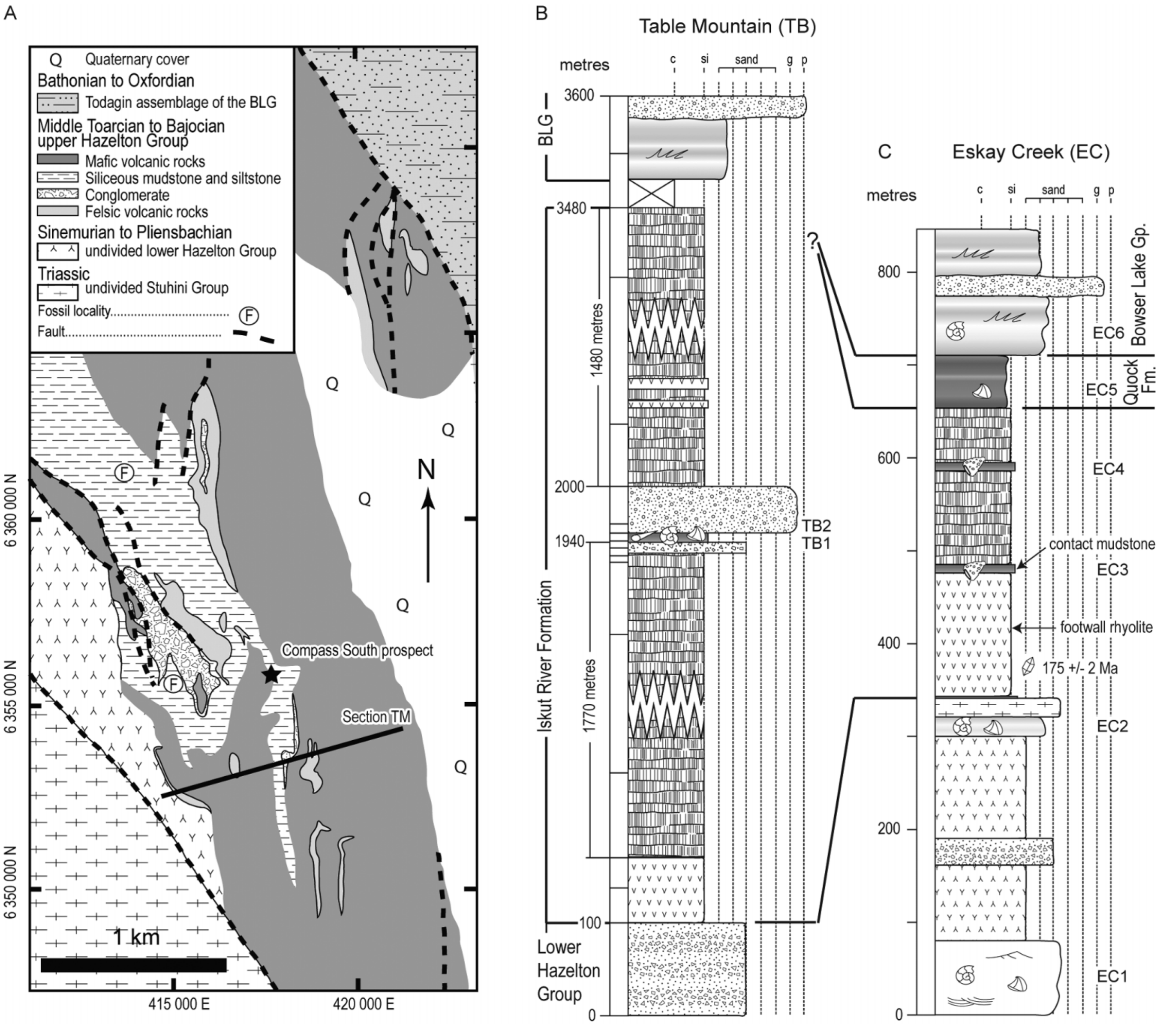
Ammonoids and radiolarians from fine-grained sedimentary rocks that appear to be laterally equivalent to the middle sedimentary unit of Alldrick et al. (2004*b*) range from Late Toarcian to Middle Bajocian in age (Souther 1972; Evenchick et al. 2001). The sedimentary rocks are overlain by at least another 1480 m of basalt (upper basalt unit of Alldrick et al. 2004*b*) lithologically similar to the lower basalt unit, exposed on the east side of Table Mountain and on Willow Ridge (Fig. 11A). Its upper contact is not exposed and has been interpreted as a fault, based on discordance with turbiditic Bowser Lake Group strata to the east (Alldrick et al. 2004*a*, 2004*b*). Regionally, however, this contact is conformable, as seen at section EC.

Eskay Creek (EC)

The geology of the Eskay Creek area (Fig. 1) is well known from detailed bedrock mapping, diamond drilling, and mining (e.g., Ettlinger 1992; Bartsch 1993; Nadaraju 1993; Roth 1993, 2002; Sherlock et al. 1994; Macdonald et al. 1996). Section EC is compiled from these sources.

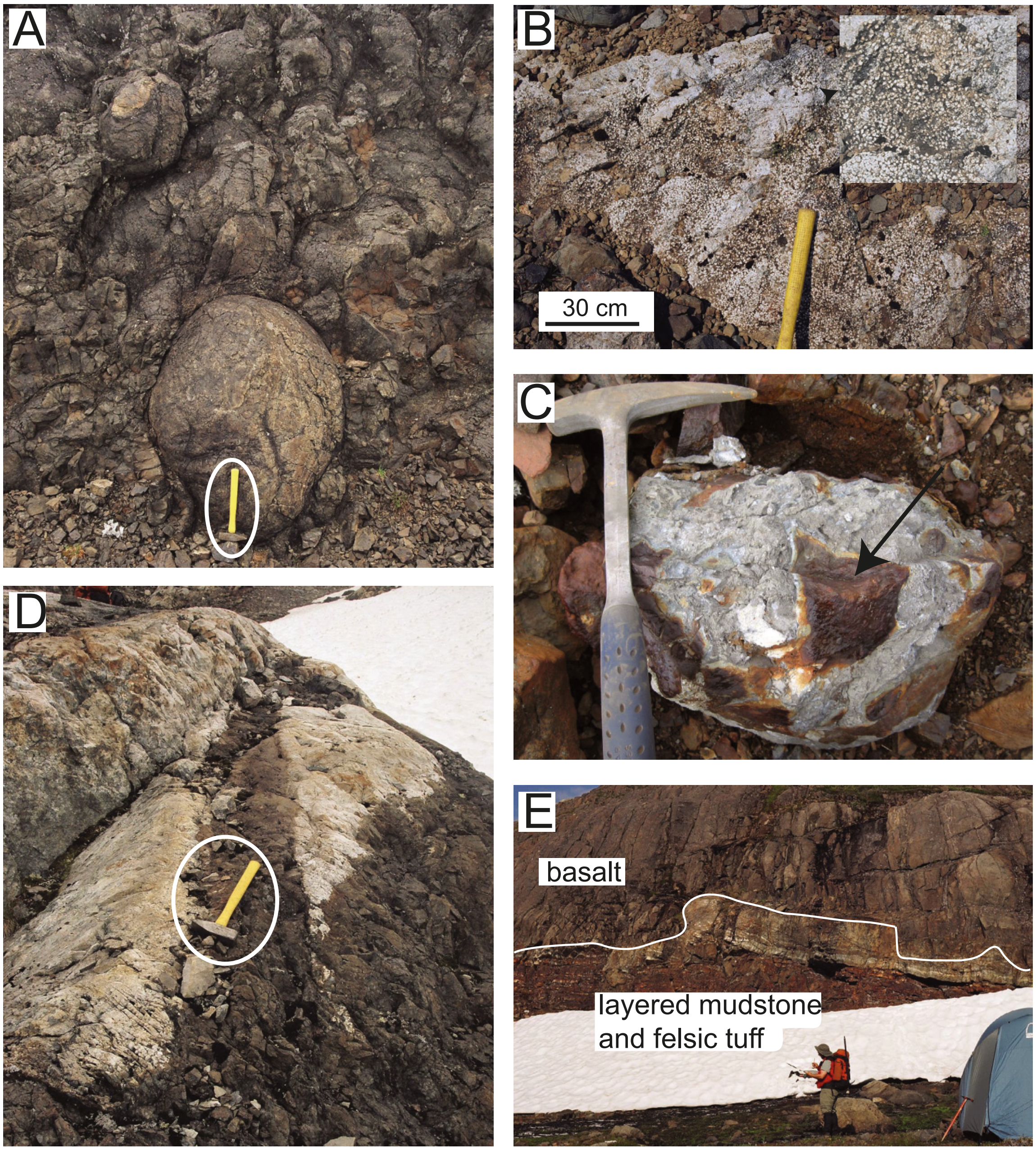
The Hazelton Group is exposed along the west limb and hinge of a NE-plunging anticline (Eskay anticline). These sedimentary and volcanic rocks, included previously in the Salmon River Formation (Anderson and Thorkelson 1990; Anderson 1993), are assigned here to the new Iskut River Formation. In contrast to the section TM (Fig. 11B), the lower contact is concordant but disconformable (340 m in Fig. 11C). Upper Pliensbachian units comprising andesitic breccia, volcaniclastic, and dacitic volcanic rocks (lower Hazelton Group) are overlain by a thick felsic unit, the "footwall

Fig. 11. Detailed measured sections in the Iskut River area located in the Eskay rift. (A) Simplified geologic map of the Table Mountain area showing the unit stratotype of the proposed Iskut River Formation. Modified from Alldrick et al. (2006). (B) Section TB (stratotype of the Iskut River Formation). (C) Section EC. See Fig. 5 for legend details and Fig. 1 for geographic locations. Coordinates are UTM zone 9, datum NAD83. BLG: Bowser Lake Group.



rhyolite", which varies in texture from massive to autobrecciated, and was interpreted by Bartsch (1993) to represent a series of flow-dome complexes. The rhyolite was dated at 175 ± 2 Ma, and a rhyolite in a similar stratigraphic position on the east limb of the Eskay anticline at $174\ ^{+2}_{-1}$ Ma (U–Pb zircon; both by Childe 1996). Overlying and interfingering in part with the rhyolite is a very fine-grained dark grey sedimentary unit known as the "contact mudstone". The contact is irregular along strike and is marked by rhyolite breccia, in which black mudstone fills the interstices of quench-fragmented rhyolite. This peperitic texture is interpreted to indicate that deposition of mudstone was contemporaneous with eruption/emplacement of the rhyolite. Clasts in the mudstone include altered rhyolite, barite, and fragmental sulphides and sulphosalts (Roth 2002). The former Eskay Creek mine exploited a stratiform volcanogenic massive-sulphide deposit at the base of the mudstone interval, which produced 2.18 million tonnes of ore with an average grade of 46 g/tonne Au and 2267 g/tonne Ag (BC Geological Survey 2008). The mudstone yielded Aalenian to possibly Early Bajocian radiolaria (Nadaraju 1993). Massive basalt sills and pillowed basalt flows and breccia, with thin (<1 m thick) intervals of bedded argillite, chert, and felsic tuff, overlie the contact mudstone. Conformably above the basalt is a thicker succession of tuffaceous mudstone, here included in the Quock Formation, which yielded a collection of Early Bajocian bivalves (Roth 2002). Conformably overlying the Quock Formation are mudstone-siltstone turbidites and thickly bedded sandstone and conglomerate of the Bowser Lake Group (Richie-Alger assemblage) with Upper Bathonian to Lower Callovian ammonoids (Evenchick et al. 2001; Roth 2002).

