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INTEGRATED STRATIGRAPHY OF THE LOWER AND MIDDLE FERNIE FORMATION IN ALBERTA AND BRITISH COLUMBIA, WESTERN CANADA

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Abstract. The lower and middle parts of the Fernie Formation in central-western Alberta and south-eastern British Columbia, ranging from Pliensbachian to ?Bathonian (Early to Middle Jurassic) in age, and consisting mainly of fossiliferous dark shales and black limestones, contain bentonitic clay horizons which have yielded radiometric ages using U-Pb analysis of zircon crystals. Here we report six new ages from the lowermost Red Deer Member (188.3 +1.5/-1 Ma); Highwood Member (ca. 173 Ma and 166.6 ± 0.2 Ma); and Grey Beds (167.0 ± 0.2 Ma, 165.6 ± 0.3 Ma, and 165.4 ± 0.3 Ma). Some of these bentonites are associated with ammonites and coccoliths which provide biostratigraphic constraints. Strontium, carbon and oxygen isotopes measured from belemnite rostra have been compared in two sections and the resulting curves are compared with those from western Europe.

Riassunto. Le parti inferiore e media della Formazione Fernie nell'Alberta centro-occidentale e nella Columbia Britannica sudorientale, la cui età va dal Pliensbachiano al ?Bathoniano (Giurassico da inferiore a medio), e che consistono principalmente in shale fossiliferi scuri e calcari neri fossiliferi, contengono orizzonti di argilla bentonitica che hanno fornito datazioni radiometriche con l'analisi U-Pb dei cristalli di zircone. Qui riportiamo sei nuove datazioni dalla parte più bassa del Membro Red Deer (188.3 +1.5/-1 Ma); dal Membro Highwood (ca. 173 Ma e 166.6 ± 0.2 Ma) e dai Grey Beds (167.0 ± 0.2 Ma, 165.6 ± 0.3 Ma, e 165.4 ± 0.3 Ma). Alcune di queste bentoniti sono associate con ammoniti e coccoliti, che forniscono le delimitazioni biostratigrafiche. Gli isotopi dello stronzio, del carbonio e dell'ossigeno misurati da rostri di belemniti sono stati confrontati in due sezioni, e le curve risultanti vengono comparate con quelle dell'Europa nordoccidentale.

Introduction

A significant number of new isotopic dates for calibration of the Jurassic time-scale, based on high precision U-Pb analyses, have recently been obtained from fossiliferous volcano-sedimentary units in the North American Cordillera (Pálfy et al. 2000). There, volcanic products are interbedded with ammonite-bearing sediments that provide good biochronological constraints. This integration of biostratigraphic and geochronologic data has allowed improved estimates for the numeric age of Jurassic stage boundaries.

Tectonism and magmatic events associated with accretion of allochthonous terranes to the western margins of ancestral North America, beginning in about Middle Jurassic time, are reflected in Jurassic sediments deposited farther east in the Western Canada Sedimentary Basin where volcanic ash layers are interbedded with ammonite-bearing dark shales of the Fernie Formation. In this paper we report six new U-Pb zircon ages from analysis of zircons in ash layers from central-western Alberta (Bighorn Creek and its eastern tributary) and south-eastern British Columbia (Fording River) (Fig. 1).

Detailed geochemical analyses on two sections, Bighorn Creek and its nearby eastern tributary, have been completed for strontium, oxygen and carbon isotopic ratios. Variations in the strontium-isotope curve derived from the analysis of belemnite rostra in these sections allow for correlation with that previously generated in Europe (Jones et al. 1994a).

Unfortunately, biochronological constraints in these two sections depend on only intermittent occurrences of ammonites, which occur as lateral impressions on bedding planes; some levels have also yielded coccolith floras.

