Initiation and Deformation of the Jurassic-Cretaceous Bowser Basin: Implications for Hydrocarbon Exploration in North-Central British Columbia[1]

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KEYWORDS: Hazelton Group, Bowser Basin, Bowser Lake Group, structure, folds

INTRODUCTION

The Bowser Basin is a large (~53 000 km^2) sedimentary basin located over the Stikine Terrane in the north-central Cordillera of British Columbia (Fig. 1). The basin is filled by up to ~6 km of Jurassic to Cretaceous sedimentary rocks, mainly assigned to the Bowser Lake Group but potentially also including upper units of the Early to Middle Jurassic Hazelton Group, as well as Cretaceous strata of the Skeena Group in the southern part of the basin (Tipper and Richards, 1976; Ricketts *et al.*, 1992; Bassett and Kleinspehn, 1997; Evenchick and Thorkelson, 2005). The economic significance of the basin includes, at the base, mineralized units (*e.g.*, the Eskay Creek Au-Ag deposit; Anderson, 1993; Roth *et al.*, 1999). Higher in the succession, the Bowser Lake Group contains significant coal beds and units with potential as petroleum source and reservoir rocks. The structure of the basin, dominated by folds, provides numerous potential traps. The petroleum potential of the basin has been discussed by Osadetz *et al.* (2003), and Evenchick *et al.* (2003).

The aims of this study are to 1) improve understanding of the structural and sedimentological conditions during the initiation of Bowser Basin subsidence; and 2) examine the Cretaceous-Tertiary deformation of the basin, with the goal of distinguishing and understanding deformation episodes in the Skeena fold belt. Organic-rich shale units at the base of the succession deposited in the Bowser Basin were investigated by Ferri and Boddy (2005), who reported total organic carbon contents up to 6% in samples from mature to overly mature parts of the basin; they suggested that original organic contents may have been 2–4 times greater, representing the greatest source potential in the basin. An improved understanding of the stratigraphic and structural relationships of these rocks (objective 1) is therefore important for an assessment of the petroleum potential of the basin. Structurally, the Skeena fold belt contains overprinted folds of at least two generations, producing dome-and-basin fold-interference patterns (*e.g.*, Evenchick 1991, 2001). Structural domes represent potential traps; an improved understanding of the origin and timing of folding, and the relationships between folds and faults (objective 2), may assist in the location of such structures in the subsurface.

Fieldwork in 2005 focused on selected regions (Fig. 1), chosen on the basis of previous mapping by Greig and Evenchick (1993), Evenchick *et al.* (2000), Evenchick (2001) and Evenchick and Thorkelson (2005) as displaying either field relations at the base of the Bowser succession or potential overprinting relationships between folds of different generations, or both. The results presented here are preliminary, and are based entirely on field results; thin-section, paleontological and analytical work will be carried out later in the project.

REGIONAL STRATIGRAPHIC UNITS

Units of the Stikine Terrane underlying the Bowser Lake Group represent a variety of Late Paleozoic to early Mesozoic arc environments, and are dominated by volcanic rocks. The Triassic (Carnian-Norian) Stuhini Group is characterized by pyroxene-phyric basalt, whereas Early to early Middle Jurassic volcanic and volcaniclastic rocks of the overlying Hazelton Group include bimodal lavas and abundant volcaniclastic rocks (Anderson, 1993). Interfingering with these, distinctive mixed sedimentary and volcanic successions of Early Jurassic to early Middle Jurassic (Pliensbachian to Bajocian) age have historically been assigned to the upper Hazelton Group and have been given a variety of formation names (*e.g.*, Thomson *et al.*, 1986; for a review, see also Marsden and Thorkelson, 1992). In the vicinity of the study areas, the term Salmon River Formation has been applied to these strata (Anderson, 1993; Greig and Evenchick, 1993; Lewis, 1996), and they are largely within the belt of the Eskay Creek and Troy Ridge facies of Anderson (1993). As elsewhere, the unit is characterized in the study areas by very thinly bedded, blocky, siliceous, very fine brown sandstone and siltstone, including fine, pale-coloured tuffaceous mudstone, which locally imparts a conspicuous striped appearance (Fig. 2). These strata are known informally as 'pyjama beds'.

At many locations visited in this study, the lower and upper Hazelton rocks are separated by a mappable angular unconformity. In contrast, the contact between the Spatsizi Formation (and its equivalents) and the overlying Bowser Lake Group is typically broadly concordant and appears transitional in many locations, though affected by later deformation. Hence, for the purposes of understanding basin evolution, it is helpful to treat the upper Hazelton and Bowser Lake groups together. The informal term 'Bowser suc-

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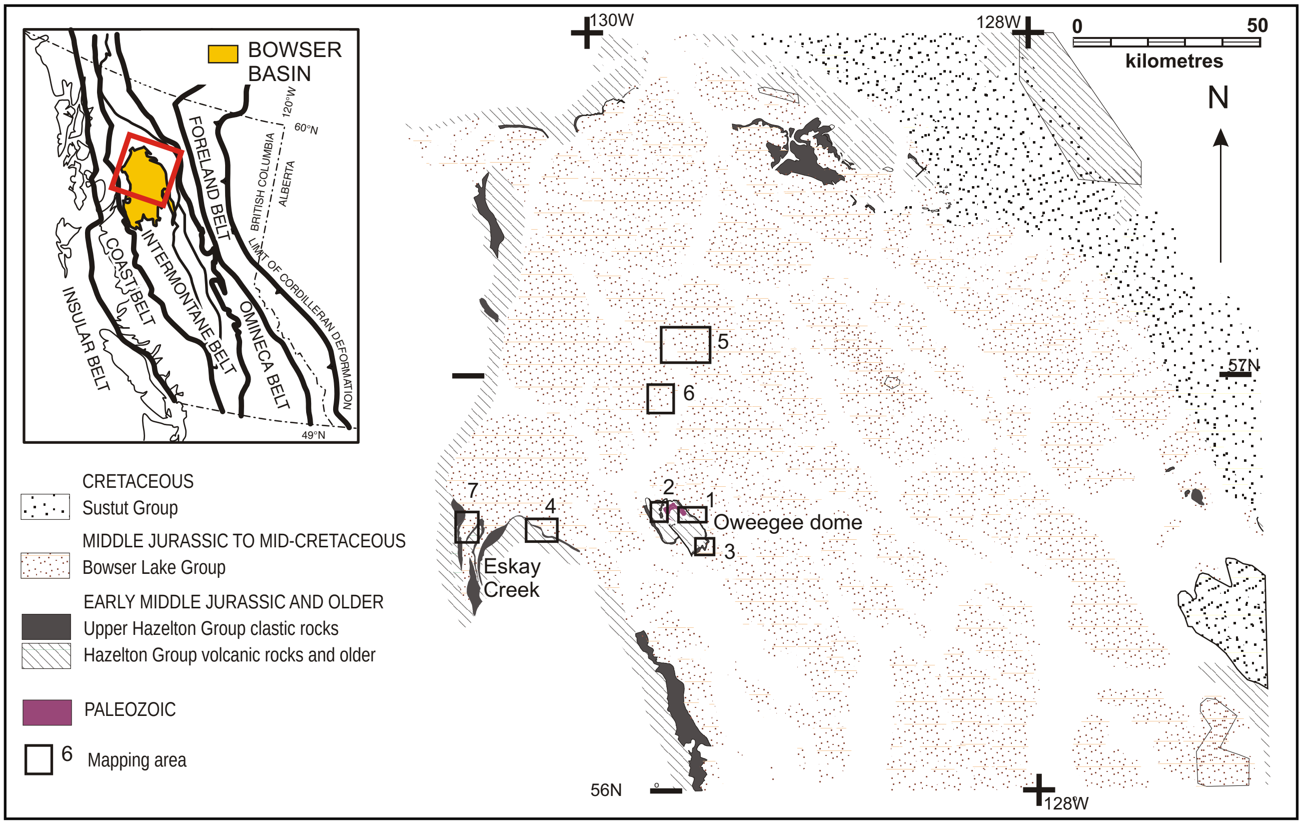