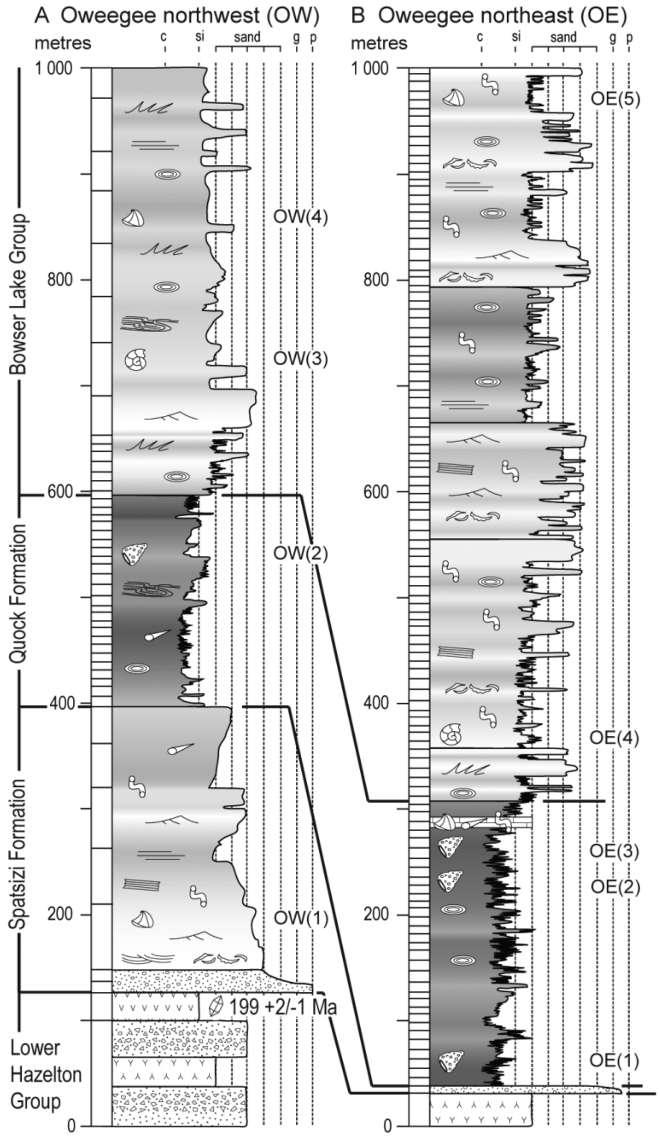
Fig. 12. Photographs of the Iskut River Formation showing distinctive lithological characteristics from units exposed at Pillow Basalt Ridge and Table Mountain (PB and TB on Fig. 1, respectively). (A) Pillow basalts exposed on Pillow Basalt Ridge. Large (>1 m diameter) pillows such as the one exposed near the base of the photograph are interpreted to indicate close proximity to eruptive centres. (B) Basalt exposed at Table Mountain displaying variolitic texture. White-weathering variolites are characteristic devitrification features found on the glassy rims of basalt. (C) Mineralized basalt breccia; dark rusty angular basalt fragments (arrow) are supported in a fine-grained sulphide matrix consisting mainly of pyrite. Photograph is from the Compass South prospect on Table Mountain. (D) Bimodal volcanic rocks on Pillow Basalt Ridge. Light-coloured rhyolite flows are intruded by a sub-volcanic mafic dike swarm that fed eruptions responsible for the overlying pillow basalts. (E) Rusty-weathering mudstone interbedded with felsic tuff, overlain by a basalt flow, on Pillow Basalt Ridge. The bedded rocks grade from mainly pyritic siliceous mudstones at the bottom to predominantly felsic tuff layers at the top. Incorporation of mudstone/tuff "rafts" into the overlying basalt during eruption resulted in an irregular contact. Hammer: 36 cm.



Oweegee Dome (OW and OE)

The Oweegee Range (Fig. 1) is a structural culmination, ~45 km east of the Eskay rift, where the Devonian – Permian Stikine assemblage and Upper Triassic Stuhini Group are unconformably overlain by the Hazelton Group (Greig and Evenchick 1993). The volcanic-dominated lower Hazelton Group is disconformably overlain by clastic rocks previously assigned to the Salmon River Formation, and those are overlain by Bowser Lake Group, which surrounds the dome-shaped inlier of older rocks (Greig 1991, 1992). Two stratigraphic

Fig. 13. Detailed measured sections on the border of the Eskay rift. (A) Oweegee Dome northwest; (B) Oweegee Dome northeast. See Fig. 5 for legend details and Fig. 1 for geographic locations.



sections on the NW and NE sides of the dome were measured (OW and OE, respectively; Fig. 13).

Lowermost rocks of the Hazelton Group at section OW comprise >100 m of well-stratified maroon and green volcaniclastic sandstone interbedded with lahars, volcanic breccia, and minor andesitic volcanic flows (Waldron et al. 2006; Fig. 13A), tentatively assigned to the Betty Creek Formation of Anderson and Thorkelson (1990). A conglomeratic bed contains a significant proportion of clasts that resemble underlying Triassic and Permian rocks, supporting the interpretation of Greig (1991, 1992) that rocks of the Stikine assemblage and Stuhini Group were uplifted prior to deposition of the Hazelton Group. At the top of the lower Hazelton Group is a white, rusty-weathering quartz-phyric rhyolite unit, with an interpreted U–Pb age of 199 ± 2 Ma (Greig and Gehrels 1995). The rhyolite is disconformably overlain by 5 m of polymictic cobble conglomerate, which fines upward gradually into calcareous arkosic sandstone beds (Fig. 13A). Planar cross-bedding and asymmetric current ripples are common sedimentary structures near the base of the sandstone interval. Stratigraphically equivalent tuffaceous bioclastic strata 3 km to the south contain abundant Toarcian marine fossils (Greig and Gehrels 1995). This clastic unit is correlated with the unnamed lower member of the Salmon River Formation defined by Anderson and Thorkelson (1990). The uppermost Hazelton Group is siliceous mudstone and tuff with Early Bajocian to Late Bathonian radiolarian fauna (Cordey et al. 1991), here assigned to the revised Quock Formation. These strata are conformably overlain by fine-grained turbidites of the Bowser Lake Group (Ritchie-Alger assemblage) with Kimmeridgian ammonites ~120 m above the contact (Evenchick et al. 2010).

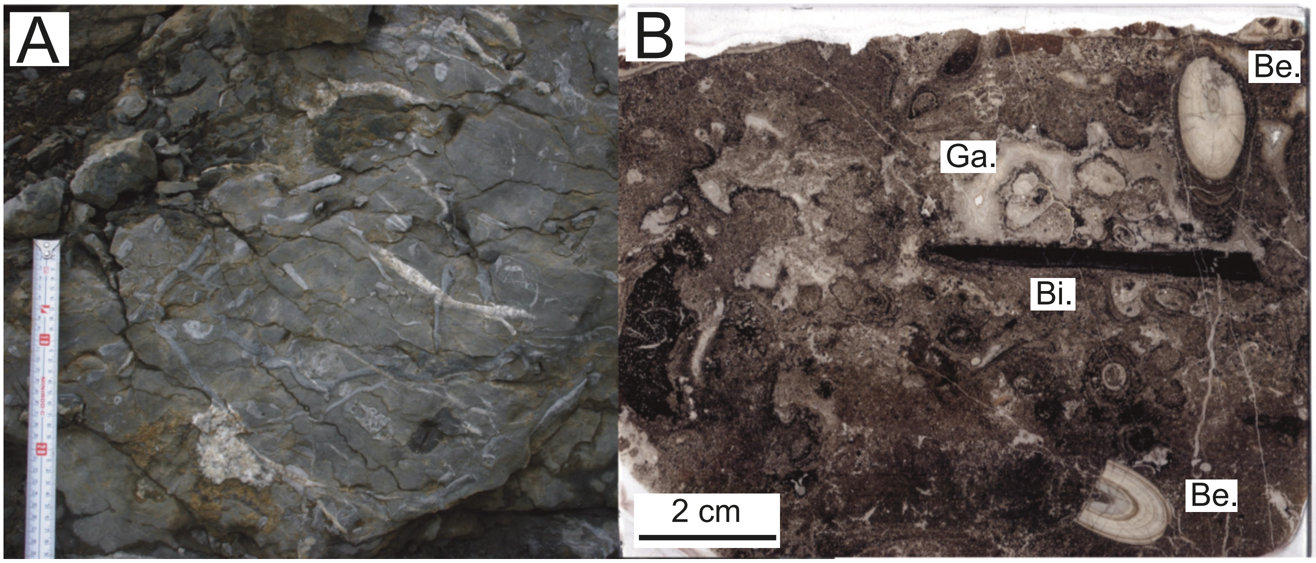
At section OE, a thin layer of poorly sorted conglomerate, tentatively correlated with the Toarcian clastic rocks elsewhere, rests on Stuhini Group with angular unconformity (Fig. 13B). The absence of well-layered volcaniclastic rocks and felsic lava flows, in contrast to section OW, is consistent with the interpretation of Greig (1992) that the unconformity below the upper Hazelton Group has significant relief. The basal conglomerate is overlain by 270 m of thinly interbedded siliceous radiolarian mudstone and ash tuff, assigned variously to the Troy Ridge facies of the Salmon River Formation (Anderson and Thorkelson 1990; Anderson 1993), to the Spatsizi Formation (Ferri and Boddy 2005), or to undifferentiated upper Hazelton Group (Evenchick et al. 2010); we assign them to the revised Quock Formation. Three radiolarian samples range from Early Bajocian to Callovian in age (Fig. 10). The unit includes numerous calcareous concretions, occasional wavy parallel laminations, and convolute slump structures. A 2 m lenticular unit of dark grey limestone with complex boundstone textures was observed near the top of the unit (Waldron et al. 2006). The limestone includes shell fragments and is locally bioturbated (Fig. 14). Even though freshly broken pieces smell of bitumen, Rock-Eval data suggest that almost all the initial hydrocarbon content was removed by oxidation and (or) high thermal maturity. Similar results, for laterally equivalent strata, led Ferri and Boddy (2005) to suggest that these units were a rich source rock prior to thermal maturation.

The gradationally overlying shale and turbiditic sandstone of the Ritchie-Alger assemblage of the Bowser Lake Group (Fig. 13B) contains fossils of Middle Jurassic or Oxfordian age. The overlying Muskaboo Creek assemblage contains Upper Oxfordian to Lower Kimmeridgian bivalves (Evenchick et al. 2001).

