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NEW HETTANGIAN AMMONITE FAUNAS AND A TRIASSIC JURASSIC BOUNDARY SUCCESSION, FERNIE FORMATION, WILLISTON LAKE, BRITISH COLUMBIA

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Abstract. A relatively new shoreline section on Peace Reach, Williston Lake, north-eastern British Columbia, provides continuous exposure through a Triassic-Jurassic boundary succession, with apparent stratigraphic continuity from the Pardonet Formation (Upper Norian) into the overlying Fernie Formation (Hettangian and younger). These rocks are part of autochthonous North America, deposited along the western margin of the Jurassic craton.

The section at Black Bear Ridge consists of 22 m of flaggy-bedded, brown-weathering siltstones and several thick, resistant siltstones, and contains calcareous concretions which have yielded most of the three-dimensional ammonites. While it is clear these ammonites represent parts of the lower, middle and upper Hettangian, the sequence of faunas differs somewhat from those reported from the Queen Charlotte Islands and Nevada. This is the first record of an extensive sequence of Hettangian strata and ammonite faunas in the Fernie Formation.

Lower Hettangian faunas include poorly preserved, laterally flattened *Psiloceras* (*P. majus, P. plicatum, P.* cf. *rectocostatum, P.* cf. *planocostatum*), occurring throughout the lower part of the section from 3.0 to 8.3 m. At 9.5 m *Waehneroceras* appears, representing the middle Hettangian, followed by *Sunrisites sunrisense* at 10.8 m, and the first *Schlotheimia* at 13.3 m. A single large specimen of *Alsatites liasicus* is associated with these faunas. Beds above 13.3 m yield several species of *Schlotheimia* (*S. angulata, S. angulata densicostata, S.* cf. *oxygonia*), *Kammerkarites frigga* and *Laqueoceras* sp., indicating the lower parts of the upper Hettangian. Uppermost Hettangian faunas occur at the top of the exposed section in beds from 21.0 to 21.7 m, and include *Badouxia* (*B. canadensis, B. striata, B. oregonensis*) and *Pseudaetomoceras doetzkirchneri*.

Riassunto. Una sezione relativamente nuova lungo la linea di costa di Peace Reach, Lago di Williston, British Columbia nordorientale, fornisce una esposizione continua di una successione che contiene il limite Triassico-Giurassico con evidente continuità stratigrafica dalla Pardonet Formation del Norico Superiore alla sovrastante Fernie Formation dell' Hettangiano. Queste rocce fanno parte dell'autoctono nordamericano che si è depositato lungo il margine occidentale del cratone Giurassico. La sezione di Black Bear Ridge è costituita da una potente successione di siltiti anche debolmente stratificate con concrezioni contenenti la maggior parte delle ammoniti. Le faune rinvenute sono riferibili all'Hettangiano e le associazioni differiscono un poco da quelle delle Queen Charlotte Islands e del Nevada. Si tratta della prima documentazione, nella Fernie Formation, di una estesa successione Hettangiana contenente ammoniti.

L' Hettangiano inferiore è rappresentato da esemplari scarsamente preservati di *Psiloceras majus, P. plicatum, P.* cf. *rectocostatum, P.* cf. *planocostatum* che sono presenti in tutta la parte inferiore della sezione. Successivamente si registra la comparsa di *Waehneroceras* seguito da *Sunrisites sunrisense* e le prime *Schlotheimia* che documentano l'Hettangiano medio. Con queste faune è associato un solo individuo di grandi dimensioni di *Alsatites liasicus*. Al di sopra compaiono diverse specie di *Schlotheimia* (*S. angulata, S. angulata densicostata, S.* cf. *oxygonia*), *Kammerkarites frigga* and *Laqueoceras* sp. che indicano la parte inferiore dell'Hettangiano superiore. La parte superiore dell'Hettangiano è documentata al tetto della sezione dalla presenza di *Badouxia* (*B. canadensis, B. striata, B. oregonensis*) e *Pseudaetomoceras doetzkirchneri*.

