Stratigraphic Record of Initiation of Sedimentation in the Bowser Basin (NTS 104A, H), Northwestern British Columbia[1]

by J-F. Gagnon[2], W. Loogman[2], J.W.F. Waldron[2], F. Cordey[3] and C.A. Evenchick[4]

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INTRODUCTION

The Bowser Basin is a sedimentary basin located over the Stikine Terrane in the Intermontane Belt of northwestern British Columbia (Fig 1). In this area, the Stikine Terrane is overlain by Early Jurassic sedimentary rocks of the upper Hazelton Group (Troy Ridge facies of the Salmon River Formation in Anderson [1993]; Spatsizi Formation in Thomson *et al*. [1986]) and then by a thick succession (approximately 6 km) of Middle Jurassic to Early Cretaceous sedimentary rocks mainly assigned to the Bowser Lake Group (Evenchick and Thorkelson, 2005). The fill of the Bowser Basin was deposited over the arc volcanic rocks and associated volcaniclastic rocks of the lower Hazelton Group. A broad variety of sedimentary environments characterized the Bowser Basin, ranging from basin-floor turbidites at the base through marginal-marine clastic rocks to nonmarine redbeds in the uppermost parts of the succession.

Recent thermal maturity investigations have shown the existence of an effective petroleum system in the Bowser Basin (Evenchick *et al*., 2002; Osadetz *et al*., 2003; Stasiuk *et al*., 2005). Black shales of the Spatsizi Formation have returned total organic carbon content up to 6%, and these values might have been two to four times greater before the expulsion of organic material (Ferri and Boddy, 2005). This suggests that under the proper conditions, organic shales of the Spatsizi Formation would have acted as excellent source rocks. However, variable thermal maturation levels throughout the basin and the lack of information regarding the linkage of source rocks of the upper Hazelton Group and potential reservoir rocks of the Bowser Lake Group create uncertainty in terms of exploration risks.

The aim of this study is to understand the conditions that led to a change in the deposition style in the Middle Jurassic from a volcanic arc-dominated environment to a subsiding sedimentary basin. For that purpose, study areas were selected based on known exposures that exhibit the transition from the Hazelton Group into the Bowser Lake Group in structurally undisturbed sections. Three areas are described in this report, Todagin Mountain, Mount Will and Oweegee Dome (Fig 1). Systematic measurements of detailed stratigraphic sections were conducted in the field to document the onset of sedimentation in the Bowser Basin.

STRATIGRAPHY OF THE LOWER HAZELTON GROUP

The lowest stratigraphic unit observed in the vicinity of Todagin Mountain consists of a mixture of greenish grey to maroon volcaniclastic rocks and light grey trachyandesitic volcanic flows. This dominantly intermediate volcanic suite and associated plutons, which uncomformably overlie the Triassic Stuhini Group, was mapped as andesite breccias and derived epiclastic rocks by Ash *et al*. (1997). Five individual intrusive bodies from this suite returned U-Pb zircon dates from 205 to 198 Ma, suggesting a Hettangian to Sinemurian age (Friedman and Ash, 1997). The lavas identified in this study are mostly aphanitic and contain calcite-filled amygdules. Small intrusive bodies of leucocratic monzogranite are also present to a lesser extent. Poorly sorted reworked tuff, containing abundant subrounded lithic fragments, is interbedded with welded lapilli tuff and recessive bands of very fine grained crystal tuff. The presence of flattened pumice (fiamme) in medium-grained lapilli tuff along with light beige euhedral feldspar crystals in a matrix of fine-grained air-fall tuff suggests that explosive volcanism was the predominant mode of deposition at that time. Hematite is a common mineral amongst these pyroclastic rocks, suggesting that they mostly accumulated in an oxidizing subaerial environment.

In the Mount Will district, the lower Hazelton Group consists of a bimodal assemblage termed the Cold Fish volcanics by Thorkelson (1992). According to Thorkelson (1992), this unit can be divided into a felsic suite of high-silica rhyolite and a mafic suite of basalt, andesite and dacite. The upper 100 m of this succession were examined approximately 10 km southwest of Gladys Lake. Maroon to green, very poorly sorted epiclastic and indurated lapilli tuffs conformably overlie a thick unit of oxidized rhyolite. The recessive volcaniclastic interval is capped by approximately 30 m of densely welded ignimbrite characterized by large open vugs, fiamme, lava particles and angular volcanic fragments. This indurated felsic ash flow constitutes the last major pulse of explosive volcanism in the region before the establishment of sedimentary conditions.