New stratigraphic framework

The Hazelton Group rocks located outside the Eskay rift can be broadly divided into a lower volcanic-dominated suite and an upper sedimentary-dominated suite (Tipper and Richards 1976; Evenchick et al. 2009). Several authors (Ferri et al. 2004; Evenchick and Thorkelson 2005; Waldron et al. 2006; Gagnon et al. 2007; Evenchick et al. 2010) informally used the term "upper Hazelton Group clastic rocks" when referring to sedimentary units of the Spatsizi, Salmon River, Smithers, or Nilkitkwa formations. Based on mapping relationships in the Oweegee Range, Todagin Mountain, and Joan Lake areas, in this study and previous work (e.g., Tipper

Fig. 14. Dark grey fossiliferous limestone located near the top of the Hazelton Group (285 m in Fig. 13B). (A) Complex boundstone textures. Measuring tape for scale is in centimetres. (B) Large-format thin section showing the diversified fossils, including belemnites (Be.), gastropod (Ga.), and bivalve shell fragments (Bi.).



and Richards 1976, Thomson et al. 1986, Marsden and Thorkelson 1992, Gagnon et al. 2007), the base of the upper Hazelton Group is marked by a widespread unconformity. Underneath this erosional surface, undivided intermediate volcanic lavas and associated volcaniclastic rocks and lahars were assigned to the lower Hazelton Group (Waldron et al. 2006; Gagnon et al. 2007). A new stratigraphic framework (Fig. 15) is here proposed based on this informal division of the group into the lower and upper Hazelton Group.

In contrast, within the Eskay rift the upper Hazelton Group comprises predominantly bimodal volcanic rocks; they are separated by an unconformity from older predominantly intermediate volcanic rocks of the lower Hazelton Group, the Triassic Stuhini Group, and the Paleozoic Stikine assemblage.

Lower Hazelton Group

The lower Hazelton Group comprises a wide range of lithologies dominated by maroon and green calc-alkaline andesitic to dacitic flows, associated volcanic breccias and tuffs, and sedimentary volcaniclastic rocks. It includes the Telkwa, Jack, Unuk River, Betty Creek, Mount Dilworth, and Toodoggone formations and the Griffith Creek and Cold Fish volcanics of previous authors (Figs. 2, 15). They rest unconformably above the Triassic volcanic rocks of the Stuhini Group (and equivalents) and, in some localities, Paleozoic rocks of the Stikine assemblage. The upper boundary of the lower Hazelton Group is typically defined by an erosional surface that separates it from the overlying upper Hazelton Group. The cluster of U–Pb ages at 190–200 Ma obtained from volcanic rocks of the Stuhini, Telkwa, and Toodoggone formations, and from the Cold Fish Volcanics, confirm that the main stage of lower Hazelton Group volcanism was contemporaneous (Hettangian–Sinemurian) across the Stikine terrane (Greig and Gehrels 1995; Thorkelson et al. 1995; Gareau et al. 1997; Duuring et al. 2009). Most volcanic rocks of the lower Hazelton Group are calc-alkaline to tholeiitic and have strong arc signatures (Tipper and Richards 1976; Anderson and Thorkelson 1990; Diakow et al. 1991; Thorkelson et al. 1995; Logan et al. 2000). Most of these units were deposited in subaerial, oxidizing environments, and likely built stratovolcanoes on an evolving arc system (Alldrick et al. 1989). An exception is the Cold Fish Volcanics, which have a bimodal geochemical signature interpreted as a product of extensional volcanism in a back-arc setting (Thorkelson et al. 1995). Discontinuous siltstone beds bearing Hettangian to Upper Sinemurian ammonites highlight the marine setting of the emergent arc.

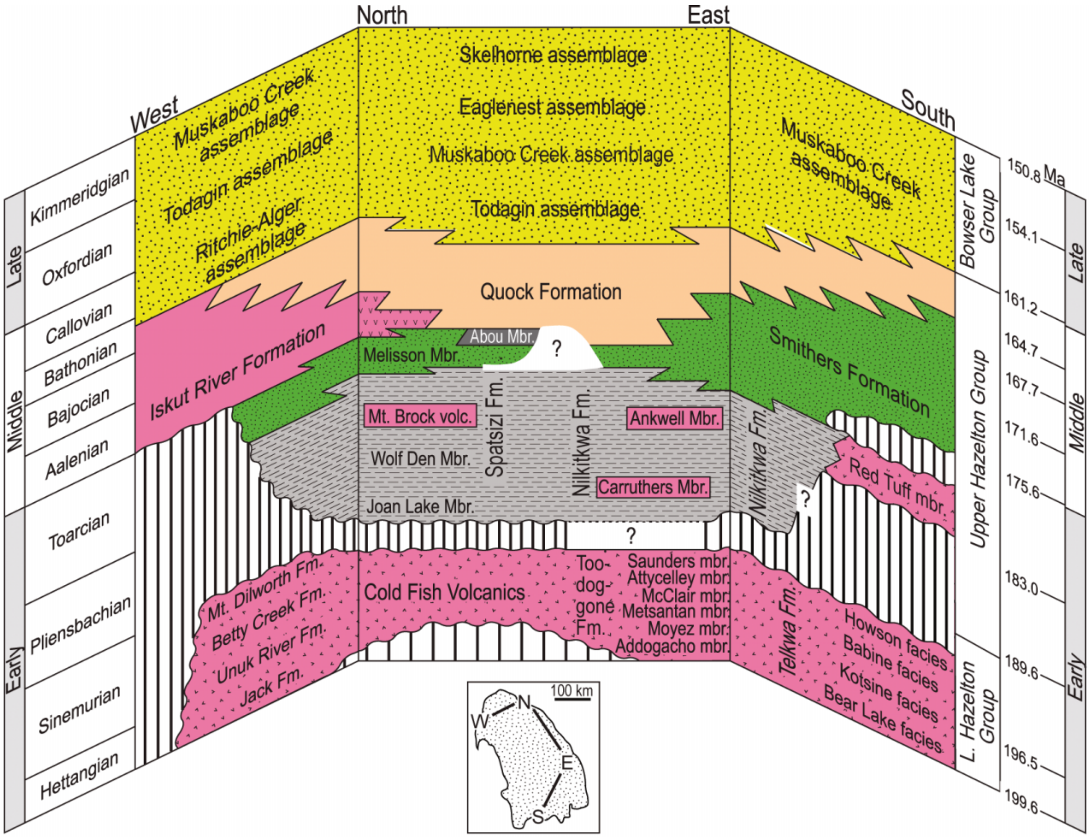
Upper Hazelton Group

Because of their greater lateral continuity and their relatively constant thickness, sedimentary units of the upper Hazelton Group are more traceable regionally than the volcanic units associated with the lower Hazelton Group. Three major stratified packages are recognized: the mainly sedimentary Smithers Formation and its equivalents, the overlying siliceous mudstones and thinly bedded tuffs of the Quock Formation, and the Eskay rift volcanic assemblage in the northwest, here named the Iskut River Formation.

Smithers Formation and equivalents

A recognizable lower package includes strata of the Smithers and Nilkitkwa formations, along with specific units assigned to the Spatsizi (Joan, Wolf Den, and Melisson members) and Salmon River (lower calcareous member) formations (Fig. 2). These units are here assigned to three formations: the Smithers and Nilkitkwa formations, and the revised Spatsizi Formation (Fig. 15, and later in the text). The unconformity at the base of these successions marks the boundary between the lower and upper Hazelton Group. In most parts of the basin, this unconformity is overlain by 1–5 m thick clast-supported conglomerate that fines upward into cross-bedded, coarse- to medium-grained sandstone, as seen at sections QM, JL, W1, W2, OW, and OA (Figs. 7A, 8A, 8B, 13A, 13B). One exception to the overall clastic

Fig. 15. Proposed stratigraphic nomenclature for the Hazelton Group exposed in the north-central Stikine terrane. Most significant changes include recognition of a diachronous unconformity at the base of the upper Hazelton Group, revision of the Spatsizi and Quock formations, and introduction of a new stratigraphic unit (Iskut River Formation) for the rift-related facies in the Iskut River area. Time scale of Ogg (2004).



nature of this package is the Toarcian Red Tuff Member of the Nilkitkwa Formation, which disconformably overlies lithologically similar red dacitic tuffs of the Sinemurian Telkwa Formation in sections AR and QM, and is in turn unconformably overlain by clastic units of the Smithers Formation.

For the most part, however, the three lower formations of the upper Hazelton Group, in part laterally equivalent, consist of interbedded tuffaceous siltstone and sandstone layers containing abundant marine fossils and trace fossils. These units are diachronous, ranging from Lower Pliensbachian – Upper Toarcian in the north to Lower Aalenian – Upper Bathonian in the south (Fig. 3). In the east, near the Nilkitkwa Range, there is a gradational lateral facies change northward from coarser clastics to finer-grained sedimentary rocks interbedded with mafic volcanics. This is attributed to deposition in a deeper-water setting with ongoing extensional volcanism, consistent with Tipper and Richards' (1976) definition of the "Nilkitkwa depression" as the main axis to the Hazelton trough. Deeper parts of the depression developed anoxic conditions and accumulated sediment rich in organic matter, preserved locally in the Nilkitkwa Formation and in the Wolf Den and Abou members of the revised Spatsizi Formation. In almost all the observed and compiled stratigraphic sections, units of the Smithers Formation and equivalents are overlain by thinly bedded siliceous mudstone and tuffaceous siltstone here assigned to the Quock Formation.

No type locality has been described for the Smithers Formation, and the reference sections measured by Tipper and Richards (1976) are incomplete. We propose section QM as the new stratotype (Figs. 7A, 7B). Based on our observations, this section meets all the necessary criteria established by the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature 2005) to serve as a type section (Table 1A).

In the eastern portion of the basin, the Nilkitkwa Formation type section described by Tipper and Richards (1976) is retained. Although individual units within the Nilkitkwa Formation are laterally continuous with some strata of the Smithers and revised Spatsizi formations, they are sufficiently different in lithology to merit separate formal designation. The stratotype proposed by Tipper and Richards (1976) contains interbedded basaltic flows, argillite, and sandstone, which are characteristic of this part of the basin.

The Nilkitkwa Formation is also retained in the southwestern part of the basin (Ashman Ridge – Quinlan Mountain). The Red Tuff Member is a thin but continuous blanket of fine-grained lithic tuff that in part is characterized by the presence of bombs. It represents an explosive eruption or eruptions in Middle Toarcian time that mark the last phase of arc volcanism in the area. It is significant that this postdates the end of lower Hazelton arc volcanism farther north by 10–20 million years.

A unit rich in thinly interbedded silicified tuffs and mudstones (revised Quock Formation) overlies the Smithers and Nilkitkwa formations in all measured sections (Fig. 3). This poses a problem in existing stratigraphic schemes, because

Table 1. Definitions of new stratigraphic units.