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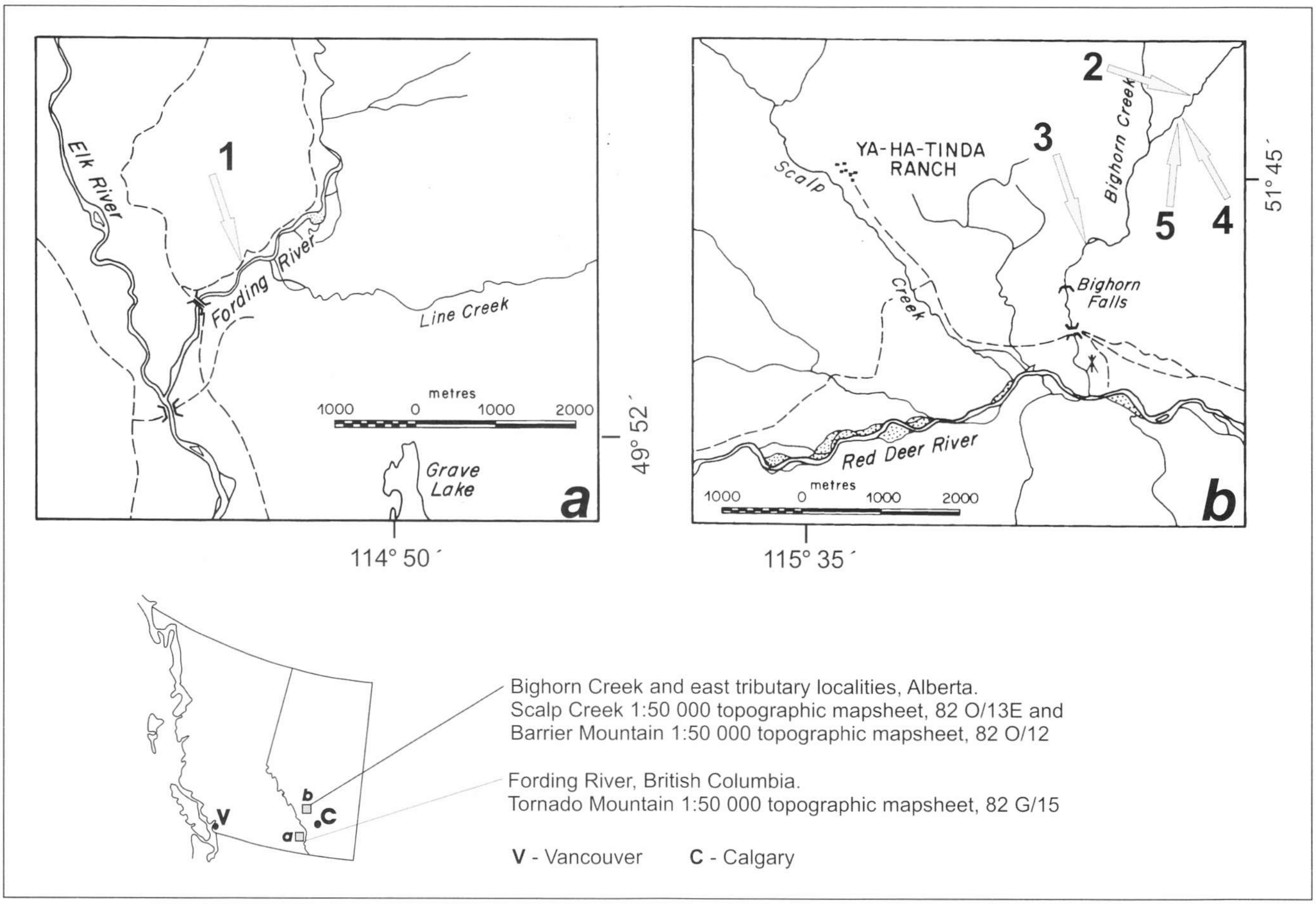