Introduction

The Jurassic in the outcrop belt of the Foothills and Front Ranges, Canadian Rocky Mountains, of western Alberta and north-eastern and south-eastern British Columbia (B.C.) is largely represented by the Fernie Formation. The lower contact is an unconformity of regional extent: it overlies upper Palaeozoic or Triassic strata with a considerable hiatus, the lowermost Jurassic strata being Sinemurian, but more commonly Pliensbachian or even Toarcian, in age (Hall 1984, 1987; Poulton et al. 1994). Hettangian ammonites were first reported from outcrop by Tozer (1982) at Black Bear Ridge in north-eastern B.C., a relatively new exposure produced by shoreline erosion along Williston Lake (Fig. 1). This body of water, formed behind the W.A.C. Bennett dam when it was completed on the Peace River in 1967, submerged previously-known river level outcrops of Jurassic strata at Neparle-pas rapids to depths of nearly 100 m.

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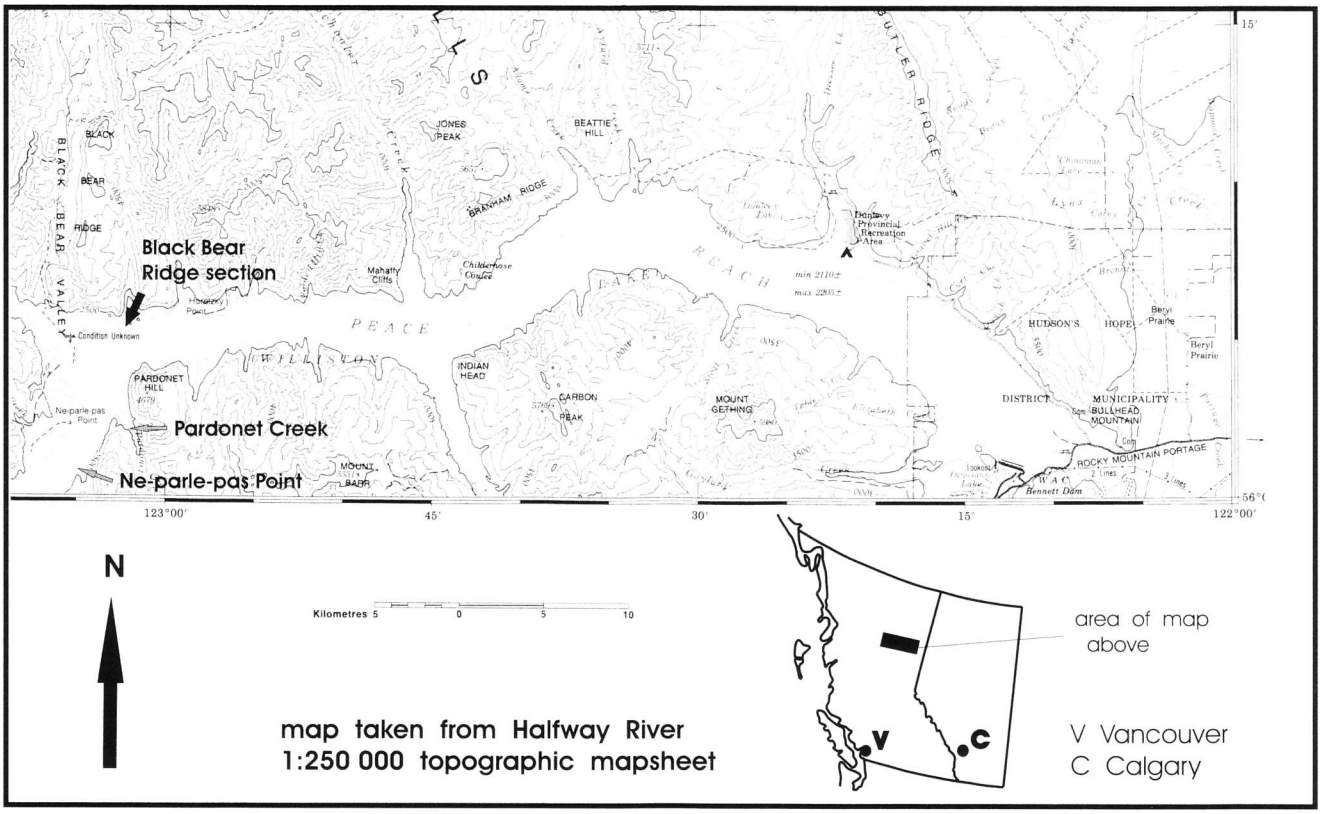


Fig. 1 - Map showing location of Black Bear Ridge section on the north shore of Williston Lake (Peace Reach) in north-eastern British Columbia, approximately 50 km west of the W.A.C. Bennett dam, at grid reference 975 155 on Mount Brewster 1:50 000 topographic mapsheet (123° 2' 23" W, 56° 5' 49" N). Other exposures of a Triassic-Jurassic boundary succession also occur at Pardonet Creek and Ne-parle-pas Point.

