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High-resolution stratigraphy of buchiid bivalves and ammonites from the Jurassic–Cretaceous boundary beds in the Paskenta area (California)

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ABSTRACT

A bed-by-bed biostratigraphical study of two key Californian outcrop sections of the Jurassic–Cretaceous transition interval is presented. The studied succession is characterized by the occurrence of abundant buchiid bivalves and a discontinuous ammonite record. Several Lower Cretaceous ammonite zones were introduced in the literature, but the precise stratigraphic position of key ammonite records remains unclear. Consequently, the buchiid zonation established in the 1970s is still considered the prime biostratigraphic tool, and ammonites have supplementary value. The buchiid zonation is revised herein, and the nomenclature and boundaries are updated. The *Buchia sublaevis* zone (upper Valanginian (?) to lower Hauterivian) is for the first time recognised in California. Two further biostratigraphic units, i.e. '*Buchia inflata* beds' (between *B. uncitoides* and *B. pacifica* zones) at McCarty Creek and '*Buchia* aff. *volgensis*-*B. unschensis* beds' (between *B. piochii* and *B. okensis* zones) at Grindstone Creek, are proposed. The positions of zonal boundaries are determined more precisely than previously, and are based on the first or mass occurrence of index species. As a result, the Panboreal correlation of Tithonian to Hauterivian buchiid zones is improved. Ammonite biohorizons are used as an additional correlative tool, and the following succession is proposed for the Upper Tithonian to earliest Hauterivian interval of the study area: *Fierrites dilleri*, *Paradontoceras storssi*, *Proniceras maupinense*, *Neocosmoceras euchrense*, *Paskentites paskentaensis*, *Kilianella crassiplicata*, *Neotollia mutabilis*, *Sarasinella hyatti*, *Thurmanniceras stippi*, *T. jenkinsi* and *Jeannoticeras jeannoti*. A new genus, *Howarthiceras* n. gen. is established for "*Groebericeras*" *baylei* Imlay and Jones.

1. Introduction

Among the different world-wide regions showing good stratigraphic succession of the Jurassic – Cretaceous boundary beds, the Eastern Pacific and, especially California, attract much attention, as they are characterized by mixed faunas permitting Boreal-Tethyan correlation based on concurrent ranges of ammonites (mainly Tethyan groups, with subordinate Boreal taxa in the Valanginian and Hauterivian), belemnites (Boreal cylindroteuthids) and bivalves (Boreal buchiids). The strong faunal provincialism during the latest Jurassic and earliest Cretaceous, including the absence of an ecotone characterized by the co-occurrence of Boreal and Tethyan ammonites, has lead to long-lasting discussions concerning the Boreal-Tethyan correlation and the position of the Volgian Stage (i.e. Zeiss, 1983, 1986; Jeletzky, 1984; Hoedemaeker, 1987; Sey and Kalacheva, 2001; Wimbledon, 2008; Zakharov, 2011; Riccardi, 2015). The special characteristics of the Californian molluscan faunas has made them most important in papers discussing the correlation of the Jurassic-Cretaceous boundary beds (Zeiss, 1983, 1986; Jeletzky, 1984; Hoedemaeker, 1987, 1991; Sei and Kalacheva, 1997; Bragin et al., 2013; Shurygin and Dzyuba, 2015, among the others). However, it should be noted that older data on molluscan distribution in California, used in all these contributions, remains unclear as discussed specimens were collected mainly for the purpose of geological mapping within numerous sections (see Jones et al., 1969; Imlay and Jones, 1970 for details), and only tentative ranges including hundreds of metres (originally feet) above or below the appearance of selected buchiid taxa were available (Imlay, 1960; Jones et al., 1969; Imlay

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and Jones, 1970). Sandy and Campbell (1994, p. 1243) stated that "older faunal investigations of these strata were imprecise with regard to exact fossil localities and to the relationships among rocks and fossils." Here we provide the first detailed data about buchiid and ammonite distribution within two key sections, Grindstone Creek and McCarty Creek (Figs. 1–3, see also Supplement 1), accompanied by semiquantative relative abundance of *Buchia*. The studied sections were previously investigated by micropaleontologists and foraminifer (Dailey, 1973), radiolarian (Pessagno, 1977; Pessagno et al., 2009) and calcareous nannofossil assemblages were studied in detail (Bralower, 1990). Furthermore, tuff horizons from the Grindstone Creek section provided radiometric ages, based on U/Pb dating of zircons (Bralower et al., 1990). Updated information about the buchiid distribution, accompanied by new ammonite records permits us to modify the buchiid zonation applied in California as well as improve the Circum-Pacific and Panboreal correlation based on bivalve and ammonite distributions. Detrital zircon studies (including analyses of samples from Grindstone Creek section) focused on the age of the Great Valley Group. However, these papers lack precise information concerning the position of the samples within the sections. Conclusions regarding the mainly Early Cretaceous ages of the basal beds of the Great Valley Group as well as suggestions concerning the re-deposited nature of the Tithonian *Buchia* occurrences mentioned in these articles (Surpless et al., 2006; Dumitru et al., 2015; Orme and Surpless, 2019) remain insufficiently proven (Rogov and Zakharov, 2019).