Fig. 1 - a - map showing location (1) of Grey Beds (Fernie Formation) at Fording River, south-eastern British Columbia; grid reference 535 293, Tornado Mountain 1:50 000 topographic mapsheet, 82 G/15; b - map showing Fernie Formation locations on Bighorn Creek and its eastern tributary, Alberta: (2) Red Deer Member, grid reference 024 354, Scalp Creek 1:50 000 topographic mapsheet, 82 O/13E; (3) Highwood Member, grid reference 010 335, Barrier Mountain 1:50 000 topographic mapsheet, 82 O/12; (4) Highwood Member, grid reference 023 353, Scalp Creek 1:50 000 topographic mapsheet, 82 O/13E ; (5) Grey Beds, grid reference 022 352, Scalp Creek 1: 50 000 topographic mapsheet, 82 O/13E.

Geological Setting

In the Foothills and Front Ranges of the Canadian Rocky Mountains the Fernie Formation represents almost the entire Jurassic; its internal subdivision into informal members, their lithostratigraphy and biostratigraphy, were summarised by Hall (1984). Lower and Middle Jurassic parts of the Fernie Formation consist predominantly of grey and black shales, with minor siltstones, sandstones, conglomerates and limestones, the source of detrital sediments being on the craton to the east. These strata represent the youngest parts of the passive margin sequence, which accumulated on the western margin of cratonic North America throughout the Paleozoic and Early Mesozoic. The uppermost part of the Fernie Formation (Passage Beds; Oxfordian) records a complete reversal in basin polarity, reflecting accretionary tectonics occurring farther west, which resulted in development of a subsiding foreland basin with influx of coarse clastics, and volcanic and igneous detritus, from a westerly source - the rising ancestral Rocky Mountains (Poulton et al. 1994).

Reaching maximum thicknesses of only about 300 m, the Fernie Formation is a recessive unit occurring as isolated outcrops along valley floors, and was intensely deformed by Cretaceous over-thrusting accompanying Cordilleran tectonism. While most units within the Fernie Formation have been reasonably well-dated using ammonite faunas, there are many faunal gaps (Hall 1984). Dating of upper Middle Jurassic units (Highwood Member, Grey Beds) is made more difficult by the strong faunal provinciality developed amongst ammonites from Late Bajocian to Early Oxfordian times (Callomon 1984).

Lithostratigraphy and descriptions of sections

Bighorn Creek

The lowermost Jurassic sediments at this locality consist of a thin (8 cm), phosphatic-pebble lag filling depressions on an erosional surface developed over Lower to Middle Triassic rocks (Sulphur Mountain Formation); fragmented ammonites indicate a Late Sinemurian age for this pebble bed (Stellare Subzone, Obtusum Zone). Above an 8 m thick covered interval, the Upper Pliensbachian Red Deer Member consists of 9 m of hard, platy, black, limestone and shale. The overly-