At Black Bear Ridge Tozer (1982) reported Jurassic ammonites from three levels in the lower Fernie Formation, 7.5 to 9 m above the *Monotis* Beds which comprise the top of the Upper Norian Pardonet Formation. He described and illustrated a single, large specimen of *Psiloceras* (*Paraphylloceras*) *calliphyllum*, but the additional material was not studied. That material has been generously made available to us and is included in this study. Tozer also briefly discussed several other localities along the shores of Williston Lake, and to the north and south of the lake, at which Triassic-Jurassic boundary sequences are exposed; faunas from these localities are not discussed further in this paper. Our collections from the section at Black Bear Ridge, made in the spring field seasons of 1999, 2000, and 2001, now number approximately 300 ammonite specimens, and another 150 ammonite fragments. In this paper we summarize the taxonomy and stratigraphic distributions of these ammonites, comment on their ages and likely correlation with already-established Hettangian zonations, and illustrate selected key taxa. Detailed taxonomic descriptions and illustrations will appear elsewhere; once this study is completed the permanent repository for this material will be the Geological Survey of Canada collections in Ottawa.

Geological setting

The lower and middle parts of the Fernie Formation consist largely of dark shales, with minor sandstones, siltstones, and black limestones, and represent the uppermost part (Hettangian to Callovian) of a passive margin sequence which had been accumulating along the western margin of the North American craton since Proterozoic time. The source of clastic sediments comprising the lower and middle Fernie Formation was to the east on the craton, but by the Late Jurassic (represented in the Passage Beds of the upper Fernie Formation) this direction had been reversed. Accretion of allochthonous terranes along the western margin of the craton resulted in magmatic activity, thrusting, and stacking of overthrust belts to produce crustal loading and initiation of a foredeep east of the deformed belt. Uplift in the Cordilleran regions to the west provided a new source of sediment (Poulton et al. 1994).

Triassic-Jurassic boundary succession

The uppermost 30 m of the Pardonet Formation consist of distinctive, crenulated beds produced by dense coquinas of *Monotis subcircularis*, with rare limestone con-