2. Geological setting

The Upper Jurassic – earliest Cretaceous succession of northern California, is represented by the Great Valley Group. This has a total thickness of up to 8500 m, and is composed of turbiditic mudstones, siltstone and sandstones with occasional conglomerate interbeds which were deposited in a submarine fan environment (Suchecki, 1984) and are characterized by significant changes of thickness of units from section to section. Studied fossils were collected mainly from carbonate bodies, which occurred as concretions or lenses throughout the sections, but badly preserved specimens were also recovered from sandstones and black shales. These carbonates, previously suggested to be of shallow-water origin (Anderson, 1945; Bailey et al., 1964), are now considered to be related to cold seeps (e.g. Campbell et al., 1993). Such interpretation of Upper Jurassic–Lower Cretaceous carbonate bodies of the studied area is supported by stable isotope signatures, indicating methane as one of the important sources of carbon (Campbell et al., 1993), seep biomarkers (Birgel et al., 2006) and presence of specific seep taxa in the fossil assemblages, which include bivalves (Campbell et al., 1993; Kiel, 2013; Jenkins et al., 2013; Kaim et al., 2014), gastropods (Campbell et al., 2008; Kaim et al., 2014) and brachiopods (Sandy and Campbell, 1994; Kiel et al., 2014). In addition to siliciclastic and carbonate rocks, volcanic influence is represented by bentonite and tuff horizons, usually only a few centimeters thick, while up to 50 cm thick beds are relatively uncommon (Bralower et al., 1990).

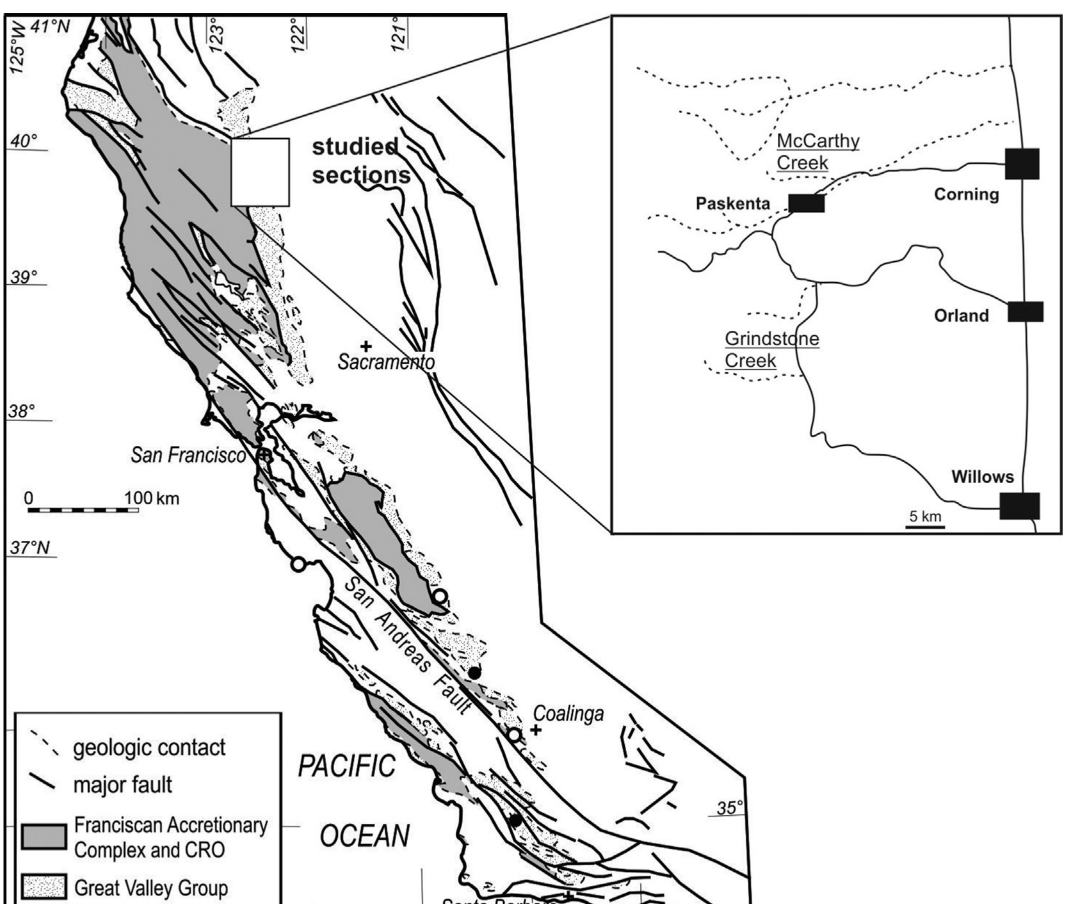


Fig. 1. Map showing location of the studied sections.