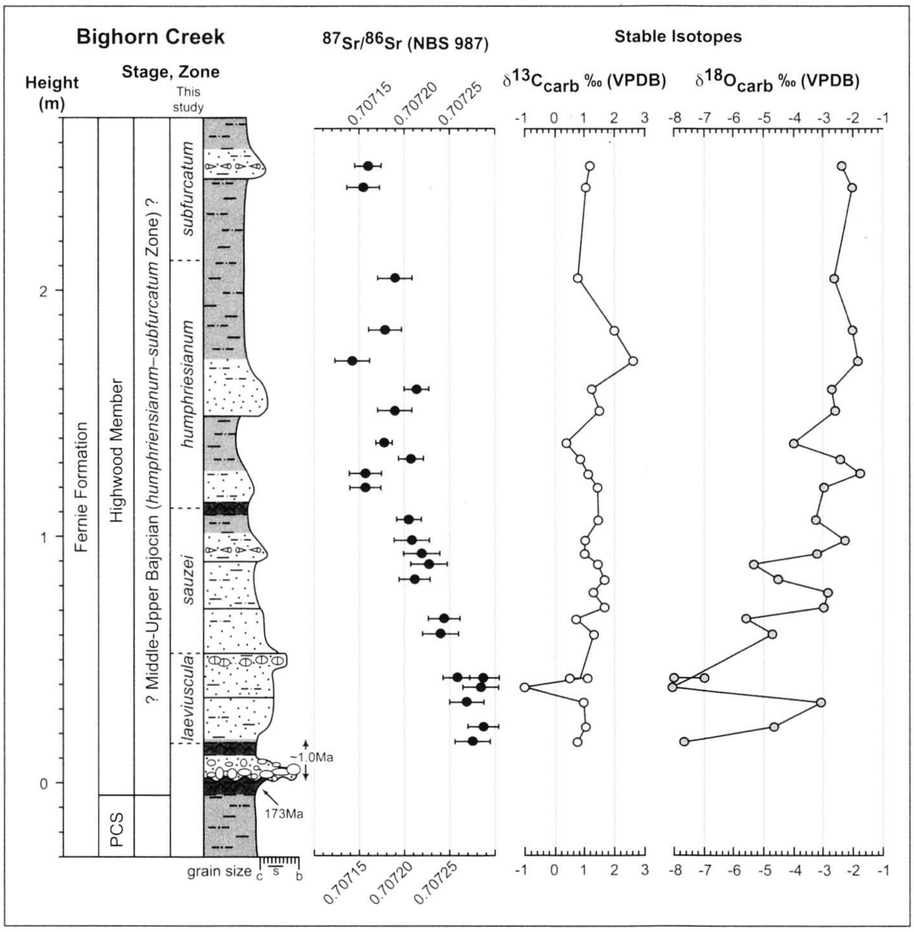

Fig. 2 - Carbon, oxygen, and strontium isotope curves for the Highwood Member of the Fernie Formation at Bighorn Creek. Placement of Stage and Zone boundaries (in columns under "this study") based on variations in isotope curves, not ammonites found in this section.

ing Poker Chip Shale, 12 m thick, consists of more fissile and papery, thinly laminated, black silty shales, and in its lower parts contains a rich ammonite fauna of early Toarcian age (Falciferum to Bifrons Zones; Hall 1987).

The dark shales of the Poker Chip Shale grade upward fairly rapidly into grey, rusty- and yellow-weathering, softer shales of the Highwood Member which here is 18 m thick. This unit contains thin bands of calcareous concretions, often accompanied by rounded, black, phosphatic pebbles, numerous fragmented belemnite rostra, and abundant secondary gypsum and goethite. Near the top of the unit there are thin, orange-white, soft bentonitic clay layers of volcanic origin. While no ammonites have been found at this locality, on the west bank at the next cutbank upstream, a similar pebbly bed containing fragmented belemnites and immediately overlying a yellow-white bentonitic clay, has produced one partial external mold of a sonniniid ammonite, indicating an early Bajocian age.

On Bighorn Creek the overlying Grey Beds are not seen in contact with the Highwood Member, but are exposed along several cutbanks farther upstream. In the section on the eastern tributary of Bighorn Creek and also at nearby Willson Creek, beds at this stratigraphic level have yielded very poorly preserved, partial ammonite impressions most likely indicative of a latest Bajocian to Boreal Late Bathonian age (Hall 1988, 1989).

East Tributary of Bighorn Creek

An unnamed tributary flowing into Bighorn Creek from the northeast exposes an almost continuous section of the lower and middle parts of the Fernie Formation. The basal contact with the resistant siltstones of the underlying Triassic Sulphur Mountain Formation is exposed on the west bank, though the basal pebble lag is not seen here. The Red Deer Member consists of ~8 m of hard, black, platy calcareous siltstones with some poorly preserved lateral impressions of Late Pliensbachian ammonites (Hall et al. 1998).