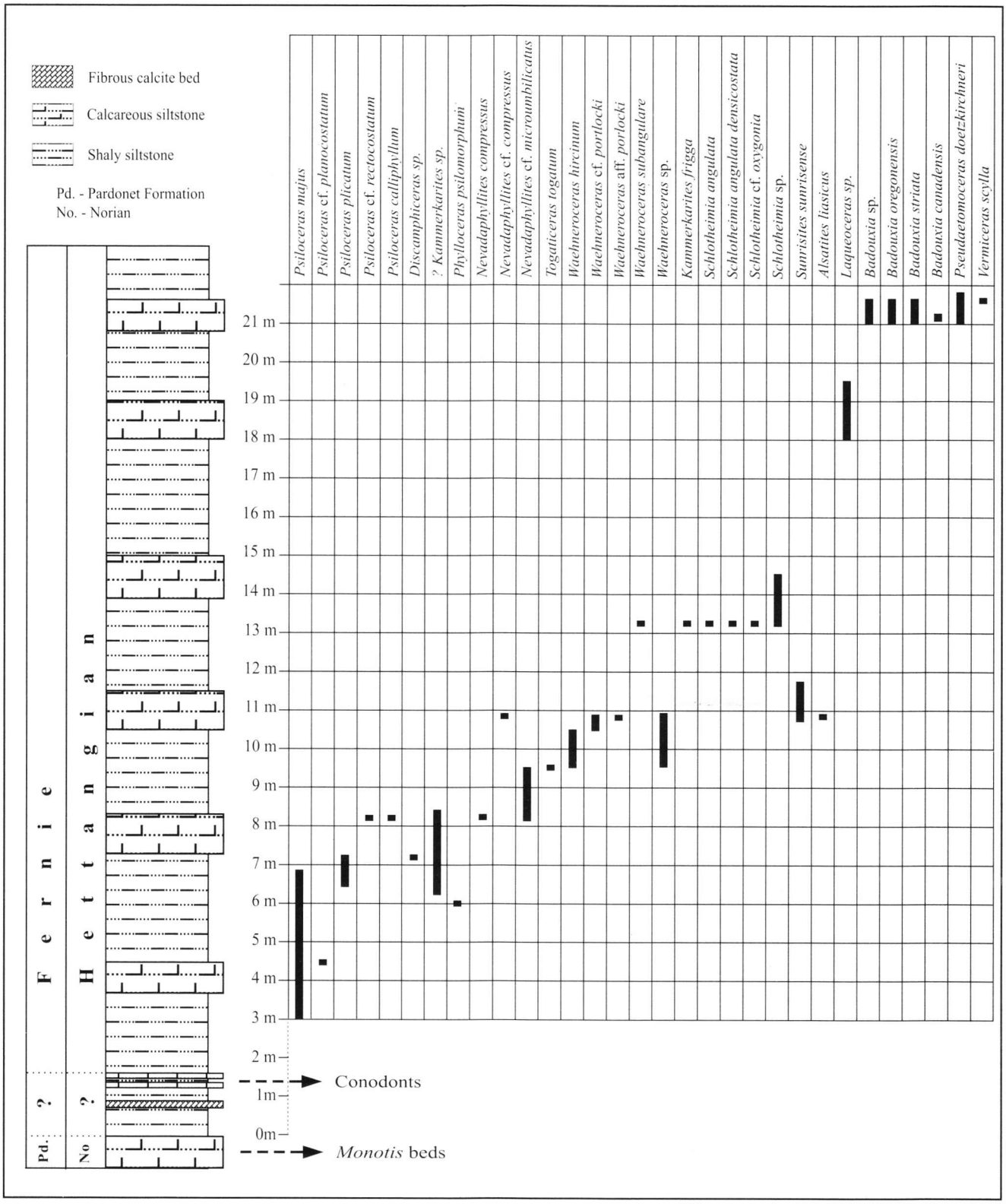


Fig. 2 - Measured section of the Lower Fernie Formation at Black Bear Ridge, with stratigraphic ranges of all identified Hettangian ammonite species. Datum (0 m) is the topmost surface of the *Monotis* beds.

cretions containing the ammonoids *Paraguembelites* and *Lissonites* (Cordilleranus Zone) and the conodonts *Epigondolella bidentata* and *Norigondolella steinbergensis* (Bidentata Zone) (Orchard et al. 2001a, b).

The so-called *Monotis* beds are conformably overlain by 3 m of poorly fossiliferous, brown-weathering, flaggy-bedded, fine siltstones below the first identifiable Hettangian (Lower Jurassic) ammonites (Fig. 2). The topmost bed of the *Monotis* beds is very resistant and provides a distinctive marker bed used as the datum in this study;

above this level *Monotis* is almost completely absent, except for an impression in a concretion 1.5 m above datum. Orchard et al. (2001a, p. 7) reported a few large conodont elements resembling *Epigondolella mosheri* and also *E.* ex gr. *bidentata* from a limestone concretion "sitting directly above the last bedding surface of *Monotis*". They suggested this association might indicate the presence of the Rhaetian Amoenum Zone. The extent of Rhaetian strata preserved in the Triassic-Jurassic boundary succession exposed at Black Bear Ridge has recently become an issue in precisely dating and interpreting the significance of carbon- and nitrogen-isotopic excursions measured there (Sephton et al. 2002; Hall & Pitaru 2003).

Interbedded with the flaggy siltstones at 0.8 m and 0.9 m above datum are two fibrous, crystalline calcite beds ("beef") which Tozer (1982) and Stott (1998) tentatively suggested marked the base of the Fernie Formation; however, there are no significant lithological differences in the bedded siltstones below and above these two beds which would warrant formational differentiation. At 1.5 m and 1.7 m above datum are two thin calcareous beds from which fragmented conodont elements of *Epigondolella* sp. have been recovered (C. Henderson pers. comm.). The first identifiable Lower Jurassic ammonites occur 3.0 m above datum, but again there is no lithological change warranting recognition of a new formation at this level. Placement of the Pardonet/Fernie formation boundary in this section remains unresolved.