Figure 1. Simplified geology of the northern two-thirds of the Bowser Basin, showing areas of detailed study in 2005. Inset shows the location of the Bowser Basin in relation to principal belts of the Cordilleran Orogen in British Columbia, with the area covered by the main map indicated by the red rectangle.

cession' is used herein to refer to this package of mainly sedimentary strata.

The overlying Bowser Lake Group consists predominantly of shale and sandstone, and, in the north and northeast, chert-pebble conglomerate (*e.g.*, Evenchick and Thorkelson, 2005) The sandstone and siltstone are less siliceous than those of the upper Hazelton Group. Petrographic investigations summarized by Evenchick and Thorkelson (2005) have revealed an abundance of detrital chert clasts, interpreted to have been derived from the Cache Creek Terrane to the northeast. The Bowser Lake Group has been informally divided by Evenchick and Thorkelson (2005) into facies assemblages based on features such as sedimentary structures, nature of cyclicity and proportions of rock types, and are interpreted to represent distinct depositional environments. Three of these assemblages were examined in the course of the 2005 field season: the Richie-Alger, Muskaboo and Skelhorne assemblages, representing submarine fan, shallow marine (Fig. 3) and deltaic environments of deposition.

STRATIGRAPHIC RELATIONSHIPS OBSERVED AT THE BASE OF THE BOWSER SUCCESSION

Lower Hazelton and Older Rocks

Relationships at the base of the Bowser succession are well displayed around the Oweegee Dome, in areas 1–3 (Fig. 1). Immediately below the base of the Bowser succession is the largely volcanic succession of the lower Hazelton Group. Good exposures of the lower Hazelton Group dip gently (20°) southwest in area 2 in the northwestern part of the Oweegee Dome (Fig. 1). The lowest unit observed consists of medium beds of weakly calcareous green chert interbedded with fine layers of fissile dust tuff, passing laterally into well-stratified maroon and green volcaniclastic sandstone interbedded with pebble to cobble conglomerate, debris flows, minor andesitic volcanic flows and pinkish volcanic breccia. Pyroclastic rocks, such as clay-altered flaky ash tuff and highly feldspathic lapilli tuff, are common within this unit. Upsection, there is a gradual increase of reworked volcanic material, producing more characteristically sedimentary rocks. Volcaniclastic siltstone and sandstone with high proportions of igneous clasts display parallel laminations, moderate sorting and fining-upward sequences. These units are overlain by an ~30 m thick unit of felsic porphyritic rhyolite.

In the vicinity of Teigen Lake (area 4, Fig. 1), the lower Hazelton Group is characterized by well-stratified, greenish grey, poorly sorted, matrix-supported pebble conglomerate with soft thin interbeds of ash and lapilli tuff. These volcaniclastic rocks are highly siliceous and locally show significant evidence of reworking by water, such as fining-upward cycles and well-sorted bands. Matrix-supported debris-flow units are also present. Volcanic flows of quartz-phyric rhyolite, and hornblende-phyric andesitic lava with calcite amygdules, are common.

Rocks of the Hazelton Group west of the Eskay Creek mine in area 7 are thinly bedded felsic volcanic tuff interbedded with intermediate plagioclase-hornblende-phyric flows. These rocks are greenish grey on fresh surfaces and usually altered to an intense reddish brown colour. Calcite and quartz veins are common.

Upper Hazelton Group

The overlying upper Hazelton Group consists of thinly interbedded sandstone and shale, localized conglomerate, occasional fissile green tuff beds and thin beds of limestone. In area 1, the basal contact of the upper Hazelton Group is clearly mappable as an angular unconformity, though rarely well exposed. Massive grey-green volcanic breccia of the lower Hazelton Group is overlain by clast-supported, poorly sorted, quartz-rich pebble conglomerate with occasional mafic pebbles. The conglomerate is indicative of a high-energy environment and likely a relatively shallow water depth. Clasts range from angular to well rounded, suggesting provenance from a range of distances. The conglomerate passes transitionally upward into more characteristic 'pyjama beds' that are similar to parts of the Salmon River Formation elsewhere. The overlying siltstone, shale and laterally continuous tuff beds suggest a lower energy, deeper water setting, with continuing distal volcanic activity. Sectional exposures of the upper Hazelton Group overlain by turbidites of the Bowser Lake Group (Ritchie-Alger assemblage) occur along the east side of Oweegee Dome (area 1). The section in Figure 4 shows the upper portion of the Hazelton Group and the basal Bowser Lake Group.

In area 2, a sharp irregular contact between green andesitic volcanic rocks and overlying polymictic cobble conglomerate is interpreted as the basal unconformity of the upper Hazelton Group. The basal conglomerate unit has a discontinuous fining-upward gradation from cobble-size clasts to coarsely laminated arkosic sandstone over a 1 m interval. This unit is mostly clast supported and contains a matrix of poorly sorted coarse to very coarse sandstone. Clasts are angular and include diorite, maroon and green lapilli and ash tuff, chert, lithic fragments and very fine grained fossiliferous limestone containing corals and crinoid fragments. Overlying conglomerate units with very similar characteristics show a cyclicity of multiple fining-upward sequences (Fig. 5). The basal conglomerate fines upward gradually into moderately calcareous arkosic sandstone beds that show cross-laminations, mud intraclasts and current ripples. Higher up, finely laminated beds of tuffaceous pale silt and orange-weathered fine sand resemble typical 'pyjama beds' (Fig. 2KB063b) and display such sedimentary structures as parallel laminations and ripples, and rusty orange–weathering carbonate lenses. Centimetre-scale normal faults and slump folds, soft-sediment deformation and bed pinchouts probably signify synsedimentary tectonism. Carbonate concretions occur at various locations throughout the sedimentary section. These can be up to 50 cm in diameter but are more commonly 5 cm. The distribution of concretions is sporadic, but they tend to be concentrated in certain beds.

A 2 m thick enigmatic unit of light to dark limestone with complex boundstone textures (Fig. 6) is present in area 3, close to the top of the Hazelton Group. The limestone includes shell fragments and is locally bioturbated. Freshly broken pieces smell of bitumen. Unfortunately, the contacts of this unit are not exposed, but the presence of thin limestone units elsewhere in the laterally equivalent successions suggest that it is an *in situ* carbonate unit and not an exotic block.