A. Smithers Formation

1. Named by Tipper and Richards (1976) after the town of Smithers, British Columbia, located ~60 km east of the proposed type section.
2. Lithological characteristics: bioturbated tuffaceous and calcareous siltstone and sandstone with abundant marine fossils.
3. Thickness at type section: 240 m.
4. Lower contact: unconformable above the oxidized tuffs of the Red Tuff Member of the Nilkitkwa Formation. Boundary defined at the base of a basal conglomerate fining upward into cross-bedded medium- to coarse-grained sandstone (UTM zone 9 555130 E 6077435 N).
5. Upper contact: conformable, defined by a fining-upward trend and gradational transition into units of the revised Quock Formation (see part B). The boundary is placed at the first occurrence of thinly interbedded siliceous siltstones and fine pale tuffaceous laminae ("pyjama beds") (UTM 554870 E 6078650 N).
6. Age: extensive fossil collections indicate an age from Middle Aalenian to Upper Bathonian (see supplementary data[2]).

B. Quock Formation

1. Named by Thomson et al. (1986) for Mount Quock, ~1 km east of the type section. Equivalent to Quock member of Evenchick and Thorkelson (2005).
2. Lithological characteristics: thinly bedded, dark siliceous blocky mudstone and rusty-weathering tuff bands ("pyjama beds"). Thin section observations show abundant recrystalized radiolarian tests in the mudstone intervals as well as ferruginous clay. The tuff bands are characterized by angular volcanic fragments and feldspar grains, in addition to white micas and chlorite. Calcareous concretionary lenses and thin limestone beds are occasionally found throughout this unit. Discontinuous exposures of calcareous to siliceous dark shale outcropping in the lower portion of the section are included in the Quock Formation as the Abou Member.
3. Thickness at type section: 200 m.
4. Lower contact: as defined by Thomson et al. (1986); conformable and gradational contact above the uppermost bioturbated sandstone of the revised Spatsizi Formation (Melisson Member) (UTM 507560 E 6372125 N).
5. Upper contact: as defined by Thomson et al. (1986); conformable and gradational with the thinly bedded fissile siltstone and shale of the Bowser Lake Group (Todagin assemblage) (UTM 505685 E 6373530 N).
6. Age: Bajocian, possibly Upper Aalenian at type section; regionally, the base of the formation may be as low as Late Toarcian, and the top may be as high as Lower Oxfordian (see supplementary data[2]).

C. Iskut River Formation

1. Named for Iskut River, the largest tributary of the Stikine River, British Columbia, which lies ~5 km east of the type section. The name of this river was previously informally applied to a Quaternary flow as Iskut River lava by Kerr (1948); also, MacIntyre et al. (1994) used the term "Iskut River stock" as an informal lithodemic term. Neither of these terms has found widespread use outside the original publications.
2. Lithological characteristics: thick volcanic piles of pillow basalt and pillow basalt breccia interbedded with intervals of rhyolite, conglomerate, and minor mudstone and dust tuff ("pyjama beds") (Fig. 12).
3. Thickness at type section: at least 3480 m.
4. Lower contact: angular unconformity along the ancient graben margin at which various stratigraphic levels of the Iskut River Formation onlap against the lower Hazelton Group; at the best exposed part of the contact (UTM 415200 E 6352500 N), rhyolite of the Iskut River Formation rests above feldspar porphyritic andesite breccia of the lower Hazelton Group. The disconformable boundary at Eskay Creek (UTM 416800 E 6279000 N) is designated as a reference section to define the lower contact to the east, in the basin (Fig. 11C). At this location, rhyolite of the Iskut River Formation is in contact with Upper Pliensbachian volcaniclastic rocks and felsic welded lapilli tuff of the lower Hazelton Group.
5. Upper contact: not observed in outcrop but closely constrained with the overlying siliciclastic rocks of the Bowser Lake Group (UTM 420000 E 6370000 N). However, structural discordance suggests that the contact may be faulted. In the reference section at Eskay Creek (Fig. 11C) the Iskut River Formation is in conformable contact with thinly bedded siliceous mudstones and very thin tuff beds of the overlying Quock Formation.
6. Age: Upper Toarcian to Lower Bajocian fossils have been obtained from thin shale units here included in the Iskut River Formation (Souther 1972; Evenchick et al. 2001; see supplementary data[2]). However, undated lower and higher parts of the formation could range as old as Early Toarcian and as young as Late Bajocian.

Note: Grid references are Universal Transverse Mercator coordinates in the North American datum 1983.

when correlated to the northern part of the basin, this lithology has been included in the Spatsizi Formation as the Quock Member (Thomson et al. 1986; Evenchick and Thorkelson 2005). We propose removing the Quock unit from the Spatsizi Formation and revision of that formation to include only the lower three members (Joan, Wolf Den, and Melisson), justified under article 19 of the North American Commission on Stratigraphic Nomenclature (2005), as a minor change to make the unit more natural for common usage. The lowest three members of the Spatsizi Formation are lithostratigraphic lateral equivalents of the Nilkitkwa and lower Smithers formations (Fig. 3).

In the Iskut River area, the Salmon River Formation of previous authors presently includes a Lower Toarcian member of bioclastic calcareous sandstone and siltstone, an Aalenian–Bajocian member mainly comprising thinly bedded tuffs and mudstones (Troy Ridge facies) equivalent to the Quock Formation, and bimodal volcanic flows (Eskay Creek facies). Furthermore, refinements and redefinitions of the Salmon River Formation in the last two decades (Anderson and Thorkelson 1990; Anderson 1993; Macdonald et al. 1996) considerably changed the scope of the formation from the original description of Schofield and Hanson (1921), such that its type area, defined by Grove (1986), is no longer valid. In addition, its type section near Mount Dilworth actually includes sedimentary rocks of the Bowser Lake Group (Evenchick and McNicoll 2002; Gagnon and Waldron 2011; Waldron and Gagnon 2011) and lacks the pillow basalt which is a major component of the Salmon River Formation at Eskay Creek (Macdonald et al. 1996; Logan et al. 2000; Alldrick et al. 2004*b*, 2005; Barresi et al. 2005). To prevent any further confusion, we recommend the abandonment of the Salmon River Formation following article 20 of the North American Commission on Stratigraphic Nomenclature (2005).

As an alternative, we propose the following changes:

- inclusion of the Toarcian bioclastic calcareous lower member in the revised Spatsizi Formation;
- inclusion of the Troy Ridge facies in the Quock Formation;
- inclusion of the volcanic-dominated successions in a new unit, named here the Iskut River Formation (see later in the text).

Quock Formation

This study recognizes thinly interlayered grey to black siliceous siltstone and beige to pink dust tuff (“pyjama beds”) at similar stratigraphic positions across the basin (Fig. 3), between the underlying Smithers Formation and equivalents, and the overlying Bowser Lake Group. In the north and west parts of the basin, these strata were assigned to the Troy Ridge facies of the former Salmon River Formation, and they are the only strata of that formation recognized outside the Iskut River area (Anderson and Thorkelson 1990; Greig 1991, 1992; Marsden and Thorkelson 1992; Anderson 1993; Evenchick and Porter 1993; Jakobs 1993; Ferri et al. 2004; Evenchick and Thorkelson 2005; Ferri and Boddy 2005; Waldron et al. 2006; Gagnon et al. 2007; Gagnon and Waldron 2008, Evenchick et al. 2010). Elsewhere, equivalent strata have been assigned to the Yuen and Bait members of the Smithers Formation (Tipper and Richards 1976) or the Quock Formation (Thomson et al. 1986). We follow Thomson et al. (1986) in considering the Quock to have formation rank, with its original type section at Joan Lake (JL) as the unit stratotype (Table 1B; see article 19e of North American Commission on Stratigraphic Nomenclature 2005). Outside the Eskay rift area (Fig. 3), the lowest occurrence of laminated siliceous and tuffaceous siltstone defines the base of the formation. Its top is at the contact with the overlying Bowser Lake Group, as redefined by Evenchick et al. (2010). However, in the Iskut River area, the characteristic siliceous mudstone and tuff lithologies interfinger laterally with thick sections of bimodal volcanic rock (Fig. 4). There, the mudstones interbedded with thick flows of volcanic rock are included in the proposed Iskut River Formation, and only the uppermost package, dominated by laminated siliceous and tuffaceous siltstones, is included in the Quock Formation.

Iskut River Formation

With assignment of the calcareous bioclastic lower facies to the revised Spatsizi Formation, and the upper Troy Ridge facies to the Quock Formation, the remaining, dominantly volcanic facies of the current Salmon River Formation requires a lithostratigraphic name; we propose the new Iskut River Formation.

At many locations close to graben-bounding faults, the lower contact of the Iskut River Formation appears to be an angular unconformity where fan conglomerates are juxtaposed on or against various units of the lower Hazelton Group, Stuhini Group, or Stikine assemblage. In a few locations, the lower part of the formation is exposed farther from the graben margin such that the conglomerates grade laterally into distal very fine-grained sedimentary rocks with intercalated tuff, and bimodal volcanics including rhyolite and voluminous tholeiitic basalt (Alldrick et al. 2005; Barresi et al. 2005). At Eskay Creek, rhyolite of the Iskut River Formation disconformably overlies Upper Pliensbachian volcaniclastic rocks and felsic welded lapilli tuff of the lower Hazelton Group (Fig. 11C). The upper contact of the Iskut River Formation is typically conformable with either the Quock Formation or siliciclastic strata of the Bowser Lake Group. Since section TM is the thickest and includes the greatest variety of lithologies, we proposed it as the stratotype for the Iskut River Formation (Figs. 11A, 11B; Table 1C). The base of the formation is placed where feldspar-phyric andesite breccia of the lower Hazelton Group is overlain by rhyolite, which is heavily altered at this locality. Because the lower contact is along a contemporaneous faulted graben margin, section EC is designated as a reference section to define the disconformable lower contact farther into the basin.

Discussion: stratigraphic and tectonic evolution

Marsden and Thorkelson (1992) proposed that Early Jurassic arc volcanism in Stikinia was generated by concurrent subduction on opposite sides of the Stikine terrane. One involved a well-documented, east-facing subduction of the Cache Creek oceanic basin on the east side of the Stikine terrane; the other, more speculative, west-facing subduction of oceanic lithosphere on the west side (directions in present-day coordinates). In the northern Hazelton trough (e.g., sections JL, W1, W2), the bimodal Upper Sinemurian to Lower Pliensbachian Cold Fish Volcanics accumulated in the back-arc area of a magmatic arc represented by calc-alkaline volcanic rocks of the Toodoggone Formation to the east (Diakow et al. 1991; Thorkelson et al. 1995). Farther north, English and Johnston (2005) interpreted the Whitehorse trough as an elongated sedimentary basin that originated in a fore-arc setting located between the arc magmatic rocks of Stikinia and the accretionary complex of the Cache Creek terrane.