Hettangian strata and ammonite faunas

Above the top of the *Monotis* beds are just over 22 m of flaggy- to massively-bedded, brown and yellowish-weathering, fine-grained siltstones containing calcareous concretions up to 0.8 m in diameter. The ammonites found in this sequence indicate the presence of lower, middle and upper Hettangian strata (Fig. 2); most of the three-dimensional ammonites are found in concretions, with lateral impressions occurring less frequently on bedding plane surfaces of the siltstones. While most specimens throughout this section are of very small size, usually less than 6 cm in diameter, one complete ammonite and several body chamber fragments indicate that some shells exceeded 30 cm in diameter. Where possible, in the following faunal descriptions our ammonite associations are correlated with the zonal scheme for the Hettangian of the western Cordilleran regions of North America proposed by Taylor et al. (2001).

Lower Hettangian faunas

The first *Psiloceras*, strongly ribbed *Psiloceras majus* (Neumayr), was found at 3.0 m, just 1.3 m above the uppermost conodont-bearing bed (Fig. 2). At 4.5 m this species is associated with *P.* cf. *planocostatum* Hillebrandt (Pl. 1, fig. 1) and these beds are correlated with the Planocostatum Subzone of South America (Hillebrandt 2000); the first costate species in the zonal scheme proposed for North America occur in the Polymorphum Zone (Taylor et al. 2001).

Psiloceras plicatum (Quenstedt) (Pl. 1, fig. 2) occurs between 6.5 and 7.3 m, associated with numerous *?Kammerkarites* sp.; this fauna is correlated with the lower part of the Polymorphum Zone of North America.

At 8.3 m *Psiloceras* cf. *rectocostatum* Hillebrandt occurs with *P. (Paraphylloceras) calliphyllum* (Neumayr), which was described and illustrated by Tozer (1982), and this level is correlated with the upper part of the Polymorphum Zone of North America and the Rectocostatum Zone of South America. Several species of *Nevadaphyllites* (*N. compressus, N.* cf. *microumbilicatus*) occur at this level.

Middle Hettangian faunas

Taylor et al. (2001) reported occurrences of both *Waehneroceras* and *Caloceras* in the uppermost part of their Polymorphum Zone, though it was noted that the upper part of the range of *C. crassicostatum* Guex may have been removed at an erosional unconformity. At Black Bear Ridge the first occurrence of *Waehneroceras* is at 9.5 m, well above the last *Psiloceras* (at 8.3 m). The middle part of our section, corresponding broadly to the standard Liasicus Zone, is dominated by schlotheimiids.