The volcanic arc rocks of the lower Hazelton Group around Oweegee Dome consist of fine layers of fissile dust

[1]*Geoscience BC contribution GBC023*

[2]*Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, AB (jfgagnon@ualberta.ca)*

[3]*Sciences de la Terre, Université Claude Bernard Lyon 1, Villeurbanne, France*

[4]*Geological Survey of Canada, Vancouver, BC*

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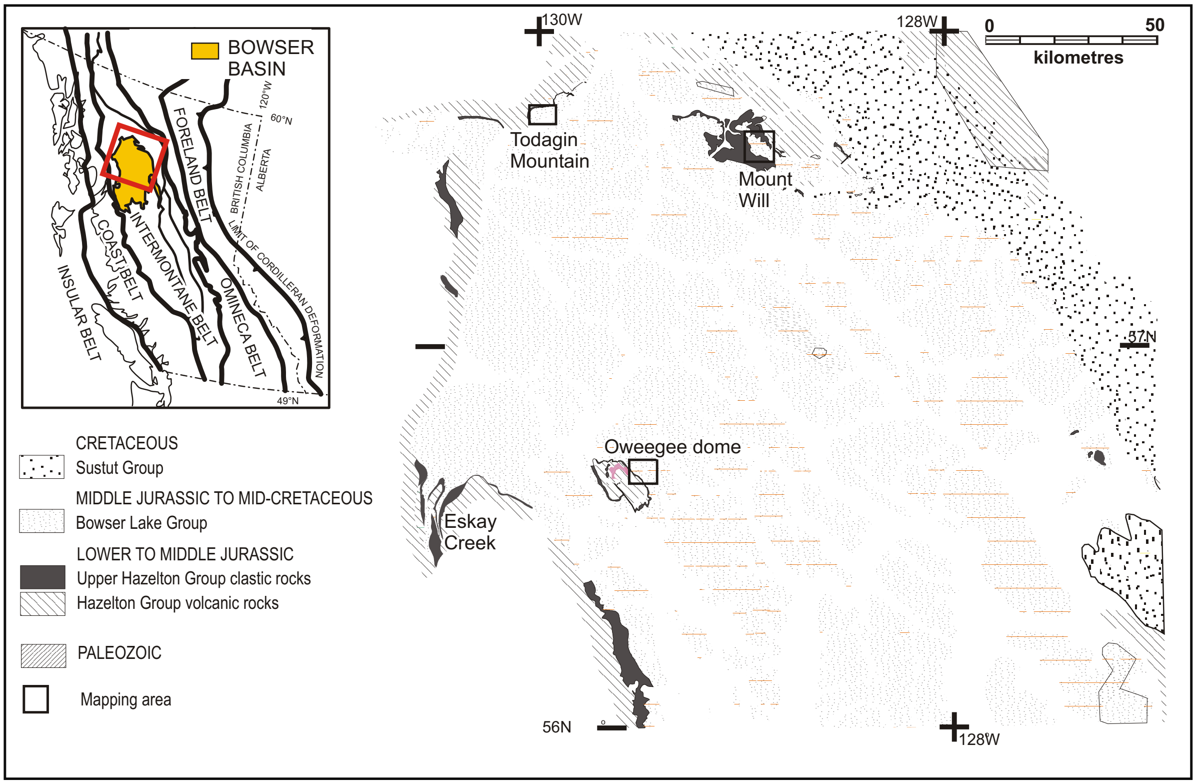

Figure 1. Simplified geology of the northern two-thirds of the Bowser Basin showing areas of detailed study in 2006, northwest BC. Inset shows the location of the Bowser Basin in relation to principal tectonic belts of the Canadian Cordilleran Orogen.

tuff interbedded with well-stratified maroon and green volcanic sandstone, pebble to cobble conglomerate, debris flows and minor andesitic volcanic flows. These units are overlain by a thick unit of felsic porphyritic rhyolite that was dated at 199 ±2 Ma by Greig and Gehrels (1995).

STRATIGRAPHY OF THE UPPER HAZELTON GROUP

Rocks assigned to the upper part of the Hazelton Group are exposed in a southwest-trending section west of Todagin Mountain (Evenchick and Green, 2004). The upper Hazelton Group consists of a bimodal volcanic suite with multiple fine-grained sedimentary intercalations. A detailed stratigraphic column representing the section is presented in Figure 2. Thick units of columnar basalt constitute most of the section. Thin intervals of marine clastic sedimentary rocks contain numerous ammonites of the Freboldi zone, which suggest a Pliensbachian age (Evenchick *et al*., 2001; T. Poulton, pers comm, 2006). The stratigraphic section contains an angular discordance at 264 m (Fig 2) where a recessive unit of altered basalt is unconformably overlain by crosslaminated limestone and oxidized basalt debris. A thin layer of dacitic lapilli tuff 50 cm above this unconformity yielded a U-Pb zircon age of 185.6 ±0.6 Ma (Palfy *et al*., 2000) which confirms the Pliensbachian age obtained from paleontological data. The top of the succession is characterized by a thick unit of vesicular marine pillow basalt and hyaloclastite indicating deposition in a submarine environment (Fig 3).