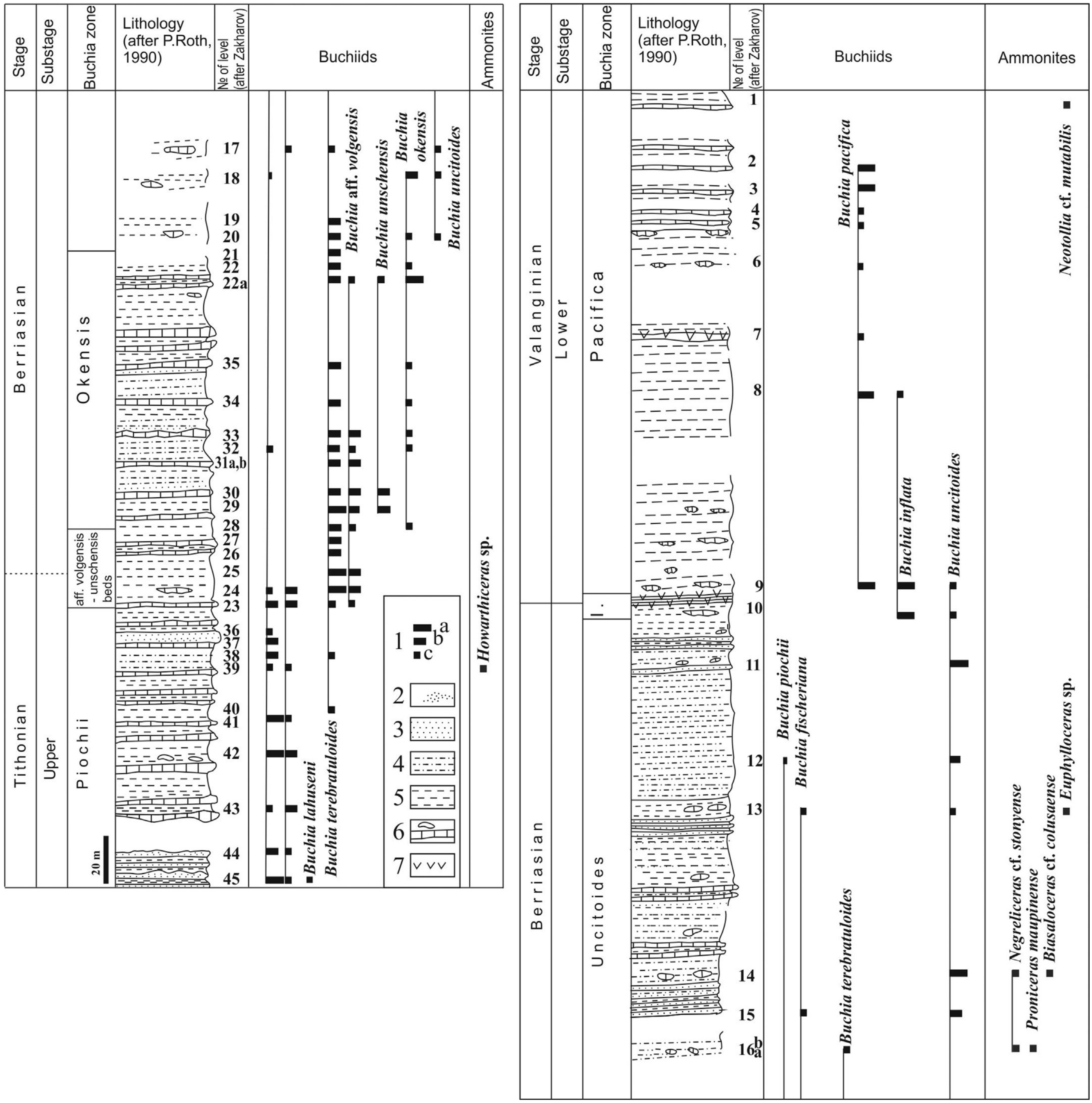


Fig. 2. Log of the Grindstone Creek section and distribution of ammonites and *Buchia* bivalves. Figure captions: 1 – relative abundance of fossils (a - abundant; b - common; c - rare); 2 – conglomerate; 3 – sandstones; 4 – siltstones; 5 – mudstones; 6 – limestone beds and carbonate bodies; 7 – tuff beds.

3. Material

Ammonites and buchias studied herein were collected in 1990 in two measured sections by V.A. Zakharov during a joint field trip with P. Roth (who also made field description of studied sections) (Fig. 1).