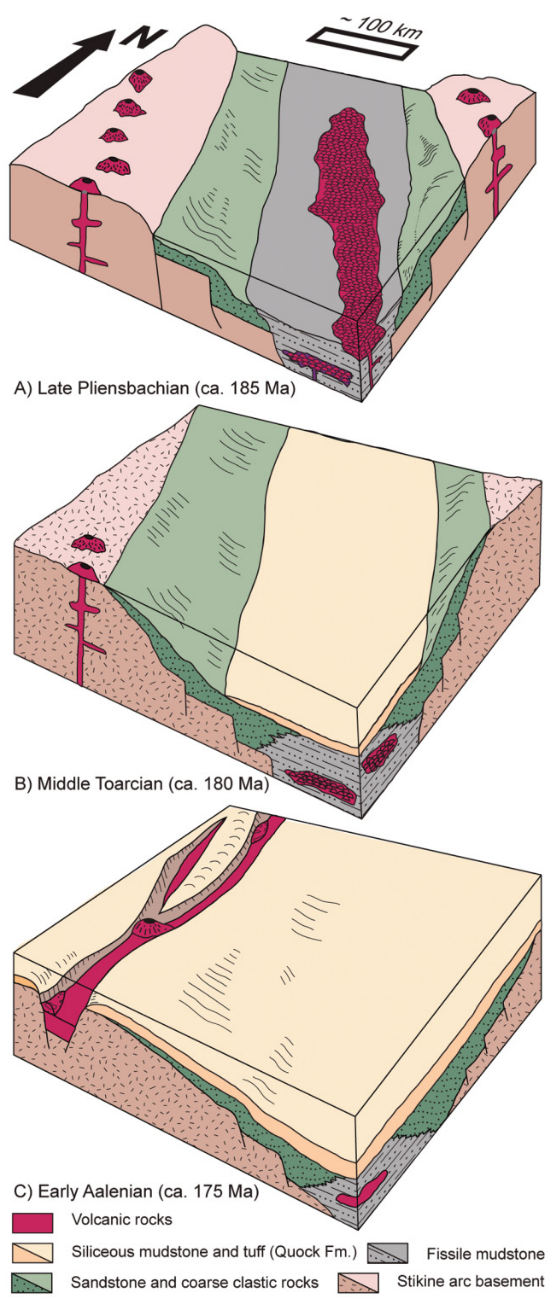
The base of the upper Hazelton Group marks the transition from a volcanic arc to a post-arc tectonic environment in northern Stikinia. Stratigraphic cross-sections shown in Figs. 3 and 4 highlight the variable character and diachronous nature of the lower–upper Hazelton Group boundary, which ranges from Early Pliensbachian in the north to Early Aalenian in the south (Fig. 15). The end of Hazelton volcanism is much less diachronous in an E–W direction: the two separate arcs proposed by Marsden and Thorkelson (1992) both ceased activity during the Pliensbachian. The last vestige of arc-related volcanism is represented only in the far southwestern part of the study area by the Toarcian Red Tuff Member of the Nilkitkwa Formation. Southerly migration of the arc axis then continued with the renewal of magmatic activity in the Whitesail (Diakow 2006) and Bella Coola (Diakow et al. 2002) areas of southern Stikinia in Bajocian and Bathonian time.

The stratigraphic data presented in this paper show that the upper Hazelton Group includes both regionally extensive, mainly sedimentary units exposed around the margins of the Bowser Basin (Spatsizi, Smithers, and Quock formations), and the areally restricted and lithologically highly variable Iskut River Formation, which is the fill of a narrow, well-defined rift at the western margin of the Bowser Basin.

Apart from the Iskut River Formation, most of the upper Hazelton Group represents a zone of regional, post-arc subsidence, controlled in part by the pre-existing paleogeography of the Hazelton trough and its elevated margins. The subsidence profile obtained by Gagnon et al. (2009) in the northwest portion of the Hazelton trough and subsequent Bowser Basin indicates that extensional faulting and thermal contraction of the crust were responsible for high subsidence rates during the Pliensbachian. These results are consistent with the crustal subsidence model of Thorkelson et al. (1995), who proposed that accumulation of a thick volcanic pile in the lower Hazelton Group in the Spatsizi River area was accompanied by at least 2 km of synvolcanic subsidence. A protracted period of volcanism during the Late Sinemurian resulted in the abundant bimodal volcanic lava of the Cold Fish Volcanics (Marsden and Thorkelson 1992; Thorkelson 1992; Thorkelson et al. 1995) and the thick Telkwa Formation (Tipper and Richards 1976). Subsequent thermal contraction of the lithosphere resulted in widespread subsidence of the Hazelton trough. Progressive reduction of volcanic activity after Sinemurian time (Fig. 16A) involved a few basaltic eruptions restricted to the Nilkitkwa depression (i.e., Mount Brock volcanics, Ankwell and Carruthers members). Exponentially decreasing thermal subsidence through the Middle Jurassic is suggested by the concave-up profile of the backstripped tectonic subsidence curve (Gagnon et al. 2009). This was followed by more rapid subsidence due to loading by clastic sediment derived from the Cache Creek terrane in the Late Jurassic.

The paleogeography established in Stikinia during development of the lower Hazelton Group, consisting of two arcs separated by a central trough, influenced subsequent crustal evolution. The lower–upper Hazelton Group contact appears conformable in the central part of the Hazelton trough (Fig. 3), where Lower Pliensbachian sedimentary rocks of the Nilkitkwa Formation directly overlie marine volcanic rocks of the Telkwa Formation (Tipper and Richards 1976). Elsewhere, outside the main trough axis, the base of the upper Hazelton Group is an unconformable surface but is somewhat diachronous (Figs. 3, 4). In the Spatsizi River area, Lower Pliensbachian shallow-marine sedimentary rocks of the Joan Member disconformably overlie the subaerial Cold Fish Volcanics, whereas a Toarcian hiatus has been reported in the Toodoggone, Iskut, Smithers, and Terrace areas (Diakow et al. 1991; Anderson 1993; Greig and Gehrels 1995; Waldron et al. 2006; Gagnon et al. 2007; Nelson et al. 2007). In this study, we recognize a 10–20 Ma hiatus at sections AR and QM separating the Sinemurian Telkwa

Fig. 16. Conceptual block diagrams showing the interpreted depositional environment of the upper Hazelton Group in the Early to Middle Jurassic. Scale very approximate and vertically exaggerated. (A) In the Pliensbachian (185 Ma), mafic volcanism and deep-water sedimentation dominated the central portion of the Hazelton trough, while coarser clastic rocks accumulated on the margins. (B) In the Toarcian (180 Ma), progressive decrease in volcanic activity led to thermal subsidence of the Stikine terrane and relative sea-level rise. Siliceous mudstone and tuff of the Quock Formation began to accumulate in the central portion of the trough. (C) In the Aalenian (175 Ma), mudstone and tuff (younger Quock Formation) were deposited throughout the basin while back-arc extension in the Iskut River area led to accumulation of rift-related facies of the Iskut River Formation.



Formation and the Toarcian Red Tuff Member of the Nilkitkwa Formation.

Stratigraphic cross-sections shown in Figs. 3 and 4 highlight the variability and diachronous nature of the lower–upper Hazelton Group boundary. Although development of a graben structure ensured continuous marine deposition within the Nilkitkwa depression, the rift margins of the Hazelton trough underwent periodic uplift and erosion (Tipper and Richards 1976).

Thermally subsiding volcanic remnants on the periphery of the graben were progressively submerged, to be overlain by transgressive shallow-water sedimentary rocks of the Smithers Formation and equivalents. This is a common feature in extensional settings such as back-arcs and continental rifts, where graben flanks become subaerially exposed in response to block tilting, and can lead to development of localized unconformities (cf. Baker et al. 1972; Kusznir and Egan 1990; Ebinger et al. 1991; Lin et al. 2003).

The diachronous nature of the lower–upper Hazelton Group transition reflects differential subsidence rates that affected the Hazelton arc during the Early to Middle Jurassic, linked to variations in the timing of the end of major volcanic activity. In depocentres characterized by intense volcanism and extensional faulting, onlap of the unconformity by shallow-marine sedimentary rocks occurred immediately after cessation of back-arc activity. This is attributed to greater post-rift subsidence rates in areas where the initial amount of lithospheric stretching was more significant (cf. McKenzie 1978; Steckler and Watts 1978). Where sedimentation around slower-subsiding areas began later, marine transgression reached its maximum extent around the Toarcian–Aalenian boundary (Fig. 16B), and a maximum flooding surface occurs close to the base of the Quock Formation.

The fine grain size and thinly bedded nature of the Quock Formation, combined with the high organic content in its mudstone components (total organic content values up to 6%, Ferri and Boddy 2005), suggest that it was deposited mainly from suspension in a deep-water, anoxic environment. These regionally extensive, condensed sections form a basin-wide stratigraphic marker near the top of the Hazelton Group (Fig. 3). The long time interval demonstrated by fossil data from the Quock Formation at Diagonal Mountain (DM) indicates that tuff and siliceous mudstone accumulated there in a deep basin setting over a protracted period (Late Toarcian to Early Oxfordian) (Evenchick and Porter 1993; Jakobs 1993; Evenchick et al. 2001, 2010).

In the Iskut River area, extension-controlled volcanism prevailed in an elongate, narrow, north-trending rift basin during a short period, from Late Toarcian to Early Bajocian time (Fig. 4). Fault-controlled subsidence led to compartmentalization of at least 12 north-trending sub-basins within the 300 km long by 50 km wide volcanic belt of the Eskay rift (Alldrick et al. 2005; Barresi et al. 2008; Fig. 16C). The irregular topography of the rift basement, characterized by depocentres and uplifted horst footwall blocks, hampers stratigraphic correlations within the Iskut River Formation. Volcanic and sedimentary units show great lateral and vertical variability because of the limited connectivity between sub-basins and the local nature of the volcanic processes. Nearly uninterrupted successions of pillow basalt up to 2 km thick (sections PB and TB) suggest rapid extrusion and basin filling, whereas other sub-basins (e.g., Eskay Creek and Treaty Glacier) have a higher proportion of fine-grained sedimentary rock and lack thick basaltic flows (Fig. 4). Intense volcanic activity above local feeder zones dominated the background accumulation of basinal tuffaceous mudstone successions in some places. Rare thin tuffaceous mudstone intervals between basaltic flows attest to lulls in volcanic activity and help link the Iskut River Formation with equivalent condensed successions (Quock Formation) elsewhere in the region. Such quiescent depositional environments were more prone to accumulation and preservation of exhalative sulphides (Alldrick et al. 2004*b*). Felsic volcanism is closely associated with mudstone intervals within the Eskay rift and is the most likely source of Aalenian-Bajocian tuffaceous intervals in the Quock Formation regionally.