Sedimentary rocks assigned to the Spatsizi Formation are exposed in the Mount Will district (Evenchick and Thorkelson, 2005), located approximately 10 km northeast of Joan Lake, where Thomson *et al*. (1986) carried out earlier stratigraphic work. The lowest stratigraphic unit of the Spatsizi Formation at Mount Will is characterized by brownish to light grey arkosic sandstone deposited on top of welded ignimbrite. The high proportion of altered volcanogenic clasts in the sandstone indicates recycling of locally derived extrusive rocks of the underlying Cold Fish volcanics. Even though no angular discordance was observed, the contact with the underlying ignimbrite is erosional and probably corresponds to an unconformity. Fine to medium-grained subrounded lithic fragments and feldspar grains are moderately sorted and sedimentary structures such as ripple crosslaminations and planar crossbedding are common. The basal sandstone unit contains multiple calcareous intervals ranging from 35 to 55 cm thick with a broad variety of marine fossils (ammonites, corals, belemnites and bivalves; Fig 4). Large pieces of fossil wood and plant fragments found in thinly laminated siltstone and very fine grained sandstone indicate that a significant quantity of terrestrial debris was transported to the basin. The abundance and high diversity of bioturbation suggest that paleoenvironmental conditions, such as oxygen content, temperature and salinity, were relatively stable. The presence of symmetric wave-generated ripples is consistent with a depositional environment above the fair-weather wave base in an open, shallow-marine setting. Upsection, there is a significant increase in silt and clay content, and the sandstone beds are usually thinner. Concretionary beds of limestone are associated with the coarser grained rock units whereas rounded calcareous concretions are mostly found in shale. Trace fossils and bivalves are omnipresent in those rocks suggesting that the depositional environment was still within the photic zone.

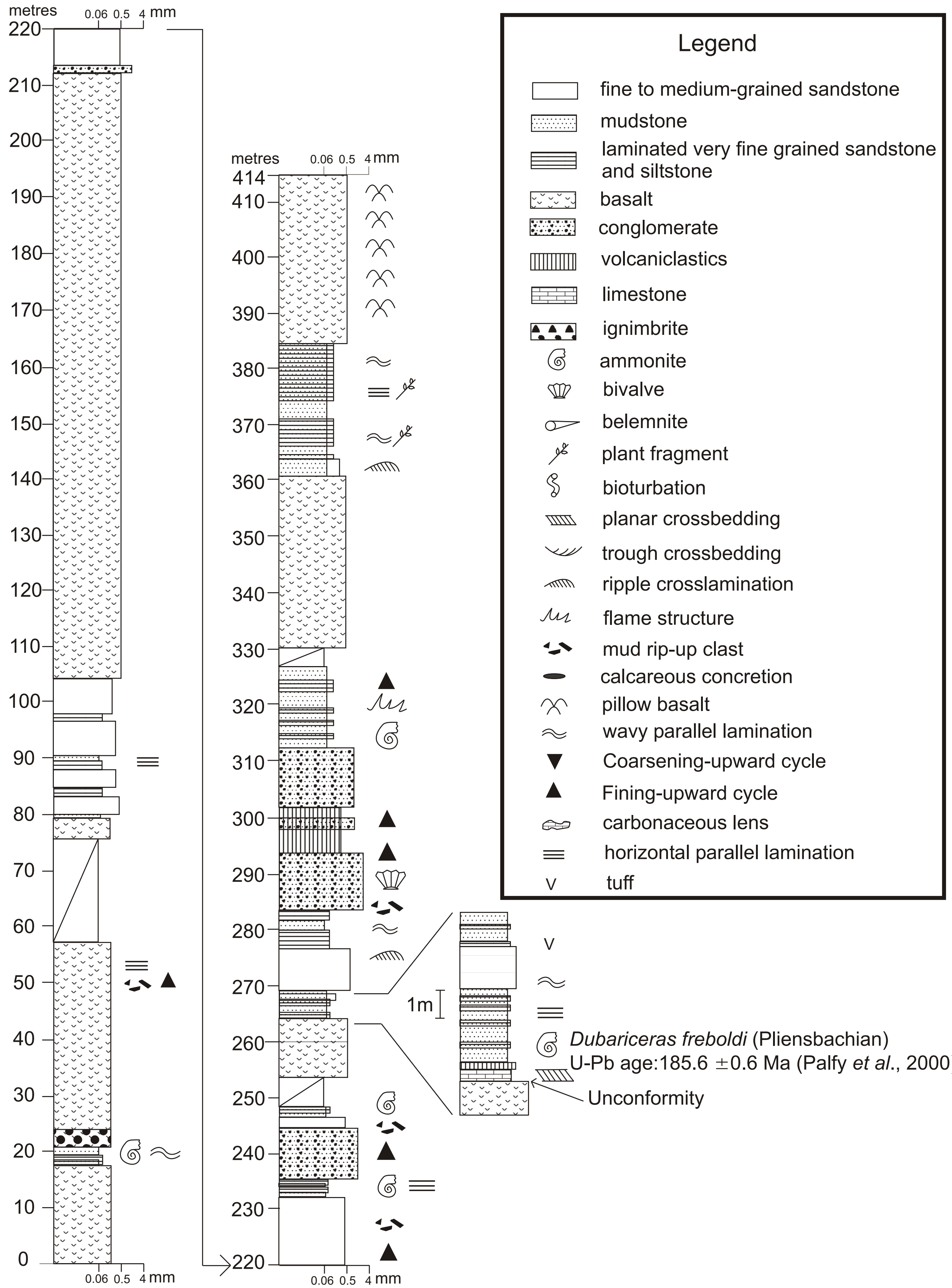

Figure 2. Detailed stratigraphic section showing interbedded volcanic rocks and marine sedimentary rocks of the upper Hazelton Group, Todagin Mountain area, BC.