Massive sandstone occurring in the higher 'pyjama beds' represents a gradational transition between the underlying upper Hazelton Group and the overlying Bowser Lake Group. Thick beds of fine grey sandstone, alternating

Figure 2. Thinly interbedded siliceous mudstone, siltstone and fine sandstone with pale bands interpreted as tuff, characteristic of the upper Hazelton Group, area 3.

Figure 3. Bioturbated siltstone and mudstone containing the trace fossil *Scolicia*, suggesting shallow marine deposition, probably Muskaboo Creek assemblage, area 5.

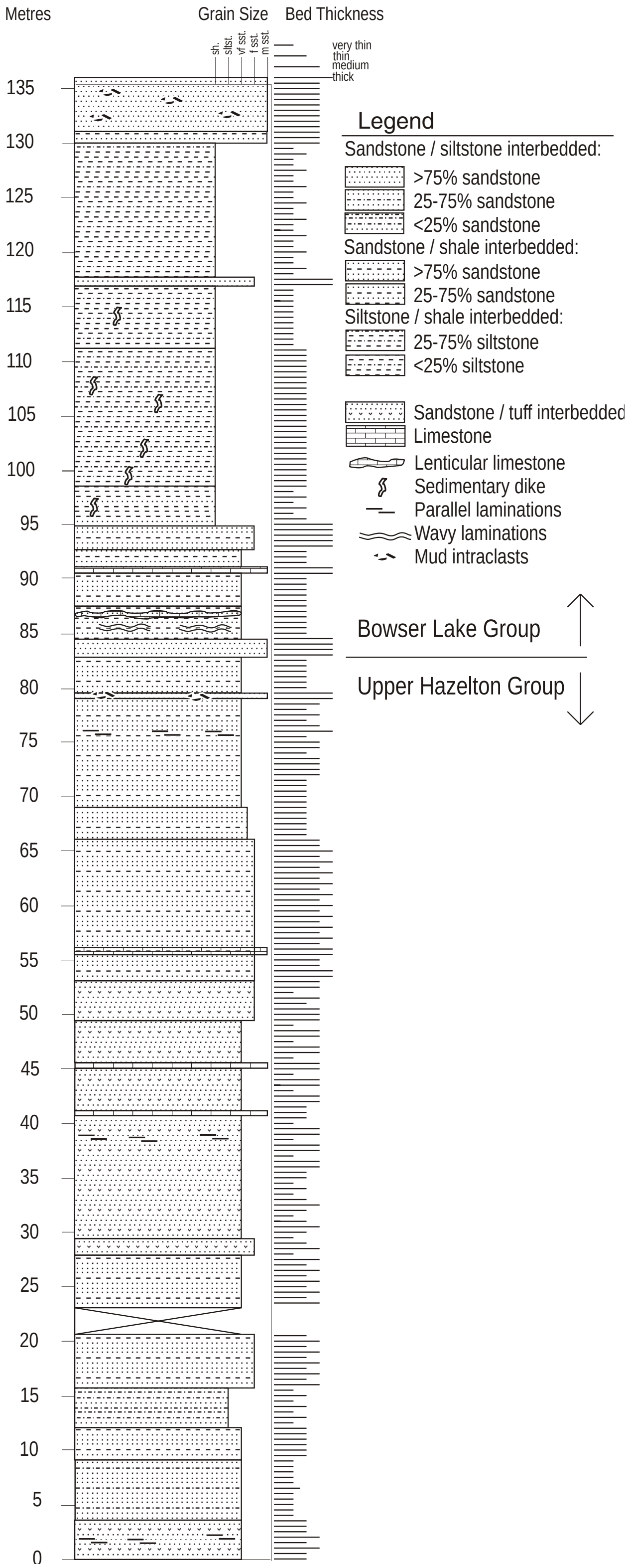

Figure 4. Stratigraphic section in upper Hazelton Group and lower Bowser Lake Group, area 1.

with thick successions of black fissile shale, represent the basal Bowser Lake Group.

In the Teigen Lake area (area 4, Fig. 1), the boundary between the volcanic-dominated lower Hazelton Group and the more sedimentary-dominated upper Hazelton Group is marked by a 30–40 m band of orange to brown-weathered outcrop. A sharp contact of lapilli tuff overlain by an arkosic medium sandstone bed emphasizes the contact, but no angular discordance was seen. The contact is offset about 30 m in a dextral sense by a small north-northeast-striking fault. Abundant marine fossils (belemnites, bivalves) occur on the top of a thick pebbly sandstone bed just above the inferred base of the upper unit. Higher in the section, finely laminated thin beds of dark grey siltstone are overlain by thickly bedded arkosic sandstone. The dark grey siltstone is locally calcareous and contains well-preserved belemnites. The very fine parallel laminations and the interbeds of black shale within this unit again suggest a deep-water depositional environment. The stratigraphically higher sandstone unit is well sorted overall and includes centimetre-thick bands of coarse grains and many rounded mud intraclasts (up to 25 cm). The rapid change of grain size in both fining and coarsening-upward sequences, and erosional features such as scoured bases and intraclasts, indicate rapid deposition in a high-energy marine environment.

Sedimentary rocks similar to those described above were observed at a single locality in area 7 (location A in Fig. 7). The limited extent of these units suggests that their contact with the purely igneous rocks of the lower Hazelton Group might be faulted.

Bowser Lake Group

The base of the Bowser Lake Group is marked by medium beds of medium-grained grey sandstone; the sandstone has a smoother appearance on weathered surfaces and is less siliceous than those of the upper Hazelton Group. The overlying succession is dominated by fine to medium sandstone beds and fissile black shale, in cyclic successions that are each several metres thick. These are representative of the Ritchie-Alger turbidite assemblage.

Approximately 15 m above the base of the Bowser Lake Group in area 1, medium-grained beige sandstone sheets are observed to cut bedding in black shale units at low to high angles (Fig. 4). Some of these sheets are planar, whereas others are tightly to ptygmatically folded, probably in response to compaction of the surrounding mud. These sheets are interpreted as sedimentary dikes, representing extensional fissures infilled by sand from above. In some locations, the dikes show offset of bedding, indicating that the fissures displayed a component of normal-sense fault motion.

The transition from the upper Hazelton Group to Bowser Lake Group sedimentary rocks is rather abrupt in area 4. There is an overall increase in the quartz content of the sandstone and mudrock becomes more fissile upward. The overlying thick succession of turbidites with Bouma sequences and interbedded fine sandstone and shale is typical of the Ritchie-Alger assemblage. Diagenetic carbonate concretions and pyrite are locally present in the siltstone. A well-defined submarine-fan channel, characterized by well-sorted chert-pebble conglomerate, locally cuts through the finer sedimentary rocks. East-trending syndepositional normal faults and sandstone dikes (Fig. 8) attest to tectonic instability.