Rift-related, bimodal volcanism in the Iskut area has been interpreted to have occurred in a back-arc setting (cf. Macdonald et al. 1996). However, this resurgence of extension and volcanism occurred 10–15 million years after the significant decline of arc activity in all but southern regions of the Hazelton trough. Even in the southern area of sections AR and QM, arc volcanism ended in the Toarcian, at about the same time as the inception of the Eskay rift and the beginning of the volcanic activity represented by the Iskut River Formation. Geometrically the north-trending Eskay rift (Fig. 1) does not appear to be related to the remnant "Red Tuff" arc of the southern sections. The Eskay rift and the Iskut River Formation therefore probably represent an independent rifting episode. In addition, the short duration of this episode (~178–168 Ma) overlaps in time with final amalgamation of Stikinia and the Cache Creek subduction complex. This deformational event is well constrained by the age of the youngest blueschists in the Cache Creek terrane (173.0 ± 0.8 Ma; Mihalynuk et al. 2004) and by the age of the oldest post-kinematic intrusions that stitched the two domains together (ca. 172 Ma; Mihalynuk et al. 1992; Bath 2003). The Alexander terrane to the southwest also became accreted to Stikinia during this interval (van der Heyden 1992; Gehrels 2001). The Eskay rift and the Iskut River Formation may therefore reflect radical plate reorganization during terrane accretion that possibly led to transcurrent shearing across Stikinia (Nelson and Colpron 2007). This would explain their unique character in a region in which post-arc thermal subsidence and mild lithospheric thinning prevailed.

Conclusions

The Hazelton Group can be divided in two distinct intervals separated by an unconformity in most places. The lower Hazelton Group is dominated by arc-related volcanic rocks, whereas the upper Hazelton Group contains mainly fine-grained clastic rocks, geographically limited bimodal rift-related volcanic rocks, and, in the far southwest of the study area, a short-lived arc-derived unit, the Red Tuff Member. An abrupt decline of volcanic activity, following back-arc rifting in the Sinemurian, led to widespread thermal subsidence of the magmatic arc and Pliensbachian initiation of sedimentation in the Hazelton trough. Thick mudstone-dominated successions (Nilkitkwa Formation and most of the revised Spatsizi Formation) accumulated in the central portion of the trough, which was locally characterized by anoxic conditions and accumulation of sediment rich in organic matter, whereas the topographically higher margins were loci of shallow marine deposition of coarser-grained clastic sediments rich in volcanic detritus (Smithers Formation and parts of the revised Spatsizi Formation). Progressive onlap of the unconformity by lowermost strata of the upper Hazelton Group was diachronous at the basin scale and reflects differential subsidence rates across the Stikine terrane. Ongoing relative rise in sea level led eventually to accumulation of siliceous mudstone and tuff of the Quock Formation above a maximum flooding surface in deep basinal conditions at the Toarcian – Aalenian boundary. Regionally, the Quock Formation constitutes an excellent, albeit diachronous, stratigraphic marker characterized by moderate to high organic content, which, under a suitable thermal regime, would have been favourable for generation of hydrocarbons. Laterally equivalent bimodal volcanic rocks of the Iskut River Formation in the northwest portion of the basin contain gold-bearing massive sulphide deposits. The northern Stikine terrane was affected by two independent rifting events during deposition of the Hazelton Group: a widespread Late Sinemurian to Early Pliensbachian extension phase in the northwest-trending Hazelton trough, and a much more focussed and intense Aalenian to Bajocian extensional event in the north-trending Eskay rift, recorded in the Iskut River volcanics. Recognizing the distinctiveness of these independent events is important for tectonic models of the evolution of Stikinia and for predictive models in mineral and hydrocarbon exploration.

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References

Alldrick, D.J. 1993. Geology and metallogeny of the Stewart mining camp, northwestern British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, Report 85.

Alldrick, D.J., Britton, J.M., Webster, I.C.L., and Russell, C.W.P. 1989. Geology and mineral deposits of the Unuk area. British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1989-10.

Alldrick, D.J., Stewart, M.L., Nelson, J.L., and Simpson, K.A. 2004*a*. Geology of the More Creek - Kinaskan Lake area, northwestern British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File Map 2004-2.

Alldrick, D.J., Stewart, M.L., Nelson, J.L., and Simpson, K.A. 2004*b*. Tracking the Eskay Rift through northern British Columbia - geology and Mineral occurrences of the Upper Iskut River area. *In* Geological Fieldwork 2003. British Columbia Ministry of Energy and Mines, Paper 2004-1, pp.1–18.

Alldrick, D.J., Nelson, J.L., and Barresi, T. 2005. Geology and mineral occurrences of the Upper Iskut River Area: tracking the Eskay rift trough northern British Columbia (Telegraph Creek NTS 104G/1, 2; Iskut River NTS 104B/9, 10, 15, 16). *In* Geological Fieldwork 2004. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 2005-1, pp. 1–30.

Alldrick, D.J., Nelson, J.L., Barresi, T., Stewart, M.L., and Simpson, K.A. 2006. Geology of the Upper Iskut River Area, British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File Map 2006-2.

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. *Edited by* G. Dunne and K. McDougall. Society of Economic Paleontologists and Mineralogists, Pacific Section, 71, pp. 477–494.

Anderson, R.G., and Thorkelson, D.J. 1990. Mesozoic stratigraphy and setting for some mineral deposits in Iskut River map area, northwestern British Columbia. *In* Current research. Geological Survey of Canada, Paper 90-1E, pp. 131–139.

Armstrong, J.E. 1944. Smithers, British Columbia. Geological Survey of Canada, Paper 44-23.

Armstrong, R.L. 1988. Mesozoic and early Cenozoic magmatic evolution of the Canadian Cordillera. *In* Processes in continental lithospheric deformation. *Edited by* S.P. Clark Jr., B.C. Burchfiel, and J. Suppe. Geological Society of America Special Paper 218. pp. 55–91.

Baker, B.H., Mohr, P.A., and Williams, L.A.G. 1972. Geology of the Eastern Rift System of Africa. Geological Society of America Special Paper 136.

Barresi, T., and Dostal, J. 2005. Geochemistry and Petrography of Upper Hazelton Group volcanics: VHMS-Favourable Stratigraphy in the Iskut River and Telegraph Creek Map Areas, Northwestern British Columbia. *In* Geological Fieldwork 2004. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 2005-1, pp. 39–47.

Barresi, T., Nelson, J.L., Alldrick, D.J., and Dostal, J. 2005. Pillow Basalt Ridge Facies: Detailed mapping of Eskay Creek-Equivalent Stratigraphy in Northwestern British Columbia. *In* Geological Fieldwork 2004. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 2005-1, pp. 31–38.

Barresi, T., Dostal, J., and Nelson, J. 2008. Metallogenic and tectonic significance of mafic volcanism in the Early to Middle Jurassic Hazelton Group, northwestern British Columbia. Atlantic Geology, **44**: 2–4.

Barrett, T.J., and Sherlock, R.L. 1996. Geology, Lithogeochemistry and Volcanic Setting of the Eskay Creek Au-Ag-Cu-Zn Deposit, Northwestern British Columbia. Exploration and Mining Geology, **5**: 339–368.

Bartsch, R.D. 1993. A rhyolite flow dome in the upper Hazelton Group, Eskay Creek area (104B/9, 10), British Columbia. *In* Geological Fieldwork 1992. Ministry of Energy, Mines and Petroleum Resources, Paper 1993-1, pp. 331–334.

Bath, A. 2003. Middle Jurassic granitic plutons within the Cache Creek terrane and their aureoles: implications for terrane emplacement and deformation. *In* Geological Fieldwork 2002. Ministry of Energy, Mines and Petroleum Resources, Paper 2003-1, pp. 51–55.

BC Geological Survey. 2008. MINFILE Record Summary 104B 008.

Available from http://minfile.gov.bc.ca/Summary.aspx?minfilno=104B++008 [accessed 19 February 2012]

Bromley, R.G., and Ekdale, A.A. 1984. *Chondrites*: A Trace Fossil Indicator of Anoxia in Sediments. Science, **224**(4651): 872–874. doi:10.1126/science.224.4651.872. PMID:17743196.

Brown, D.A., Logan, J.M., Gunning, M.H., Orchard, M.J., and Bamber, W.E. 1991. Stratigraphic evolution of the Paleozoic Stikine assemblage in the Stikine and Iskut rivers area, northwestern British Columbia. Canadian Journal of Earth Sciences, **28**(6): 958–972. doi:10.1139/e91-087.

Childe, F.C. 1996. U-Pb geochronology and Nb and Pb isotope characteristics of the Au-Ag-rich Eskay Creek volcanogenic massive sulfide deposit, British Columbia. Economic Geology and the Bulletin of the Society of Economic Geologists, **91**(7): 1209–1224. doi:10.2113/gsecongeo.91.7.1209.

Cordey, F., Greig, C.J., and Orchard, M.J. 1991. Permian, Triassic, and Middle Jurassic microfaunal associations, Stikine terrane, Oweegee and Kinskuch areas, northwestern British Columbia. *In* Current Research. Geological Survey of Canada, Paper 92-1E, pp. 107–116.

Dawson, G.M. 1877. Report on explorations in British Columbia. Geological Survey of Canada.

Diakow, L.J. 2006, Geology of the Tahtsa Ranges between Eutsuk Lake and Morice Lake, Whitesail map area, west-central British Columbia; BC Geological Survey Open-File Map 2006-5, 1:50,000 scale.

Diakow, L., and Mihalynuk, M.G. 1987. Geology of Whitesail Reach and Troitsa Lake map areas (93E/10W, 11E). *In* Geological Fieldwork 1986. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1987–1, pp. 171–180.

Diakow, L.J., Panteleyev, A., and Schroeter, T.G. 1991. Jurassic Epithermal Deposits in the Toodoggone River Area, Northern British Columbia: Examples of Well-Preserved, Volcanic-Hosted, Precious Metal Mineralization. Economic Geology and the Bulletin of the Society of Economic Geologists, **86**(3): 529–554. doi:10.2113/gsecongeo.86.3.529.

Diakow, L.J., Mahoney, J.B., Gleeson, T.G., Hrudey, M.G., Struik, L.C., and Johnson, A.D. 2002, Middle Jurassic stratigraphy hosting volcanogenic massive sulphide mineralization in eastern Bella Coola map area, southwest British Columbia; *In* Geological Fieldwork 2001. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 2002-1, p. 119–134.

Duffell, S., and Souther, J.G. 1964. Geology of Terrace Map-Area, British Columbia. Geological Survey of Canada, Memoir 329.

Duuring, P., Rowins, S.M., McKinley, B.S.M., Dickinson, J.M., Diakow, L.J., Kim, Y.-S., and Creaser, R.A. 2009. Examining potential genetic links between Jurassic porphyry Cu-Au+/–Mo and epithermal Au+/–Ag mineralization in the Toodoggone district of North-Central British Columbia, Canada. Mineralium Deposita, **44**(4): 463–496. doi:10.1007/s00126-008-0228-9.

Ebinger, C.J., Karner, G.D., and Weissel, J.K. 1991. Mechanical strength of extended continental lithosphere. Constraints from the Western Rift System. Tectonics, **10**(6): 1239–1256. doi:10.1029/91TC00579.