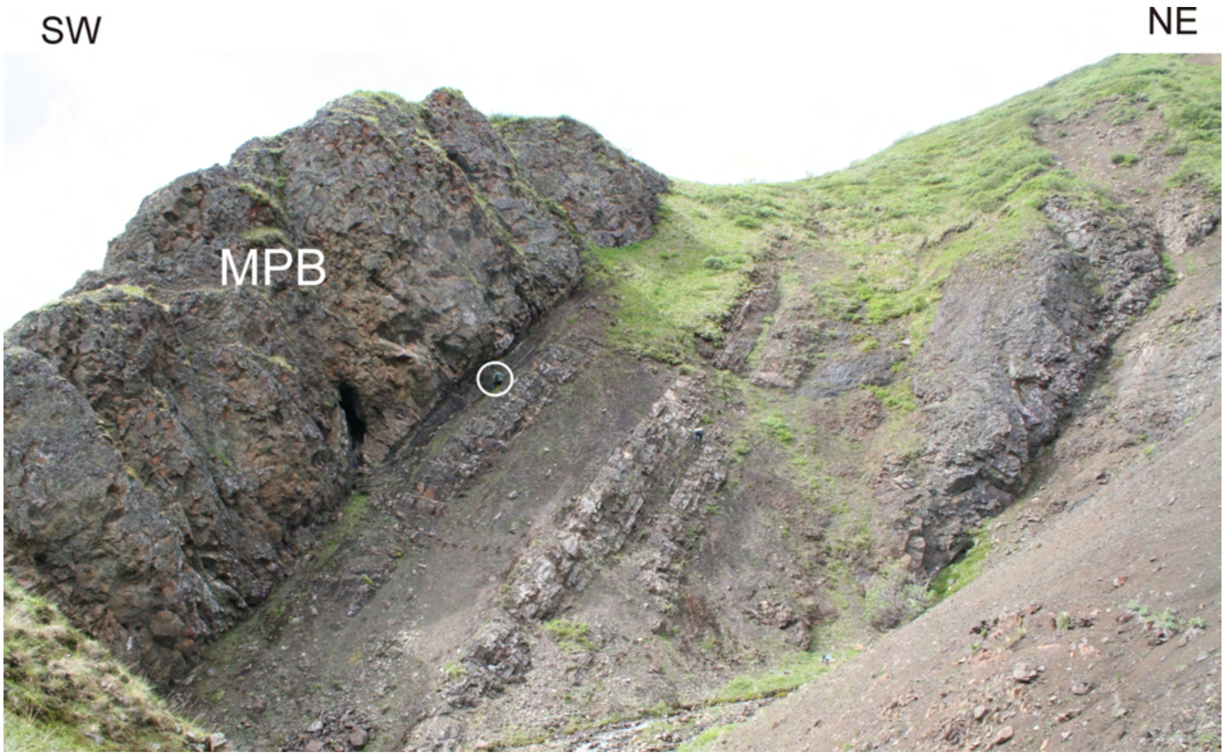

Figure 3. Upper part of the detailed section (335–414 m) measured west of Todagin Mountain, BC, showing thinly laminated siltstone and shale overlain by marine pillow basalt (MPB). *See* person for scale.

Figure 4. Well-preserved ammonite fossil of the Spatsizi Formation, Mount Will area, BC.

The fossiliferous shallow-marine succession is overlain by 140 m of interbedded black siliceous mudstone and pale orange tuffaceous siltstone (Fig 5). This unit was originally classified as the Quock Formation of the Spatsizi Group by Thomson *et al.* (1986) and later lowered to member status within the Spatsizi Formation by Evenchick and Thorkelson (2005). In the regions surrounding the Bowser Basin, correlative rocks are attributed to the informal name of pyjama beds because of the alternation of pale orange and black weathered layers that give them a striped appearance (Fig 6). Ammonite faunal assemblages at the base of the succession indicate an early Bajocian age (Thomson *et al*., 1986). In the measured sections, the siliceous shales are generally blocky and indurated. The siliceous mudstone contains abundant radiolarian microfossils, which suggest deposition from suspension in a low energy environment. Even though Thomson *et al*. (1986) considered the volcanic ash to be the primary source of silica in the rocks, observations of the pyjama beds in thin sections suggest that introduction of silica content to the system via remobilization of silica from radiolarian tests was significant. Recessive fine-grained tuff bands vary from 1 to 5 cm in thickness and attest to distal volcanism. Chlorite and plagioclase are the most common mineral phases in the crystal tuffs. The rarity of trace fossils along with high organic content can probably be related to oxygen-deficient conditions in a deeper water environment. However, the occurrence of thin to medium-bedded limestone in the section signifies that sediments accumulated above the carbonate compensation depth.