No direct contact between the Hazelton Group and the Bowser Lake Group was observed in area 7; however, because the transition is abrupt, occurring over a relatively small unexposed distance (~50 m), and lacks transitional facies seen elsewhere, the contact is here interpreted to be a fault. The Bowser Lake Group consists of interbedded shale, dark grey siltstone and light grey fine-grained sandstone with parallel laminations. Sedimentary structures, such as flame structures, convolute laminations and partial (bcd) Bouma sequences, suggest that these rocks were deposited as turbidites in a submarine-fan setting. Distorted fossils, such as ammonites and belemnites, are common in this rock type and attest to the marine environment.

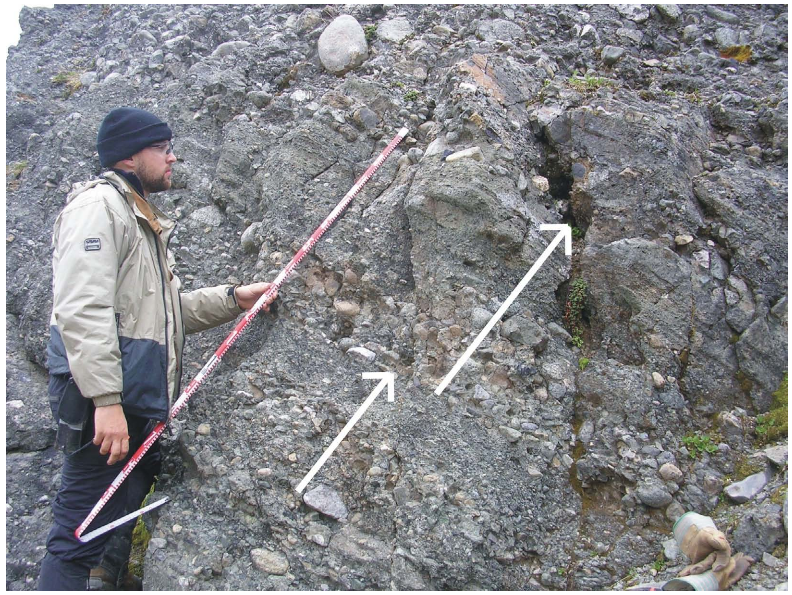

Figure 5. Conglomerate at base of upper Hazelton Group, area 2.

DEFORMATION

Deformation in the Lower Hazelton Group

The lower Hazelton Group on the margins of Oweegee Dome displays numerous faults that do not appear to continue, based on this summer's observations, into the overlying Bowser succession. The scale of faulting ranges from meso to macroscopic, but only the larger faults have associated gouge. Faults with gouge dip steeply, with strikes ranging from southwest to west. Volcaniclastic rocks display protomylonitic texture, with localized C-S fabric indicating a component of dextral shear, adjacent to a conspicuous west-striking fault zone with extensive fault gouge and orange-weathering gossan. These observations suggest that deformation occurred close to the brittle-ductile transition. Numerous veins are present, filled by both calcite and quartz; in some cases, intersecting veins indicate multiple generations of fracturing and movement of hydrothermal fluid. Veins are typically quartz where they cut chert and rhyolite, but calcite in the pyroclastic rocks, intermediate lava flows and sedimentary rocks.

On the west side of the dome (area 2), at least two well-developed foliation fabrics are developed in the lower Hazelton Group: a steeply dipping (80º) east-trending cleavage and a shallower (20º) fabric with similar orientation to bedding, which dips gently west-southwest. The intersection lineation created by the superimposed cleavages results in an elongated pencil-like breaking habit. The foliations are best developed in maroon and green volcaniclastic rocks and in the fine-grained sedimentary rocks; they are difficult to see in the more competent units, such as chert, rhyolite and conglomerate. Extensional features, including joint and vein sets, are common in this area.

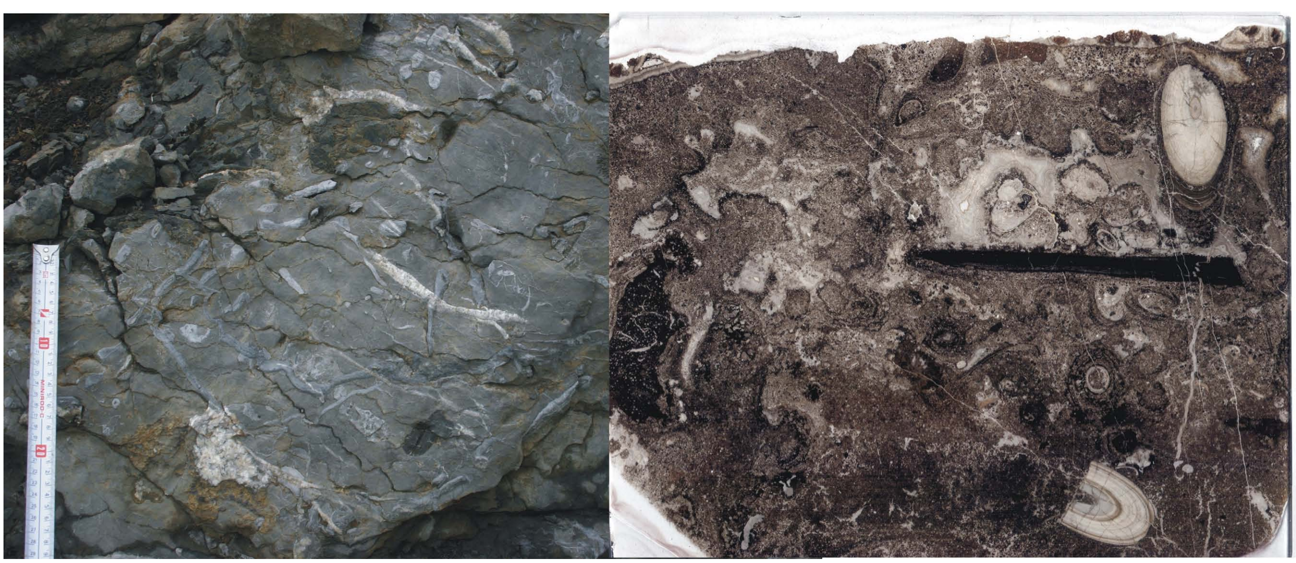

Figure 6. Complex boundstone unit at the top of the Hazelton Group, area 3. Field photograph (left) and large-format thin section (right). Field of view of thin section ~10 cm.