Eisbacher, G.H. 1985. Pericollisional strike-slip faults and synorogenic basins, Canadian Cordillera. *In* Strike-slip deformation, basin formation, and sedimentation. *Edited by* K.T. Biddle and N. Christie-Blick. Society of Economic Paleontologists and Mineralogists Special Publication 37, pp. 265–282.

English, J.M., and Johnston, S.T. 2005. Collisional orogenesis in the northern Canadian Cordillera: Implications for Cordilleran crustal structure, ophiolite emplacement, continental growth, and the terrane hypothesis. Earth and Planetary Science Letters, **232**(3–4): 333–344. doi:10.1016/j.epsl.2005.01.025.

Ettlinger, A.D. 1992. Hydrothermal alteration and brecciation underlying the Eskay Creek polymetallic massive sulphide deposit (104B/9W), British Columbia. *In* Geological Fieldwork 1991. Ministry of Energy, Mines and Petroleum Resources, Report 1992-1, pp. 535–542.

Evenchick, C.A., and McNicoll, V.J. 2002. Stratigraphy, structure, and geochronology of the Anyox Pendant, northwest British Columbia, and implications for mineral exploration. Canadian Journal of Earth Sciences, **39**(9): 1313–1332. doi:10.1139/e02-036.

Evenchick, C.A., and Porter, J.S. 1993. Geology of west McConnell Creek map area, British Columbia. *In* Current Research. Geological Survey of Canada, Paper 93-1A, pp. 47–55.

Evenchick, C.A., and Thorkelson, D.J. 2004. Geology, Cold Fish Lake, British Columbia. Geological Survey of Canada, Map 2030A, 1:50,000 scale.

Evenchick, C.A., and Thorkelson, D.J. 2005. Geology of the Spatsizi River map area, north-central British Columbia. Geological Survey of Canada, Bulletin 577.

Evenchick, C.A., Poulton, T.P., Tipper, H.W., and Braidek, I. 2001. Fossils and facies of the northern two-thirds of the Bowser Basin, British Columbia. Geological Survey of Canada, Open File 3956.

Evenchick, C.A., Ferri, F., Mustard, P.S., McMechan, M.E., Osadetz, K.G., Stasiuk, L.D., et al. 2003. Recent results and activities of the Integrated Petroleum Resource Potential and Geoscience Studies of the Bowser and Sustut Basins project, British Columbia. *In* Current Research. Geological Survey of Canada, Paper 2003-A13.

Evenchick, C.A., Ferri, F., Mustard, P.S., McMechan, M.E., Ritcey, D., McNicoll, V.J., et al. 2005. Highlights of recent research in the Bowser and Sustut Basins Project, British Columbia. *In* Current research. Geological Survey of Canada, Paper 2005-A1.

Evenchick, C.A., McMechan, M.E., McNicoll, V.J., and Carr, S.D. 2007*a*. A synthesis of the Jurassic-Cretaceous tectonic evolution of the central and southeastern Canadian Cordillera: exploring links across the orogen. *In* Whence the mountains? *Edited by* J.W. Sears, T.A. Harms, and C.A. Evenchick. Geological Society of America, Special Publication, 433. pp. 117–145.

Evenchick, C.A., Mustard, P.S., McMechan, M.E., Ferri, F., Porter, S., Hadlari, T., and Jakobs, G.K. 2007*b*. Geology, McConnell Creek, British Columbia. Geological Survey of Canada, Open File 5571, 1:125,000 scale.

Evenchick, C.A., Mustard, P.S., McMechan, M.E., Ritcey, D.H., and Smith, G.T. 2008*a*. Geology, northeast Terrace and northwest Smithers, British Columbia. Geological Survey of Canada, Open File 5895, 1:125,000 scale.

Evenchick, C.A., McMechan, M.E., Mustard, P.S., Ritcey, D., Smith, G.T., Ferri, F., and Waldron, J.W.F. 2008*b*. Geology, Hazelton, British Columbia. Geological Survey of Canada, Open File 5704, 1:125,000 scale.

Evenchick, C.A., Mustard, P.S., McMechan, M.E., Greig, C.J., Ferri, F., Ritcey, D., et al. 2009. Geology, Compilation Geology of Bowser and Sustut Basins Draped on Shaded Relief Map, North-central British Columbia. Geological Survey of Canada, Open File 5794, 1:500,000 scale.

Evenchick, C.A., Poulton, T.P., and McNicoll, V.J. 2010. Nature and significance of the diachronous contact between the Hazelton and Bowser Lake groups (Jurassic), north-central British Columbia. Bulletin of Canadian Petroleum Geology, **58**(3): 235–267. doi:10.2113/gscpgbull.58.3.235.

Ferri, F., and Boddy, M. 2005. Geochemistry of Early to Middle Jurassic Organic-rich Shales, Intermontane Basins, British Columbia. *In* Summary of Activities 2005. British Columbia Ministry of Energy, Mines and Petroleum Resources, pp. 132–151.

Ferri, F., Osadetz, K.G., and Evenchick, C.A. 2004. Petroleum source rock potential of Lower to Middle Jurassic clastics, Intermontane

Basins, British Columbia. *In* Summary of Activities 2004. British Columbia Ministry of Energy, Mines and Petroleum Resources, pp. 87–97.

Gabrielse, H., Wanless, R.K., Amrstrong, R.L., and Erdman, L.R. 1980. Isotopic dating of Early Jurassic volcanism and plutonism in north-central British Columbia. *In* Current research. Geological Survey of Canada, Paper 80-1A, pp. 27–32.

Gagnon, J.-F. 2010. Stratigraphic and Tectonic Evolution of the Jurassic Hazelton Trough–Bowser Basin, Northwest British Columbia, Canada. Ph.D. thesis, University of Alberta, Edmonton.

Gagnon, J.-F., and Waldron, J.W.F. 2008. Ashman Ridge Section Revisited: New Insights for the Evolution of the Bowser Basin, Northwestern British Columbia (NTS 93 L/13). *In* Summary of Activities 2007. Geoscience British Columbia, Report 2008-1, pp. 121–128.

Gagnon, J.-F., and Waldron, J.W.F. 2011. Sedimentation styles and depositional processes in a Middle to Late Jurassic slope environment, Bowser Basin, Northwestern British Columbia, Canada. Marine and Petroleum Geology, **28**(3): 698–715. doi:10.1016/j.marpetgeo.2010.06.004.

Gagnon, J.-F., Loogman, W., Waldron, J.W.F., Cordey, F., and Evenchick, C.A. 2007. Stratigraphic Record of Initiation of Sedimentation in the Bowser Basin (NTS 104A, H), Northwestern British Columbia. *In* Geological Fieldwork 2006. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 2007-1, pp. 275–283.

Gagnon, J.-F., Evenchick, C.A., Waldron, J.W.F., Cordey, F., and 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**(4): 430–448. doi:10.2113/gscpgbull.57.4.430.

Gareau, S.A., Friedman, R.M., Woodsworth, G.J., and Childe, F.C. 1997. U-Pb ages from the northeastern quadrant of the Terrace map area, west-central British Columbia. *In* Current research. Geological Survey of Canada, Paper 1997-A/B, pp. 31–40.

Gehrels, G.E. 2001. Geology of the Chatham Sound region, southeast Alaska and coastal British Columbia. Canadian Journal of Earth Sciences, **38**(11): 1579–1599. doi:10.1139/e01-040.

Greig, C.J. 1991. Stratigraphic and structural relations along the west-central margin of the Bowser Basin, Oweegee and Kinskuch areas, northwestern British Columbia. *In* Current research. Geological Survey of Canada, Paper 91-1A, pp. 197–205.

Greig, C.J. 1992. Fieldwork in the Oweegee and Snowslide ranges and Kinskuch Lake area, northwestern British Columbia. *In* Current Research. Geological Survey of Canada, Paper 92-1A, pp. 145–155.

Greig, C.J., and Evenchick, C.A. 1993. Geology of Oweegee Dome (geochemistry and paleontology), Delta Peak (104A/12) and Taft Creek (104A/11W) map areas, northwestern British Columbia. Geological Survey of Canada, Open File 2688.

Greig, C.J., and Gehrels, G.E. 1995. U–Pb zircon geochronology of Lower Jurassic and Paleozoic Stikinian strata and Tertiary intrusions, northwestern British Columbia. Canadian Journal of Earth Sciences, **32**(8): 1155–1171. doi:10.1139/e95-095.

Grove, E.W. 1986. Geology and mineral deposits of the the Unuk River - Salmon River - Anyox area. British Columbia Ministry of Energy, Mines and Petroleum Resources, Bulletin 63.

Hanson, G. 1925. Driftwood Creek map-area, Babine Mountains, British Columbia. *In* Summary Report 1924, Geological Survey of Canada, Part A, pp. 19–37.

Henderson, J.R., Kirkham, R.V., Henderson, M.N., Payne, J.G., Wright, T.O., and Wright, R.L. 1992. Stratigraphy and Structure of the Sulphurets Area, British Columbia. *In* Current research. Geological Survey of Canada, Paper 92-1A, pp. 323–332.

Jakobs, G.K. 1993. Jurassic stratigraphy of the Diagonal Mountain area, McConnell Creek map area, north-central British Columbia. *In* Current research. Geological Survey of Canada, Paper 93-1A, pp. 43–46.

Jakobs, G.K. 1997. Toarcian (Early Jurassic) ammonoids from Western North America. Geological Survey of Canada, Bulletin 428.

Johnston, K.K. 2002. Taxonomy and biostratigraphy of Middle Jurassic ammonites, western and central British Columbia. M.Sc. thesis, Department of Geosciences, University of Calgary, Calgary AB.

Kerr, F.A. 1948. Lower Stikine and western Iskut River Areas, British Columbia. Geological Survey of Canada, Memoir 246.

Kusznir, N.J., and Egan, S.S. 1990. Simple-shear and pure-shear models of extensional sedimentary basin formation: Application to the Jeanne d'Arc Basin, Grand Banks of Newfoundland. *In* Extensional Tectonics of the North Atlantic Margins. *Edited by* A.J. Tankard and H.R. Balkwill. AAPG Memoir 46, pp. 305–322.

Leach, W.W. 1910. The Skeena River District. *In* Summary report 1910. Geological Survey of Canada, Sessional Paper 26, pp. 61–68.

Lewis, P.D., Thompson, J.F.H., Nadaraju, G., Anderson, R.G., and Johannson, G.G. 1993. Lower and Middle Jurassic stratigraphy in the Treaty glacier area and geological setting of the Treaty glacier alteration system, northwestern British Columbia. *In* Current research. Geological Survey of Canada, Paper 93-1A, pp. 75–86.

Lin, A.T., Watts, A.B., and Hesselbo, S.P. 2003. Cenozoic stratigraphy and subsidence history of the South China Sea Margin in the Taiwan region. Basin Research, **15**(4): 453–478. doi:10.1046/j.1365-2117.2003.00215.x.

Logan, J.M., Drobe, J.R., and McClelland, W.C. 2000. Geology of the Forest Kerr - Mess Creek area, Northwestern British Columbia (104B/10,15 & 104G/2 & 7W). British Columbia Ministry of Energy, Mines and Petroleum Resources, Bulletin 104.