On the eastern edge of Oweegee Dome, a 270 m succession with sedimentary characteristics similar to the Quock Member was observed above andesitic and volcaniclastic rocks of the lower Hazelton Group. There, the lower and upper Hazelton Group are separated by an angular unconformity (Greig, 1991; Waldron *et al*., 2006). In this area of the basin, the thinly interbedded siliceous radiolarian mudstones and ash tuffs have been classified as the Troy Ridge facies of the Salmon River Formation (Anderson, 1993; Greig, 1991). The pyjama beds, identified around Oweegee Dome, are thinly interbedded with occasional wavy parallel laminations and convolute slump structures. Carbonate content is common in the recessive coarser tuffaceous bands whereas the mudstone is blockier and completely cemented by silica. Well-preserved radiolarian samples in black siliceous mudstone have yielded an early Bajocian to early Bathonian age for the upper part of the section, which seems slightly older than the Bathonian to Callovian age obtained in the same area by Evenchick *et al*. (2001). The preliminary results are presented in Table 1. Near the top of the section, the tuff bands

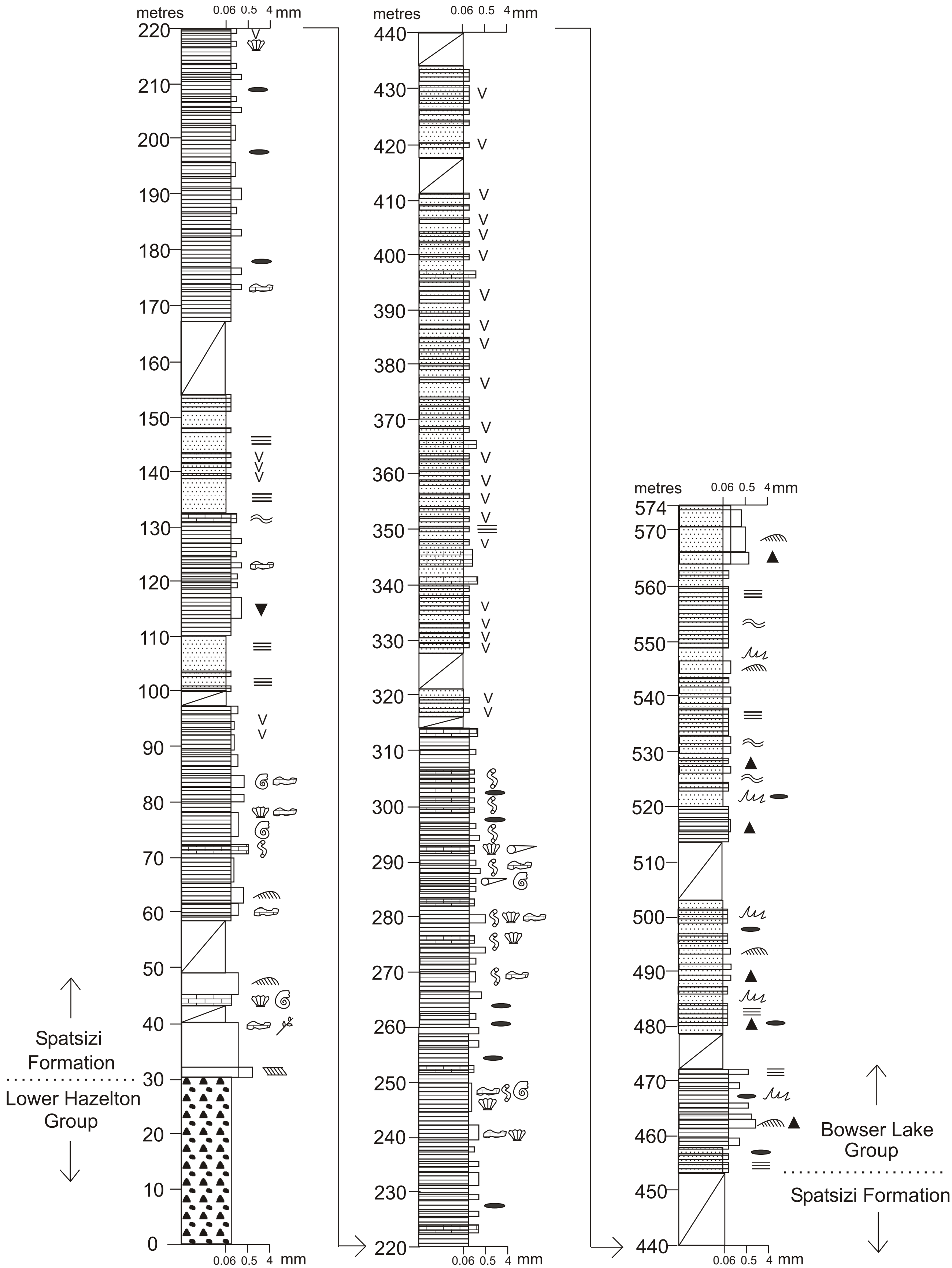

Figure 5. Detailed stratigraphic section showing uppermost volcanic unit of the lower Hazelton Group, marine sedimentary rocks of the Spatsizi Formation and the contact with the overlying Bowser Lake Group, Mount Will area, BC. *See* Figure 2 for legend.