The overlying Poker Chip Shale can here be seen in direct contact with the Red Deer Member, and is almost continuously exposed in low outcrops along both sides of the creek, providing a measured stratigraphic thickness of at least 12 m. Its basal contact with the Red Deer Member is marked by a change from hard and thicker-bedded black, calcareous siltstones to softer, more platy, black fine siltstones. It is difficult to pick the upper contact with the overlying Highwood Member, as the color differences and weathering characters used to separate these members elsewhere are not so obvious here. The contact almost certainly lies somewhere just below a resistant chert pebble and cobble bed, with a black, sandy matrix, and containing abundant, current-oriented belemnite rostra (at 23.2 m on Fig. 3).

The Highwood Member consists of just over 10 m of mainly platy, dark grey shales with several thin, cemented horizons and five soft, yellow-white-orange, bentonitic clay layers containing numerous fragmented belemnite rostra and rounded, black phosphatic pebbles. Four metres of platy grey shales overlying the Highwood Member at the top of this section belong to the Grey Beds, and have yielded lateral impressions of *Kepplerites* cf. *costidensus* (Imlay), ?*Choffatia*, and ?*Xenocephalites*, suggesting a Boreal Late Bathonian age.

Geochronological Methods

U-Pb analyses of zircon crystals from volcanic ashes were performed in the Geochronology Laboratory at the Geological Survey of Canada, utilizing analytical methods outlined in Parrish et al. (1987) with analysis on