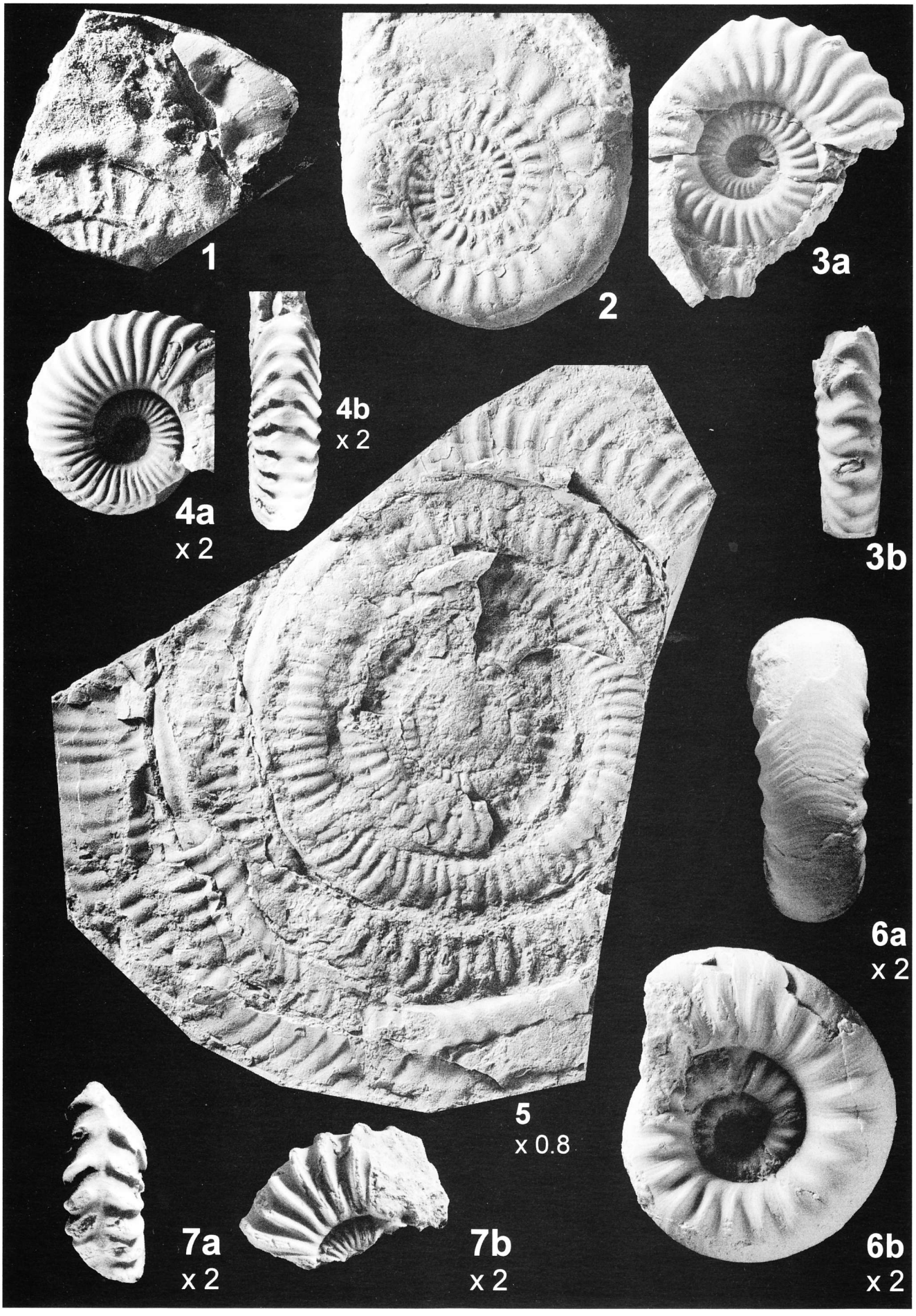
Beds from 9.5-10.7 m contain *Waehneroceras hircinum* (Quenstedt), with highly compressed whorls ornamented by heavy, strongly sinuous, unbranching ribs which increase in height approaching the venter, where they reach maximum height, and are projected forward over the venter (forming an angle of 150°) but are not interrupted; this gives the venter a crenulated appearance in lateral view (Pl. 1, figs. 3 a,b). *Nevadaphyllites* cf. *microumbilicatus* Taylor and one small specimen of *Togaticeras togatum* (Neumayr) are associated with *W. hircinum* at 9.5 m, and *W.* cf. *portlocki* (Wright) appears near the top of the range of the latter taxon, at 10.7 m. This species has very strong, sharp ribs which are only slightly sigmoidal, attain maximum height on the ventral margins, but are then abruptly interrupted to leave a smooth band along the venter, at least on juvenile whorls (Pl. 1, figs. 7 a,b).

At 10.8 m *Waehneroceras* cf. *portlocki* and other specifically indeterminate specimens belonging to this genus are associated with numerous small specimens of *Sunrisites sunrisense* Guex, and at 10.9 m, a single, large specimen of *Alsatites liasicus* (d'Orbigny). *Sunrisites sunrisense*, which ranges up to 11.8 m, is evolute, with round to slightly depressed whorl cross-sections, and blunt, heavy, evenly-spaced and slightly concave ribs which fade near mid-flank leaving a smooth, broadly-rounded venter crossed only by abundant fine striae which occur on and between the ribs on the flanks and then project forward over the venter (Pl. 1, figs. 6 a,b). The many-whorled, serpenticone specimen of *A. liasicus* has a relative umbilical diameter of 70%, and dense (36-44 per half-whorl), strong, concave, and evenly-spaced ribs (Pl. 1, fig. 5).

PLATE 1

Lower and middle Hettangian ammonites from Black Bear Ridge. All specimens reproduced at natural size except where otherwise indicated.