Figure 6. Thinly interbedded resistant siliceous mudstone and recessive tuffaceous siltstone (pyjama beds) of the Quock Member, Mount Will area, BC. *See* hammer for scale.

become thinner and are less abundant. The transition into the overlying turbidites of the Bowser Lake Group appears concordant and gradational.

STRATIGRAPHY OF THE BOWSER LAKE GROUP

The basal unit of the Bowser Lake Group in the vicinity of Mount Will consists of thinly laminated very fine grained sandstone with pale orange weathering and dark grey siltstone with shale intervals. It was classified as the Todagin assemblage of the Bowser Lake Group by Evenchick and Thorkelson (2005) and is interpreted to represent a prodelta slope setting. Pebble to cobble chert-rich conglomerate units are also found in the prodelta slope lithofacies assemblage. The thickness of these coarse-grained packages is highly variable and can reach up to 50 m. They are characterized by sharp erosive bases that show scouring into underlying fine-grained rocks. Measurements on flutes and groove casts indicate paleocurrent directions towards the southeast. Near Todagin Mountain, Green (1991) interpreted similar conglomerate bodies as channelized deposits in incised canyons and gullies in a slope environment. Overbank sand deposits with trough crossbedding and planar crosslaminations are also common on the edge of the main channel axes. Centimetre-scale calcareous concretions are abundant in the fine-grained rock units and are usually associated with diagenetic pyrite. Differential compaction indicates concretionary growth early in the diagenetic processes when pores were still filled with water. Soft-sediment deformation features such as load structures, sedimentary dikes and syndepositional folds and faults are common features in the Todagin assemblage. These are interpreted to represent high fluid pressure combined with rapid sediment accumulation rates that created instability in the sediment pile and resulted in slope failure.

Sedimentary facies at the base of the Bowser Lake Group near Oweegee Dome are slightly different from those observed in the northern part of the basin. Thick beds of massive well-sorted sandstone interbedded with calcareous fissile shales are found above the pyjama beds. The impressive lateral extent of the sandbodies along with graded beds and partial Bouma sequences suggest that these sediments were deposited as deepwater turbidites in submarine-fan complexes. Sharp erosive bases, convolute laminations and flame structures are common. The absence of bioturbation features and shelly fossils is interpreted to represent a hostile environment where sedimentation influx was too high to sustain biogenic activity on the basin floor.

These turbidite deposits, assigned to the Ritchie-Alger assemblage by Evenchick *et al.* (2006), rapidly grade up into shallower sedimentary facies of the Muskaboo Creek assemblage (Evenchick *et al*., 2006). An uninterrupted stratigraphic section displaying multiple sequences was measured along an east-trending ridge east of Oweegee

TABLE 1. SUMMARY OF THE RADIOLARIAN FAUNA IDENTIFIED IN PYJAMA BEDS EAST OF OWEEGEE DOME. SAMPLE INDICATED AN EARLY BAJOCIAN TO EARLY BATHONIAN AGE NEAR THE TOP OF THE UNIT (BASED ON ZONATIONS FROM CARTER *ET AL*. [1988] AND BAUMGARTNER *ET AL*. [1995]).

Sample KA031A	Sample KA032B
Emiluvia chica s.l. Foreman	*Podobursa* sp.
Higumastra sp.	*Paronaella* sp.
Hsuum sp.	*Parvicingula* sp. D Carter
Orbiculiforma sp.	*Orbiculiforma* sp.
Napora sp.	
Parvicingula sp. *cf. dhimenaensis s.l.* Baumgartner	
Parvicingula sp. *cf. schoolhousensis gr.* Pessagno & Whalen	
Perispyridium sp.	
Tetratrabs izeensis Yeh	

Dome (Fig 7, 8). Alternating packages of fine to medium-grained sandstone and silty shale are interpreted to represent fluctuations of relative sea-level, this being the primary control on the mode of sedimentation. Coarsening-upward cycles in calcareous coquina beds found at the bases of the sandy intervals contain mud rip-up clasts derived from each underlying shale unit. The cyclicity of these deposits suggests that a shelf environment was periodically subjected to storm-induced high energy conditions that transported skeletal material away from the place of growth. The sandstone intervals vary from 35 to 100 m in thickness and contain abundant trace fossils, bivalves and ripple crosslaminations. They are capped by maximum flooding surfaces above which are laminated shale and siltstone, which accumulated from suspension during relative highstands.