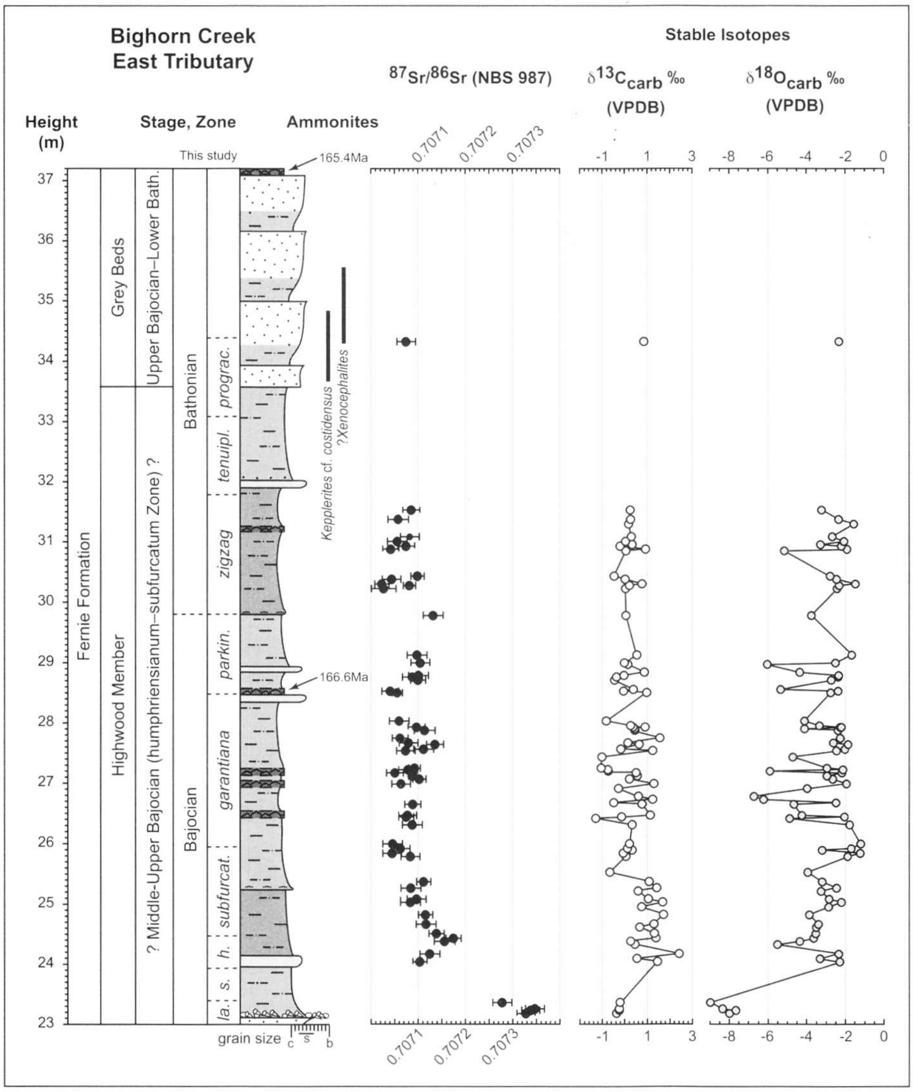

Fig. 3 - Carbon, oxygen, and strontium isotope curves for the Highwood Member and Grey Beds, Fernie Fomation, at Bighorn Creek east tributary. Placement of Stage and Zone boundaries (in columns under "this study") based on variations in isotope curves, not ammonites found in this section.

a Triton TI thermal ionization mass spectrometer. Treatment of analytical errors follows Roddick (1987), with errors on the ages reported at the 2σ level. All of the zircon crystals chosen for analysis were well faceted and optically clear, without fractures or apparent inherited cores. Multigrain zircon fractions analyzed were very strongly air abraded following the method of Krogh (1982).

Integrated biochronology and geochronology

In this section dates derived from U-Pb analyses of zircons are compared with the ages for Jurassic stage boundaries on the time scale proposed by Pálfy et al. (2000).

The thin phosphate-pebble veneer at the base of the Fernie Formation on Bighorn Creek has yielded several partial specimens of *Epophioceras* cf. *breoni* (Reynès) and *Asteroceras stellare* (J. Sowerby), indicating correlation with the lowermost Upper Sinemurian Obtusum Zone (Hall 1987).

The upper 2 m of the Red Deer Member has yielded lateral impressions of *Amaltheus* cf. *stokesi* (J. Sowerby), ?*Amauroceras*, ?*Aveyroniceras* and *Protogrammoceras*, indicating correlation with the Margaritatus Zone (Upper Pliensbachian). Strata 1.2 – 1.4 m above a bed with abundant pectinid bivalves have produced coccoliths consistent with a Late Pliensbachian age: *Crepidolithus cavus*, *C. crassus*, and *Lotharingius sigillatus*. On the east tributary a bentonitic clay layer occurs in the Red Deer Member, 1 m above the basal contact of the Fernie with the Triassic. Analysis of 5 zircon fractions from this bentonite resulted in a spread of data intersecting concordia from 189-188 Ma, reflecting perhaps a small degree of inheritance or Pb loss. A preliminary age interpretation of 188.3 +1.5/-1 Ma is assigned based on the weighted average of the $^{206}Pb/^{238}U$ ages of the analyses and the range of errors on those ages. Further data are required to refine this age interpretation. This provides an Early Pliensbachian age for these strata which is consistent with a coccolith flora, including *Biscutum novum*, *Crepidolithus crassus*, *Mitrolithus elegans*, *Parhabdolithus liasicus*, *Similiscutum praecarium*, and *Tubirhabdus patulus* which occurs just