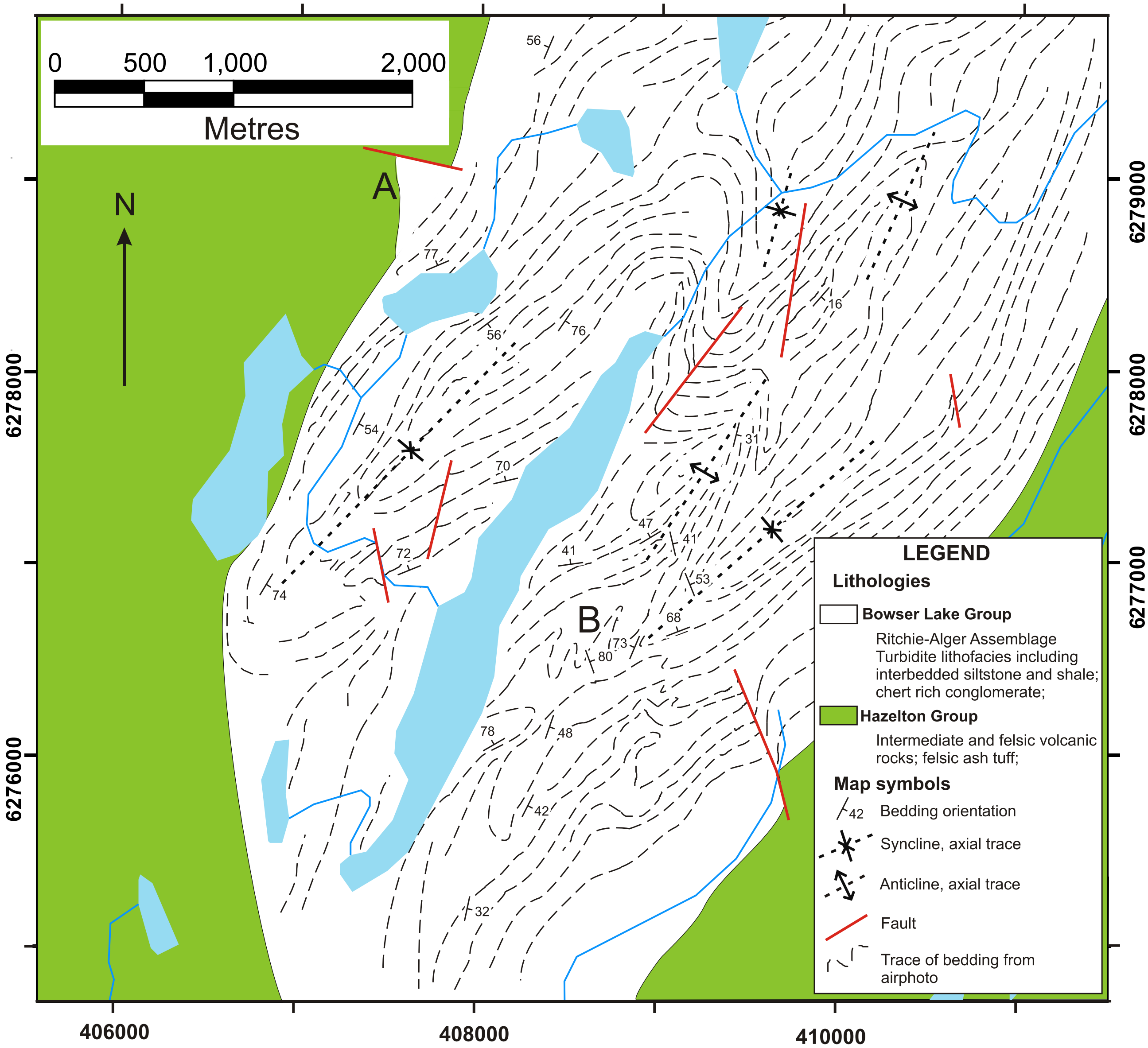

Figure 7. Generalized geology of area 7, showing traces of bedding and major structures based on mapping and airphoto interpretation, and locations A and B.

Deformation in the Bowser Succession

REGIONAL FOLDS AND CLEAVAGE

Oweegee Dome Area

Previous mapping was carried out in the Oweegee Dome area by Greig and Evenchick (1993). The authors have examined selected areas in detail (Fig. 1), confirming the map-scale structures shown by them. Folds, with wavelengths estimated to range from hundreds of metres to kilometres, occur in the Bowser Lake Group overlying the Oweegee Dome. In general, the amplitude of folding increases away from the margins of the dome, suggesting that shortening in higher parts of the stratigraphy is balanced by faults or ductile shearing deeper in the succession. At least some of the folds are therefore probably detachment folds (*e.g.*, Jamison, 1987) related to shearing in the lower shaly strata of the Bowser Lake Group. Most folds trend south-southeast in this area and plunge gently; south-southwest and north-northeast-plunging folds are present locally. Figure 9 displays a typical kink-fold pair, with fold hinges plunging gently north-northwest. Smaller folds, with wavelengths of metres to tens of metres, are locally abundant, particularly in area 3. Plots of poles to bedding from selected areas around the Oweegee Dome clearly show girdle distributions related to the predominant fold axes that trend south-southeast (Fig. 10, 11), consistent with the major structures mapped by Greig and Evenchick (1993).

Cleavage is very sporadically developed around the Oweegee Dome; cleavage orientations are also plotted in Figures 10 and 11. Local pencil fabric was observed, resulting from simultaneous splitting of the rock along tectonic cleavage and a strong bed-parallel fabric. On the east margin of the dome, a majority of cleavage orientations strike south-southeast and could be consistent with an axial-planar relationship to the main folds. However, they are much more widely dispersed than the bedding poles. At the south margin of the dome, the scattered cleavage observations show a predominant east-southeasterly strike, again scattered in a diffuse girdle about a steeply south-southwest-plunging axis. These relationships are consistent with an early development of cleavage, perhaps associated with east-southeast-trending F_1 folds and subsequent refolding by F_2 folds with a Cordilleran (north-northwest) trend.

Because of the difficulty of resolving the relative timing of fold generations, an area of previously recorded diverse fold orientations (area 5) was selected for study near Tumeka Creek. Kilometre-scale northwest-trending chevron folds are observable from several locations. Locally, concentric and kink folds occur at the cores of larger structures, with planar bedding on the flanks. However, plotted bedding orientations show a diffuse cluster, with no clear girdle distribution (Fig. 12). Cleavage is well developed in this area, particularly in the dark grey siltstone. Cleavage predominantly strikes north-northeast, with steep dips. In contrast to the observed fold hinges, which mainly trend south-southeast, bedding-cleavage intersection lineations show a wide scatter, including predominant north-northeasterly trends. Cleavage orientations are also significantly more dispersed than bedding, forming a short segment of a girdle distribution about a steeply plunging axis (Fig. 12). These observations suggest that cleavage predates the majority of observed folds and was refolded about a steeply plunging axis by development of south-southeast-striking F_2 folds.

Folds are rare at the basin margin near Teigen Lake (area 4), but penetratively foliated shale contains at least two different cleavages (oriented 089°/84°S and 217°/75°W) that form a steep pencil lineation. Although the sequence of deformation is uncertain because of poor outcrop, it again appears that the steeper, south-dipping fabric (S_2) cuts an older northwest-dipping S_1.

The Bowser Lake rocks in area 7 show an overall structural pattern dominated by tight, northeast-plunging, steeply inclined anticlines and synclines (Fig. 7, 13). This generation of folds is associated with a penetrative cleavage with a mean orientation of 053°/80°S. The map-scale folds are commonly surrounded by outcrop-scale parasitic folds with a cleavage trace that is nearly parallel to the axial plane (047°). At location B (Fig. 7, 14), the northeast-trending cleavage is disturbed and changes direction significantly by more than 30° at outcrop scale. The deflection of both F_1 folds and their associated cleavage (S_1) indicates that a second generation of open F_2 folds is present, with an average axial trace striking 120°. A second, locally developed disjunctive cleavage (S_2) associated with the F_2 folds shows constant orientation of 315°/85°E, without any sign of curvature, and is therefore believe to be related to a later and different episode of deformation. On a regional scale, the superimposed F_2 folds create a distortion of the F_1 folds by gently bending their limbs (Fig. 7). The overprinting of the two cleavage planes locally creates a steeply north-plunging L_2 intersection lineation.