DISCUSSION

Units of the lower Hazelton Group observed in all the study areas seem to indicate that these rocks mostly accumulated in an oxidizing, subaerial environment. The transition from the lower to the upper Hazelton is abrupt and marked by a regional erosional surface. Above this unconformity, the deposition style of the Spatsizi Formation and equivalents is quite variable on the basin scale, depending on the paleotopography and the distance from active volcanic centres. In volcano-sedimentary successions, the ratio of volcaniclastic rocks to marine sedimentary rocks is a function of proximity to the eruptive centre. For instance, the Pliensbachian to Bajocian fine-grained sedimentary rocks at Todagin Mountain are interbedded with thick intervals of marine pillow basalt and hyaloclastite, whereas calcareous fossiliferous sandstone and siltstone of the same age in the Mount Will district show only minor volcanic input.

Basal sedimentary rocks of the Spatsizi Formation are heavily bioturbated, fossil rich and contain multiple sedimentary structures such as symmetrical wave ripples and planar crosslaminations, which attest to a shallow marine clastic-shelf environment. Upsection, the percentage of fine-grained sedimentary rocks increases gradually and shelly fossils are rare. This is interpreted to represent a progressively deepening environment where clastic sediments accumulated via turbiditic input. Laminated siliceous mudstones and calcareous tuffaceous siltstones (pyjama beds) were found in every measured stratigraphic section. Detailed mapping conducted in this study revealed strong similarities between rocks of the Troy Ridge facies and the pyjama beds of the Quock Member, as noted in previous work (Greig, 1991; Anderson, 1993; Ferri and Boddy, 2005). In the sections at Oweegee Dome and Mount Will, calcareous beds are present throughout the unit and the proportion of rust-coloured volcanic ash gradually decreases near the top. Furthermore, radiolarian samples extracted from black siliceous mudstone suggest a early Bajocian to early Bathonian age for the upper part of the Oweegee section (Table 1). These results are consistent with previous ages obtained from ammonites by Thomson *et al.* (1986) for the Quock Member in the Joan Lake area. The transition from the pyjama beds of the upper Hazelton Group to the overlying clastic deepwater sedimentary rocks of the Bowser Lake Group is subtle and covered in most sections. The absence of vein material in the float and consistent bedding measurements on either side of the contact indicate that the latter is likely to be concordant with no structural offset.

An unusually thin succession of deepwater sedimentary rocks was observed around Oweegee Dome. Sand-rich turbidites of the Ritchie-Alger assemblage rapidly grade up into shallow-marine clastic-shelf deposits of the Muskaboo Creek assemblage (Evenchick *et al*., 2006). This is interpreted to be the result of deposition over an uneven topography, where Oweegee Dome constituted a structural high in the Bowser Basin. The abundance of soft-sediment deformation, erosive bases and sedimentary dikes in the Todagin and Ritchie-Alger assemblages are attributed to high sedimentation rates in a deepwater environment. This marks a drastic change from the underlying pyjama bed units where coarse clastic input was almost nonexistent.

The occurrence of organic radiolarian mudstones above structural highs such as Oweegee Dome suggests that these potential source rocks have been deposited and preserved throughout the entire basin. Thick and laterally extensive sandbodies deposited on the edge of the Middle Jurassic clastic shelf during relative lowstands might constitute excellent reservoir rocks for petroleum exploration.

Based on the observations made in the measured stratigraphic sections, it appears that continuous sedimentation took place in a tectonically active, shallow marine basin on Stikinia from the early Pliensbachian to early Bajocian. Depending on the relative position of active volcanoes, the sediments incorporated more or less volcanic input and were deposited along with subaqueous and subaerial bimodal volcanic flows. Rapid lateral facies change and the variability of sediment thickness in the upper Hazelton Group are attributed to active normal faulting during an extensional back-arc stage that isolated multiple sub-basins. A significant decrease of volcanism during the Aalenian and Bajocian is attributed to the cessation of subduction of oceanic crust under Stikinia and to the final accretion of volcanic-arc rocks with the Cache Creek Terrane. Following the end of magmatism, thermal relax-

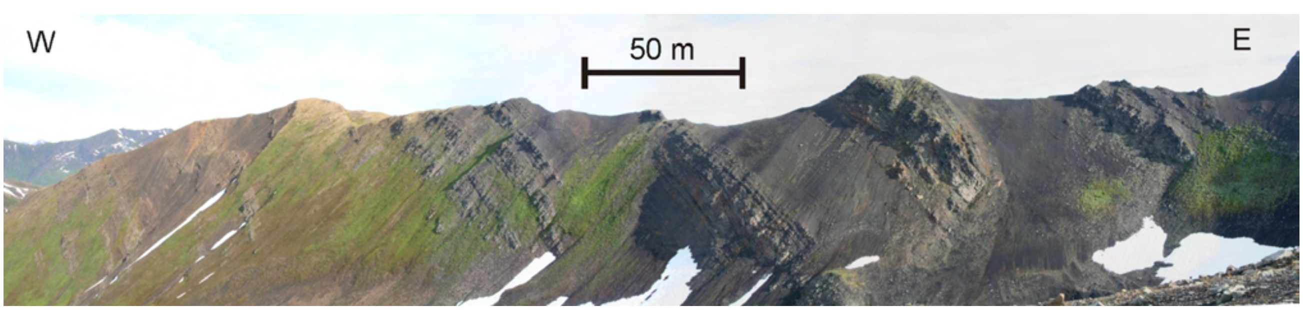

Figure 7. Panorama view of the detailed measured stratigraphic section west of Oweegee Dome, BC.

