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Abstract

The Upper Carnian-Lower Norian (Upper Triassic) Luning Formation at Berlin-Ichthyosaur State Park (BISP) in central NV (USA) has been sampled using for the first time the bed-by-bed approach for ammonoids, pelagic bivalves, and conodonts, more than 60 years after its first description by Silberling (U.S. Geological Survey Professional Paper 322: 1–63, 1959). BISP is historically important for the definition of the uppermost Carnian of the North American Triassic chronostratigraphic scale and is known worldwide as one of the most important ichthyosaur fossil-Lagerstätte because of its extraordinary record of 37 articulated, large-sized specimens of *Shonisaurus popularis*. Nearly 190 ammonoids were collected from two stratigraphic sections, documenting all the latest Carnian to Early Norian ammonoid faunas previously described by Silberling. Halobiids were collected from five levels, and the first report of conodonts from BISP includes faunas from 13 levels. The ~340-m thick Brick Pile section, the most complete in the study area, includes the uppermost Carnian Macrolobatus zone, which provides conodont faunas of the lower *primitia* zone and *Halobia septentrionalis*. The 200-m thick lowermost Norian Kerri zone, which begins 52 m above the Macrolobatus zone, yields conodonts of the upper *primitia* zone in its lower part, together with *H.* cf. *beyrichi* and *H.* cf. *selwyni*. The ichthyosaur-bearing interval, whose stratigraphic position has been interpreted quite differently by previous authors, is documented in the uppermost Carnian Macrolobatus zone and is characterized by rich *Tropites*-dominated ammonoid faunas and by the onset of *Halobia*. All models proposed by various workers to explain the unusual ichthyosaur record are discussed and an additional explanation for the main ichthyosaur-bearing bed is proposed. The new hypothesis is that a harmful algal bloom (HAB) may have been the trigger for the mass mortality recorded in this level. Although the C/N boundary in the Brick Pile section lies within a 52 m interval that presently lacks paleontologic data, this succession is included in a small group of sections that are expected to contribute to the definition of the GSSP of the Norian stage. Correlation of the Brick Pile with the best Carnian/Norian sections in northeastern British Columbia is discussed. Compared to the British Columbia Juvavites cove and the GSSP candidate Black Bear Ridge sections, the Brick Pile section exhibits an ammonoid and *Halobia* record that is slightly more similar to that of the Tethyan sections. Correlation of the Brick Pile with the second GSSP candidate Pizzo Mondello (Sicily, Italy) well demonstrates the significant problems encountered in calibration of the Tethyan and North American scales.

Kurzfassung

Die oberkarnische bis unternorische (Späte Trias) Luning Formation im Berlin-Ichthyosaur State Park (BISP) in Zentral-Nevada (USA) wurde mehr als 60 Jahre nach der ersten Beschreibung durch Silberling (U. S. Geological Survey Professional Paper 322: 1–63, 1959) erstmals bankweise auf Ammoniten, pelagische Bivalven und Conodonten untersucht. Der BISP ist von historischer Bedeutung für die Definition des obersten Karn in der chronostratigraphischen Tabelle der nordamerikanischen Trias und ist eine der weltweit bekanntesten Ichthyosaurier Fossillagerstätten, ausgezeichnet durch den außergewöhnlichen Fund von 37 artikulierten, großen Exemplaren von *Shonisaurus popularis*. Nahezu 190 Ammoniten aus zwei stratigraphischen Abschnitten belegen oberstes Karn bis Unternor, wie schon früher durch Silberling beschrieben. Halobiiden liegen aus fünf Niveaus vor, und der Erstnachweis von Conodonten im BISP beinhaltet Faunen aus 13 Niveaus. Der ca. 340 m mächtige Brick Pile Aufschluss ist der kompletteste im untersuchten Gebiet. Er schließt die rund 20 m mächtige Macrolobatus zone des obersten Karn mit Conodonten-Faunen aus der unteren *primitia* zone und *Halobia septentrionalis* ein. Nach einer Lücke im Fossilbefund von 52 m folgt die 200 m mächtige Kerri zone des untersten Nor, welche im unteren Teil Conodonten der oberen *primitia* zone gemeinsam mit *H.* cf. *beyrichi* und *H.* cf. *selwyni* erbrachte. Das

Ichthyosaurier führende Intervall, von bisherigen Autoren teils ins Karn und/oder ins Nor eingestuft, ist durch eine ergiebige *Tropites*-Fauna und das Einsetzen von *Halobia* charakterisiert und kann damit in das obere Karn eingestuft werden. Alle Modelle, die von verschiedenen Autoren für die Erklärung des außergewöhnlichen Ichthyosaurier-Vorkommens vorgeschlagen wurden, werden diskutiert und um ein zusätzliches Genesemodell für die Haupt-Ichthyosaurier-Bank erweitert. Nach der neuen Hypothese führte wohl eine schädliche Algenblüte zu einem Massensterben in diesem Horizont. Obwohl die Karn/Nor Grenze des Brick Pile Aufschlusses im Bereich des fossilleeren 52-m-Intervalls liegt, wird er zu der kleinen Gruppe von Profilen gezählt, welche wesentlich zur Definition des GSSP der Norischen Stufe beitragen können. Die Korrelation von Brick Pile mit den wichtigsten Karn/Nor-Grenzprofilen von British Columbia und Sizilien wird diskutiert. Verglichen mit Juvavites cove und dem GSSP-Kanditaten Black Bear Ridge in B.C., weist Brick Pile bei den Ammonoideen und Halobien einen etwas stärkeren Tethys-Bezug auf. Ein Vergleich von Brick Pile mit dem zweiten GSSP-Kandidaten Pizzo Mondello (Sizilien, Italien) zeigt die signifikanten Probleme, welche bei der Korrelation tethyaler und nordamerikanischer Biochronologien auftreten.

Keywords (separated by '-')	Upper Triassic - Fossil-Lagerstätte - Nevada - Ammonoids - Halobia - Conodonts - Ichthyosaurs - Mass mortality - Chronostratigraphy
Schlüsselwörter (separated by '-')	Späte Trias - Fossillagerstätte - Nevada - Ammonoideen - *Halobia* - Conodonten - Ichthyosaurier - Massensterben - Chronostratigraphie
Footnote Information	N. J. Silberling: retired.

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RESEARCH PAPER

The Carnian/Norian boundary succession at Berlin-Ichthyosaur State Park (Upper Triassic, central NV, USA)

Marco Balini · James F. Jenks · Riccardo Martin · Christopher A. McRoberts · Michael J. Orchard · Norman J. Silberling

Received: 3 December 2013 / Accepted: 22 August 2014

Abstract The Upper Carnian-Lower Norian (Upper Triassic) Luning Formation at Berlin-Ichthyosaur State Park (BISP) in central NV (USA) has been sampled using for the first time the bed-by-bed approach for ammonoids, pelagic bivalves, and conodonts, more than 60 years after its first description by Silberling (U.S. Geological Survey Professional Paper 322: 1–63, 1959). BISP is historically important for the definition of the uppermost Carnian of the North American Triassic chronostratigraphic scale and is known worldwide as one of the most important ichthyosaur fossil-Lagerstätte because of its extraordinary record of 37 articulated, large-sized specimens of *Shonisaurus popularis*. Nearly 190 ammonoids were collected from two stratigraphic sections, documenting all the latest Carnian to Early Norian ammonoid faunas previously described by Silberling. Halobiids were collected from five levels, and the first report of conodonts from BISP includes faunas from 13 levels. The ~340-m thick Brick Pile section, the most complete in the study area, includes the uppermost Carnian Macrolobatus zone, which provides conodont faunas of the lower *primitia* zone and *Halobia septentrionalis*. The 200-m thick lowermost Norian Kerri zone, which begins 52 m above the Macrolobatus zone, yields conodonts of the upper *primitia* zone in its lower part, together with *H.* cf. *beyrichi* and *H.* cf. *selwyni*. The ichthyosaur-bearing interval, whose stratigraphic position has been interpreted quite differently by previous authors, is documented in the uppermost Carnian Macrolobatus zone and is characterized by rich *Tropites*-dominated ammonoid faunas and by the onset of *Halobia*. All models proposed by various workers to explain the unusual ichthyosaur record are discussed and an additional explanation for the main ichthyosaur-bearing bed is proposed. The new hypothesis is that a harmful algal bloom (HAB) may have been the trigger for the mass mortality recorded in this level. Although the C/N boundary in the Brick Pile section lies within a 52 m interval that presently lacks paleontologic data, this succession is included in a small group of sections that are expected to contribute to the definition of the GSSP of the Norian stage. Correlation of the Brick Pile with the best Carnian/Norian sections in northeastern British Columbia is discussed. Compared to the British Columbia Juvavites cove and the GSSP candidate Black Bear Ridge sections, the Brick Pile section exhibits an ammonoid and *Halobia* record that is slightly more similar to that of the Tethyan sections. Correlation of the Brick Pile with the second GSSP candidate Pizzo Mondello (Sicily, Italy) well demonstrates the significant problems encountered in calibration of the Tethyan and North American scales.

N. J. Silberling: retired.

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Keywords Upper Triassic · Fossil-Lagerstätte · Nevada · Ammonoids · Halobia · Conodonts · Ichthyosaurs · Mass mortality · Chronostratigraphy

Kurzfassung Die oberkarnische bis unternorische (Späte Trias) Luning Formation im Berlin-Ichthyosaur State Park (BISP) in Zentral-Nevada (USA) wurde mehr als 60 Jahre nach der ersten Beschreibung durch Silberling (U. S. Geological Survey Professional Paper 322: 1–63, 1959) erstmals bankweise auf Ammoniten, pelagische Bivalven und Conodonten untersucht. Der BISP ist von historischer Bedeutung für die Definition des obersten Karn in der chronostratigraphischen Tabelle der nordamerikanischen Trias und ist eine der weltweit bekanntesten Ichthyosaurier Fossillagerstätten, ausgezeichnet durch den außergewöhnlichen Fund von 37 artikulierten, großen Exemplaren von *Shonisaurus popularis*. Nahezu 190 Ammoniten aus zwei stratigraphischen Abschnitten belegen oberstes Karn bis Unternor, wie schon früher durch Silberling beschrieben. Halobiiden liegen aus fünf Niveaus vor, und der Erstnachweis von Conodonten im BISP beinhaltet Faunen aus 13 Niveaus. Der ca. 340 m mächtige Brick Pile Aufschluss ist der kompletteste im untersuchten Gebiet. Er schließt die rund 20 m mächtige Macrolobatus zone des obersten Karn mit Conodonten-Faunen aus der unteren *primitia* zone und *Halobia septentrionalis* ein. Nach einer Lücke im Fossilbefund von 52 m folgt die 200 m mächtige Kerri zone des untersten Nor, welche im unteren Teil Conodonten der oberen *primitia* zone gemeinsam mit *H.* cf. *beyrichi* und *H.* cf. *selwyni* erbrachte. Das Ichthyosaurier führende Intervall, von bisherigen Autoren teils ins Karn und/oder ins Nor eingestuft, ist durch eine ergiebige *Tropites*-Fauna und das Einsetzen von *Halobia* charakterisiert und kann damit in das obere Karn eingestuft werden. Alle Modelle, die von verschiedenen Autoren für die Erklärung des außergewöhnlichen Ichthyosaurier-Vorkommens vorgeschlagen wurden, werden diskutiert und um ein zusätzliches Genesemodell für die Haupt-Ichthyosaurier-Bank erweitert. Nach der neuen Hypothese führte wohl eine schädliche Algenblüte zu einem Massensterben in diesem Horizont. Obwohl die Karn/Nor Grenze des Brick Pile Aufschlusses im Bereich des fossilleeren 52-m-Intervalls liegt, wird er zu der kleinen Gruppe von Profilen gezählt, welche wesentlich zur Definition des GSSP der Norischen Stufe beitragen können. Die Korrelation von Brick Pile mit den wichtigsten Karn/Nor-Grenzprofilen von British Columbia und Sizilien wird diskutiert. Verglichen mit Juvavites cove und dem GSSP-Kanditaten Black Bear Ridge in B.C., weist Brick Pile bei den Ammonoideen und Halobien einen etwas stärkeren Tethys-Bezug auf. Ein Vergleich von Brick Pile mit dem zweiten GSSP-Kandidaten Pizzo Mondello (Sizilien, Italien) zeigt die signifikanten Probleme, welche bei der Korrelation tethyaler und nordamerikanischer Biochronologien auftreten.

Schlüsselwörter Späte Trias · Fossillagerstätte · Nevada · Ammonoideen · *Halobia* · Conodonten · Ichthyosaurier · Massensterben · Chronostratigraphie

Introduction

Berlin-Ichthyosaur State Park (BISP), located in the Shoshone Mountains of central NV (Fig. 1), is a Late Triassic paleontologic locality known worldwide for its unique large-sized ichthyosaur record, consisting of 37 articulated specimens discovered between the mid-1950s and 1960s within a thin stratigraphic interval of the Luning Formation (Camp 1976, 1980). Established in 1957 to protect this exceptional paleontologic locality, BISP's most impressive attraction is a sheltered exhibit of several meticulously exposed and well-preserved, ~15-m long specimens of the ichthyosaur *Shonisaurus popularis*. Indeed, this extraordinary record of *Shonisaurus* led Bottjer et al. (2002) and Bottjer (2002) to include BISP as one of the most unique fossil-Lagerstätten (Seilacher 1970) sites in the world.

Notwithstanding the attraction of this Lagerstätten to vertebrate paleontologists as well as amateurs, BISP is also extremely important to invertebrate paleontologists because of the cephalopod, bivalve, and brachiopod faunas that are also preserved in the Luning Formation. Its ammonoid faunas are of outstanding value not only for their abundance and good preservation, but more importantly because they played a crucial role in the definition of the North American Triassic chronostratigraphic scale (Silberling and Tozer 1968; Tozer 1967, 1981b, 1984, 1994) that is still regarded as the most complete and finely subdivided in the world (for historical summary see Tozer 1984; Balini et al. 2010a~~, b~~).

Ammonoids were discovered together with the first ichthyosaur remains by Siemon W. Muller of Stanford University in the late 1920s (Camp 1980: 141–142). Extensive paleontologic investigations were initiated in the early 1950s when Muller's student, N.J. Silberling, began his PhD studies in the Berlin area. In 1953, Muller and Silberling also guided C.L. Camp, a vertebrate paleontologist from the University of California, Berkeley, in his first survey of the vertebrate localities. Silberling (1959) described the ammonoid faunas in an outstanding monograph that included not only the first detailed geologic map of Berlin area, but also the lithostratigraphy of all geologic formations in the area and the systematic descriptions of ammonoids, nautiloids, and bivalves, as well as the definition of three ammonoid zones, namely the *Klamathites*

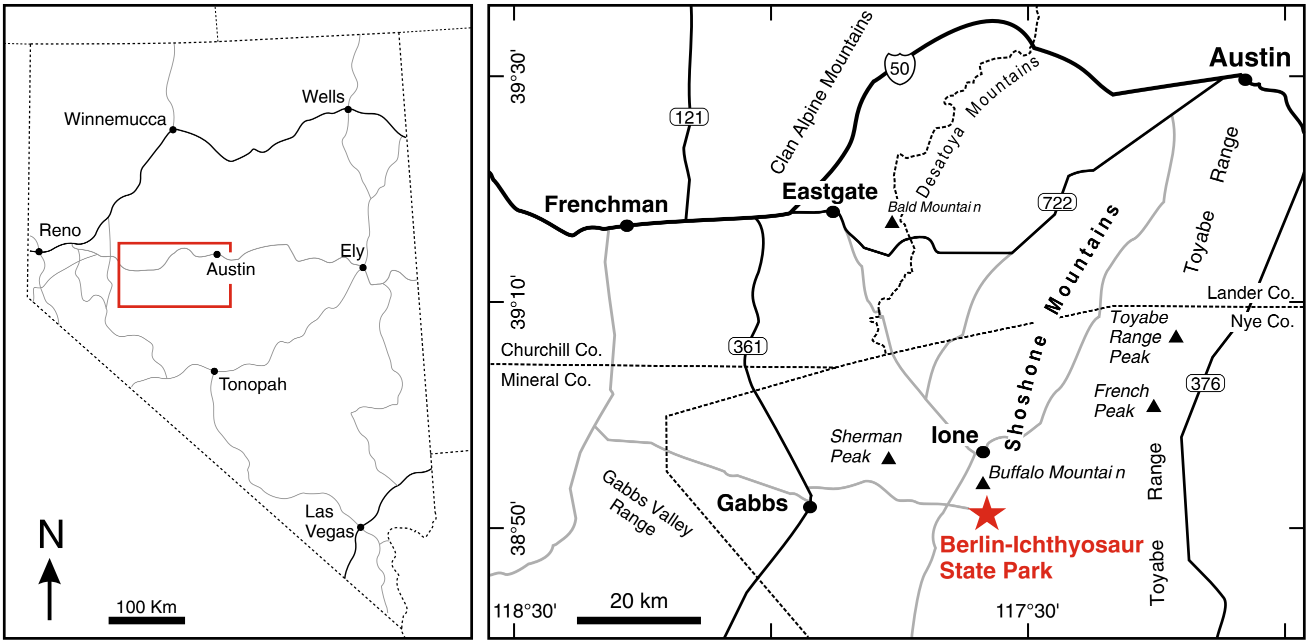

Fig. 1 Location map of Berlin-Ichthyosaur State Park, central NV (USA). A detailed road log with access information for this locality is provided in Lucas et al. (2007)

		Index species	*Type locality*
NORIAN	Lower	*Juvavites magnus*	Brown Hill, BC
		Malayites dawsoni	Brown Hill, BC
		Stikinoceras kerri	Brown Hill, BC
CARNIAN	Upper	*Klamathites macrolobatus*	Shoshone Mts, Nevada
		Tropites welleri	Shasta County, CA
		Tropites dilleri	Shasta County, CA
	Lower	*Sirenites nanseni*	Ewe Mountain, BC
		Austrotrachyceras obesum	Ewe Mountain, BC
		Trachyceras desatoyense	South Canyon, Nevada

Fig. 2 Lower Carnian-Lower Norian ammonoid zones of the most recent version of the North American Triassic chronostratigraphic scale (Tozer 1994). Zones are represented by index species and type-localities (for their definitions, see Tozer 1994). This scale was developed by Tozer and Silberling over a period of about 30 years (Silberling and Tozer 1968; Tozer 1967, 1981b, 1984, 1994)

schucherti, *K. macrolobatus*, and *Guembelites* zones in ascending chronologic order. Recognition of these zones was crucial for the resolution of a bio-chronostratigraphic problem that had hindered the completion of the Upper Triassic part of the North American chronostratigraphic scale (Fig. 2), i.e., the correlation of the ammonoid faunas from the Carnian Hosselkus Limestone in northern California, monographed by Smith (1927), and the Lower Norian ammonoid-rich successions of British Columbia, studied by F.H. McLearn between the 1940s and the early 1960s. Thus, correlation of the BISP ammonoid zones with the California successions was proposed by Silberling (1959), while correlation with those of British Columbia was proposed by Silberling and Tozer (1968). The link between the California and British Columbia successions is represented by the Macrolobatus zone (type locality BISP, Shoshone Mountains, NV: Fig. 2), which is bracketed between the underlying Schucherti zone (correlated to the Welleri zone of the Hosselkus Limestone) and the overlying Guembelites zone (correlated to the Lower Norian Kerri zone of British Columbia).