Loogman, W. 2008. Structure and Kinematic Development of the northwest Skeena Fold Belt, northwestern British Columbia. M.Sc. thesis, Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, AB.

Macdonald, A.J., Lewis, P.D., Thomson, J.F.H., Nadaraju, G., Bartsch, R.D., Bridge, D.J., et al. 1996. Metallogeny of an Early to Middle Jurassic Arc, Iskut River Area, Northwestern British Columbia. Economic Geology and the Bulletin of the Society of Economic Geologists, **91**(6): 1098–1114. doi:10.2113/gsecongeo.91.6.1098.

MacIntyre, D.G., Desjardins, P., and Tercier, P. 1989. Jurassic stratigraphic relationships in the Babine and Telkwa Ranges (93 L/10, 11, 14, 15). *In* Geological Fieldwork 1988. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1989-1, pp. 195–208.

MacIntyre, D., Ash, C., and Britton, J. 1994. Nass-Skeena (93/E, L, M; 94/D; 103/G, H, I, J, P; 104/A, B). British Columbia Department of Energy and Mines Open File, 1994-14.

MacIntyre, D.G., Webster, I.C.L., and Villeneuve, M. 1997. Babine Porphyry Belt Project: Bedrock Geology of the Old Fort Mountain Area (93M/1), British Columbia. *In* Geological Fieldwork 1996. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1997-1, pp. 47–68.

Marsden, H., and Thorkelson, D.J. 1992. Geology of the Hazelton Volcanic Belt in British Columbia: Implications for the Early to Middle Jurassic Evolution of Stikinia. Tectonics, **11**(6): 1266–1287. doi:10.1029/92TC00276.

McClelland, W.C. 1992. Permian and older rocks of the southwestern Iskut River map area, northwestern British Colombia, In Current Research, Part A: Geological Survey of Canada Paper 12-01A, pp. 303–307.

McKenzie, D. 1978. Some remarks on the development of sedimentary basins. Earth and Planetary Science Letters, **40**(1): 25–32. doi:10.1016/0012-821X(78)90071-7.

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, **29**(11): 2463–2477. doi:10.1139/e92-193.

Mihalynuk, M.G., Erdmer, P., Ghent, E.D., Cordey, F., Archibald, D.A., Friedman, R.M., and Johannson, G.G. 2004. Coherent French Range blueschist: Subduction to exhumation in <2.5 m.y? Geological Society of America Bulletin, **116**(7): 910–922. doi:10.1130/B25393.1.

Monger, J.W.H. 1977. Upper Paleozoic rocks of the western Canadian Cordillera and their bearing on Cordilleran evolution. Canadian Journal of Earth Sciences, **14**(8): 1832–1859. doi:10.1139/e77-156.

Monger, J.W.H., and Church, B.N. 1977. Revised stratigraphy of the Takla Group, north-central British Columbia. Canadian Journal of Earth Sciences, **14**(2): 318–326. doi:10.1139/e77-031.

Nadaraju, G. 1993. Triassic-Jurassic Biochronology of the eastern Iskut River map area, northwestern British Columbia. M.Sc. thesis, Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, B.C.

Nelson, J.L., and Colpron, M. 2007. Tectonics and metallogeny of the Canadian and Alaskan Cordillera, 1.8 Ga to present. *In* Mineral Deposits of Canada: A Synthesis of Major Deposit Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods *Edited by* W.D. Goodfellow. Mineral Deposit Division, Geological Association of Canada, Special Publication, **5**, pp. 755–791.

Nelson. J.L., and Kennedy, R. 2007*a*. Geology of the Doreen south half (103I/16S) and Terrace east half (103I/10E) map areas, near Terrace, British Columbia; BC Ministry of Energy, Mines and Petroleum Resources Open-File 2007-4, 1:50,000.

Nelson, J.L., and Kennedy, R. 2007*b*. Terrace regional mapping project Year 2: New geological insights and exploration targets (NTS 103I/16S, 10W), west-central British Columbia. *In* Geological Fieldwork 2006. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 2007-1, pp. 149–162.

Nelson, J.L., Kennedy, R., Angen, J., and Newman, S. 2007. Geology of Terrace area. British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 2007-04, 1:50,000 scale.

North American Commission on Stratigraphic Nomenclature. 2005. North American Stratigraphic Code. AAPG Bulletin, **89**(11): 1547–1591. doi:10.1306/07050504129.

Ogg, J.G. 2004. The Jurassic Period. *In* A Geologic Time Scale 2004. *Edited by* F.M. Gradstein, J.G. Ogg, and A.G. Smith. Cambridge University Press. pp. 307–343.

Osadetz, K.G., Jiang, C., Evenchick, C.A., Ferri, F., Stasiuk, L.D., Wilson, N.S.F., and Hayes, M. 2007. Compositions and significance of crude oil stains in Bowser and Sustut basins (Intermontane Belt) British Columbia. Bulletin of Canadian Petroleum Geology, **55**(4): 285–305. doi:10.2113/gscpgbull.55.4.285.

Pálfy, J., and Schmidt, K.L. 1994. Biostratigraphic and facies studies of the Telkwa Formation (Lower Jurassic), Smithers map area, British Columbia. *In* Current research. Geological Survey of Canada, Paper 1994-E, pp. 29–38.

Pálfy, J., Mortensen, J.K., Smith, P.L., Friedman, R.M., McNicoll, V., and Villeneuve, M. 2000. New U–Pb zircon ages integrated with ammonite biochronology from the Jurassic of the Canadian Cordillera. Canadian Journal of Earth Sciences, **37**(4): 549–567. doi:10.1139/e99-115.

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, **120**: 1119–1122.

Roth, T. 1993. Surface geology of the 21A zone, Eslay Creek, British Columbia (104B/9W), British Columbia. *In* Geological Fieldwork 1992. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1993-1, pp. 325–330.

Roth, T. 2002. Physical and chemical constraints on mineralization in the Eskay Creek Deposit, northwestern British Columbia; evidence from petrography, mineral chemistry, and sulfur isotopes. Ph.D. thesis, Department of Earth and Ocean Sciences, University of British Columbia, Vancouver.

Roth, T., Thompson, J.F.H., and Barrett, T.J. 1999. The precious metal - rich Eskay Creek deposit, northwestern British Columbia. *In* Volcanic-Associated Massive Sulfide Deposits: Processes and Examples in Modern and Ancient Settings. *Edited by* C.T. Barrie and M.D. Hannington. Reviews in Economic Geology 8, pp. 357–373.

Samson, S.D., McClelland, W.C., Patchett, P.J., Gehrels, G.E., and Anderson, R.G. 1989. Evidence from neodymium isotopes for matle contributions to Phanerozoic crustal genesis in the Canadian Cordillera. Nature, **337**(6209): 705–709. doi:10.1038/337705a0.

Samson, S.D., Patchett, P.J., McClelland, W.C., and Gehrels, G.E. 1991. Nd isotopic characterization of metamorphic rocks in the Coast Mountains, Alaska and Canadian Cordillera: ancient crust bounded by juvenile terranes. Tectonics, **10**(4): 770–780. doi:10.1029/90TC02732.

Schofield, S.J., and Hanson, G. 1921. Salmon River District, British Columbia. *In* Summary Report 1920. Geological Survey of Canada, Part A, pp. 6–12.

Sherlock, R.L., Barrett, T.J., Roth, T., Childe, F.C., Thomson, J.F.H., Kuran, D., Marsden, H., and Allen, R. 1994. Geological investigations of the 21B deposit, Eskay Creek, northwestern British Columbia (104B/9W). *In* Geological Fieldwork 1993. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1994-1, pp. 357–364.

Sherlock, R.L., Roth, T., Spooner, E.T.C., and Bray, C.J. 1999. Origin of the Eskay Creek Pecious Metal-Rich Volcanogenic Massive Sulphide Deposit: Fluid Inclusion and Stable Isotope Evidence. Economic Geology and the Bulletin of the Society of Economic Geologists, **94**(6): 803–824. doi:10.2113/gsecongeo.94.6.803.

Simpson, K.A., and Nelson, J.L. 2004. Preliminary interpretations of mid-Jurassic volcanic and sedimentary facies in the East Telegraph Creek map area. *In* Current Research, Geological Survey of Canada, Paper 2004-A1, pp. 1–8.

Souther, J.G. 1972. Telegraph Creek map-area, British Columbia (104G). Geological Survey of Canada, Paper 71-44.

Steckler, M.S., and Watts, A.B. 1978. Subsidence of the Atlantic-type continental margin off New York. Earth and Planetary Science Letters, **41**(1): 1–13. doi:10.1016/0012-821X(78)90036-5.

Stevens, C.H., and Rycerski, B. 1989. Early Permian colonial rugose corals from the Stikine River area, British Columbia, Canada. Journal of Paleontology, **63**: 158–181.

Thomson, R.C., and Smith, P.L. 1992. Pliensbachian (Lower Jurassic) Biostratigraphy and Ammonite Fauna of the Spatsizi Area, North-Central British Columbia. Geological Survey of Canada, Bulletin 437.

Thomson, R.C., Smith, P.L., and 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**(12): 1963–1973. doi:10.1139/e86-182.

Thorkelson, D.J. 1992. Volcanic and Tectonic Evolution of the Hazelton Group in the Spatsizi River (104H) map-area, North-Central British Columbia. Ph.D. thesis, Department of Earth Sciences, Carleton University, Ottawa, Ont.

Thorkelson, D.J., Mortensen, J.K., Marsden, H., and Taylor, D.C. 1995. Age and tectonic setting of Early Jurassic episodic volcanism along the northeastern margin of the Hazelton Trough, northern British Columbia. *In* Jurassic magmatism and tectonics of the North American Cordillera. *Edited by* D.M. Miller and C.J. Busby. Geological Society of America Special Paper 299, pp. 83–94.

Tipper, H.W., and Richards, T.A. 1976. Jurassic stratigraphy and history of north-central British Columbia. Geological Survey of Canada, Bulletin 270.

van der Heyden, P. 1992. A Middle Jurassic to Early Tertiary Andean-Sierran arc model for the Coast Belt of British Columbia. Tectonics, **11**(1): 82–97. doi:10.1029/91TC02183.

Waldron, J.W.F., and Gagnon, J.-F. 2011. Recognizing soft-sediment structures in deformed rocks of orogens. Journal of Structural Geology, **33**(3): 271–279. doi:10.1016/j.jsg.2010.06.015.

Waldron, J.W.F., Gagnon, J.-F., Loogman, W., and Evenchick, C.A. 2006. Initiation and deformation of the Jurassic-Cretaceous Bowser Basin: implications for hydrocarbon exploration. *In* Geological Fieldwork 2005. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 2006-1, pp. 349–360.

Woodsworth, G.J., Hill, M.L., and Van der Heyden, P. 1985. Preliminary geologic map of Terrace (NTS 103I East Half) map area, British Columbia. Geological Survey of Canada, Open File 1136, 1: 125,000 scale.