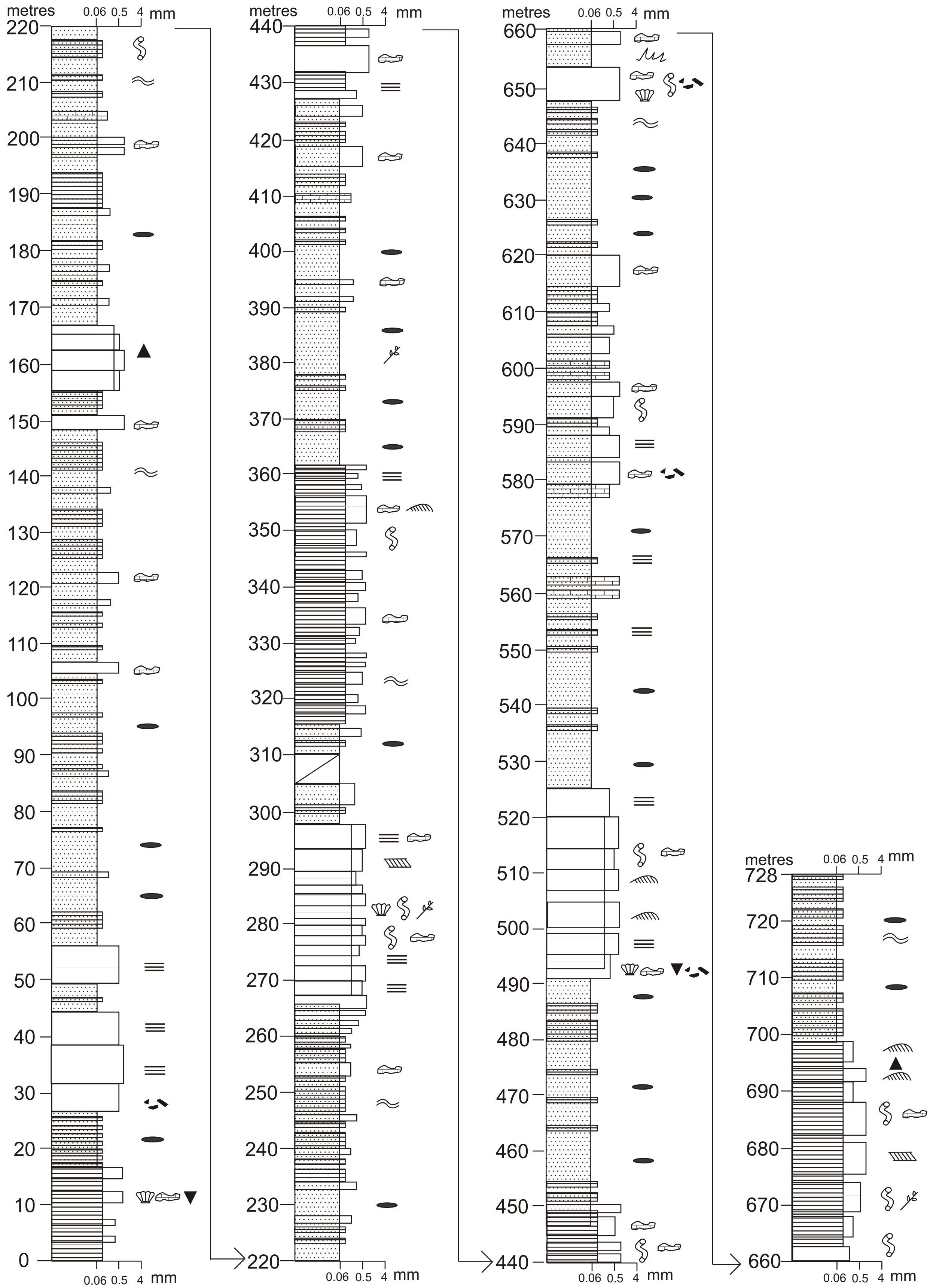

Figure 8. Detailed stratigraphic section showing alternating sandstone and shale intervals of the Muskaboo Creek assemblage of the Bowser Lake Group, BC. *See* Figure 2 for legend.

ation of the crust combined with eustatic sea-level rise generated new accommodation space in the basin where condensed sections of fine-grained deepwater sediments were deposited. Obduction of the Cache Creek Terrane along the King Salmon thrust fault (Evenchick and Thorkelson, 2005) generated a new source of chert-rich sediments that were shed in the basin via turbiditic input and fan-deltas corresponding to the deposition of the Bowser Lake Group.

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