Despite the world class nature of the fossils preserved in the BISP area, the site apparently has not attracted all that much attention from paleontologists. Such a conclusion seems inescapable after an examination of the very scarce literature subsequent to Silberling's work. Since that time, the locality has been visited by Kristan-Tollmann and Tollmann (1983), who illustrated a few Late Carnian and Early Norian ammonoids and halobiids, as well as some benthic foraminifera. Brachiopods were described by Sandy and Stanley (1993), and cnidairans, which are rather common in the Luning Formation in the Pilot Mountain area (SW of BISP), are known only from a single occurrence of a chonrdophorine hydrozoan (Hogler and Hanger 1989). Crustaceans and trace fossils are also known from single specimens (McMenamin et al. 2013). One would expect that such scant invertebrate literature would be

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greatly overshadowed by literature regarding the area's vertebrate fossils. Surprisingly, this is not the case. There is no record in the literature of any significant new field work in the area since the time of Camp's extensive excavations. Literature published after the 1980s is based either on a re-examination of Camp's specimens from a taphonomical point of view (Hogler 1992), or their anatomical restoration and taxonomic position (e.g., Kosch 1990; McGowan and Motani 1999). A few authors have attempted to explain the reason for the great number of ichthyosaurs (Massare and Callaway 1988; Hogler 1992; McMenamin and Schulte McMenamin 2011), but no explanation has yet been agreed upon.

A recent integrated stratigraphic review of continuous marine successions pertinent to the definition of the GSSP (Global Stratotype Section and Point) of the Norian stage pointed to the potential value of a rigorous bed-by-bed re-examination of the Carnian-Norian sedimentary succession in the BISP area. This research, carried out within the framework of the activities of the Carnian/Norian boundary Working Group of the Subcommission on Triassic Stratigraphy, was conceived in order to test the quality of the fossil record in the BISP area and to compare it with those of the two best Carnian/Norian boundary sections thus far selected as GSSP candidates: Black Bear Ridge in British Columbia (Canada) and Pizzo Mondello (Sicily, Italy). Compared with these two sections, the ammonoid record of the BISP succession is known to be richer and more complete, but its halobiid and conodont records are not yet that well understood. Conodonts in particular have never been studied in the BISP area, and their occurrence would be important not only to complete the understanding of the BISP fossil record, but also to improve its correlation with the other two GSSP candidate sections.

In order to test the potential of the BISP succession for the definition of the GSSP, a preliminary sampling campaign was planned for 2010. Norman J. Silberling was the mentor for this project, and he provided invaluable assistance during the planning stage of this initial field work. He generously provided us with unpublished data including his field notes and a stratigraphic log as well as suggestions for the best sites to sample. Because of his age and deteriorating health, he was unable to participate in the October 2010 fieldwork, but he maintained contact with the field team. He also stayed in contact during the initial phase of the paleontologic study of the samples, but unfortunately he passed away on September 27, 2011. In honor of his highly significant contribution, we have included Norman in the authorship of this paper and, to further express our gratitude, we dedicate this work to his memory.

Geological and stratigraphic setting

Most of BISP is located within West Union Canyon, but a smaller, satellite portion is situated near the mouth of Berlin Canyon, the next canyon to the north (Fig. 3). These two ENE-WSW oriented canyons cut the central western slope of the Shoshone Mountains. The ghost-town of Berlin, located in the complex geologic structure of central-western NV, lends its name to one of the allochthon units of the Paradise Terrane (sensu Silberling 1991). The Berlin allochthon (Silberling et al. 1987), together with the nearby Lodi allochthon, is characterized as the most complete Triassic succession of the Paradise Terrane (=Paradise subterrane sensu Speed et al. 1989: Fig. 19). Although the Berlin succession is faulted and thrusted, it is not as deformed and metamorphosed as the Lodi unit.

The most accurate and complete description of Triassic strata in the BISP area was provided by Silberling, who reported a total thickness of about 1.2 km (Silberling 1959: pl. 11; Fig. 4). The Triassic units, lying between the Permian Pablo Formation (Ferguson and Cathcart 1954) and the overlying Cenozoic volcanics, consist of the Middle Triassic Grantsville Formation and the Upper Triassic Luning Formation. Though highly fractured with minor faults, the succession is only cut by two main faults, namely the Richmond Hill Fault (Fig. 3), a west-dipping normal fault, and the West Union Canyon Fault, which shows a strike-slip component as demonstrated by the positive flower structure (Fig. 3) affecting the northern side of West Union Canyon.

Despite the extensive faulting, the stratigraphic relationships of the Permian and Triassic formations are still well preserved. The Grantsville and Luning formations are each characterized by a sharp erosional unconformity at their base, followed by a transgressive trend that begins with coarse-grained conglomerates. The ~200-m thick Grantsville Formation (Muller and Ferguson 1939) consists of a lower clastic member and an upper calcareous member, which yields poorly preserved ammonoids interpreted by Silberling (1959) as Ladinian in age.

In the BISP area, the Luning Formation (Muller and Ferguson 1936, 1939) exhibits a different lithologic succession with respect to that in its type area (Pilot Mountains, southwestern NV). Silberling (1959) distinguished four informal members in the Shoshone Mountains (Fig. 4) as follows. The basal clastic member (~200-m thick) is overlain by the shaly limestone member (~180 m), which includes a 30–40-cm thick alternation of limestones and marls. Conformably overlying the shaly limestone member is the ~170-m thick calcareous shale member, which is dominated by marls with rare intercalations of thin bedded limestones. The uppermost subdivision is represented by the +450-m thick carbonate member, consisting

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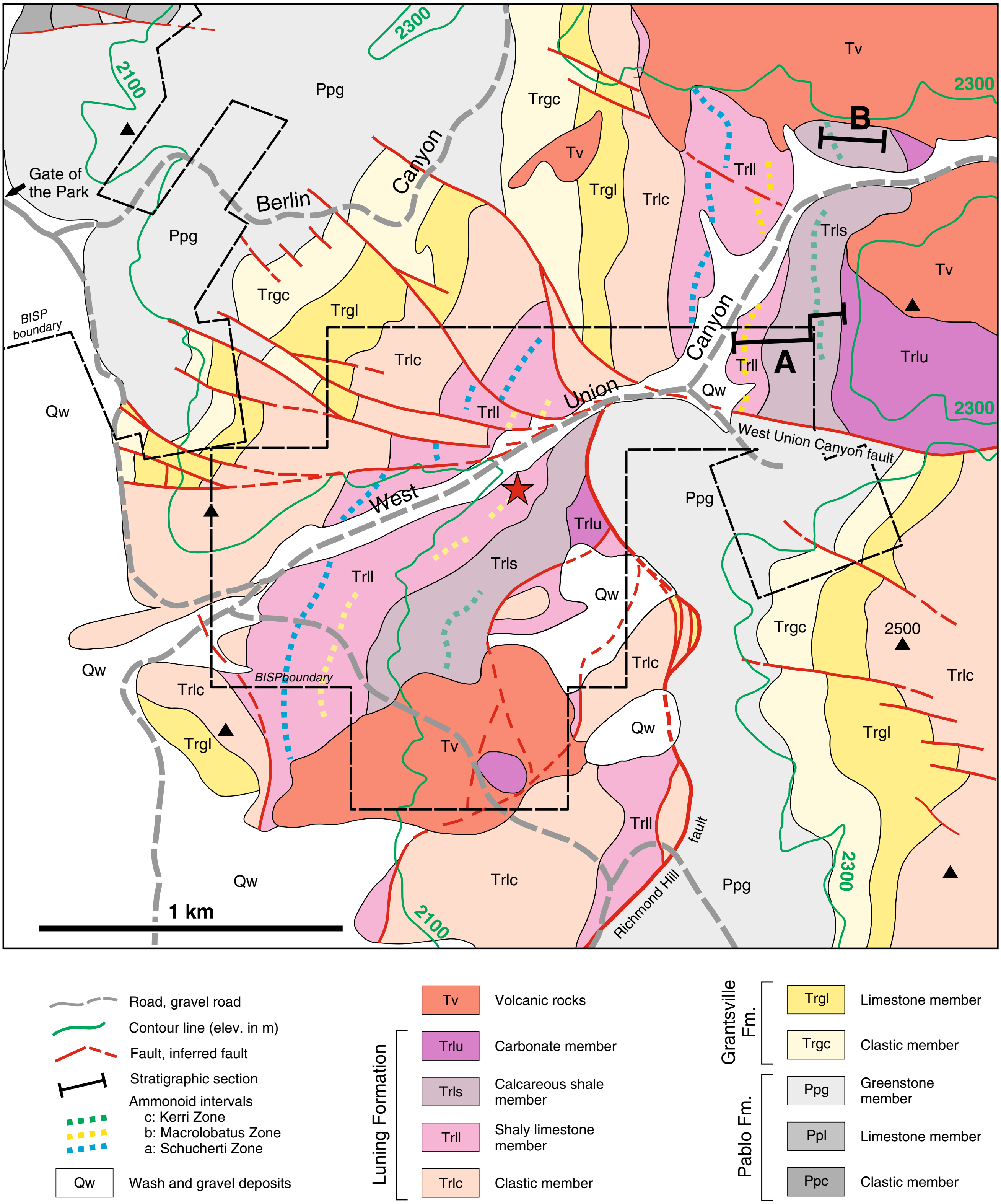

Fig. 3 Geological map of West Union Canyon (Shoshone Mountains) and Berlin-Ichthyosaur State Park, showing positions of the two studied stratigraphic sections (*A* and *B*). Map is redrawn from Silberling (1959). Only two elevation contour lines (2,100 and 2,300 m) have been reproduced. *Star* indicates position of the ichthyosaur shelter

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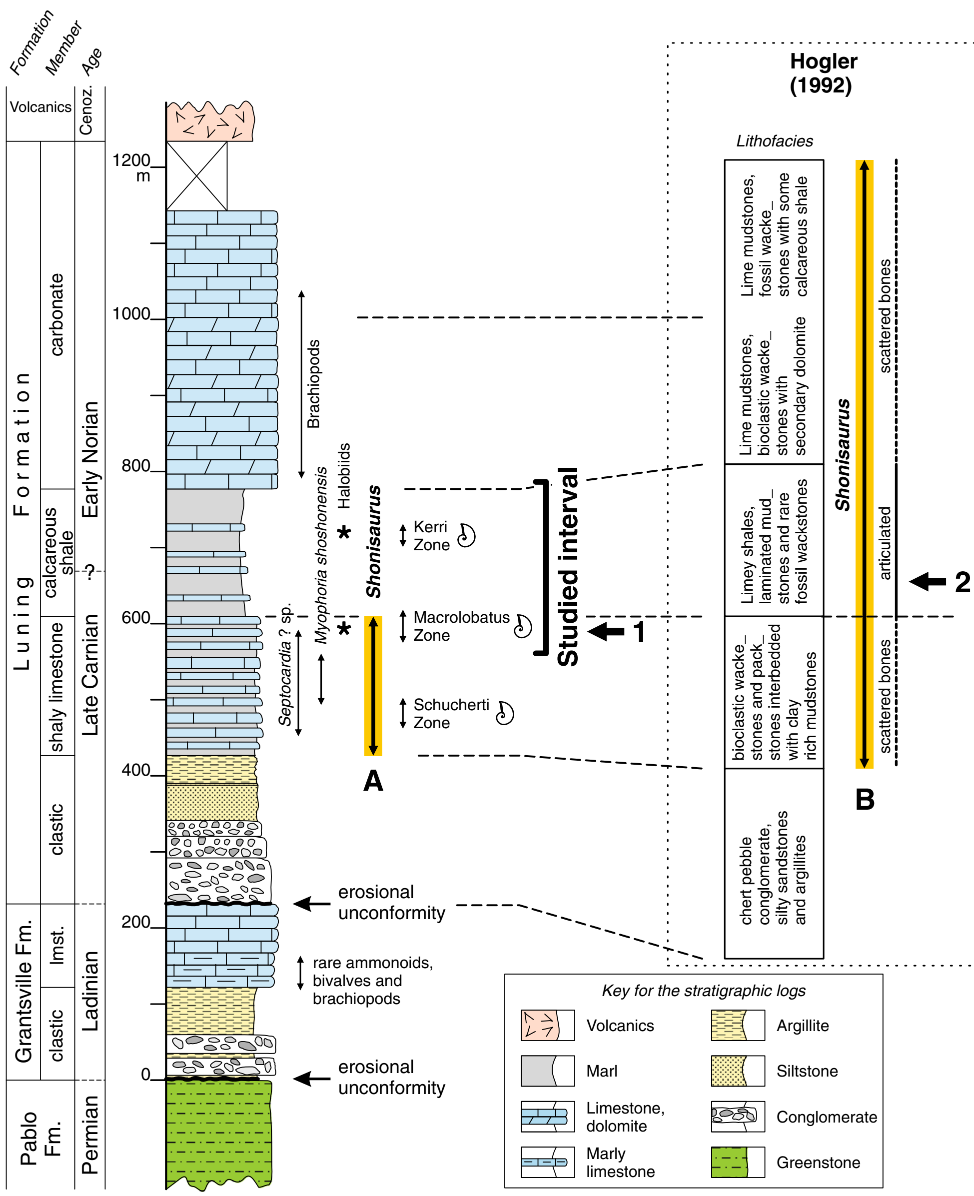

Fig. 4 Triassic lithostratigraphy and fossil record of the Berlin-Ichthyosaur State Park area. Lithostratigraphy and ammonoids from Silberling (1959), brachiopods from Sandy and Stanley (1993), bivalves from Silberling (1959) and Kristan-Tollmann and Tollmann (1983). Two very different interpretations of the stratigraphic distribution of *Shonisaurus* are presented in the literature. **a** Camp (1980) reported *Shonisaurus* from Silberling's shaly limestone member (p. 142–143; see also text); **b** Hogler (1992, Fig. 3) reported *Shonisaurus* remains from nearly the entire Luning Formation, with the main concentration in the lowest 50 m of facies equivalent to Silberling's calcareous shale member (see Hogler 1992: Fig. 3). These two authors also provided different stratigraphic positions for the main ichthyosaur bearing level that yielded the specimens protected by the on-site shelter ("Fossil House" of Hogler 1992): (1) position by Camp (1980; see also Fig. 3), (2) position by Hogler (1992: Fig. 3)

of massive limestones with intercalations of thick to very thick beds of crystalline dolomite in its lower part.

The Luning Formation contains an abundant fossil record, especially in the shaly limestone and calcareous shale members. The shaly limestone member yielded the 37 specimens of *Shonisaurus* collected and described by Camp (1976, 1980). Ichthyousaur remains were reported by Camp from throughout this member, but many of the articulated specimens were referred to a 9-m thick interval in the upper part of the member (Camp 1980: 143). The shaly limestone member also provided interesting bivalves described by Silberling (1959) as *Septocardia*? sp. and *Myophoria shoshonensis*, and more importantly, he reported the occurrence of *Halobia* sp. (op. cit., p. 19) from its upper part, although the taxon was not described. The more common invertebrates of this member, however, are

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ammonoids and in particular, the Upper Carnian faunas of the Schucherti and Macrolobatus zones (Fig. 4). Although Silberling (1959) did not include a range chart for the ammonoids found in his bed-by-bed sampled section on the southern slope of the West Union Canyon (USGS localities M71 and M72a–c, northwest of the Richmond Mine), he did report the stratigraphic position of his faunas and in his synthetic log (op. cit., p. 37; pl. 11). He also indicated the position of his ammonoid zones along strike on his 1:24.000 scale geological map (Silberling 1959, pl. 10; Fig. 3). Silberling recognized the Schucherti zone in a 38-m thick interval starting about 38 m above the base of the member. He recognized the Macrolobatus zone as extending from about 30 m below the top of the shaly limestone member (about 76 m above the Schucherti zone) through the lowermost 9 m of the overlying calcareous shale member.

In addition to ammonoids of the uppermost part of the Macrolobatus zone, the calcareous shale member also includes ammonoid faunas referred to the Kerri zone by Silberling and Tozer (1968). These faunas were reported from about 91 to 122 m (USGS Locality M73) above the base of the ~170-m thick member, i.e., more than 80 m above the highest occurring Carnian ammonoid taxon. This member also yielded halobiids, although very few data are available. Silberling (1959, p. 19) mentioned the presence of *Halobia* sp., and Kristan-Tollmann and Tollmann (1983) figured *Perihalobia beyrichi* and *Halobia hochstetteri* from a locality on the north side of West Union Canyon.

The carbonate member, the uppermost unit of the Luning Formation in the BISP area, has yielded a few benthic foraminifera (Kristan-Tollmann and Tollmann 1983) and brachiopods (Sandy and Stanley 1993), including the spiriferid *Spondylospira lewesensis* (Lees) and the terebratulids *Plectoconcha aequiplicata* (Gabb), *Rhaetina gregaria* Suess, and *Zeilleria* cf. *Z. elliptica*. Despite the shallow water paleoenvironment, this member has not yet provided cnidarian faunas, even though they are common in the patch reefs of the lower part of the Luning Formation in the Pilot Mountain range, close to Mina, NV (Stanley 1977, 1979; Kristan-Tollmann and Tollmann 1983; Martindale et al. 2012; Roniewicz and Stanley 2013).

Materials and methods

The stratigraphic interval selected for study includes the upper part of the shaly limestone member, recording the uppermost Carnian Macrolobatus zone, and the overlying calcareous shale member, documenting the lowermost Norian Kerri zone. Based on detailed information provided by NJS, the area chosen for investigation is located in the northeastern part of BISP and in the surrounding Toyabe National Forest (Fig. 3). Areas within BISP are protected, and it was necessary to secure special permission from the NV Division of State Parks (NDSP) to conduct paleontologic sampling during the 2010 field season. The relatively minor portion of field work planned for Toyabe National Forest (USFS land) consisted only of surface collecting and a special permit was not required for this activity. Actual field work conducted in October 2010 (MB, JJ, and RM) included a preliminary survey of both sides of West Union Canyon and the measurement of two stratigraphic sections. These sections were measured with a 20-m long tape and compass, and then sampled following a strict bed-by-bed approach for ammonoids, bivalves, and conodonts. However, because of permit restrictions, no excavations were made and samples were taken only from the surface. Very strict procedures were followed regarding sample numbering and designation. Samples taken from the same level, but from different positions along strike were given separate numbers. The same distinction was applied to float pieces of rock moved slightly downslope from their original bed: the eight samples BIS10, BIS10A to 10F, and BIS11 each represent a small, float limestone block collected no more than 50 cm below limestone bed BIS12. Faunal composition, lithology, and thickness of the blocks fully support the attribution of these samples to bed BIS12.

No ichthyosaur remains were discovered during field work, but Camp's Quarry 2 was visited and its location verified on the geological map provided by Silberling (1959: Fig. 3). Conodont samples were sent to MJO for preparation and study, while preparation of macrofossils was carried out at the laboratories of the Dipartimento di Scienze della Terra (University of Milano). Bivalves were sent to CAM for study. All figured fossils are stored at the New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104-1375. Inventory numbers are NMMNH P- 67692 to 67737.

The stratigraphic sections

Exposures of the shaly limestone and calcareous shale members in West Union Canyon are quite poor because of their soft weathering nature and the relatively gentle topography in the outcrop area as well as the heavy vegetation cover (sagebrush, trees, etc.). Nevertheless, Silberling's accurate geological map and the relative abundance of fossil invertebrates made it fairly easy to identify the ammonoid-bearing intervals in the field. Following our survey of both sides of the canyon, the two best exposures were identified; the first (Brick Pile section) is located on the southern side, about 2 km from the mouth of the canyon, starting from the prominent brick pile in the bottom of the canyon (A, Fig. 3), and the second (North

Capital letter: Zone

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section) is located about 2.6 km from the mouth of the canyon on its northern side (B, Fig. 3).