STRUCTURES ASSOCIATED WITH THE BASE OF THE BOWSER SUCCESSION

Outcrop-scale structures are well exposed in the upper Hazelton Group adjacent to the Oweegee Dome. On the east margin of the dome, the formation contains thrust faults that cut bedding and terminate in outcrop-scale fault-propagation folds with chevron geometry and kink-like fault-bend folds, related to ramp-flat geometries on the faults. These have fold hinges with a shallow plunge to the northwest. South-striking centimetre-scale extensional faults are also present, but there is no clear evidence of their timing relative to the thrusts.

Farther upsection, the upper Hazelton Group and the overlying Bowser Lake Group are separated in area 1 by a zone of intense veining, folding and fabric development in shale, defining a shear zone between the two formations. Shale within this shear zone displays multiple orientations

Figure 8. Synsedimentary dikes in basal Bowser Lake Group, area 4.

Figure 9. View of kink-style folds in area 3. Field of view approximately 300 m wide.

of fabric (Fig. 15). The first fabric generation suggests that the shear zone initially behaved as a southwest-directed thrust fault, producing a shear fabric oblique to the fault. Later reactivation of the fault with a normal sense of displacement produced an intermediate upright fabric in response to the change in sense of movement.

In area 4, the regional moderate to steep northeaster dip of bedding is relatively constant. However, a tight synform and antiform in 'pyjama beds' plunge gently southeast. This style of deformation is only observed in upper Hazelton and Bowser Lake sedimentary rocks and seems to be absent in the older Hazelton volcaniclastic rocks. Therefore, a décollement at the top of the lower Hazelton Group might have occurred during the formation of the Skeena fold belt.

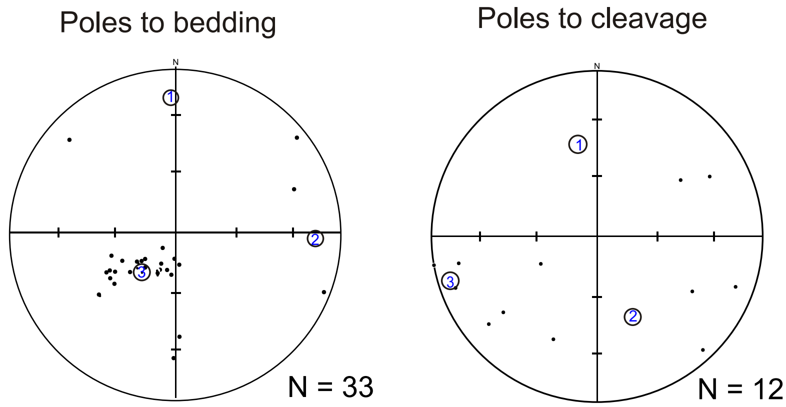

Figure 10. Lower hemisphere, equal-area projections showing the orientation of structures in area 1. Circled numbers 1, 2 and 3 represent eigenvectors of the distribution.

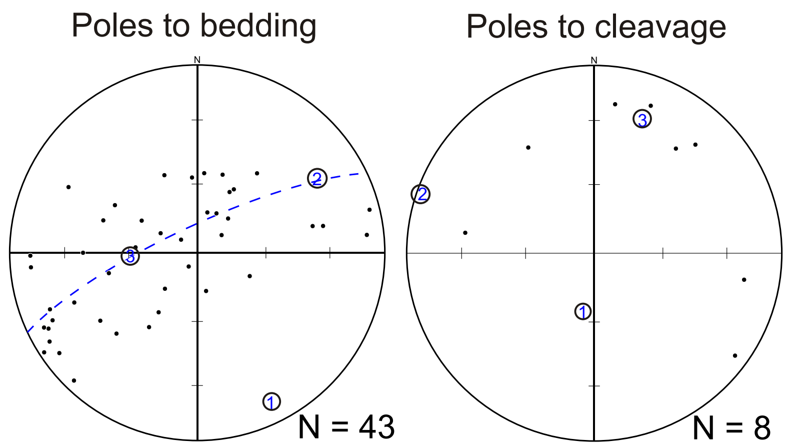

Figure 11. Lower hemisphere, equal-area projections showing the orientation of structures in area 3. Circled numbers 1, 2 and 3 represent eigenvectors of the distribution. Dashed line represents best-fit great circle to girdle distribution.

STEEP BRITTLE STRUCTURES IN THE BOWSER SUCCESSION

Steep brittle structures are seen at other localities. On the west side of the Oweegee Dome, brittle structures are developed in the lowest stratigraphic unit of the upper Hazelton Group, a unit of heavily sheared silicified conglomerate that shows intense veining. Multiple quartz veins recut each other in variable directions along a 5 m band that strikes 032°. The white-weathering colour of the rock is likely to be the result of siliceous fluids circulating in the fractures. Systematic conjugate joints sets (015°/75°E; 322°/75°E) are also present in the competent conglomerate unit, suggesting north-south compression consistent with sinistral shear on the north-northeast-striking fault. The fault zone continues into an adjacent section of 'pyjama beds'.

Veining is locally intense in folded regions north of the Oweegee Dome at Tumeka Creek (area 5); veins are dominantly filled by quartz. However, anhydrite veins with brecciated sandstone clasts were noted, distributed over an area several hundred metres square. Faults are also abundant in this area. The largest of these is a southwest-striking dextral strike-slip fault.

Faults in area 7 strike predominantly southeast, roughly parallel to the second (S_2) cleavage. Since the S_1 cleavage seems to be distorted and cut by multiple small-scale faults, the timing of faulting is clearly post F_1. One recorded fault, striking 290º, shows Riedel shears that suggest sinistral motion. Locally, veins show an 'en échelon' arrangement and are believed to be synthetic Riedel shears formed during strike-slip movement associated with the second folding event (F_2).