Fig. 1 - *Psiloceras* cf. *planocostatum* Hillebrandt from 4.05 m; Fig. 2 - *Psiloceras plicatum* (Quenstedt) from 7.3 m; Fig. 3a,b - *Waehneroceras hircinum* (Quenstedt) from 10.0 m; Fig. 4a,b - *Waehneroceras subangulare* (Oppel), x 2, from 13.3 m; Fig. 5 - *Alsatites liasicus* (d'Orbigny), x 0.8 from 10.9 m; Fig. 6a,b - *Sunrisites sunrisense* Guex, x 2, from 11.8 m.; Fig. 7a,b - *Waehneroceras* cf. *portlocki* (Wright), x 2, from 10.5 m.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5
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7b
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Schlotheimia angulata (Schlotheim), *S. angulata densicostata* Lange, and *S.* cf. *oxygonia* Lange occur with *Waehneroceras subangulare* (Oppel) (Pl. 1, figs. 4 a,b) and a single, small specimen of *Kammerkarites frigga* (Waehner) at 13.3 m. *Schlotheimia angulata* (Pl. 2, figs. 5 a,b) has strong, unbranched, proverse ribs which reach maximum height on the ventral margins, and form an angle of 90° on the venter where they flatten or fade to produce a pseudo-groove along the venter. *Schlotheimia angulata densicostata* differs in having slightly more numerous ribs (19-20 vs. 15-16 per half-whorl at the same diameter) which meet in a slightly larger angle on the venter (Pl. 2, figs. 4 a,b). *Waehneroceras subangulare* has evenly-spaced, unbranched ribs, mostly concave, with only the slightest sinuosity and arching forward on the venter where they are flattened and broaden, but are not interrupted (Pl. 1, figs. 4 a,b). The highest schlotheimiids occur at 14.5 m.

Upper Hettangian faunas

Above an unfossiliferous interval between 14.5 and 18.0 m, upper Hettangian ammonites appear in abundance: first *Laqueoceras* (Pl. 2, fig. 3), then at 21.0 m *Badouxia* and *Pseudaetomoceras*, and these beds are correlated with the Peruvianus through lower Canadensis zones of South America and the Oregonensis to Canadensis zones of North America (generally equivalent to the standard Angulata Zone of northwest Europe). Associations at this level offer the firmest correlations, both with other North American successions as well as those in South America. The inner whorls of *Badouxia striata* Guex (Pl. 2, fig. 1) have blunt ribs which fade on the flanks and, during ontogeny, are replaced by sinuous striae; specimens of *B. canadensis* (Frebold), which appears a little higher, and *B. oregonensis* Taylor are all very small and with their outer preserved whorls crushed. The associated *Pseudaetomoceras doetzkirchneri* (Guembel) is an evolute, highly compressed form with strong, heavy ribs which are straight on the lower flanks, then become sickle-shaped, with marked forward projection on the upper two-thirds of the flanks; a sharp, narrow keel is present (Pl. 2, fig. 2).

Comparisons with other Hettangian ammonite sequences from western North America

So far at this locality, no specimens have been found of smooth species of *Psiloceras*, such as *P. tilmanni* and *P. pacificum*, which characterize lowermost Hettangian strata in Nevada (Taylor et al. 2001) and South America (Hillebrandt 2000).

While the schlotheimiid-bearing beds 6.3 m to 14.5 m above datum are correlated with the interval represented by the Polymorphum, Mulleri, Occidentalis, Coronoides and lower Pleuroacanthitoides zones of Taylor et al.'s (2001) zonal scheme, more detailed correlations are difficult. The occurrence of ?*Kammerkarites* sp. with psiloceratids would represent a lower occurrence than elsewhere in North America (generally lower middle Hettangian) if our generic assignment is confirmed. The association of ?*Kammerkarites* with *Discamphiceras* at 7.2 m suggests a correlation of this part of the succession with the lowest interval faunas recorded by Pálfy et al. (1999) in the Alaska Peninsula (*Euphyllites-Franziceras* beds).

Our middle Hettangian faunas are dominated by species of *Waehneroceras* and *Schlotheimia* which are less common in some other western North American faunas. Conversely, some genera which occur elsewhere are absent at Black Bear Ridge, specifically *Pleuroacanthites, Euphyllites, Mullerites, Fergusonites, Angulaticeras, Eolytoceras*, and *Franziceras*. These absences may reflect the more northerly location of the Black Bear Ridge section compared to Nevada, which was some 2000 km farther south along the Jurassic cratonic margin, and the Queen Charlotte Islands (Tipper & Guex 1994) which, as part of the accreted Wrangellia Terrane, were also at least that far south in Early Jurassic time (Smith & Tipper 1986).