The most complete section (Brick Pile: A, Fig. 3), measured up-slope to the east from the Brick Pile (WGS84 coordinates of the base 38°52′41.5″N, 117°34′58.9″W), includes the interval from the upper part of the shaly limestone member to the base of the carbonate member (Fig. 5), for a total thickness of about 340 m. This particular section was measured at approximately the same location from which Silberling (1959, pl. 11) described the upper portion of his stratigraphic log of the Luning Formation and subsequently recognized four fossiliferous levels (M72a, M72b, M72c, and M73), which correspond to the lower, middle, and upper parts of the Macrolobatus zone and the overlying Guembelites (=Kerri) zone (1959, p. 37). Site 2 of Kristan-Tollmann and Tollmann (1983: Fig. 7) also represents the same locality.

About 38 m of the Brick Pile section belongs to the shaly limestone member, whereas about 300 m are ascribed to the calcareous shale member. This thickness is greater than Silberling's (1959) original estimate of about 550 ft (~167 m) for this member as well as that by Hogler (1992) who reported 200 m. Measurements were taken with tape and compass, and bedding measurements were made every 5–10 m. It is highly probable that our measurements are more accurate than those reported in the literature because the wide variation (21°–52°) in dip angle of the relatively few exposed beds along the slope east of the Brick Pile has a significant influence on the conversion of tape measurements into stratigraphic distance. Although the numerous calcite veins in the lower half of the member point to the presence of several concealed faults, they most probably do not result in significant repetitions of the succession, at least from the base of the member to level BIS40. In support of this conclusion, it is noted that on the eastern side of the West Union Canyon, north of the West Union Canyon fault (Fig. 3), the lower and upper boundaries of the calcareous shale member (easily mappable in agreement with Silberling 1959: p. 16) follow a topographic course that is consistent with a tabular rock body. Folding appears to occur only in the uppermost 22 m of the calcareous shale member (Fig. 5). Such deformation was reported by Silberling (1959: 17) as resulting from "minor readjustment" between the two contrasting rock types.

The North section (WGS84 coordinates of the base: 38°53′04.2″N, 117°34′44.4″W) lies entirely within the calcareous shale member at a site where, according to Silberling (1959), only the Kerri zone is documented. Kerri zone ammonoids and halobiids were also collected by Kristan-Tollmann and Tollmann from this site (1983: locality 6). Unfortunately, the 45-m thick ammonoid-bearing interval is surrounded by a thick debris cover that makes it nearly impossible to pinpoint its stratigraphic position within the calcareous shale member. The lower boundary of the member is covered, and the interval's position with respect to the lower part of the overlying carbonate member cannot be used to estimate its stratigraphic position because of the presence of volcanic rock outcrops (not shown on the map). The occurrence of three thick limestone intervals (1.4-, 2-, and 3-m thick: Fig. 6) suggests an approximate correlation of this section with the upper part of the Brick Pile section, where similar calcareous intervals are documented. A more accurate correlation is not possible at this time.

Fig. 5 Stratigraphic log of the Luning Formation, Brick Pile section ▶ (West Union Canyon) showing distribution of ammonoids, bivalves (*Halobia*) and conodonts. *Closed circle* are highly confident identifications; *open circles* are poorly preserved specimens

Ichthyosaur record

Although ichthyosaurs cannot serve as a biostratigraphic tool for the definition of the Carnian/Norian boundary, it is impossible to deal with the BISP fossil record without referring to this important group of vertebrates. The BISP ichthyosaur record, with its numerous articulated and well-preserved individuals, is so remarkable that Bottjer et al. (2002) and Bottjer (2002) were motivated to include the site in an inventory of the most significant fossil-Lagerstätten in the world. However, with regard to this BISP record we must emphasize a significant discrepancy in the literature concerning the stratigraphic position of ichthyosaur remains within the Luning Formation. Figure 4 summarizes the two distribution models thus far proposed. Camp (1980: 142–143), who spent at least seven field seasons collecting ichthyosaurs at BISP, described "all presently known vertebrates" from the shaly limestone member of Silberling (1959), with Quarries X and 4 lying within the Schucherti zone, and the other specimens (Quarries 1–3, 5–9) within the Macrolobatus zone. Camp (1980: 145–146) also provided descriptions of the type of bone preservation, as well as the lithology and stratigraphy of the most important quarries that are all consistent with a position within the shaly limestone member.

Hogler (1992) improved the knowledge in many respects regarding the life and death of the BISP *Shonisaurus*, by providing a well-presented taphonomical analysis of bones and articulated specimens (especially those preserved under the shelter), as well as a paleobiological analysis of the ichthyosaur-bearing succession. However, Hogler's (1992: Figs. 3, 4) illustrated record of ichthyosaurs is totally different with respect to that described by Camp (1980), which leads to a certain amount of confusion regarding the stratigraphic position and age of *Shonisaurus*.

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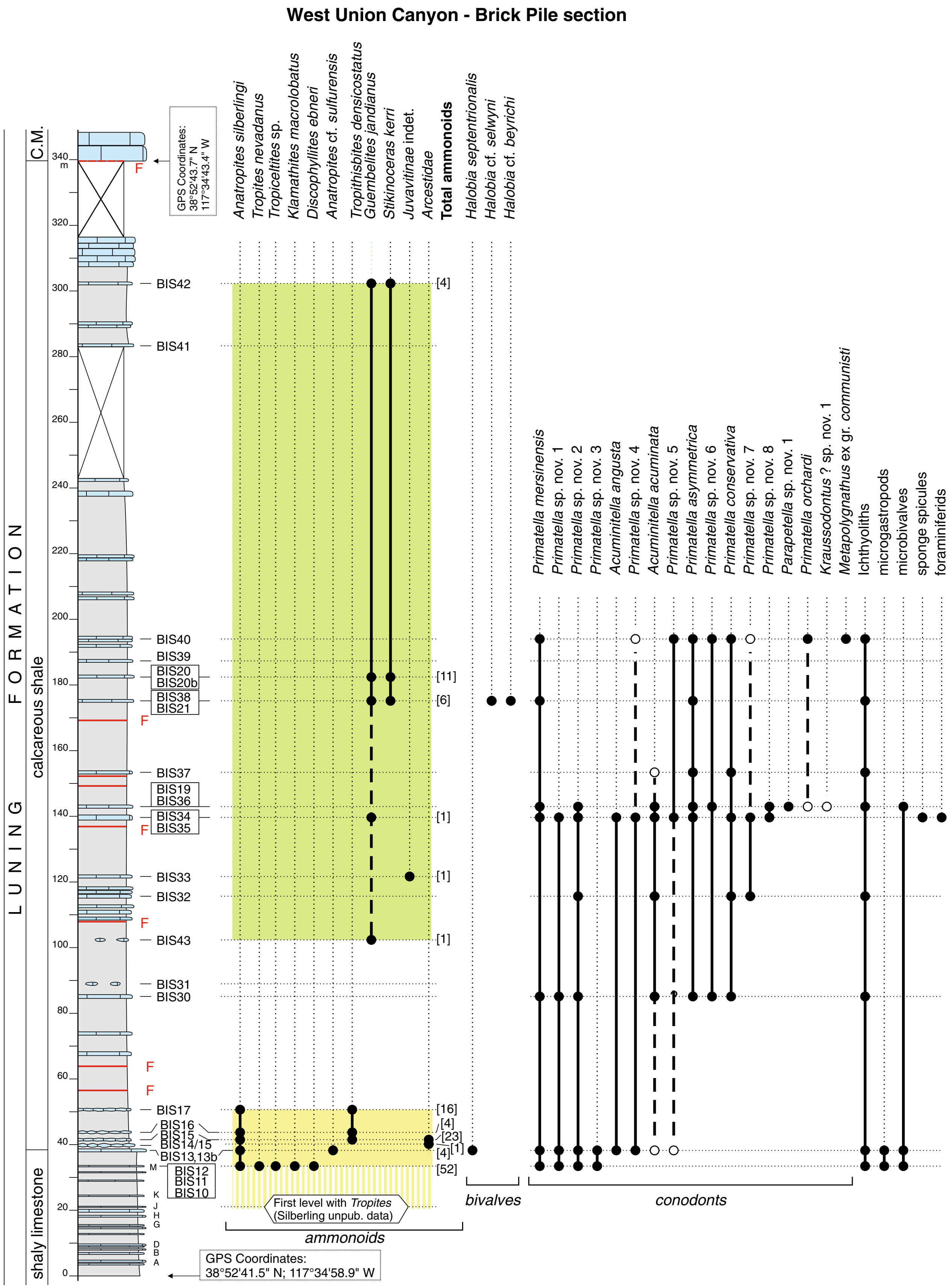

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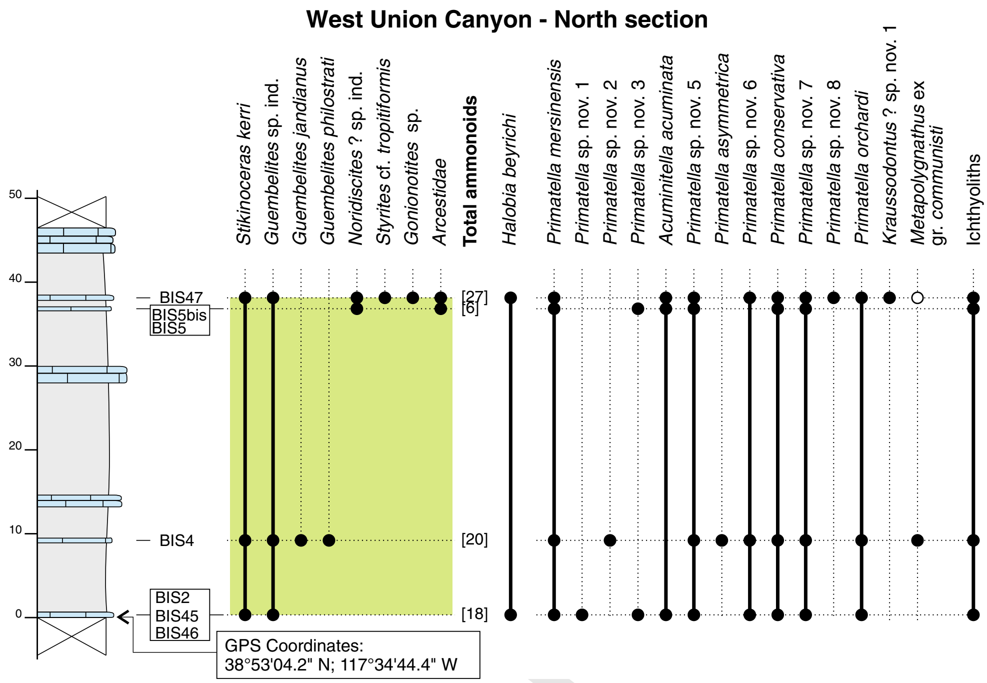

Fig. 6 Stratigraphic log of the Luning Formation, North section (West Union Canyon), showing the distribution of ammonoids, bivalves (*Halobia*), and conodonts

Although Hogler did not specifically refer to Silberling's lithostratigraphy, her subdivision of the Luning Formation (Hogler 1992: Fig. 3) can be correlated with that of Silberling (Fig. 4). Articulated ichthyosaurs, including those protected under the shelter (Quarry 2 of Camp 1980, equivalent to "Fossil House" of Hogler), are referred to a lithofacies equivalent to Silberling's calcareous shale member, whereas isolated bones were reported as collected from a lithofacies equivalent to the shaly limestone member and from two different lithofacies that are equivalent to the carbonate member (see Fig. 4 for summary). This latter occurrence is especially surprising because thus far, Triassic ichthyosaurs have never been reported from carbonate platform facies (e.g., see the general overview by Merriam 1908; Callaway and Massare 1989), and instead are typical of the inner- to outer-shelf settings (e.g., Sander 2000).

We found no ichthyosaur remains during our 2010 field survey, but we did confirm the lithostratigraphic attribution of Camp's Quarries 1–3 and 5–9, including Quarry 2 ("Fossil House"), to the shaly limestone member. This conclusion is based on (a) the direct experience of NJS; (b) Silberling's highly accurate geological map, which we verified in the field; (c) our verification of the position of the quarries shown on Silberling's geological map (Fig. 3); and (d) the lithofacies of the sites, especially as regards Quarry 2. The nine specimens in the sheltered exhibit are preserved on top of a ~30-cm thick limestone bed, and such thick limestone beds are very typical of the shaly limestone member.

The confirmation of Camp's attribution demonstrates a Late Carnian age for the BISP *Shonisaurus* record. This is in contrast with the Late Carnian to Early Norian age suggested by Hogler's stratigraphic reconstruction. We cannot exclude the possibility that some bones/specimens may occur within the calcareous shale member, as this facies is very close to the typical ichthyosaur-bearing facies, but we feel safe in rejecting the carbonate member occurrence. It is difficult to understand why Hogler came to this conclusion, but her emphasis was on ichthyosaur study rather than the stratigraphic framework. This approach unfortunately is quite common in marine vertebrate paleontology (see Balini and Renesto 2012), but it leads to the loss of important information regarding the understanding of the mode of vertebrate life, as well as their age dating.

Ammonoid record

As mentioned in the Introduction, literature regarding the study of ammonoids from BISP is limited to Silberling's (1959) monograph and an additional contribution in the early 1980s by Kristan-Tollmann and Tollmann (1983), who made a short visit to the site during a tour of Triassic localities in the American West. Silberling provided a complete account of the faunas of the upper part of the shaly limestone member and the overlying calcareous shale member as well as a description of the faunas from a taxonomic point of view. He also included a synthetic

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stratigraphic chart (pl. 11) and proposed a biostratigraphic classification of the succession.

The faunas of the Schucherti, Macrolobatus, and Kerri zones as documented by Silberling, including a few taxa reported by Kristan-Tollmann and Tollmann (1983), are shown with the original taxonomic classification in Tables 1 and 2. Ammonoid taxonomy was not modified by Silberling and Tozer (1968) and Tozer (1971), who followed Silberling (1959) in considering *Stikinoceras* McLearn, 1930 as junior synonym of *Mojsisovicsites* Gemmellaro, 1904. Afterwards, the separation of the two genera was suggested by Tozer (1981a) and then confirmed in 1994 in his final review of Canadian Triassic ammonoid faunas. In the same monograph, Tozer established the new (monotypic) genus *Tropithisbites* for *Tropiceltites*? *densicostatus* Silberling and described the new species *Anatropites silberlingi* for *Anatropites* sp. of Silberling.

New data

The relatively short time period allotted for fossil sampling (about 5 days) obviously was not sufficient to allow for the collection of a large, representative number of macrofossil specimens. However, we did collect (bed-by-bed) about 190 well-preserved ammonoids from the studied interval of the Luning Formation (Fig. 4). These specimens are significant in that they allow us to outline the ammonoid record, which in turn provides a bio-chronostratigraphic calibration for *Halobia* and the collected conodont samples.

Ammonoids from the shaly limestone member are normally found in limestone beds and are preserved three-dimensionally. Those from the calcareous shale member are found within marls or in thin marly limestone beds and are usually deformed by sediment compaction. Their body chambers are nearly always collapsed, with major damage occurring to the ventral area.

The frequency of specimens may change from bed to bed, but specimens are quite often abundant, especially in the shaly limestone member (e.g., level BIS12 and blocks from this level). Ammonoid bearing levels are rarer in the calcareous shale member, but some levels yield a fairly high number of specimens (e.g., samples BIS15, BIS17, BIS47). All of the more common taxa reported by Silberling were found (Figs. 5, 6; Tables 1, 2). These taxa allow us to identify easily the various ammonoid zones because ammonoid faunal composition, even at the generic level, changes quite significantly from one zone to the next (Tables 1, 2).

The Macrolobatus zone is recognized within the Brick Pile section (Fig. 5) from level BIS12, about 5.6-m below the top of the shaly limestone member, to level BIS17, about 12 m above the base of the calcareous shale member.

Capital letter: Zone

Table 1 Cephalopod and bivalve taxa identified in the Upper Carnian Schucherti and Macrolobatus zones by Silberling (1959) and Kristan-Tollmann and Tollmann (1983)

Macrolobatus zone
Silberling (1959)
Klamathites macrolobatus n. sp. (30)
Tropites latumbilicatus n. sp. (12)
Tropites subquadratus n. sp. (over 200)
Tropites crassicostatus n. sp. (60)
Tropites nodosus n. sp. (24)
Tropites nevadanus n. sp. (sev. hundred)
Anatropites sp. (∼100)
Tropiceltites? *densicostatus* n. sp. (18)
Juvavites (*Anatomites*) cf. *inflatus* Gemmellaro
Griesbachites? cf. *cornutus* Diener
Arcestes sp.
Clydonautilus sp. (1)
Paranautilus sp.
Proclydonautilus sp.
Aulacoceras sp.
Kristan-Tollmann and Tollmann (1983)
Klamathites macrolobatus Silberling
Anatropites sp.
Tropites sp.
Schucherti zone
Silberling (1959)
Klamathites schucherti Smith (50)
Juvavites (Anatomites) cf. *J.* (*A.*) *elegans* Gemmellaro
J. (A.) spp.
Discophyllites ebneri (Mojsisovics) (6)
Arcestes sp.
Germanonautilus kummeli n. sp. (10)
Phloioceras mulleri n. sp. (1)
Proclydonautilus sp.
"*Orthoceras*" sp.
Aulacoceras sp.
Myophoria shoshonensis n. sp. (sev. dozen)
Septocardia sp. (extr. abundant)
Pinna sp.
Kristan-Tollmann and Tollmann (1983)
Klamathites sp.
Gonionotites sp. ex gr. *italicus*
Arcestes
Gonionotites sp.
Michelinoceras
Nautilus
Projuvavites
Terquemia sp.

Should read: Klamathites

Juvavites (Anatomites)

See text for explanation of the historical changes in the names of the zones. Taxa from Silberling (1959) include those described in the Systematic Descriptions and those quoted in the text (p.19). The number of specimens collected is shown in parentheses when available. Kristan-Tollmann and Tollmann provided citation of taxa in the text (p. 226 and 228) and some illustrations, but no systematic descriptions

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Table 2 Cephalopod and bivalve taxa identified in the Lower Norian Kerri zone by Silberling (1959) and Kristan-Tollmann and Tollmann (1983)

Kerri zone
Silberling (1959)
Mojsisovicsites robustus (McLearn) (15)
Mojsisovicsites kerri (McLearn) (30)
M. cf. *crassecostatus* Gemmellaro (40)
Guembelites clavatus (McLearn) (14)
Guembelites jandianus Mojsisovics (~80)
Guembelites philostrati Diener (10)
Styrites cf. *subniger* Mojsisovics
Styrites cf. *vermetus* (Dittmar)
Styrites cf. *signatus* (Dittmar)
Styrites cf. *tropitoides* Gemmellaro
Dimorphites cf. *monti-ignei* Dittmar
Arcestes sp.
Paranautilus sp.
Cosmonautilus cf. *pacificus* Smith
Halobia sp.
Kristan-Tollmann and Tollmann (1983)
Guembelites clavatus (McLearn) frühe Form
Guembelites clavatus (McLearn) typische Form
Guembelites jandianus Mojsisovics
Guembelites philostrati Diener
Stikinoceras kerri (McLearn)
Stikinoceras robustus (McLearn)
Anatropites sp.
Griesbachites sp.
Thisbites sp.
Perihalobia beyrichi (Mojsisovics)
Halobia hochstetteri (Mojsisovics)

For explanation of data source see caption for Table 1. The number of specimens collected is shown in brackets when available

please, insert the word specimen after Arcestidae

Anatropites silberlingi occurs throughout this interval and appears to be the most common taxon of the upper part of the Macrolobatus zone.