DISCUSSION

Figure 16 shows comparative sections through the base of the Bowser succession, based on the authors' observations in areas 1–4. The predominantly volcanic rocks of the lower Hazelton Group are interpreted (following Thorkelson *et al.*, 1995) as representing volcanic-arc environments that existed during the final stages in the existence of Stikinia as an independent terrane. The observations made at Mount Skowill (area 2) in the northern part of Oweegee Dome show that there is a gradual increase of more convincingly sedimentary rocks upsection in the Hazelton Group, suggesting a progressive decline in volcanic activity; several debris flows suggest that the basin was still tectonically unstable. The boundary between the lower and upper Hazelton Group is an unconformity, as clearly illustrated by the map relationships at the Oweegee Dome (Greig and Evenchick, 1993). The basal conglomerate of the upper Hazelton Group progressively fines upward through feldspathic medium sandstone to black shale. This overall transgressive sequence indicates an increase in the basin depth in response to some combination of sea-level change, tectonics and thermal subsidence. Variations in the thickness and facies of the upper Hazelton Group suggest transgression over an uneven surface (Fig. 16). The thinness of the Richie-Alger assemblage on the east side of the Oweegee Dome (area 1) suggests that the domal structure possibly originated during the development of the basin (Evenchick *et al.*, 2005). The abundance of fractures and brittle deformation structures in the lower Hazelton Group support significant deformation and suggest that the Bowser Basin was developed over a topography developed by

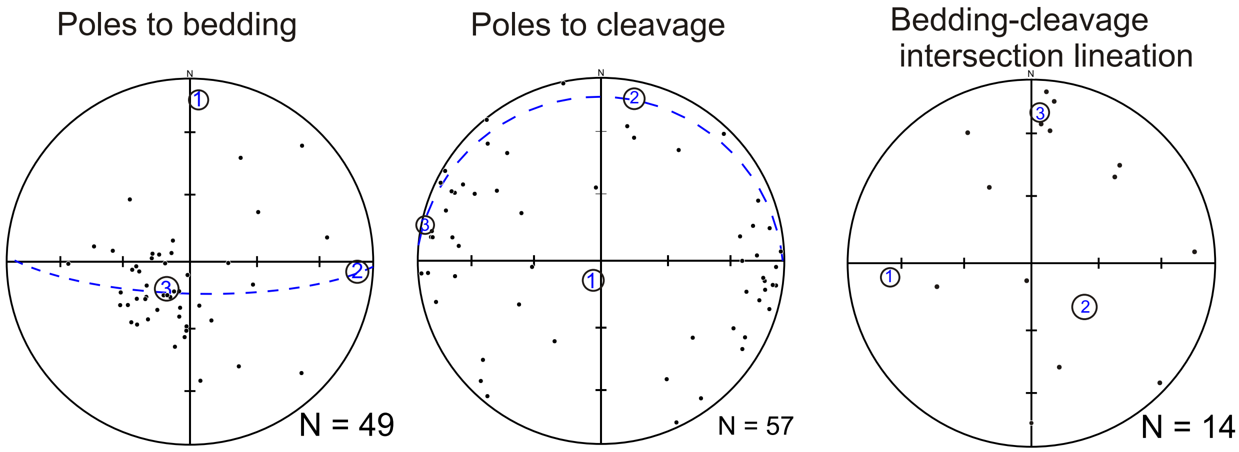

Figure 12. Lower hemisphere, equal-area projections showing the orientation of structures in area 5. Circled numbers 1, 2 and 3 represent eigenvectors of the distribution. Dashed line represents best-fit great circle to girdle distribution.

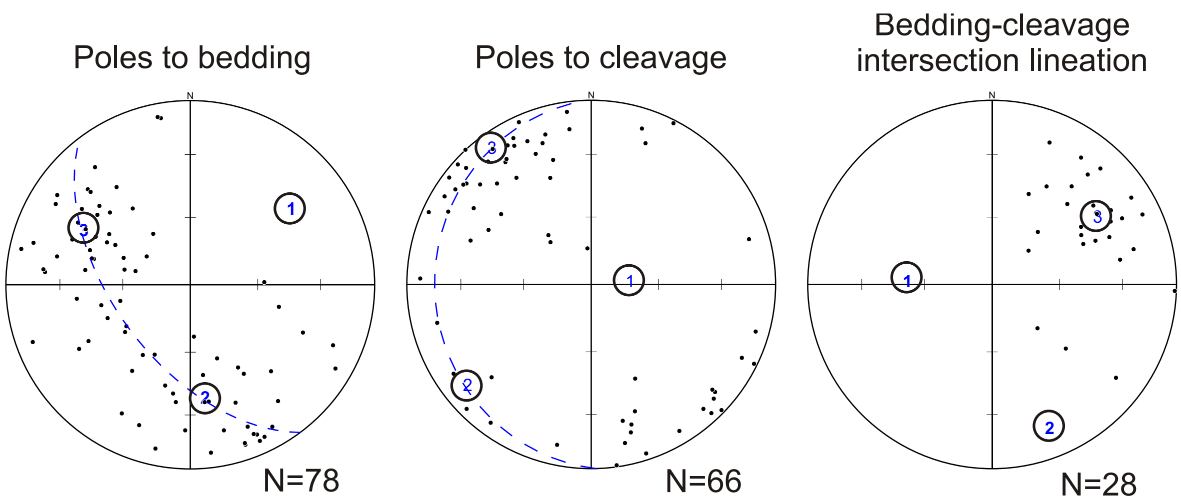

Figure 13. Lower hemisphere, equal-area projections showing the orientation of structures in area 7. Circled numbers 1, 2 and 3 represent eigenvectors of distribution. Dashed line represents best-fit great circle to girdle distribution.

faulting of the underlying Stikinia Terrane. Tectonic instability continued during deposition of the early Bowser Lake Group, indicated by an abundance of synsedimentary dikes.

Following deposition of the Bowser Lake Group, major deformation by folding occurred. Cleavage was also developed locally in the shaly units. Most of the mapped areas show some indication of overprinted fold generations and, in most areas, either northeast or northwest-trending folds predominate, confirming the observations of Evenchick (2001). Where evidence for overprinting is present, the authors noted a consistent overprinting of generally northeast-trending early folds or northeast-striking cleavage by later folds, with less well developed cleavage, that display ‘Cordilleran’ northwest or southeast trends. These results are consistent with earlier interpretations (Evenchick, 2001) that the northeast-trending folds were related to an early phase of Mesozoic sinistral transpression in the development of the Cordillera. The Cordilleran F_2 folds increase in amplitude with stratigraphic height above the base of the Bowser succession, suggesting that detachment occurred at this level, in addition to those below and above interpreted by Evenchick (1991). Low-angle thrusts that postdate S_1 cleavage, observed near the base of the succession, were probably developed as a result of this process.

At several locations, minor extensional structures were observed that appear to postdate F_2 folding. The authors speculate that these developed during Cenozoic extension, or perhaps dextral transtension.

Northeast-trending F_1 and S_1 structures are much more intensely developed in area 7 than elsewhere. This area coincides with the region of back-arc extension, or Eskay rift (e.g. Anderson, 1993; Alldrick *et al.*, 2005), a major structure in the underlying Hazelton Group that controls the distribution of facies and mineralization. The authors speculate that the faults associated with extension were inverted during the early stages of shortening in the Bowser Basin, and that the northeast-trending structures roughly follow pre-Bowser extensional features in underlying Stikinia. Since the Eskay Creek mine is located in a fault-bounded anticline, understanding the timing of the different structural elements that characterize the Bowser Lake rocks is potentially useful for predicting the location of the Eskay horizon (and possible mineral deposits) that might occur in the shallow subsurface. In addition, inversion structures are likely to propagate throughout the overlying Bowser succession, providing potential targets for hydrocarbon explo-