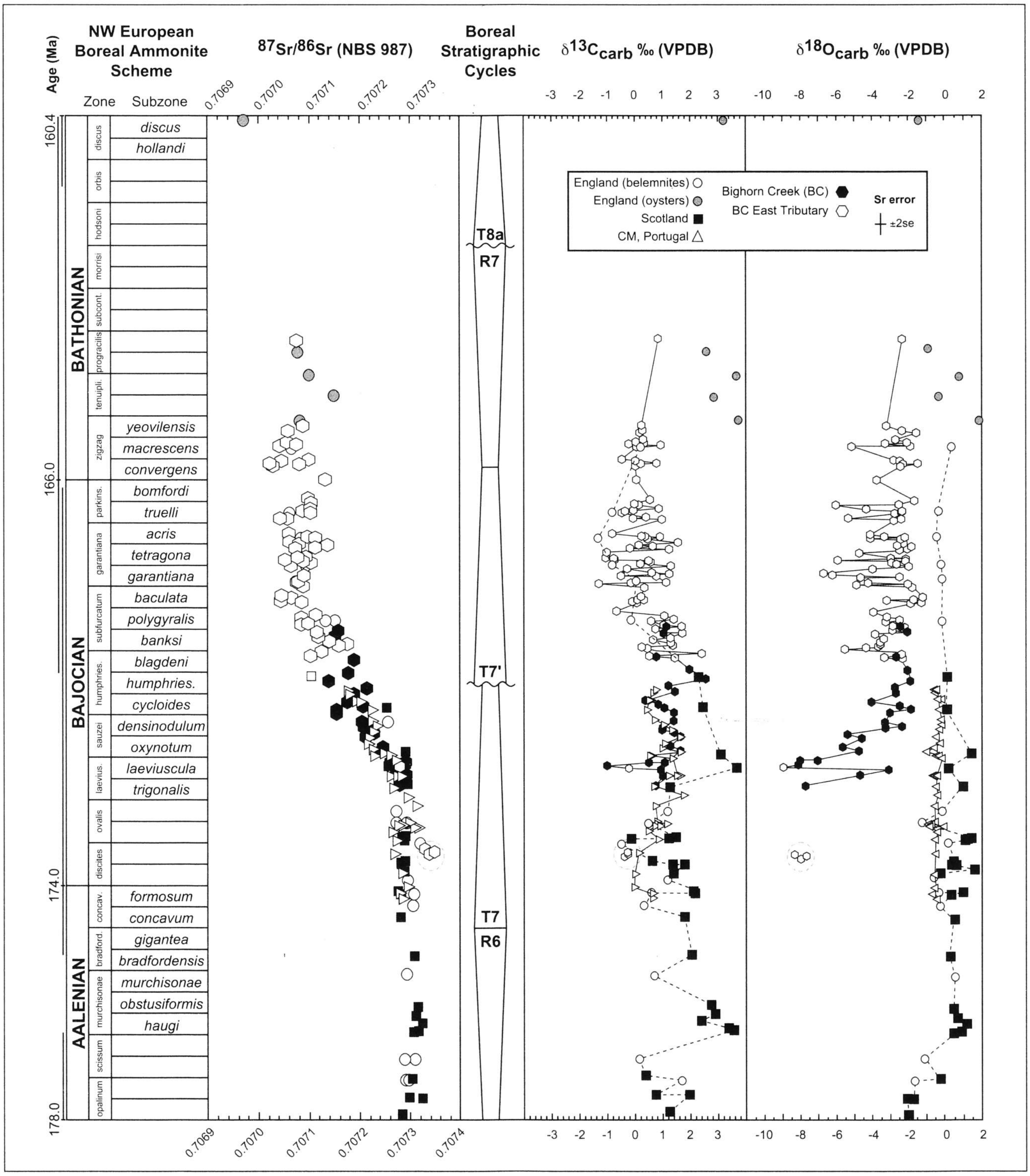

Fig. 4 - Composite carbon, oxygen, and strontium isotope curves for the Aalenian-Bajocian-Bathonian interval, showing data from western Europe and results from this study at Bighorn Creek and its eastern tributary. Ammonite subzones are assumed to be of equal duration. Note the highly negative oxygen-isotope values (very warm paleotemperatures) from Bighorn Creek in the Lower Bajocian; all samples are defined as non-diagenetic based on Jones et al. (1994a).

0.2 m above the base of the formation. Strata from 3.2 – 8.1 m above the base yield a coccolith flora consisting of *Biscutum grandis*, *B. novum*, *Crepidolithus crassus*, *Crucirhabdus primulus*, *Lotharingius hauffi*, *L. sigillatus*, *Orthogonoides hamiltoniae*, and *Tubirhabdus patulus*, consistent with a Late Pliensbachian age, confirmed by partial impressions of the ammonites *Amaltheus* and *Amauroceras* in the same interval.