Level BIS12 is an ammonoid-rich level recognized by Silberling (1959: 19) as a "1-ft bed of limestone about 20 ft below the top of the shaly limestone member" characterized by the occurrence of *Tropites nevadanus*. The fauna collected from this level and eight float blocks (labels BIS10, BIS10A-10F; BIS11) found a short distance down slope from BIS12, consists of *Tropites nevadanus* Silberling (Fig. 7e–i) and *Anatropites silberlingi* Tozer (Fig. 7a–c), with rare *Klamathites macrolobatus* Silberling, *Discophyllites ebneri* Mojsisovics, and *Tropiceltites* sp. A faunal change occurs around the boundary of the shaly limestone and calcareous shale members that marks the disappearance of *Tropites* and the onset of *Tropithisbites*.

Fig. 7 Ammonoids of the Late Carnian Macrolobatus zone, Luning ▶ Formation, Berlin-Ichthyosaur State Park, Brick Pile section. **a–i** Shaly limestone member; **j–k** calcareous shale member. **a–c** *Anatropites silberlingi* Tozer, 1994: **a** specimen NMMNH P-67698 (BIS10b-2), **a1** lateral view, **a2** apertural view; **b** specimen NMMNH P-67699 (BIS11-13), **b1** lateral view, **b2** ventral view; **c** specimen NMMNH P-67700 (BIS6-3), lateral view. **d** *Anatropites* sp. ind., NMMNH P-67701 (BIS10f-2), **d1** lateral view, **d2** ventral view. **e–i** *Tropites nevadanus* Silberling, 1959: **e** specimen NMMNH P-67702 (BIS10-8), depressed morphotype (cf. Silberling 1959: pl. 5, Figs. 3, 4 and 6, 7), **e1** lateral view, **e2** apertural view; **f** specimen NMMNH P-67703 (BIS10b-5), **f1** lateral view, **f2** apertural view; **g** specimen NMMNH P-67704 (BIS10a-2), lateral view; **h** specimen NMMNH P-67705 (BIS10b-1), lateral view; **i** specimen NMMNH P-67706 (BIS10b-4), **i1** lateral view, **i2** ventral view. **j–k** *Tropithisbites densicostatus* (Silberling, 1959): **j** specimen NMMNH P-67707 (BIS16-1), lateral view; **k** specimen NMMNH P-67708 (BIS26-3), **k1** lateral view, **k2** ventral view. All specimens whitened with ammonium chloride. *Bar scale* 1 cm for all specimens

The small number of specimens available from BIS13 to BIS14/15 for the moment does not allow us to delineate accurately this boundary, but the faunal change is most likely related to the facies change. Samples BIS13 and BIS13b yielded two specimens each of *Anatropites silberlingi* and *A.* cf. *sulfurensis*, while BIS14/15 yielded only one Arcestidae. The upper part of the Macrolobatus zone (levels BIS15-17) is dominated by *Tropithisbites densicostatus* (Fig. 7j–k) with less abundant *Anatropites silberlingi* Tozer.

Based on our preliminary sampling, the first occurrence of Early Norian Kerri zone ammonoids from the Brick Pile section (Fig. 5) is recorded in level BIS43, about 64 m above the base of the calcareous shale member and about 52 m above the uppermost ammonoid of the Macrolobatus zone. In this section the Kerri zone ranges upwards for about 200 m to level BIS42. The genus *Guembelites*, common from BIS43 to BIS42, is represented by nine specimens from a total of 29. Several partly crushed specimens attributable to *G.* cf *jandianus* were collected from levels BIS43 and BIS35, while well-preserved *G. jandianus* Mojsisovics occurs from BIS21 to BIS42 (Fig. 8a) together with *Stikinoceras kerri* McLearn. Such a high stratigraphic occurrence of *G. jandianus* and *S. kerri* is new, because Silberling (1959: pl. 11) reported these two species only in the lower part of the Kerri zone, while the upper part was characterized by the *G. clavatus* (McLearn) and *Mojsisovicsites* cf. *crassecostatus* assemblage.

This high stratigraphic position of the LO of *S. kerri* is also documented in the North section (Fig. 6), where *Guembelites* and *Stikinoceras* were collected from the lowermost to the uppermost fossil bearing level. In addition to *S. kerri* (Fig. 8c, d), level BIS4 is especially rich in *Guembelites* (11 specimens out of a total of 20), with *G. jandianus* the most common species and *G. philostrati*

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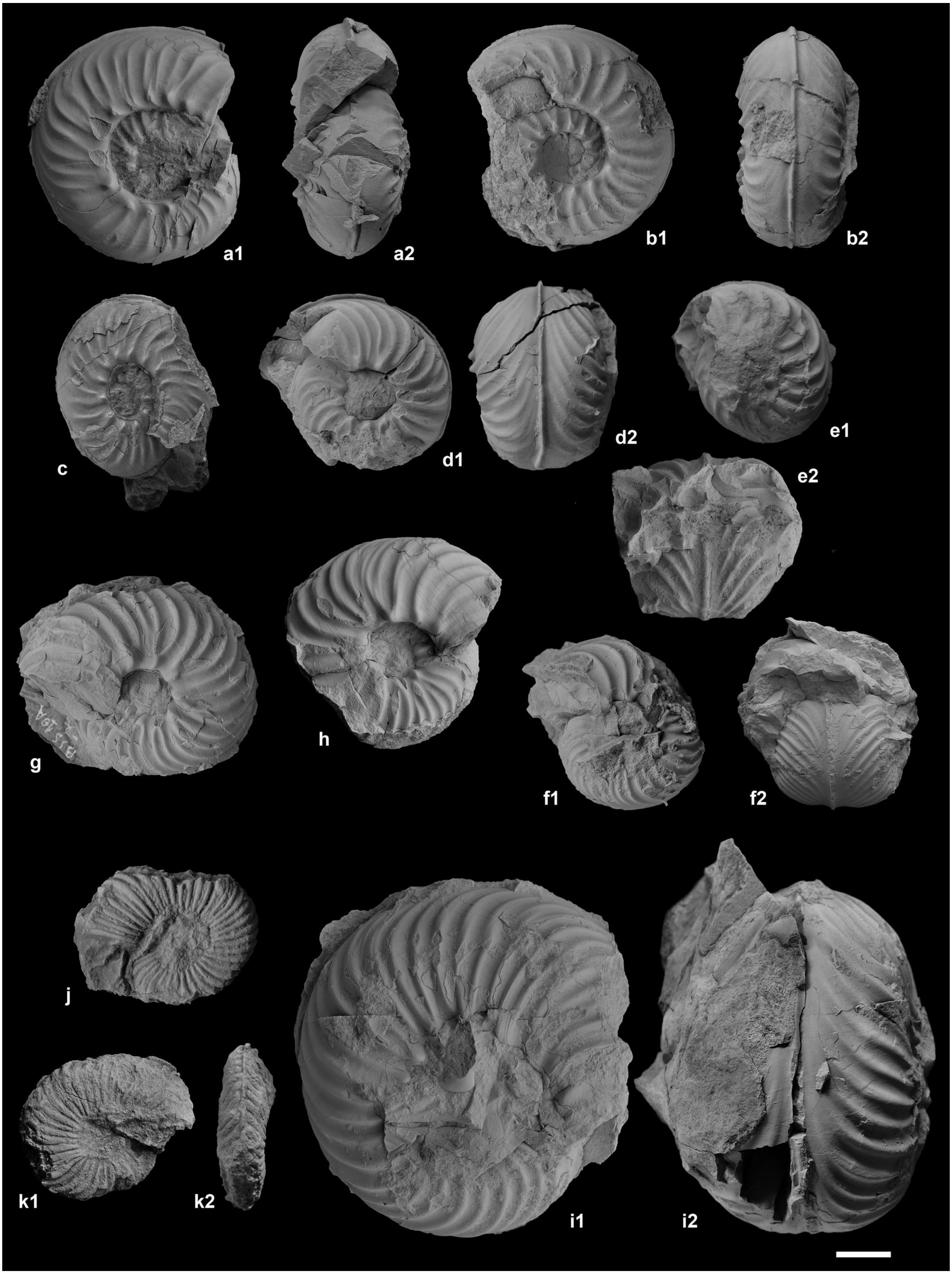

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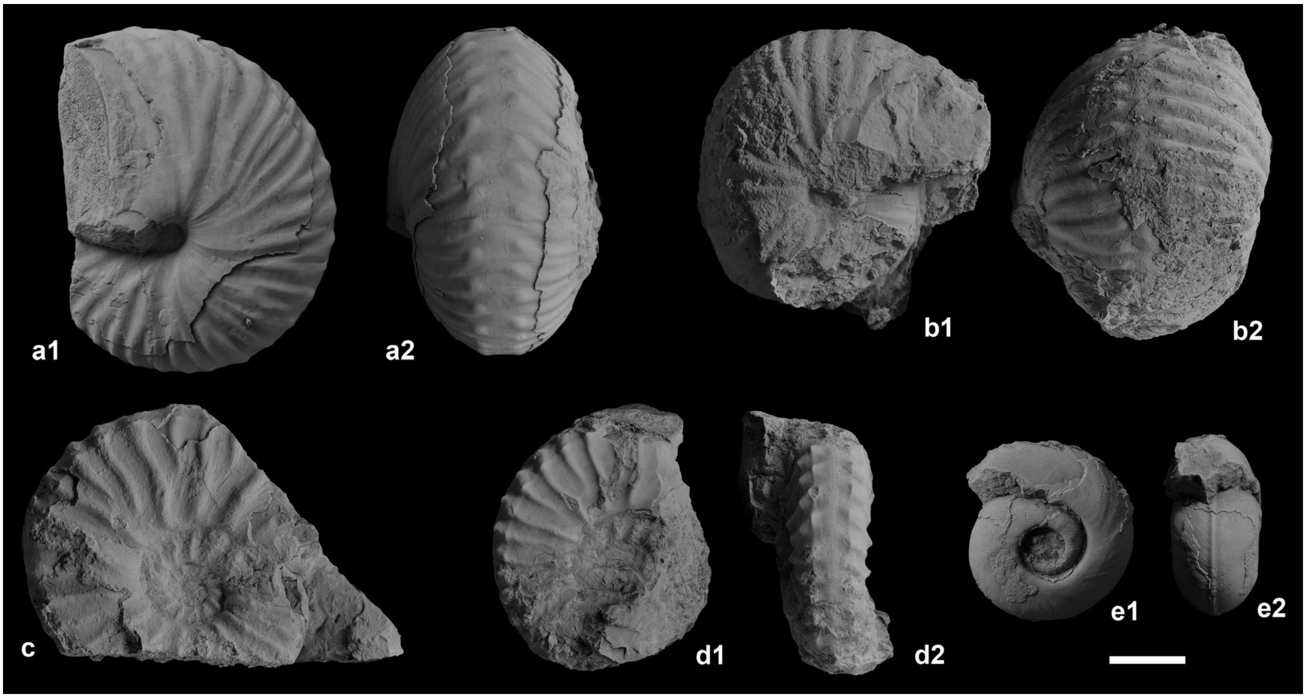

Fig. 8 Ammonoids of the Early Norian Kerri zone, Luning Formation, calcareous shale member, Berlin-Ichthyosaur State Park. **a**, *Guembelites jandianus* Mojsisovics, 1896, NMMNH P-67709 (BIS38-3), Brick Pile section, **a1** lateral view, **a2** ventral view; **b** *Guembelites philostrati* Diener, 1923, NMMNH P-67710 (BIS4-12), North section, **b1** lateral view, **b2** ventral view. **c–d** *Stikinoceras kerri* McLearn, 1930: **c** specimen NMMNH P-67711 (BIS4-16), North section, lateral view; **d** specimen NMMNH P-67712 (BIS4-17), North section, **d1** lateral view, **d2** ventral view; **e** *Styrites* cf. *tropitiformis* Mojsisovics, 1893, NMMNH P-67713 (BIS47-26), North section, **e1** lateral view, **e2** apertural view. All specimens whitened with ammonium chloride. *Bar scale* 1 cm for all specimens

Diener (Fig. 8b) occurring less frequently. The uppermost fossil bearing levels of the section, BIS5bis and BIS47, yielded the most diverse ammonoid fauna of the two stratigraphic sections under study. The largest collection was made from level BIS47, whose fauna include *Styrites* cf. *tropitiformis* (Fig. 8e), *Guembelites* (*G.* sp. and *G.* cf. *clavatus*), *Stikinoceras kerri* McLearn and *Gonionotites* sp. in decreasing order of frequency. Unfortunately, the lithology of these levels is rather marly and specimens are quite often crushed by sediment compaction. It is very difficult to extract medium to large sized specimens that are sufficiently complete to permit full classification.

Taxonomic remarks

Although the purpose of this paper is not to provide taxonomic descriptions of the BISP ammonoids, some taxonomic remarks are necessary in order to explain better the range charts and to introduce the following discussion items. Two points are herein presented: (1) the intraspecific variability of *Tropites*, and (2) a few taxonomic problems regarding *Tropithisbites densicostatus* Silberling.

1. Variability of *Tropites*. Silberling (1959) emphasized the wide intraspecific variability of most species of *Tropites*. This conclusion was based on a population analysis of bed-by-bed-collected specimens that led him to differentiate and present a summarized stratigraphic succession (p. 19) of species within the Macrolobatus zone, in ascending order as follows (measurements represent distance below top of shaly limestone member): *T. latiumbilicatus*, 60 ft (18.3 m); *T. subquadratus*, *T. crassicostatus,* and *T. nodosus*, 50 ft (15.2 m); *T. nevadaus*, 20 ft (6.1 m). Additionally, more detailed information regarding the range of these individual species within the 18-m thick interval is provided in the systematics section of Silberling's monograph. Within this succession of species, *T. subquadratus*, *T. crassicostatus,* and *T. nevadanus* display the widest variability, especially with regard to the height/width (H/W) ratio and the degree of coiling. Extreme variants range from morphotypes with a low degree of coiling and H/W ratios $<$ or $<<1$ to those with a medium degree of coiling and H/W ~ 1. Such variability is confirmed by newly collected *Tropites nevadanus* specimens from the penultimate bed of the shaly limestone member (BIS12 and float samples BIS10, BIS10A to 10F, and BIS11) (Fig. 7f–i).
2. Classification of *Tropithisbites densicostatus*. Specimens classified as *Tropithisbites densicostatus*

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(Fig. 7j–k) fully conform to the original description of the species given by Silberling (1959), but not to the interpretation of Tozer (1994). He attributed to *T. densicostatus* Silberling some specimens from the Peril Formation, Queen Charlotte Island (British Columbia) with ribs "extending to the keel" (Tozer 1994: 232). This particular detail does not agree with the ventral side of the BISP specimens described by Silberling (1959: 52) that exhibit furrows bordering the keel. Unfortunately, Tozer included this "ribs extending to the keel" feature of the Queen Charlotte specimens in the diagnosis of *Tropithisbites* (p. 231), a new monotypic genus he erected to accommodate *Tropiceltites*? *desicostatus* Silberling, 1959, which Silberling left in a doubtful generic position. According to Tozer, *Tropithisbites* is characterized by a "ventral keel rounded smooth, not bordered by sulci", but this diagnosis must be emended because the type species of the genus exhibits furrows separating the termination of the ribs from the smooth keel.

Biostratigraphic remarks

Based on our work thus far, the stratigraphic distribution of ammonoids within the Macrolobatus zone closely agrees with that documented by Silberling (1959). This zone probably can be divided into two different units of possible zonal rank once three key points are clarified by further investigation. These include the stratigraphic position of *Tropites nodosus* Silberling, the FO of the index *Klamathites macrolobatus,* and the FO of *Anatropites*, all of which would eventually have to be recorded in the lower part of the Macrolobatus zone, an interval not investigated in the present work.

According to Silberling, the lower and middle parts of the Macrolobatus zone (equivalent to levels J to BIS10: Fig. 5) are characterized by a mass occurrence of *Tropites* as well as by *Klamathites macrolobatus*. *Tropites nodosus* SIlberling is one of five new species of *Tropites* described by Silberling from this interval, but it is of special significance because it is the only species showing two rows of distinct and well-developed nodes in both the ventrolateral and umbilical positions. Such a feature suggests the attribution of *T. nodosus* Silberling to *Margaritropites* Diener, 1916, as already hypothesized by Krystyn (1982: 32). This genus, however, is thus far known only from the Welleri zone in California and Canada (Tozer 1994) and the equivalent Subbullatus zone in the Tethys realm (Krystyn 1982). If the occurrence of *Margaritropites nodosus* is eventually confirmed in the lower part of the Macrolobatus zone as reported by Silberling, this datum would support the separation of this part of the Macrolobatus zone as an independent unit equivalent at least to the upper part of the Welleri zone. Additional elements that must be considered are the FO of *Klamathites macrolobatus*, which thus far seems to be the marker event of the base of the Macrolobatus zone, and the FO of *Anatropites*, which will be discussed below.

Zone with capital letter

In the upper part of the Macrolobatus zone, Silberling (1959: 19, pl. 11) emphasized a key level with *Tropites nevadanus*, the youngest representative of Tropites in the Luning Formation, which is "confined to a 1-ft bed about 20 ft below the top of the shaly limestone member". Our sampling confirms the occurrence of *T. nevadanus* and *K. macrolobatus* in level BIS12 at exactly the same position reported by SIlberling, as well as a lack of *Tropites* above this level. Although this conclusion is not necessarily supported by the very few specimens found in the uppermost bed of the shaly limestone member (samples BIS13 and BIS13b), it certainly is demonstrated by our more abundant collections from levels BIS15 to BIS17.

The two most important taxa within the upper part of the Macrolobatus zone are *Anatropites silberlingi* and *Tropithisbites densicostatus. A. silberlingi* has been found from level BIS12 to the top of the zone (BIS17), while *T. densicostatus* has been collected from levels BIS15 through BIS17. The bio-chronostratigraphic potential of these two taxa is quite different. A facies change most likely influences the FO of *T. densicostatus* since it first occurs just above the boundary of the shaly limestone-calcareous shale members. Moreover, given that the paleogeographic distribution of this species is unknown (see the taxonomic problems), a separation of the uppermost part of the Macrolobatus zone on the basis of this particular taxon would have only local significance.

Conversely, the bio-chronostratigraphic significance of *Anatropites silberlingi* is much more important, as demonstrated by the following three points: (1) the species is relatively facies-independent, since it occurs both above and below the boundary of the shaly limestone and calcareous shale members; (2) the taxon is also known from northeastern British Columbia, Canada (Tozer 1994), i.e., from intermediate paleolatitudes; (3) the genus *Anatropites* is very common in Tethyan successions, from western Tethys to Tethys Himalaya (e.g., Krystyn 1974, 1980, 1982; Krystyn et al. 2002; Balini et al. 2012), where it is the index ammonoid of the uppermost Carnian Spinosus zone. Indeed, the main reason we have not yet formally designated the upper part of the Macrolobatus zone as a new subzone based on this taxon is our uncertainty concerning the stratigraphic position of its FO. We have documented *A. silberlingi* in level BIS12, which is the lowermost level thus far sampled, and Silberling did not mention *Anatropites* from levels underlying the bed with *Tropites nevadanus.* On the other hand, he did not

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document the non-occurrence of this taxon from the lower part of the Macrolobatus zone. He only reported (p. 51) *Anatropites* from the upper part of the shaly limestone member and the lower part of the calcareous shale member.

Though 200-m thick, available data do not justify further subdivision of the Kerri zone. The FO of *Guembelites* (BIS43) is recognized below the FO of *Stikiniceras kerri* (BIS38), but since we only found three ammonoids below level BIS38 (Fig. 5), the discrepancy between the two FOs may not be that significant. With regard to the distribution of ammonoids within the Kerri zone, a few remarks are necessary, especially for the occurrence of the three species of *Guembelites*.