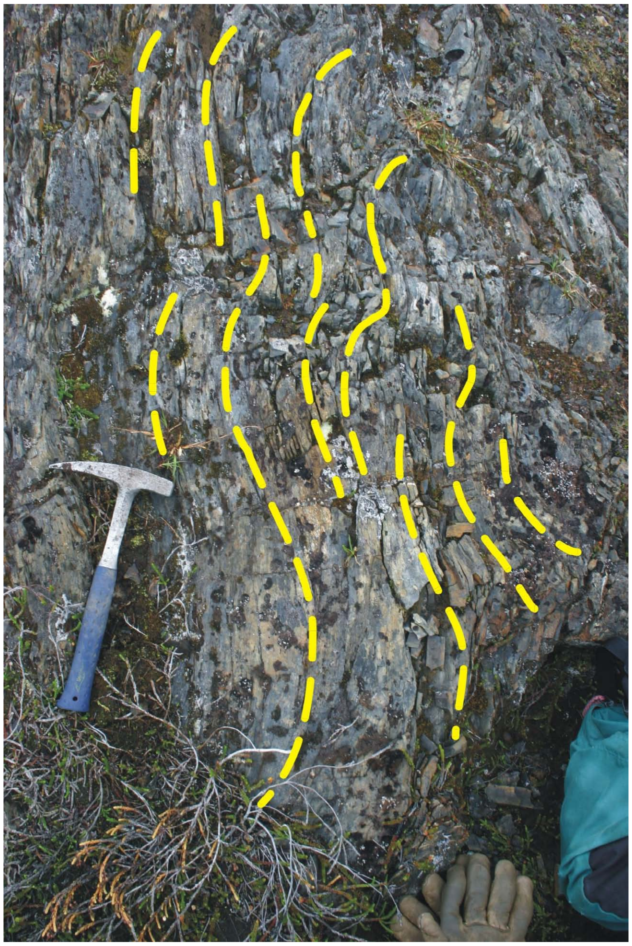

Figure 14. F_2 folds distorting S_1 cleavage, area 7.

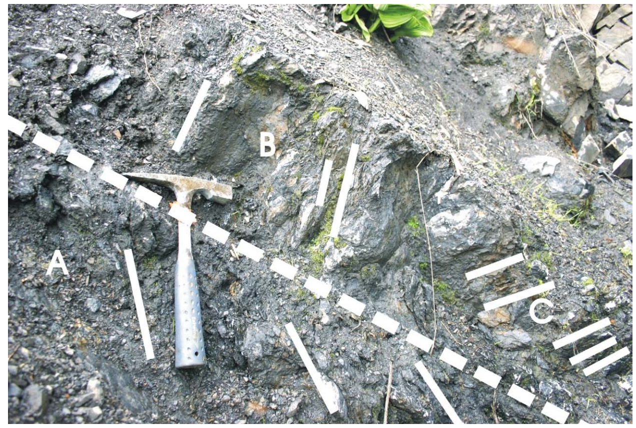

Figure 15. Shear zone containing fabric with multiple orientations. At A, the fabric dips steeply northeast, consistent with southwest shearing on shear zone (indicated by dashed line). At B and C, the fabric is progressively rotated to a moderate northwesterly dip, in-

ration that juxtapose thick successions of organic-rich upper Hazelton Group in the deep subsurface with anticlinal and or fault traps in potential reservoir rocks at higher stratigraphic levels. Further detailed geological mapping is needed to assess the timing relationship between faults and the two fold generations on a larger scale, and to improve the constraints on the geometry and timing of structures.

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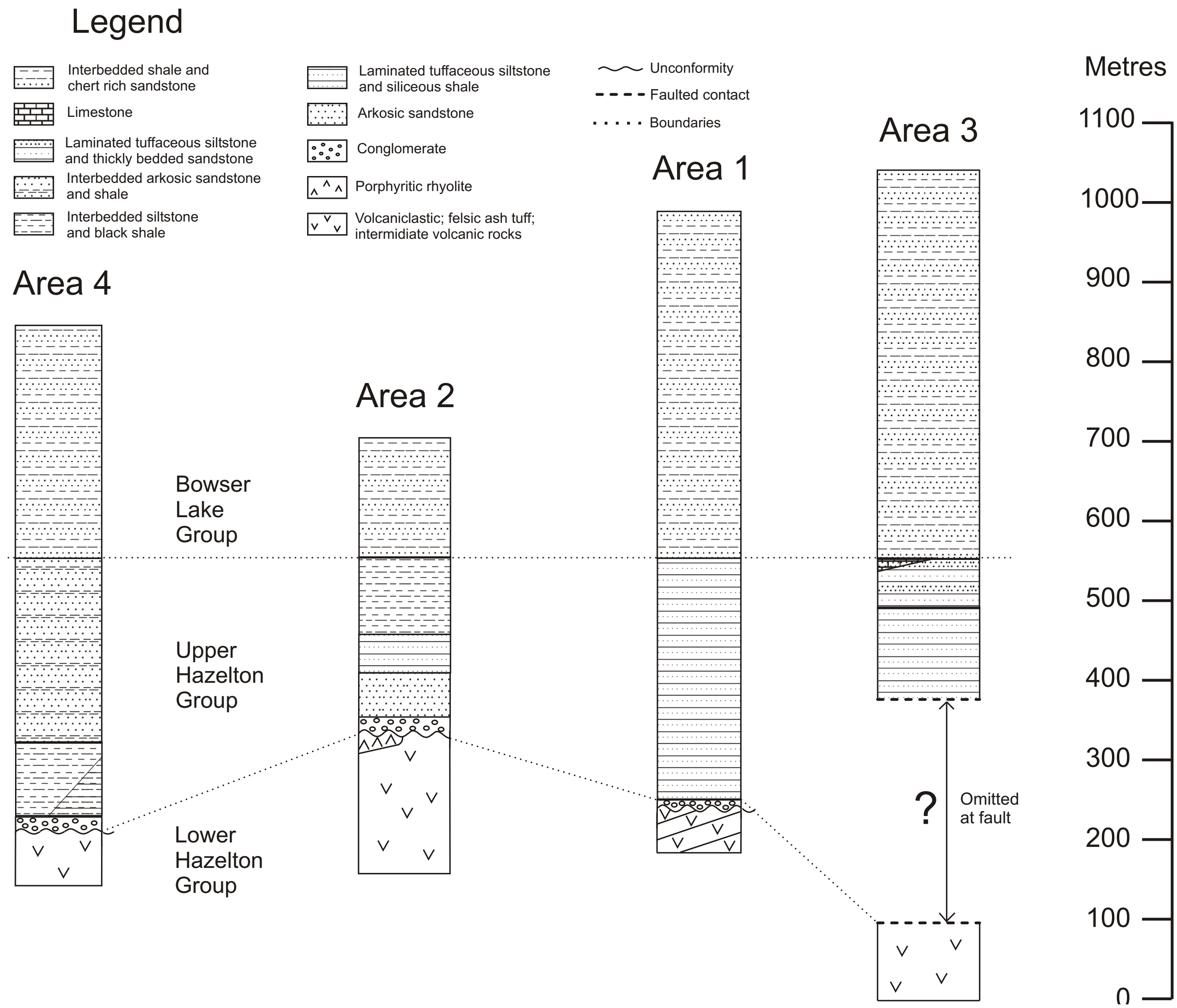

Figure 16. Comparative stratigraphic sections through the upper Hazelton Group in areas 1–4.

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