On Bighorn Creek, the overlying Poker Chip Shale near its base contains the ammonites *Harpoceras* cf. *H. falciferum* (J. Sowerby), *Hildaites* cf. *H. serpentiniformis* Buckman, *Dactylioceras* cf. *athleticum* (Simpson), and *Polyplectus* cf. *subplanatus* (Oppel) [subsequently re-as-belemnites were then thoroughly cleaned using deionised water and dried at room temperature. The subsequent chemical treatment was first described by Jones (1992) and is outlined in Jones et al. (1994a). Strontium-isotope measurements were performed on a modified VG Isomass 54E thermal ionization mass spectrometer. All $^{87}Sr/^{86}Sr$ values were internally normalised to $^{87}Sr/^{86}Sr$ ratio of 0.1194 and the resultant data were then adjusted using a National Bureau of Standards 987 (NBS 987) value of 0.710250.

Isotopic Results and Discussion

Based on the strontium-isotope curve generated from Scotland, England and Portugal (Jones et al. 1994a, b; Gröcke 2001; Jenkyns et al. 2002) it is possible to correlate the Bighorn Creek sections, that have relatively poor biostratigraphy, with a NW European Boreal ammonite scheme. The variations in strontium-isotope ratios from belemnites at Bighorn Creek show reasonable scatter compared to the European data when plotted on the same scale (Fig. 4). However, stratigraphically the variation is minor and is almost sinusoidal in nature (Figs. 2, 3), which has been reported elsewhere and may reflect global orbital cycles (Gröcke 2001; Jenkyns et al. 2002). How this is possible considering the long residence time of strontium in the oceans is difficult to understand and more research is required in producing high-resolution strontium-isotope stratigraphy in orbitally-calibrated successions.

Due to the scatter in strontium-isotope ratios (which have all been diagenetically screened using the methodology of Jones et al. 1994a) we have adopted a two-pronged method of correlation by also assuming that the carbon-isotope variation is global in nature in contrast to oxygen, which reflects local environmental conditions. Using both strontium and carbon it is possible to correlate the Bighorn Creek sections with a NW European Boreal ammonite scheme with a high degree of confidence (Fig. 4) and it has subsequently allowed a NW European Boreal ammonite scheme to be drawn against the Bighorn Creek sections (Figs. 2, 3). The only major discrepancy with this method was the absence of a Laeviuscula Zone positive carbon-isotope excursion (Fig. 2), as recorded in Scotland; however, this positive excursion also has not been recorded at Cabo Mondego (Portugal) and so may only be a local northern European seaway phenomenon. The strontium-isotope curve is relatively stable in the Aalenian and drops dramatically to less radiogenic values at the Laeviuscula–Sauzei Zone boundary and continues until the upper Subfurcatum Zone in the Bajocian, after which the strontium curve becomes more variable. The variability in the strontium-isotope curve here may be real, but due to a lack of other biostratigraphically well-constrained localities with which to correlate we are less confident with this part of the curve. The only tie-point available from Bighorn Creek is the occurrence of one partial lateral impression of a sonniniid ammonite from a pebble bed, indicating an Early Bajocian age.

Conclusions

In this study we have synthesized biostratigraphic and numerical ages with secular isotopic curves in three stratigraphic sections through the Lower and Middle Jurassic parts of the Fernie Formation in Alberta and British Columbia. The Early Pliensbachian and Early Bajocian U-Pb ages obtained from zircons in volcanic ash layers are in general agreement with ammonites and coccoliths from some of the enclosing strata. Another three U-Pb ages, obtained from zircons in bentonites interbedded with siltstones that yielded ammonites suggesting Late Bathonian ages, are older than expected, but this interpretation depends on which of several previously published Jurassic time-scales is applied. We have compared strontium and carbon isotopic curves from the unfossiliferous Highwood Member (Bajocian and Bathonian) with established curves from NW Europe in order to test use of such geochemical variations for intercontinental correlation.

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