Guembelites jandianus is the most common species of the Kerri zone in the West Union Canyon sections, but only two specimens of *G. philostrati* and one of *G.* cf. *clavatus* were collected. This proportion is rather consistent with the collections reported by Silberling (1959), who described *G. jandianus* on the basis of 80 specimens, while *G. clavatus* and *G. philostrati* were represented in his collection by 14 and 10 specimens, respectively. The stratigraphic distribution of these taxa (Fig. 6) is also consistent with the distribution illustrated by Silberling in plate 11, in which *G. jandianus* is shown to occur in the same beds with *G. philostrati*, while *G. clavatus* occurs in younger levels. This record differs significantly from that reported from other localities in North America and, in part, from the Tethys. In British Columbia, Tozer (1994) reported *G. clavatus* from subzone 1 of the Kerri zone and *G. jandianus* from subzone 2. These two species are also known from the Tethyan Realm, where Krystyn (1982) documented a phyletic lineage *G. clavatus* → *G. jandianus* → *G. philostrati* from the 2nd subzone of the Jandianus zone. However, the range of *G. clavatus* In the Tethyan Realm mostly overlaps the range of *G. jandianus*, while *G. philostrati* occurs in slightly younger beds (Krystyn 1982, Fig. 13). Further investigation would be necessary in the BISP section in order to confirm the occurrence of *G. clavatus* and *G. philostrati*, as well as their separation from *G. jandianus* on the basis of a population analysis of their intraspecific variability.

Halobiid record

Although Silberling (1959) noted the presence of *Halobia* from both the shaly limestone and calcareous shale members of the Luning Formation in west Union Canyon, they were either not well enough preserved or too few in number to warrant species-level determination or illustration. More recently, however, Gruber (in Kristan-Tollmann and Tollmann 1983) recognized two halobiid taxa from the Luning Formation at Union Canyon: *Perihalobia beyrichi* (Mojsisovics) and *Halobia hochstetteri* (Mojsisovics). Although the specimens illustrated by Gruber (pl. 8, Figs. 2, 3 in Kristan-Tollmann and Tollmann 1983) are very poorly preserved, the *Perihalobia beyrichi* (now referred to the genus *Halobia*) likely corresponds to those attributed to this taxon from the Kerri zone (see below). However, the specimens attributed to *H. hochstetteri* by Gruber are somewhat more problematical due to preservation issues and are best considered indeterminate at the species level. Regardless, both illustrated specimens are reported to come from the calcareous shale member from the north side of West Union Canyon and were reported to be closely associated with several ammonoids including *Stikinoceras* and *Guembelites* indicative of the Kerri zone (see ammonoid discussion above).

The current study resulted in much better preserved halobiids that permit delimitation of at least three distinct halobiid taxa and also allowed for a better resolution of latest Carnian and earliest Norian strata (Fig. 9). The lowest stratigraphic levels containing halobiids occur on the south side of West Union Canyon at the Brick Pile section. Here, *Halobia septentrionalis* Smith occurs in level BIS13 (Fig. 9a–b) and is assigned to the Macrolobatus zone. These specimens are closely related to *Halobia radiata* Gemmellaro in having densely packed and very fine radial ribs, but differ in that the ribs are demarcated by a distinct change in course (the growth stop of Campbell 1994; McRoberts 2011). *Halobia septentrionalis* is closely related to, if not conspecific with, forms regarded as *H.* cf. *rugosa* reported from several west-Tethyan localities including the uppermost Carnian at the classic Feuerkogel locality Austria and Pizzo Mondello, Sicily (McRoberts 2011; Levera 2012). However, *Halobia septentrionalis* differs from true *Halobia rugosa* Gümbel, which is relegated to the Lower Carnian, in its outline and because it has finer radial ornament later in ontogeny. *Halobia septentrionalis* occurs from several North American localities near the Carnian-Norian boundary and most often in the uppermost Macrolobatus zone (McRoberts 2011). At the Black Bear Ridge section, *H. septentrionalis* occurs up to within 2 cm of the FO of *H. austriaca* and is relegated to the uppermost Macrolobatus zone.

Higher up in the Brick Pile section, specimens referred to *Halobia* cf. *selwyini* McRoberts and *Halobia* cf. *beyrichi* (Mojsisovics) occur about 140 m above the base of the calcareous shale member. Although determinations of these specimens are not definitive due to small sample sizes (Fig. 9e, f), they are best compared to *Halobia beyrichi* (Mojsisovics) and *Halobia selwyni* McRoberts and are likely representative of the Kerri zone. Although *H. beyrichi* is discussed in more detail below, *H. selwyni* has previously only been known from its type locality at the Black Bear Ridge section at Williston Lake in northeastern

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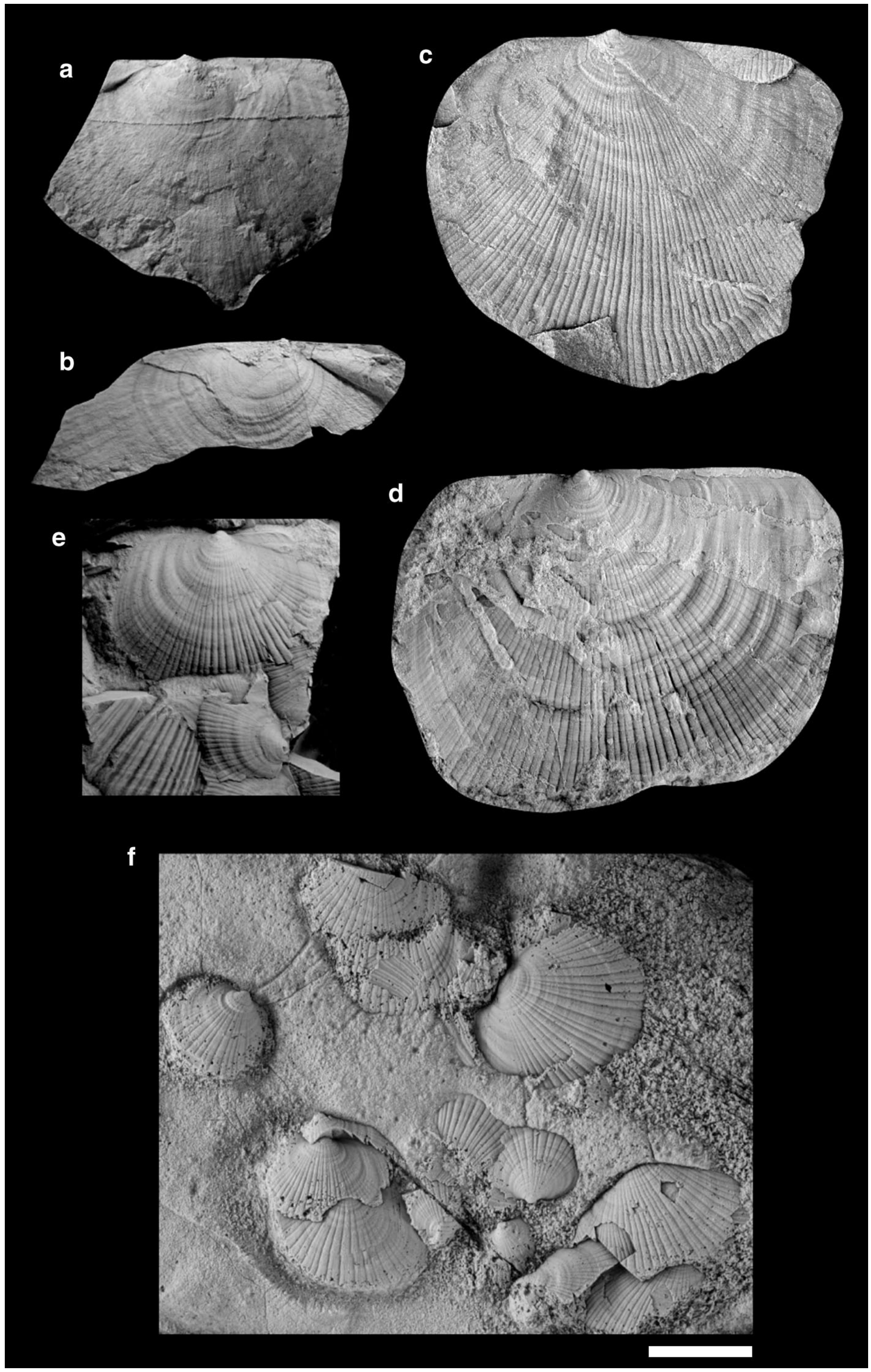

Fig. 9 Late Carnian and Early Norian *Halobia* from Luning Formation, Berlin-Ichthyosaur State Park. **a**–**b** from the Brick Pile section, shaly limestone member; **e**–**f** from the same section, calcareous shale member; **c**–**d** from the North section, calcareous shale member. **a**–**b**, *Halobia septentrionalis* Smith 1927, NMMNH P-67692 (BIS13-2), left valve exterior; **b** *Halobia septentrionalis* Smith 1927, NMMNH P-67693 (BIS13-2), right valve exterior; **c** *Halobia beyrichi* (Mojsisovics 1874), NMMNH P-67694 (BIS45), left valve exterior; **d** *Halobia beyrichi* (Mojsisovics 1874), left valve, NMMNH P-67695 (BIS2); **e** *Halobia* cf. *H. beyrichi* (Mojsisovics 1874), NMMNH P-67696 (BIS38), right valve exterior; **f** *Halobia cf. H. selwyni* McRoberts 2011, slab with numerous individuals, NMMNH P-67697 (BIS21). *Bar scale* 1 cm for all specimens

British Columbia. At Black Bear Ridge, *H. selwyni* is known from a relatively short interval at the base of the lower Kerri zone (McRoberts 2011). Additional material will be needed to confirm the equivalence of these two taxa.

From the West Union Canyon North section, *Halobia beyrichi* (Mojsisovics) occurs from two stratigraphic levels BIS2/45 and BIS47 in the calcareous shale member. Specimens from both horizons (Fig. 9c, d) are relatively well preserved permitting confident assignment to *Halobia beyrichi*. This taxon is quite important in being a key zonal index of the Lower Norian in eastern Panthalassa and in the western Tethys (see McRoberts 2010). Unfortunately, a proper evaluation of Mojsisovics' type specimen of *H. beyrichi* from near Bad Aussee in Austria is not possible (it cannot be located in the Geologische Bundesanstalt,

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Vienna, Austria), its illustration (Mojsisovics 1897, pl. 1, Fig. 7) along with topotype specimens provided by L. Krystyn and collected by the author confirm species assignment. Similar occurrences elsewhere in western North America demonstrably show that it co-occurs with the ammonoid *Stikinoceras kerri* at several localities including Vancouver Island and Haida Gwaii (Fredrick Island), British Columbia, and Kuiu Island, southeast AK (~~McRoberts~~ McRoberts 2010, 2011, and unpbl.) and in the western Tethys (e.g., De Capoa Bonardi 1984; Levera 2012) where it is closely associated with *Halobia styriaca* (Mojsisovics). At Pizzo Mondello, *H. beyrichi* first occurs approximately 4 m above *H. austriaca* and in close association with *H. stryiaca* higher in the section (Levera 2012).

Conodont record

Conodonts recovered during this investigation are poorly to moderately well preserved, but many are broken and all are thermally altered with a color alteration index (CAI) of 5 and occasionally 5.5. Some collections (e.g., BIS30, BIS32) also appear to be more recrystallized and elements commonly have adhering matrix. Nevertheless, 17 taxa are differentiated and their distribution in both sections of West Union Canyon is shown in Figs. 5 and 6. The ages of these collections are discussed below with reference to the succession established at the prospective GSSP for the Carnian-Norian boundary at Black Bear Ridge, British Columbia, Canada, where preliminary conodont zones have been introduced pending the full description of the fauna (Orchard 2013). Pending the completion of that work and stabilization of the nomenclature, the informal nature of the zones or faunal intervals is emphasized in this account by denoting them in lower case, i.e. lower, upper, zones. Of the 17 taxa recorded, all but one are known from Black Bear Ridge. Ten remain undescribed and are kept in open nomenclature.

In addition to the conodonts, a variety of other microfossils were recovered. Although they do not presently provide biochronological constraints, these microfossil associations may have paleoecological implications. Ichthyoliths are most common, but phosphatised micromolluscan steinkerns are occasionally numerous. Siliceous sponge spicules and foraminiferids occur in one sample (BIS4 = BIS35: Fig. 5).

Two conodont collections from levels BIS11 and BIS12, from about 30 m in the Brick Pile section, contain long ranging *Primatella mersinensis* (Kozur and Moix), and a further three un-named species of that genus (Figs. 5, 10c, e, j). At Black Bear Ridge, *P. mersinensis* ranges throughout the lower to upper *primitia* zones (Orchard 2013), whereas the other three new species make a later appearance in the upper part of the lower *primitia* zone. *Primatella* sp. nov. 2 ranges no higher than the boundary fauna characterized as the *parvus* zone (Orchard 2013). A collection from slightly higher in the section (level BIS13b), also yielded *Acuminitella angusta* Orchard (Fig. 11c) and *P.* sp. nov. 4, both of which also have a last appearance near the top of the *parvus* zone. Notably absent from each of these collections are representatives of typical Carnian conodonts *Kraussodontus* and *Quadralella*, which are common at Black Bear Ridge, but which largely disappear around the Carnian-Norian boundary after which they become strongly subordinate to both *Primatella* species and diminutive representatives of *Metapolygnathus* (including the nominate *M. parvus*) and *Parapetella* (Orchard 2007, Fig. 5). None of the *parvus* zone indicators occur in the present collections, although they are known to be widespread (e.g., Carter and Orchard 2013), so the lowest three collections at Brick Pile are judged to lie very close to the top of the lower *primitia* zone in the uppermost Carnian.

Fig. 10 Conodonts from Luning Formation, Berlin-Ichthyosaur State Park. **a1-3**, *Primatella conservativa* Orchard, NMMNH P-67715 (BIS45); **b1-3**, *Primatella conservativa* Orchard, NMMNH P-67716 (BIS5); **c1-3**, *Primatella* sp. nov. 3, NMMNH P-67717 (BIS45); **d1-3**, *Primatella* sp. nov. 5, NMMNH P-67718 (BIS47); **e1-3**, *Primatella mersinensis* (Kozur & Moix), NMMNH P-67719 (BIS47); **f1-3**, *Primatella* sp. nov. 3, NMMNH P-67720 (BIS5); **g1-3**, *Primatella orchardi* (Kozur), NMMNH P-67722 (BIS47); **h1-3**, *Primatella* sp. nov. 7, NMMNH P-67721 (BIS4); **i1-3**, *Primatella* sp. nov. 1, NMMNH P-67723 (BIS13b); **j1**, *Primatella* sp. nov. 6, NMMNH P-67724 (BIS45). *Bar scale* 200 µm for all specimens

Additional conodont collections from the Brick Pile section originate from some 50 m higher and above, spanning some 110 m in total. Level BIS30 marks the appearance of *Primatella conservativa* Orchard (Fig. 10a, b), which has a long range throughout the *primitia* zones at Black Bear Ridge; it is accompanied by most of the species identified in the stratigraphically lower collections. More significantly, both undisputed *Acuminitella acuminata* Orchard (Fig. 11e–g) and *P. asymmetrica* Orchard (Fig. 11k, j) appear: these two taxa dominate the fauna and are common through the remainder of the sampled Brick Pile section. Both species first occur near the top of the lower *primitia* zone at Black Bear Ridge, but are more common in the upper *primitia* zone. Furthermore, both species also occur in Haida Gwaii (Carter and Orchard 2013) and may represent useful Norian indicators. A third species appearing in level BIS30 is *Primatella* sp. nov. 6 (Fig. 10j), which also appears immediately below the *parvus* fauna and ranges into the upper *primitia* zone at Black Bear Ridge. The same first appearance is recorded for *Primatella* sp. nov. 7 (Fig. 10g), which occurs in the next higher sample, level BIS32. In overlying levels

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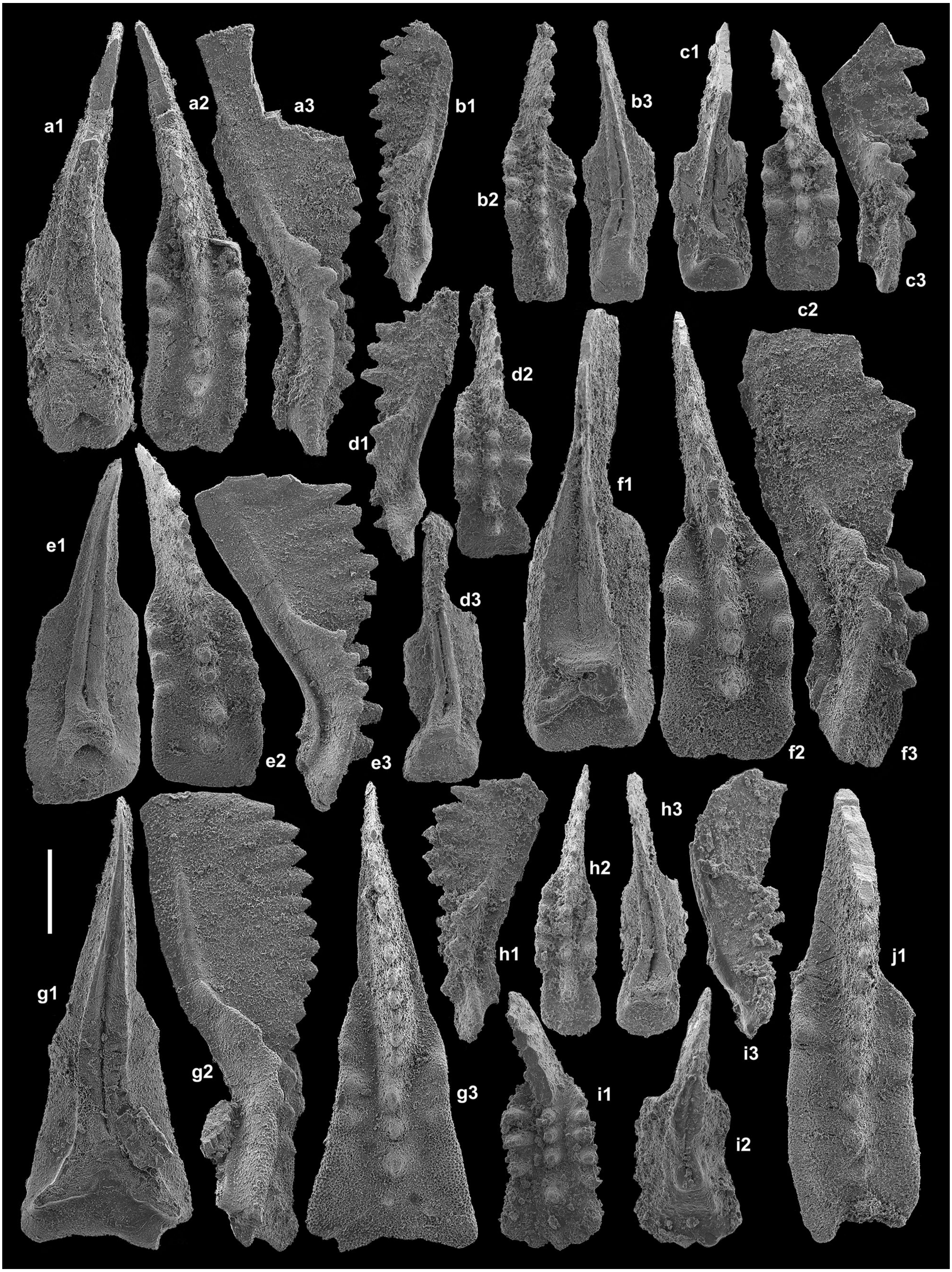

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BIS34 and BIS36, the long ranging *Primatella* sp. nov. 8 (Fig. 11d) occurs and in the higher of these two beds it is accompanied by a single specimen of *Parapetella* sp. nov. 1 (Fig. 11a), the only representative of this genus so far recovered from the Nevadan section: at Black Bear Ridge, this species has been found ranging into the *parvus* zone but no higher. The highest collection recovered from the east section is from level BIS40 and includes both *Primatella orchardi* (Kozur) (Fig. 10h) and uncommon *Metapolygnathus* ex gr. *communisti* Hayashi (Fig. 11h), both of which have a long range through the boundary beds at Black Bear Ridge. In total, the collections from levels BIS30 through BIS40 are regarded as Norian and are assigned to the upper *primitia* zone, which is known to correspond to the Kerri ammonoid Zone in many Canadian localities (Orchard and Tozer 1997). Notable also is the absence of *Norigondolella* in any of the West Union Canyon samples: this genus is occasionally abundant in Canadian Norian sections, although its sporadic appearance there has been related to environmental change. If present, the position of the distinctive boundary *parvus* fauna, is likely to be in the unsampled interval below level BIS30.