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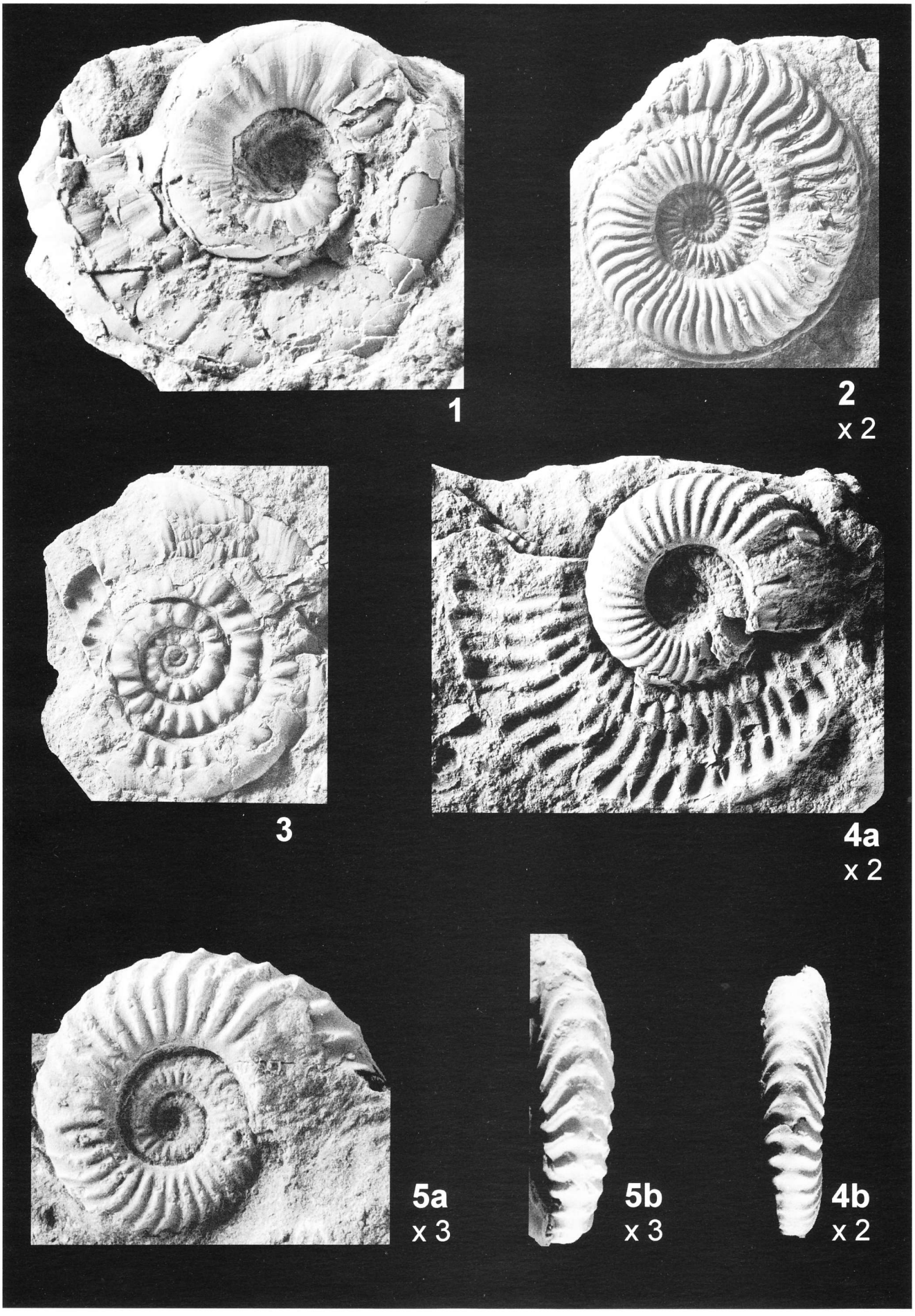
PLATE 2

Upper Hettangian ammonites from Black Bear Ridge. All specimens reproduced at natural size except where otherwise indicated.
Fig. 1 - *Badouxia oregonensis Taylor*, x 2, from 21.0 m; Fig. 2 - *Pseudaetomoceras doetzkirchneri* (Guembel), x 2, from 21.7 m; Fig. 3 - *Laqueoceras* sp., from 18.0 m; Fig. 4a,b - *Schlotheimia angulata densicostata* Lange, x 2, from 13.3 m; Fig. 5a,b - *Schlotheimia angulata* (Schlotheim), x 3, from 13.3 m.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4a
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