Four collections of conodonts were recovered from the relatively short North section (Fig. 6). These contain most of the species identified in the former section, including, in the lowest sample (BIS45), *Acuminitella acuminata*, *Primatella* sp. nov. 7 (Fig. 10g), and *P.* sp. nov. 8 (Fig. 11d); *P. asymmetrica* occurs in the next higher sample (BIS4; Fig. 11k). Associated taxa are consistent with an upper *primitia* zone age, as implied by co-occurring Kerri Zone ammonoids. A single specimen from near the top of the section (level BIS47) is referred to *Kraussodontus*? sp. nov. 1 (Fig. 11b), a species that is not known from Black Bear Ridge.

Integrated stratigraphy at BISP and its significance on a local and global scale

Ammonoid data from this study are fully consistent with that from the literature (Silberling 1959; Kristan-Tollmann and Tollmann 1983), and when examined from a biochronostratigraphic point of view, they can be combined with bivalve and conodont data to provide a much better constrained dating of the Luning Formation. In addition to this refined dating, the ensuing integrated stratigraphy based on ammonoids, bivalves and conodonts provides interesting information useful for the discussion of a set of geological problems. On a local scale, the integration of data from the different fossil groups results in an improved understanding of the BISP Fossil-Lagerstätte. On a global scale, the BISP succession is now considered to be a key

Fig. 11 Conodonts from Luning Formation, Berlin-Ichthyosaur State ▶ Park. **a1-3**, *Parapetella* sp. nov. 1, NMMNH P-67725 (BIS36); **b1-3**, *Kraussodontus*? sp. nov. 1, NMMNH P-67726 (BIS47); **c1-3**, *Acuminitella angusta* Orchard, NMMNH P-67727 (BIS13b); **d1-3**, *Primatella* sp. nov. 8, NMMNH P-67728 (BIS34); **e1**, *Acuminitella acuminata* Orchard, NMMNH P-67729 (BIS30); **f2-3**, *Acuminitella acuminata* Orchard, NMMNH P-67730 (BIS36); **g1-3**, *Acuminitella acuminata* Orchard, NMMNH P-67731 (BIS47); **h1-3**, *Metapolygnathus* ex gr. *communisti* Hayashi, NMMNH P-67732 (BIS40); **i1-3**, *Primatella* sp. nov. 2, NMMNH P-67733 (BIS4); **j1-3**, *Primatella* sp. nov. 2, NMMNH P-67734 (BIS30); **k1-3**, *Primatella asymmetrica* Orchard, NMMNH P-67735 (BIS4); **l1-3**, *Primatella asymmetrica* Orchard, NMMNH P-67736 (BIS34); **m1-3**, *Primatella* sp. nov. 4, NMMNH P-67737 (BIS34). *Bar scale* 200 µm for all specimens

section with regard to the definition of the Carnian/Norian boundary.

Towards a better understanding of the BISP Fossil-Lagerstätte

Although the research conducted at BISP in 2010 focused on the study of the Carnian/Norian boundary interval with regard to the definition of the Norian GSSP, the resultant new data for ammonoids, bivalves, and conodonts improve the understanding of the unusual BISP Fossil-Lagerstätte.

The most impressive paleontological feature of the Luning Formation within BISP consists of the above-mentioned extraordinary record of 37 articulated specimens of *Shonisaurus* found in the shaly limestone member at 10 localities or quarries within the park (Camp 1980). This unusually high number of specimens is especially surprising, when one considers that almost all of them were discovered on the surface of natural outcrops. Camp (1980: 143) described the ichthyosaur record very meticulously. While most of the specimens were collected from several beds within a 9-m thick interval in the lower part of the Macrolobatus Zone, some were discovered on the same bedding plane. Hogler (1992) very carefully studied the specimens from Camp's Quarry 2, now protected by the shelter ("Fossil House"), and recognized nine articulated specimens preserved on a 8 × 20-m bedding plane.

The abundance of ichthyosaur specimens preserved on the same bedding plane combined with occurrences in several different levels makes it quite challenging to achieve a clear understanding of the BISP Fossil-Lagerstätte. Because the BISP *Shonisaurus* specimens include no trace of soft tissue preservation, the site cannot be considered a classic obrutionary Lagerstätte (Seilacher 1970; Seilacher and Westphal 1971; Seilacher et al. 1985). On the other hand, concentration Lagerstätten are usually related to event sedimentation (Seilacher 1970; Seilacher and Westphal 1971), but the limestone beds of the shaly limestone member of the Luning Formation are described

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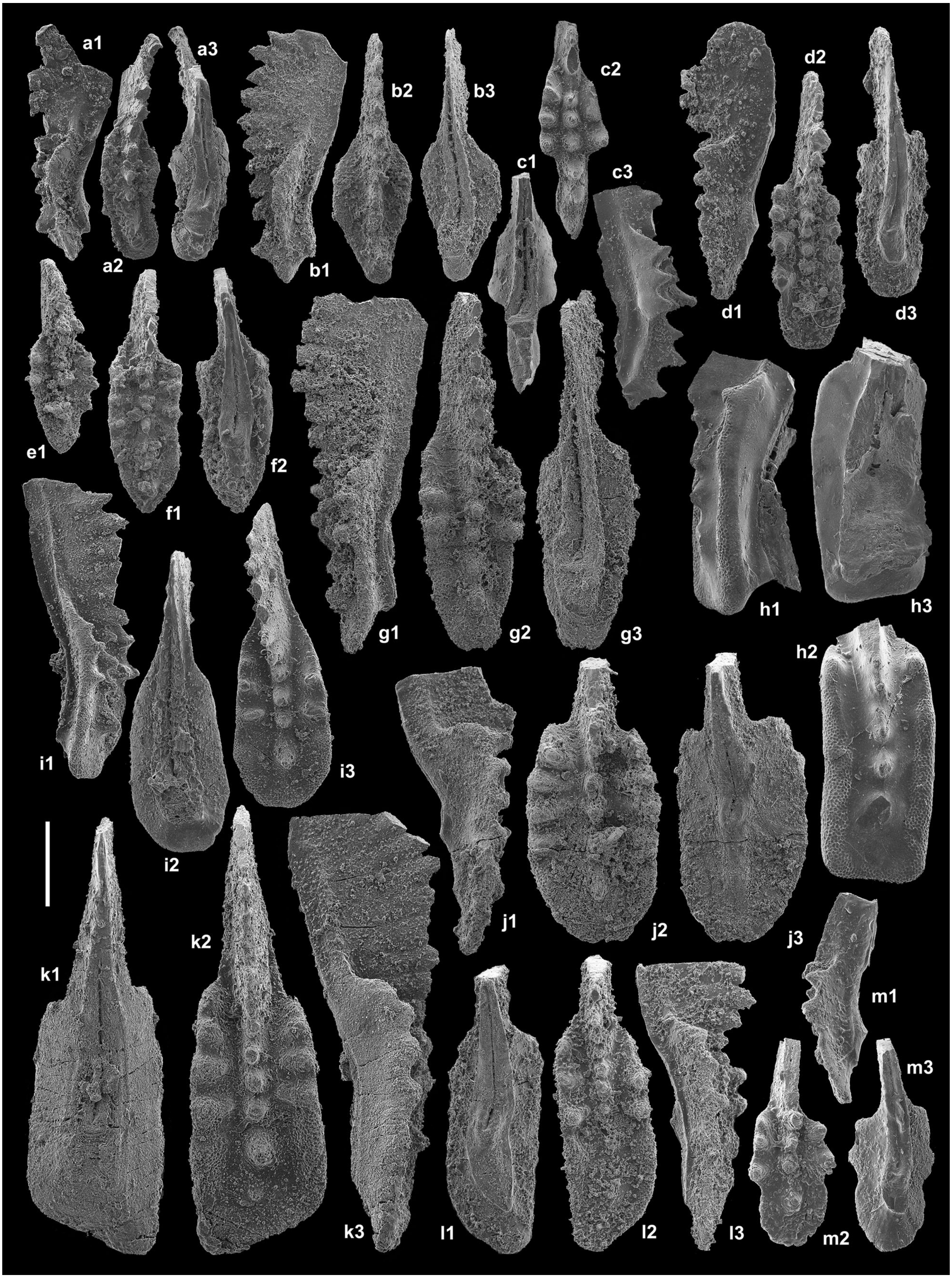

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as fine grained (Camp 1980; Hogler 1992) and do not exhibit features of storm or turbidite deposits. Moreover, BISP ichthyosaurs are articulated, and such preservation is not consistent with event sedimentation.

A number of hypotheses have been proposed to explain the unusual ichthyosaur record of BISP. Camp (1980: 196–197) suggested a marine sedimentary environment similar to a backwater or embayment with quiet water for the shaly limestone member of the Luning Formation. This reconstruction was based on the combination of fine grained sediments with marine invertebrates (brachiopods, clam-like bivalves, cephalopods). Within this environmental framework, he hypothesized that *Shonisaurus* may have foraged in shallow waters during high tide periods, but then on occasion became trapped and was unable to escape during low tides.

Another reconstruction was suggested by Massare and Callaway (1988) who emphasized the occurrence of at least one ichthyosaur embryo among the BISP specimens. Camp (1980: 197) documented the presence of this embryo in the belly region of specimen A, Quarry 5, but did not attach much significance to the occurrence. Massare and Callaway revaluated this specimen and suggested that BISP may have been part of a breeding or birthing area in order to explain the rich *Shonisaurus* record. They also remarked that the specimens were not deposited simultaneously and excluded mass mortality.

Hogler (1992) studied in detail the preservation of the specimens collected by Camp and gave special attention to those protected by the "Fossil House" (Camp's Quarry 2). She correctly emphasized that the sedimentological features of the Luning Formation are not consistent with a shallow-water, tide-dominated environment as proposed by Camp (1980), but instead, are indicative of an off-shore environment. She discussed a combination of attritional and catastrophic mortality that could account for the scattered isolated specimens and the closely-spaced large-sized individuals preserved on the same bedding plane (e.g., "Fossil House"), respectively. However, no particular cause was proffered as most likely responsible.

The most recent explanation for the BISP ichthyosaur record was proposed by McMenamin and Schulte McMenamin (2011), who bizarrely speculated that "the shonisaurs were killed and carried to the site by an enormous Triassic cephalopod, a "kraken," with an estimated length of approximately 30 m, twice that of the modern Colossal Squid *Mesonychoteuthis*". However, such a large-sized cephalopod has never been described, neither for the Triassic, nor for the rest of the evolutionary history of cephalopods, and there is no science that supports this hypothesis.

Significance of the new data

The most common feature of the four models thus far proposed to explain the Ichthyosaur record of BISP is the near total absence of significance given to invertebrate fossils at this locality. Camp (1980) actually referred to the presence of invertebrates in order to prove a marine environment for the Luning Formation, but the weight of this evidence was not all that important because ichthyosaurs, even in the 1970s, were unknown in fresh waters. Moreover, his model of intertidal environment for the shaly limestone member is not consistent with the abundance of ammonoids and the lithology of limestones that led Silberling (1959: 16) to reconstruct a normal marine environment for this member, documented by echinoid spines identified in thin section, with upward trend of reduction of energy, interpreted as probably due to "increasing of depth of water".

Hogler (1992) stated, "there is no evidence of unusual mortality in the rest of the pelagic fauna" (p. 115), but this conclusion probably resulted from the erroneous reconstruction of the stratigraphic position of the ichthyosaur-rich interval (see Ichthyosaur record chapter). Hogler (1992, Fig. 3) attributed the *Shonisaurus*-rich interval ("Fossil House") to the lowest 50 m of the calcareous shale member, which according to Silberling (1959) and our bed-by-bed data, is the nearly barren part of the succession. Conversely, our stratigraphic data fully confirm Camp's attribution of the 9-m thick ichthyosaur-rich interval (including those preserved in the "Fossil House") to the Macrolobatus Zone (1980:143), and to the portion of the succession with the most abundant record of fossil invertebrates. Figure 12, which presents a synthesis of available information, includes Silberling's (1959) data for the Schucherti Zone and lower part of the Macrolobatus Zone as well as our new data from level BIS12 upward.

The ichthyosaur-bearing interval not only contains a peculiar ammonoid fauna, but it also records important faunal changes with regard to bivalves. *Septocardia* and *Myophoria*, which are abundant in the Schucherti Zone and common in the overlying beds without ammonoids, are replaced by *Halobia* in the Macrolobatus Zone. The base of the Macrolobatus Zone is marked by the onset of *Tropites*, which is extremely abundant from the lower part of this zone (see Table 1) through level BIS12. This onset apparently represents a very important environmental change, since *Tropites* is a genus with worldwide distribution that is often found in high diversity assemblages. Furthermore, *Tropites* is very common in the Upper Carnian Dilleri and Welleri zones of the North American scale and the Dilleri and Subbullatus zones of the Tethyan scale. Indeed, *Tropites* serves as the index ammonoid for all these zones, but at BISP this genus does not occur in the

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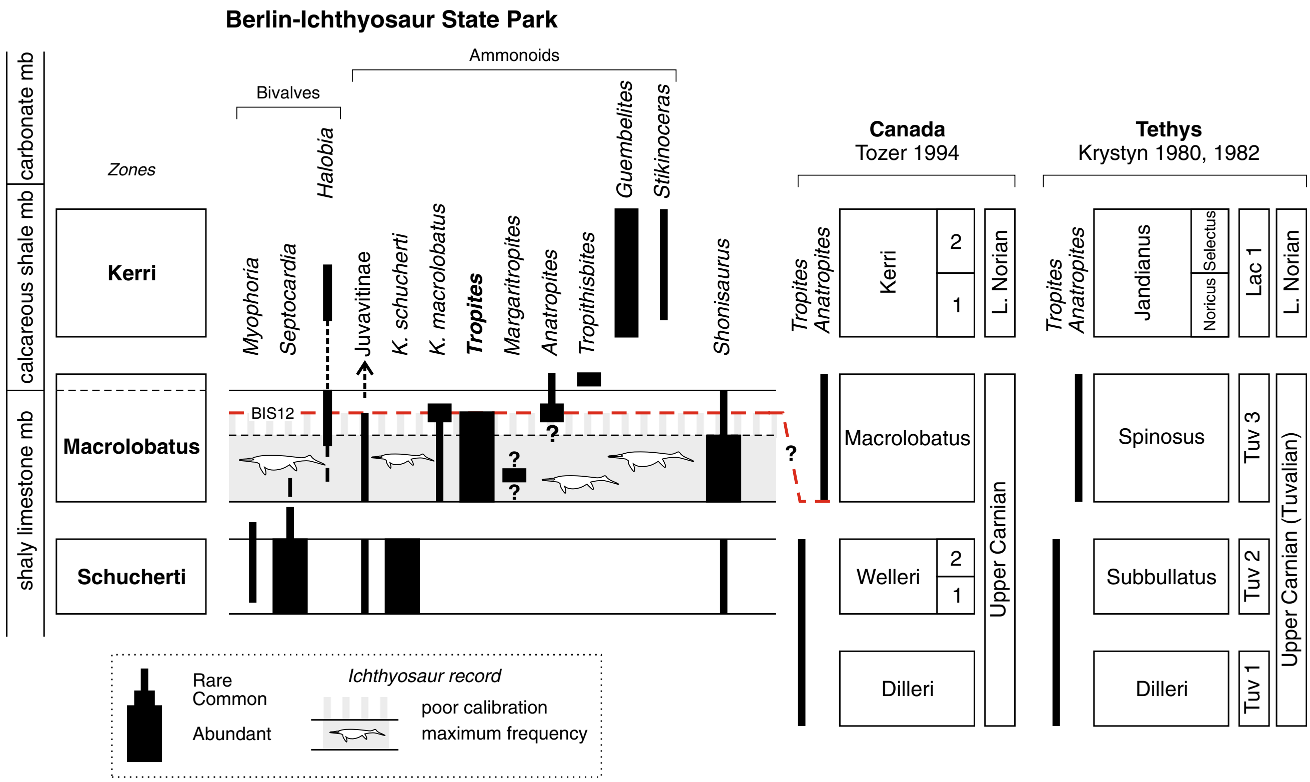

Fig. 12 Summary of faunal changes recorded in the shaly limestone and calcareous shale members of the Luning Formation at BISP. Ammonoid and bivalve data for the Schucherti zone and the lower part of the Macrolobatus zone are from Silberling (1959). Data from level BIS12 and stratigraphically above are fully consistent with that reported from the same interval by Silberling (1959). Distribution of *Shonisaurus* as reported by Camp (1980). Thick dashed line shows the lowermost occurrence of the ammonoid *Anatropites* and its correlation with ammonoid successions in British Columbia (Macrolobatus zone, sensu Tozer 1994) and Tethys. Further sampling is necessary to confirm the absence of *Anatropites* in the lower part of the BISP succession. Thus far, it may be possible that the scope of the Macrolobatus zone in British Columbia as recognized by Tozer (1994) overlaps only the upper part of the zone in its type locality (BISP). See text for more detailed discussion

Schucherti Zone, which is coeval with the Welleri Zone according to Silberling and Tozer (1968), but instead has its first occurrence in the overlying Macrolobatus zone.

Faunal diversity in the *Tropites*-rich interval at BISP is, however, quite low. According to Silberling (1959), only one or, at the most, two species of *Tropites* are documented in the same bed, but they always exhibit very wide intraspecific variability. Such a low diversity faunal composition clearly reflects a stressed environment that is believed to be related to the rich *Shonisaurus* record. The onset of *Halobia* might be related to disaerobic conditions, which are quite consistent with the preservation of fully articulated ichthyosaurs.

The composition of the conodont faunas is also of interest in connection with the environmental scenarios discussed above. At the moment, we do not know the characteristics of the microfauna below the highest strata assigned to the Macrolobatus zone (BIS12-BIS17). As noted above, the conodont faunas from West Union Canyon are dominated by *Primatella* and similarly ornate *Acuminatella* while less ornate or inornate *Kraussodontus*, *Metapolygnathus*, and *Quadralella* are rare. This is also the case in Kerri zone collections from Black Bear Ridge and other sections on Williston Lake, but not in the latest Carnian collections. The faunal turnover illustrated by Orchard (2007) in the Williston Lake sections has no obvious paleoecological cause within the succession that Zonneveld et al. (2010) has interpreted as representing deposition in a deep marine environment. The conodont faunal turnover at Black Bear Ridge, which is regarded as a significant evolutionary event, corresponds to a small negative shift in organic $\delta^{13}C$ signaling a reduction in net primary production (Williford et al. 2007). Elsewhere, a positive excursion in carbonate $\delta^{13}C$ is identified in the CNB interval at Pizzo Mondello (Muttoni et al. 2014), but this approximates level T2, a deeper stratigraphic level compared with the anomaly at Black Bear Ridge. Mazza et al. (2010) has linked the C isotope excursions to changes in the ratio of conodont genera in Sicily, but this is not evident in British Columbia.

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Although their taxonomic nomenclature differs, Mazza et al. (2010) argued that *Epigondolella* (in part *Primatella* of this report) proliferated in seawater with a lower $\delta^{13}C$ relative to *Metapolygnathus, Norigondolella,* and *Paragondolella* (in part *Quadralella* of this report), which they regarded as opportunistic genera. Isotope data are not currently available from West Union Canyon, so we do not know whether the rarity of the inornate conodont group in the Macrolobatus zone can be explained by generally low $\delta^{13}C$ values. At Black Bear Ridge, the inornate group is still present in the Macrolobatus zone, but is far less common in the Kerri zone, where *Norigondolella* is also occasionally abundant. The virtual exclusion of those conodonts in the sampled upper Carnian part of the Brick Pile section, and of *Norigondolella* in the Norian, is anomalous in terms of Canadian data and may be caused by environmentally restricted conditions, as is proposed to explain the low diversity of the subjacent *Tropites* rich interval.

As a preliminary conclusion, a review of available data from BISP suggests a stressed environment during the deposition of the ichthyosaur-bearing interval. Most intriguing is the relationship between *Shonisaurus* and *Tropites*, but this is impossible to resolve with the available data. The abundance of articulated, closely spaced *Shonisaurus* specimens ("Fossil House") is due to a mass mortality that may have been induced by algal blooming. Although we do not have supporting evidence, this hypothesis should at least be considered. Harmful algal blooming (HAB) is regarded as one of the most common natural causes of mortality events of marine vertebrates in modern settings, and a suggestion that it may have also occurred in the past was recently advanced by Pyenson et al. (2014), who described an extraordinary accumulation of fossil marine vertebrates from a Late Miocene locality in Atacama, Chile. Further investigation is necessary at BISP in order to test this hypothesis, whose weak point may be the relatively deep water deposition of ichthyosaurs in contrast with the supratidal stranding reported for cetaceans and fishes, and the monospecific composition of the BISP vertebrate fauna.

The abundance of *Tropites* may be due to trophic relationships with *Shonisaurus.* Either *Shonisaurus* was feeding on schools of *Tropites*, or *Tropites* may have been a scavenger, necrophagously feeding on a low oxygenated sea bottom rich in organic matter, or even on *Shonisaurus* carcasses. The occurrence of *Tropites* might also have been influenced by HAB, but again, this is speculation. Many groups of modern cephalopods (e.g., cuttlefishes, squids, and octopods) are known to accumulate HAB toxins and act as vectors in modern food webs (Robertson et al. 2004; Costa et al. 2005; Bargu et al. 2008; Monteiro and Costa 2011; Lopes et al. 2013), but no data are available on living *Nautilus*. Literature regarding a possible algal blooming influence on fossil cephalopods is also quite meager, consisting only of a report of mass mortality of Jurassic coleoidea (Wilby et al. 2004).

Importance of BISP sections for the definition of the GSSP of the Norian stage

The importance of the BISP sections and the Brick Pile section in particular for the definition of the Carnian/Norian boundary has been enhanced significantly with the discovery of conodonts in the ammonoid and *Halobia*-bearing succession. Thus, the Brick Pile section is now included in a very small group of worldwide stratigraphic sections that demonstrate a Late Carnian to Early Norian marine fossil record consisting of more than one taxonomic group. This small group includes sections at Feuerkogel in the Northern Alps (Austria; Krystyn 1973, 1980; Krystyn and Gallet 2002; Balini et al. 2012), Black Bear Ridge together with a few nearby sections in northeastern British Columbia (Canada; Tozer 1967, 1994; Orchard et al. 2001; McRoberts 2007; Orchard 2007; Zonneveld et al. 2010; McRoberts 2011; Orchard 2013), and Haida Gwaii, B.C. (Carter and Orchard 2013), a few sections in the Primorye region and Yana Okhotskaya River in northeastern Siberia (Bychkov 1995; Zakharov 1997), Silicka Brezova in Slovakia (Krystyn and Gallet 2002), a few sections in Turkey (Kavaalani, Bölücektasi Tepe, and Erenkolu Mezarlik 2: Krystyn et al. 2002), and Pizzo Mondello in Sicily (Italy; Muttoni et al. 2001, 2004; Mazza et al. 2010, 2011, 2012; Balini 2012; Levera 2012; Muttoni et al. 2014).

Given the condensed nature of the sections from Feuerkogel and Turkey, and the Boreal Realm attribution (sensu Tozer 1981b; Dagys 1988) of the northeastern Siberian sections, the Brick Pile section is of great significance as an ideal "bridge" for correlation between the uncondensed mid-paleolatitude sections of British Columbia and those from the western Tethys because of its relatively low latitude paleogeographic position on the western margin of North America. At present, however, the high resolution correlation of the Brick Pile section with the best sections from British Columbia and the western Tethys is influenced by the quite different amount of available data. The two GSSP candidate sections for the definition of the Norian stage, Black Bear Ridge (British Columbia) and Pizzo Mondello, have been under study for more than 10 years and have been sampled several times with special attention directed at the C/N boundary interval. In contrast, the Brick Pile section has been sampled only once (2010), but this sampling is considered adequate to at least place the position of the C/N boundary within the 52-m thick still unsampled interval between samples BIS17

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and BIS43 (Fig. 5). Despite the differing amount of available data, we believe that the correlation of the Brick Pile section with the most significant Carnian/Norian boundary sections is a worthwhile and necessary intermediate step in the complex procedure required for selection of the Norian GSSP.

Correlation with British Columbia sections

Several localities in British Columbia have provided Upper Carnian to Lower Norian fossil records. The most important, at least with regard to combined macro and microfossil records, is in the Peace River Valley (Eastern Cordillera), and others are located in Haida Gwaii (formerly the Queen Charlotte Islands), such as, for example, at Huxley Island (Orchard 1991).

The Peace River area was first surveyed by McLearn in the 1930s and 1940s (McLearn 1960 and literature therein), who discovered several localities and provided the first description of many ammonoids. Many of McLearn's localities, however, consisted of small exposures surrounded by vegetation, or float blocks from debris. Then, in the 1960s, Tozer discovered many new localities, and with the use of improved sampling methods, he reviewed the Upper Carnian and defined all Lower Norian ammonoid zones at Brown Hill (Tozer 1965, 1967). The construction of the WAC Bennett Dam in the 1960s and the subsequent flooding of much of the Peace River Valley in the 1970s inundated many of the historical localities, but at the same time created new, well exposed, and easily accessible outcrops along the shoreline of Williston Lake. These outcrops are perfectly suited for bed-by-bed sampling, which was initiated in the early 1980s. A general review of the stratigraphic setting of the most important Carnian/Norian boundary sections is provided by Zonneveld et al. (2010). Black Bear Ridge and Juvavites Cove are among the best sections for comparison with the BISP Brick Pile.

Black Bear Ridge

Among the sections exposed along the shoreline of Williston Lake, Black Bear Ridge (BBR) is the most interesting for the definition of the GSSP of the Norian stage. At this locality, the C/N boundary interval occurs within the Pardonet Formation and is not affected by a change of facies. Consequently, BBR has been proposed as the GSSP candidate section (Orchard 2007; Zonneveld et al. 2010; McRoberts and Krystyn 2011). The section is rich in conodonts (Orchard 2007, 2013) and halobiids (McRoberts 2007, 2011), and it has also yielded a relatively poor, but important ammonoid fauna (Orchard et al. 2001; Krystyn in Balini et al. 2012; Krystyn pers. comm.) as well as a record of organic $\delta^{13}C$ variation (Williford et al. 2007). Available ammonoid data are shown in Fig. 13, together with halobiid data from McRoberts (2011). Since the taxonomic study of conodonts is still in progress, Fig. 13 does not include the range of conodont taxa, but instead presents only the conodont zonation from Orchard (2013). Ammonoid zonation strictly conform to the definition by Tozer (1994).

Ammonoids are quite rare at BBR and often the samples consist only of single specimens, many of which are sometimes poorly preserved. *Gonionotites* has been collected from several levels and is the most common ammonoid across the C/N boundary in this section. The most important taxon for the identification of the Macrolobatus zone is *Anatropites*, often accompanied by *Tropiceltites*. However, *Tropiceltites* is not a marker of the Macrolobatus zone because it can be also found in the Kerri zone (e.g., Tozer 1994). The same also applies to *Thisbites,* but this genus has never been reported from the Welleri zone (cf. Tozer 1994); hence, the occurrence of *Thisbites* in the lowermost part of the section is used to mark the lower boundary of the Macrolobatus zone.

Discostyrites ireneanus, index ammonid of Kerri subzone 1 has not yet been found at BBR, but the lower boundary of this subzone is placed at the FO of *Pterosirenites*, even though the chronostratigraphic significance of this event is still not yet fully calibrated (see Balini et al. 2012). This position falls near the base of the *parvus* zone. The upper boundary of Kerri subzone 1 is marked by the only occurrence of *Guembelites clavatus* (McLearn), a taxon known only from this subzone in Canada (Tozer 1994). Kerri subzone 2 is recognized on the occurrence of *Stikinoceras kerri* McLearn, a rare species at BBR, whose FO is presently placed about 15 m above the occurrence of *G. clavatus*. Conversely the lower part of the Dawsoni zone is well documented at BBR because *Malayites* is very abundant in three levels, starting about 40 m above the section datum.

Juvavites cove

This section is exposed at Pardonet Hill, on the southern shoreline of Williston Lake opposite Black Bear Ridge. Here, the C/N boundary is affected by a change of facies that occurs at the boundary between the Baldonnel and Pardonet formations. However, the section is of great interest for its abundant conodont faunas, which are presently under study by MJO, and its well-preserved ammonoid faunas of the Kerri and Dawsoni zones. In this respect, Juvavites cove provides the best record of the Kerri zone in the Williston Lake area, and it is not coincidental that Tozer (1994) defined the lower subdivision of the Kerri zone (subzone 1, index *Discostyrites ireneanus* [McLearn]) at this section. Bivalve data are not yet available from this

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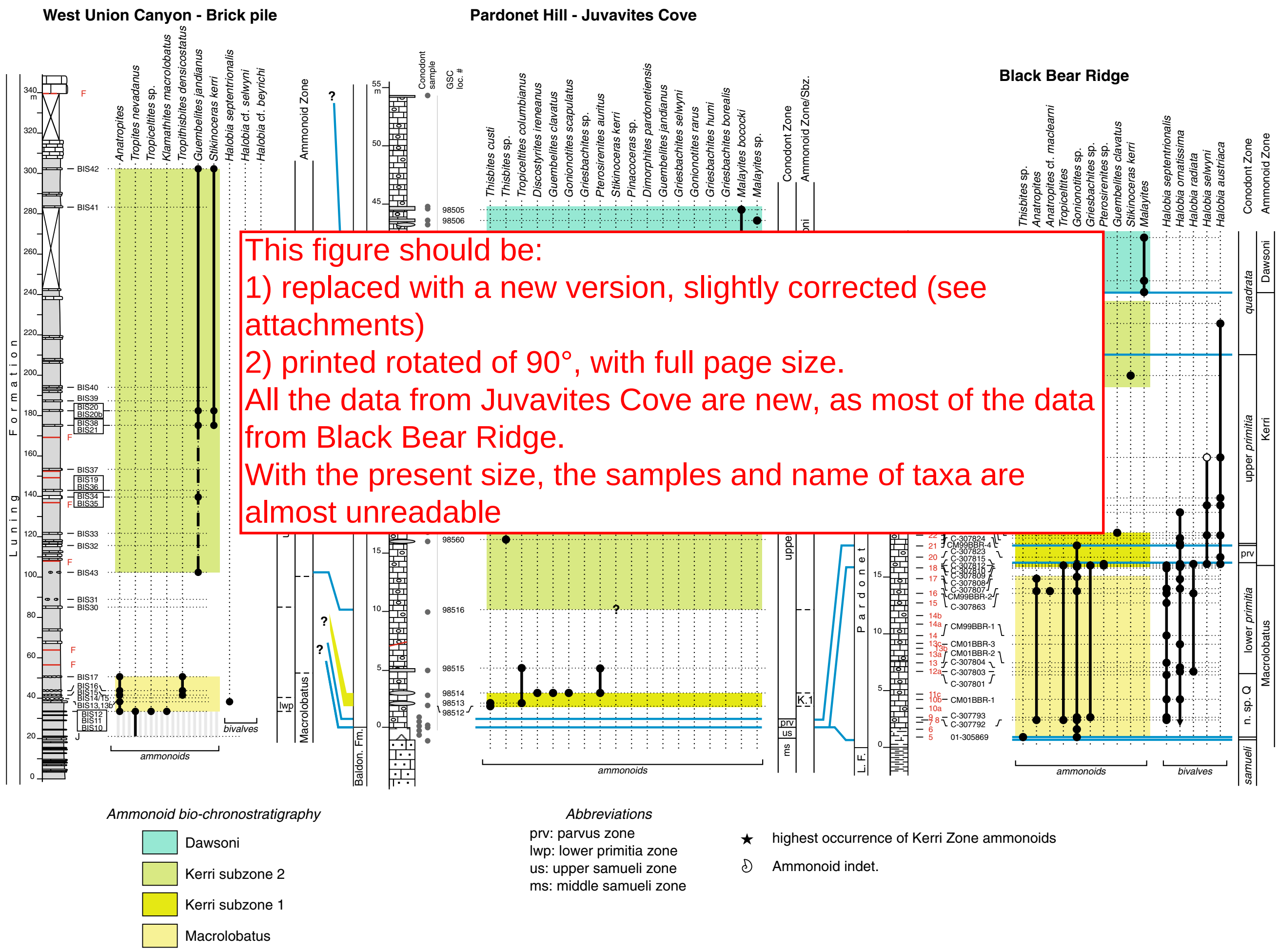

Fig. 13 Correlation of Brick Pile section (BISP) with Juvavites cove and Black Bear Ridge sections (northeastern British Columbia, Canada). The range chart for Brick Pile reports only the most significant ammonoids and bivalves, see Fig. 5 for the distribution of all taxa recognized. The range chart for Juvavites cove is new and results from the re-examination (by MB) of all collections from this locality housed at the Geological Survey of Canada facilities in Vancouver. The range chart for Black Bear Ridge includes also data published by McRoberts (2011) and Krystyn in Balini et al. (2012). The scale for the Black Bear Ridge section is optimized with that of Juvavites cove, in order to show the uppermost Carnian to Lower Norian zonation of the Pardonet Formation. Consequently, the C/N boundary interval, sampled at this locality with centimetric detail (see Orchard 2007; McRoberts 2011), appears very compressed. The Norian part of the Brick Pile section is clearly expanded. Ammonoid zones and subzones are recognized following the definition by Tozer (1994), while conodont zones follow the classification by Orchard (2013). For details on the lithology of the British Columbia sections, see Zonneveld and Orchard (2002) and Zonneveld et al. (2010)

section. The ammonoid faunal composition of some levels (=GSC localities) was provided by Tozer (1994: appendix), but he included only part of the collections from Juvavites cove. All available specimens from this locality, stored at Geological Survey of Canada in Vancouver, have been studied and classified for this work by MB; hence, the ammonoid range chart in Fig. 13 provides the most updated record of ammonoid faunas from this locality.

Ammonoids are quite abundant at Juvavites cove and their preservation is much better than at BBR. They mostly occur in limestone levels in the lowest 5 m of the Pardonet Formation as well as in two intervals about 15–20 m and 30–45 m above its base (Fig. 13). Ammonoid faunas consisting of tens of well-preserved specimens are common, especially in the lower and middle intervals.

Kerri subzone 1 is recognized from the lowermost ammonoid level of the section (GSC locality 98512) up to level 98514. The *parvus* conodont fauna is identified a short distance below the ammonoid levels, and upper *primitia* zone faunas occur in association with the Kerri zone macrofauna. *Discostyrites ireneanus* (McLearn), the index ammonoid of this subzone, occurs only in level 98514, but the occurrence of *Thisbites custi* McLearn in 98512 and 98513, together with *Tropiceltites columbianus* (McLearn), is sufficient evidence to include these levels in subzone 1, because these two species have never been

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reported from the Macrolobatus zone (Tozer 1994). The subzonal attribution of level 98515 is unresolved for the moment, because its ammonoid assemblage consists of *Tropiceltites columbianus* (McLearn) and *Pterosirenites auritus* Tozer, both of which occur in Kerri subzone 1 and 2.

The base of subzone 2 is presently placed at level 98516, based on the occurrence of a poorly preserved specimen tentatively attributed to *Stikinceras kerri* McLearn. Most ammonoids were collected from levels 98900 to 98562, which provided abundant *S. kerri* together with very well preserved *Dimorphites pardonetiansis* McLearn, *Guembelites jandianus* Mojsisovics, *Griesbachites humi* (McLearn), and the very common but long ranging, *Gonionotites rarus* McLearn. Conodonts from these beds comprise a lower *primitia* zone fauna.

Level 98897, which yields *Griesbachites borealis* Tozer, represents the uppermost horizon of subzone 2, and the FO of *Malayites bococki* (McLearn) at GSC 98896 marks the base of the Dawsoni zone. The transition from *primitia* to *quadrata* conodont faunas occurs within this uppermost part of the Kerri zone.

Correlation discussion

The Black Bear Ridge and Juvavites cove sections can be easily correlated on the basis of conodont and ammonoid biostratigraphy. Correlation of the top of the *samueli* zone and the lower boundary of the *parvus* zone document a hiatus at Juvavites cove at the boundary between the Baldonel and the Pardonet formations, where both n. sp. Q and lower *primitia* zones are missing. This unconformity is probably diachronous over short distances because ammonoid faunas of the Macrolobatus zone (corresponding to the missing conodont zones) were first described by Tozer (1965, 1967: Fig. 10) from the Pardonet Formation on the slope of Pardonet Hill, a few hundreds of meters upslope from the present day exposure along the lake shoreline.

The Kerri zone is thicker at Juvavites cove (~38 m) than at BBR (~24–25 m), but it is rather difficult to trace laterally specific macrofossil biohorizons within the Kerri zone because of the large difference in quality and richness of the ammonoid record between the two sections. Since conodont-bearing levels are more frequent in both sections, we consider the conodont zone boundaries closer if not equal to the time lines, especially regarding the *parvus* zone (Fig. 13). The *parvus* zone overlaps the lower part of Kerri subzone 1 at BBR, whereas it underlies Kerri subzone 1 at Juvavites cove. This anomaly is here interpreted as due to facies control (and possibly collection failure) at the lower boundary of the Kerri subzone 1 at Juvavites cove. This boundary coincides with the first ammonoid level of the section, while conodonts, including those of the *parvus* zone, have been found in the underlying beds. Therefore, Kerri subzone 1 at Juvavites cove is probably equivalent to only the upper part of this subzone at BBR.

Correlation of the Williston Lake sections with the Brick Pile section (Fig. 13) is similarly affected by the dishomogeneous quality of their records, but despite these limitations, it is possible to make the following observations:

1. The ammonoid, bivalve and conodont record of the Brick Pile section is fully consistent with that of the two Williston Lake sections, as discussed in the preceding Ammonoid, Bivalve, and Conodont record chapters.
2. For the most part, the BISP sections exhibit only a few slight differences with respect to the Williston Lake sections in terms of ammonoid faunal composition, which suggest a certain amount of Tethyan similarity. These include: (1) the abundance of Tropitidae in the uppermost Carnian; (2) the absence of *Pterosirenites* in the Norian; (3) the abundance of *Guembelites clavatus* [known only from the 2nd subzone of the Jandianus zone in the Tethyan Realm (Krystyn 1980, 1982), and reported only from Kerri subzone 1 in Canada]; (4) the occurrence of *G. philostrati*, thus far not yet found in Canada; and (5) the great abundance of *Guembelites* (often representing up to 80 % of some Tethyan assemblages: Krystyn 1982: 10; see the Ammonoid record chapter) combined with the rare occurrence of *Gonionotites*. The occurrence of a *Halobia* taxon similar to *H. beyrichi* is also herein considered as possible evidence of Tethyan influence since *H. beyrichi* is known to occur in terranes from Nevada to Alaska, but has never been reported from the Williston Lake area (McRoberts 2011).
3. The discovery of conodont faunas at the Brick Pile equivalent to those of British is potentially of great significance for the solution of the correlation of the British Columbia conodont scale (Orchard et al. 2001; Orchard 2007, 2013), and in particular the *parvus* zone, with that of the Tethys (Mazza et al. 2010, 2011, 2012), because Brick Pile shows a certain degree of Tethyan affinity. Additional sampling across the C/N boundary at the Brick Pile section is necessary in order to determine the presence of this zone, but the underlying and overlying conodont faunas of this short bio-chronostratigraphic unit have been already identified.
4. Available data suggest that the *parvus* zone and Kerri subzone 1 correlate with at least part of the ~52-m thick unsampled interval in the lower part of the calcareous shale member of the Brick Pile section.

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5. The Kerri zone identified in the BISP sections correlates with subzone 2 of the Kerri zone in its type area, northeastern British Columbia. This correlation is based on the common occurrence of *Guembelites jandianus* and *Stikinoceras kerri*, but *Gonionotites rarus* (McLearn), index ammonoid of this subzone, has not yet been found in the Brick Pile section.
6. Integrated chronostratigraphy suggests that the lithologic change from the shale-limestone alternation of the shaly limestone member to the shale-dominated calcareous shale member of the Luning Formation (BISP, Brick Pile) resulted from a sudden increase in sedimentation rate. Data in support of this conclusion come from the comparison of the thickness of the ammonoid chronozones. The restored record of the Macrolobatus zone at the Brick Pile section is ~30 m, the same order of magnitude as the 15 m record at BBR, while the record of the Kerri zone at the Brick Pile section is 200 m, nearly one order of magnitude thicker than the ~26 m at Juvavites cove.
7. For further analysis, we suggest that the time duration of subzone 1 of the Kerri zone, may have been significantly shorter than that of subzone 2. This hypothesis would require further study, but the documented record of subzone 1 at Juvavites cove is about 1 meter, whereas subzone 2 is almost 24 m. This difference is not an artifact due to the hiatus at the contact between the Baldonel and Pardonet formations because this gap is documented at the base of the *parvus* zone. Most probably the lower part of Kerri subzone 1 is not documented by ammonoids at Juvavites cove, but the missing part is probably only 1–1.5 m, based on the conodont correlation with BBR. However, even in this case the corrected Kerri subzone 1 would only be about 2.5-m thick, with respect to the 24 m of Kerri subzone 2.
8. The record at the Brick Pile does not detract from the possibly short duration of Kerri subzone 1. The observed record of the Kerri Zone at the Brick Pile (=to Kerri subzone 2 of British Columbia) is about 200 m, or ~four times thicker than the 52-m thick interval not yet sampled between levels BIS17 and BIS43, which would be in part the time-equivalent of subzone 1.

Correlation with Pizzo Mondello and other sections

At present, the Brick Pile section cannot be directly correlated with sections in the Primorye region and the Yana Okhotskaya River area because of significant paleobiogeographic differences that have resulted in vastly dissimilar ammonoid faunas. In these regions, ammonoid assemblages are dominated by several genera of Sirenitinae (Bychkov 1995; Zakharov 1997) accompanied by more rare *Pinacoceras*, Arcestidae, and Phylloceratina.

Correlation of the Brick Pile section with Pizzo Mondello (Fig. 14), the second GSSP candidate section for the base of the Norian, must be examined and it is useful to emphasize some problems whose solutions are necessary in order to define the calibration of the North American and Tethyan chronostratigraphic scales.

The Pizzo Mondello succession consists of well-bedded, light-colored micritic and cherty limestones of the Scillato Formation, which were deposited in a fully pelagic setting. Although the succession is very rich in conodonts (Mazza et al. 2010, 2011, 2012) and *Halobia* (Levera 2012), as well as radiolarian faunas at certain levels (Nicora et al. 2007; Balini et al. 2010a, b), its ammonoid record is not particularly abundant (Balini et al. 2012). Figure 14 provides a summary of ammonoid and *Halobia* distribution as well as an updated chronostratigraphic subdivision of the section based on ammonoid occurrences (Balini et al. 2012), which directly tie the succession to Tethyan ammonoid chronozones and *Halobia* species (Levera 2012), whose ranges are now rather well calibrated with the ammonoid chronostratigraphy. This correlation required tens of years of research, which was carried out by Krystyn (e.g., 1973, 1974, 1980, 1982; Krystyn et al. 2002; Krystyn in Balini et al. 2012) in the Northern Alps, Turkey, Himalaya, and Timor.

Even though ammonoids are quite rare in the succession, many taxa such as *Discotropites plinii* (Mojsisovics), *Microtropites*, *Anatropites*, *Dimorphites noricus* Balini, Krystyn, Levera & Tripodo, and *Dimorphites selectus* Mojsisovics are chronostratigraphically important. These taxa led to the recognition (Balini et al. 2012) of the *Discotropites plinii* and *Gonionotites italicus* subzones of the uppermost Carnian Spinosus zone and the *Dimorphites noricus* and *D. selectus* subzones of the lowermost Norian Jandianus zone.

Subbullatus zone

The lowermost part of the Pizzo Mondello section, which is characterized by the occurrence of *Halobia carnica* Gruber and *Hyattites,* is herein tentatively attributed to the Subbullatus zone (=Welleri zone of the North American scale). *Hyattites* provides no support to this assignment, however, because its stratigraphic position cannot be calibrated (see Balini et al. 2012 for discussion); hence, attribution to the Subbullatus zone relies only on the presence of *H. carnica*. The calibration of this rare species, on the other hand, is not considered to be all that precise because *H. carnica* is known only from the Tuvalian 2 of the Raschberg section (northern Alps; Gruber 1976),which Krystyn (1973, 1982)

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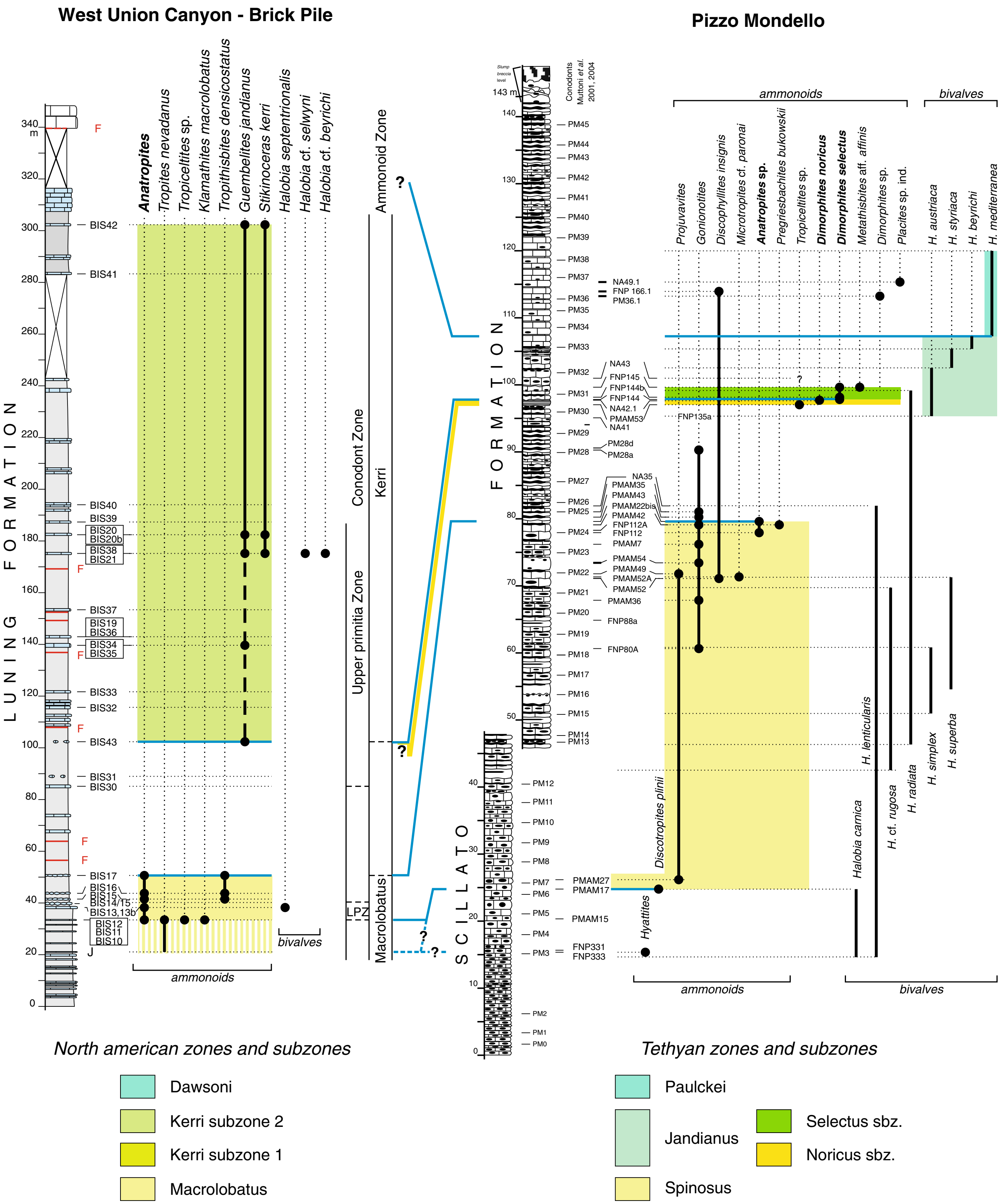

Fig. 14 Correlation of Brick Pile section (BISP) with Pizzo Mondello section (western Sicily, Italy). The two sections show a completely reversed trend in sedimentary evolution: for the Late Carnian to Early Norian interval the sedimentation rate was notably increasing at Brick Pile while at Pizzo Mondello this rate was notably decreasing. The range chart of Pizzo Mondello is based on data from Balini et al. (2012) and Levera (2012); the integrated chronostratigraphy is updated from Balini et al. (2012). Thick correlation lines are not time lines s.s. because the fossil-bearing intervals are between intervals without fossils. *Dashed correlation lines* show two alternative options for the correlation of the Welleri/Macrolobatus and the Subbullatus/Spinosus boundaries (see text for discussion)

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attributed to the Subbullatus zone on the basis of ammonoid faunal analysis.

Correlation of this portion of the Pizzo Mondello section with the Brick Pile section is thus far uncertain and will remain so until further fieldwork determines the FO of *Anatropites* and the position of *Margaritroptes* at the Brick Pile. Basically, the problem is not with the Pizzo Mondello section, but instead, it is related to the correlation of this part of the Tethyan scale with the North American scale. If the FO of *Anatropites* is identified at the base of the Macrolobatus zone, then the Subbullatus zone of the Tethys (and Pizzo Mondello) can be correlated with the Schucherti zone at BISP (not exposed at Brick Pile section). If instead the FO of *Anatropites* is confirmed at level BIS10-BIS12 of the Brick Pile section above the bed(s) with *Margaritropites*, it will then be possible to correlate the Subbullatus zone of the Tethys and Pizzo Mondello with the lower part of Macrolobatus zone of the North American scale.

Spinosus zone

The Spinosus zone is about 55 m thick at Pizzo Mondello and can be directly correlated with at least the upper part of the Macrolobatus zone in the Brick Pile section (levels BIS10,11,12 to BIS17). This correlation is based on the occurrence of *Anatropites*, which has been collected only from the upper part of the Spinosus zone at Pizzo Mondello (levels FNP112 and PMAM22bis). However, in the Tethys Realm *Anatropites* ranges from the *D. plinii* subzone to the top of the Spinosus zone (cf. Krystyn 1980, 1982). No data are available on the occurrence of *Anatropites* within the as yet unsampled lower part of the Macrolobatus zone at the Brick Pile (levels J to BIS10, see above), thus correlation of this part with Pizzo Mondello is still unresolved.

Jandianus zone

The Jandianus zone, which is documented at Pizzo Mondello by the occurrence of *Dimorphites noricus* and *D. selectus* from levels NA42.1 to FNP145, accounts for a thickness of about 3 m. This chronozone's scope can be extended both downward and upward based on of the distribution of *Halobia austriaca* Mojsisovics, *H. styriaca* Mojsisovics, and *H. beyrichi* Mojsisovics provided by Levera (2012), because the scope of these species is precisely calibrated with the ammonoid scale (cf. Krystyn et al. 2002; Balini et al. 2012: Fig. 10). Thus, the resulting thickness of the Jandianus zone is about 12.5 m, extending from the FO of *H. austriaca* (FNP135a) to the LO of *H. beyrichi* (FNP154b). The upper part of this interval, from the FO of *D. selectus* (FNP 144) to the LO of *H. beyrichi* (FNP154b), can be correlated with the Kerri zone at the Brick Pile section, based on the occurrence of *Guembelites*. This taxon has not been found at Pizzo Mondello, but *Guembelites* is known to occur only in the *D. selectus* subzone in other important localities in the Tethys Realm, such as Feuerkogel, type locality of the subzone (section F1 W: Krystyn 1980; section F5: Krystyn 1980; Balini et al. 2012), and Jomsom (Krystyn 1982).

At the present time, the lower subzone of the Jandianus zone, index taxon *Dimorphites noricus*, cannot be correlated with the Brick Pile section. *D. noricus* has not yet been reported from North America and *Halobia austriaca* has not yet been found in the Brick Pile section. Thus, correlation of the *D. noricus* subzone with Kerri subzone 1 is as problematical as is that of the base of the Macrolobatus zone with the base of the Spinosus zones, which well demonstrates the problem of calibration of the Tethyan scale with the North American scale.

Paulckei zone

The upper part of the Pizzo Mondello section, ranging from levels to PM34.1 to NA51.1 (Levera 2012), is attributed to the Paulckei zone based on the occurrence of *H. mediterranea*, whose chronostratigraphic position is very well constrained (Krystyn et al. 2002). Unfortunately, the few ammonoids from this interval are not age diagnostic: *Discophyllites* and *Placites* are long-ranging taxa, still consistent with the Paulckei zone, while the occurrence of *Dimorphites* sp. is new for this zone. On the whole, the Paulckei zone of Pizzo Mondello is younger than the calcareous shale member of the Luning Formation at the Brick Pile section.

Conclusions

Integrated stratigraphic research conducted on the Upper Carnian/Lower Norian Luning Formation at BISP has provided a wealth of new data that are of interest for several paleontologic and stratigraphic problems on a local as well as a global scale. These results are summarized as follows:

1. Field work in the Luning Formation of West Union Canyon identified two sections with significant fossil records that were measured and sampled employing a careful bed-by-bed approach. The Brick Pile section, encompassing the Carnian/Norian boundary, is the most complete while the North section is limited to just the Lower Norian.
2. Ammonoids, bivalves and, for the first time, conodonts have been found in the studied sections.
3. Ammonoid and bivalve data indicate that the uppermost Carnian Macrolobatus zone ranges from the

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shaly limestone member up into the lowermost calcareous shale member, while the lowermost Norian Kerri zone occurs higher in the calcareous shale member. Conodont data are fairly consistent with the ammonoid and bivalve record, but they do not yet permit high-resolution dating. Conodont faunas found in the Macrolobatus zone are referred to the lower *primitia* zone, while those from the Kerri zone document the upper *primitia* zone sensu Orchard (2013).

4. The stratigraphic position of the ichthyosaur-bearing interval at BISP is revised. The ichthyosaur interval occurs within the shaly limestone member of the Luning Formation in the Upper Carnian Macrolobatus zone. This interval is characterized by rich *Tropites*-dominated ammonoid assemblages and a bivalve faunal turnover from *Septocardia*-dominated to *Halobia*-dominated assemblages.
5. Models suggested by various workers to explain the accumulation of large-sized, closely spaced ichthyosaurs such as those preserved in the "Fossil House" are discussed. Most of these have weak points or are not consistent with available geologic and paleontologic data, which document a relatively deep, stressed, and low oxygenated/dysoxic environment during the deposition of the ichthyosaur-bearing interval. As pure speculation, we suggest that the accumulation of ichthyosaurs may have been influenced by harmful algal blooming (HAB).
6. Based on our new data, the stratigraphic position and range of the Macrolobatus zone is confirmed as reported by Silberling (1959), while the range of the Kerri zone is extended downwards significantly. Its range is now about 200 m, which is more than twice that reported by Silberling (1959).
7. The Upper Carnian-Lower Norian record of the BISP Brick Pile section is compared with that of the most important sections in the world for the C/N boundary definition: Black Bear Ridge (GSSP candidate) and Juvavites cove in northeastern British Columbia (Canada), and Pizzo Mondello (GSSP candidate) in southern Italy. All available ammonoid collections from Juvavites cove have been reviewed to ensure the most up-to-date and accurate correlation. Moreover, an updated ammonoid-bivalve integrated chronostratigraphy of Pizzo Mondello section is provided.
8. The BISP Brick Pile section is easily correlated with Black Bear Ridge and Juvavites cove on the basis of the three taxonomic groups discussed in this work. Ammonoid faunal composition suggests a Tethyan influence on the BISP faunas because of the abundance of Tropitidae in the Carnian, the lack of *Pterosirenites* in the Norian, the abundance of *Guembelites*, the occurrence of the Tethyan species *G. philostrati*, the stratigraphic position of *G. clavatus* and the rare occurrence of *Gonionotites*. The occurrence of an undescribed species of *Halobia* similar to *H. beyrichi* may also provide additional evidence of Tethyan influence.
9. Correlation of the Brick Pile section with Juvavites cove and Black Bear Ridge shows that the thickness of the Macrolobatus zone is of the same order of magnitude as the British Columbia sections, while the scope of the Kerri zone is at least one order of magnitude thicker. This suggests that the lithologic change from the shaly limestone member to the shale-dominated calcareous shale member of the Luning Formation at the Brick Pile (BISP) resulted from a huge increase in sedimentation rates. Comparison of the records of subzone 1 and 2 of the Kerri zone suggest a significantly shorter time-duration for subzone 1 with respect to subzone 2.
10. Correlation of the BISP Brick Pile section with Pizzo Mondello demonstrates the difficulties encountered when attempting to calibrate the Tethyan and North American chronostratigraphic scales. Significant problems include correlation of the boundary between the Welleri/Macrolobatus zones with that of the Subbullatus/Spinosus zones and correlation of the boundary between the Macrolobatus/Kerri zones with the Spinosus/Jandianus zones. The solution to the first problem requires the location of the FO of *Anatropites* by bed-by-bed sampling of the North American section(s), a bioevent that has already been determined for several Tethyan sections. In this respect, the Brick Pile section appears to be the only key section in North America. Resolution of the second significant problem is more difficult because the exact location of the Macrolobatus/Kerri boundary has yet to be documented within the unsampled 52-m thick interval between the last sample providing Carnian fossils and the first level yielding Norian fossils.

Most of the unresolved issues resulting from the investigation initiated in 2010, are specifically addressed in a new field plan scheduled for summer 2015, when the Brick Pile section will be trenched from the base of the Macrolobatus zone to the middle part of the Kerri zone.

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