Detailed logs with position of all recorded ammonites and *Buchia* bivalves are presented in Figure 2 (Grindstone Creek) and Figure 3 (McCarty Creek); for more detailed bed-by-bed description of the studied sections see Supplement. All figured specimens came from the carbonate seep bodies, because their preservation in these rocks is especially good. Presence of fine sculptural elements in ammonites (such as lappets in microconchs or spines in some neocomitids), prevalence of well-preserved articulate bivalve shells as well as absence of any encrusters suggesting in situ record of bivalves and sub-authochtonous record of ammonites, inhabited near-seep area. Studied fossil assemblages are strongly resembles coeval high-latitude assemblages described from the Jurassic–Cretaceous transitional beds of Spitsbergen (Hryniewicz et al., 2015), dominated by *Buchia* bivalves.

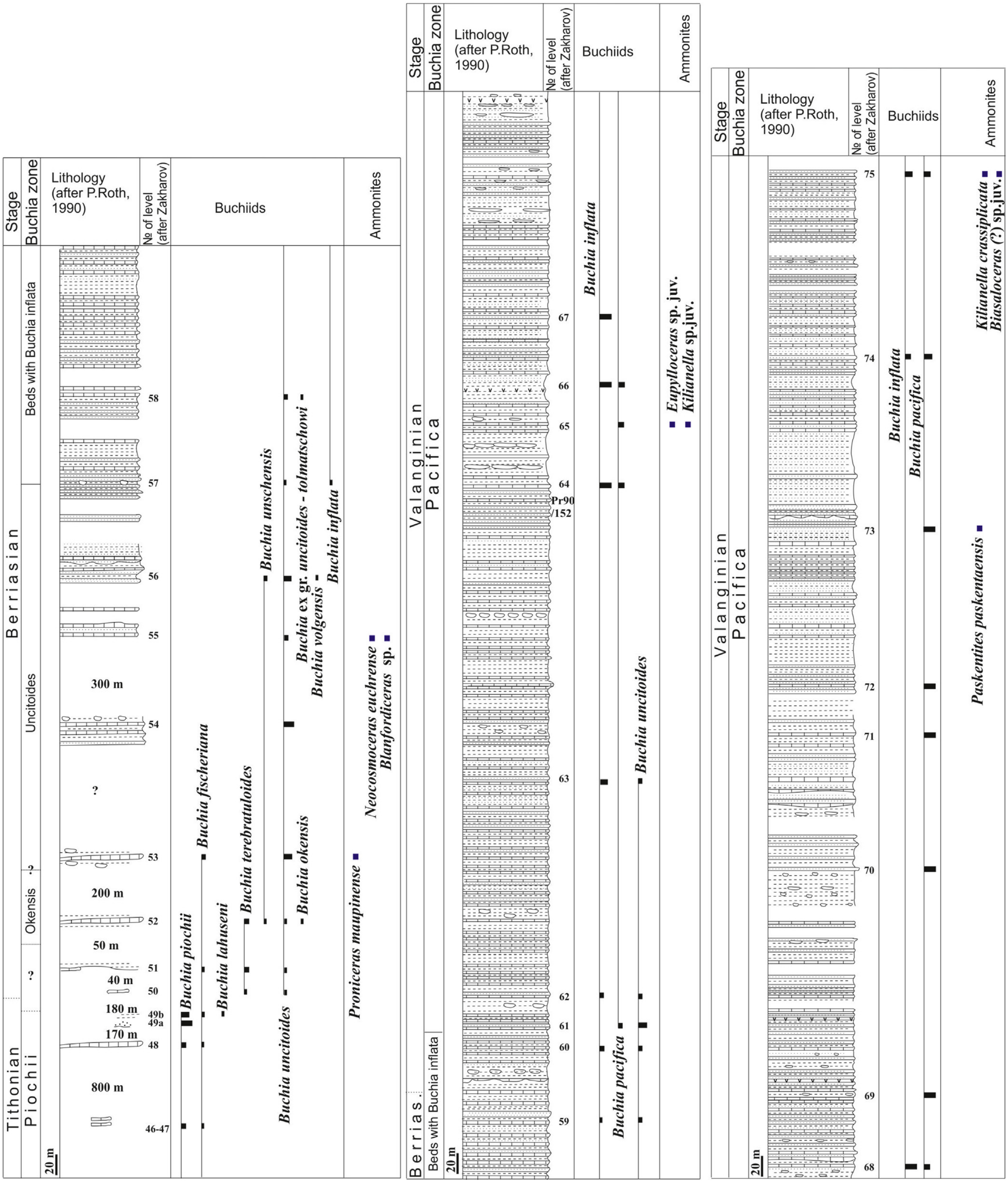


Fig. 3. Log of the McCarty Creek section and distribution of ammonites and *Buchia* bivalves. For figure captions see Fig. 2.

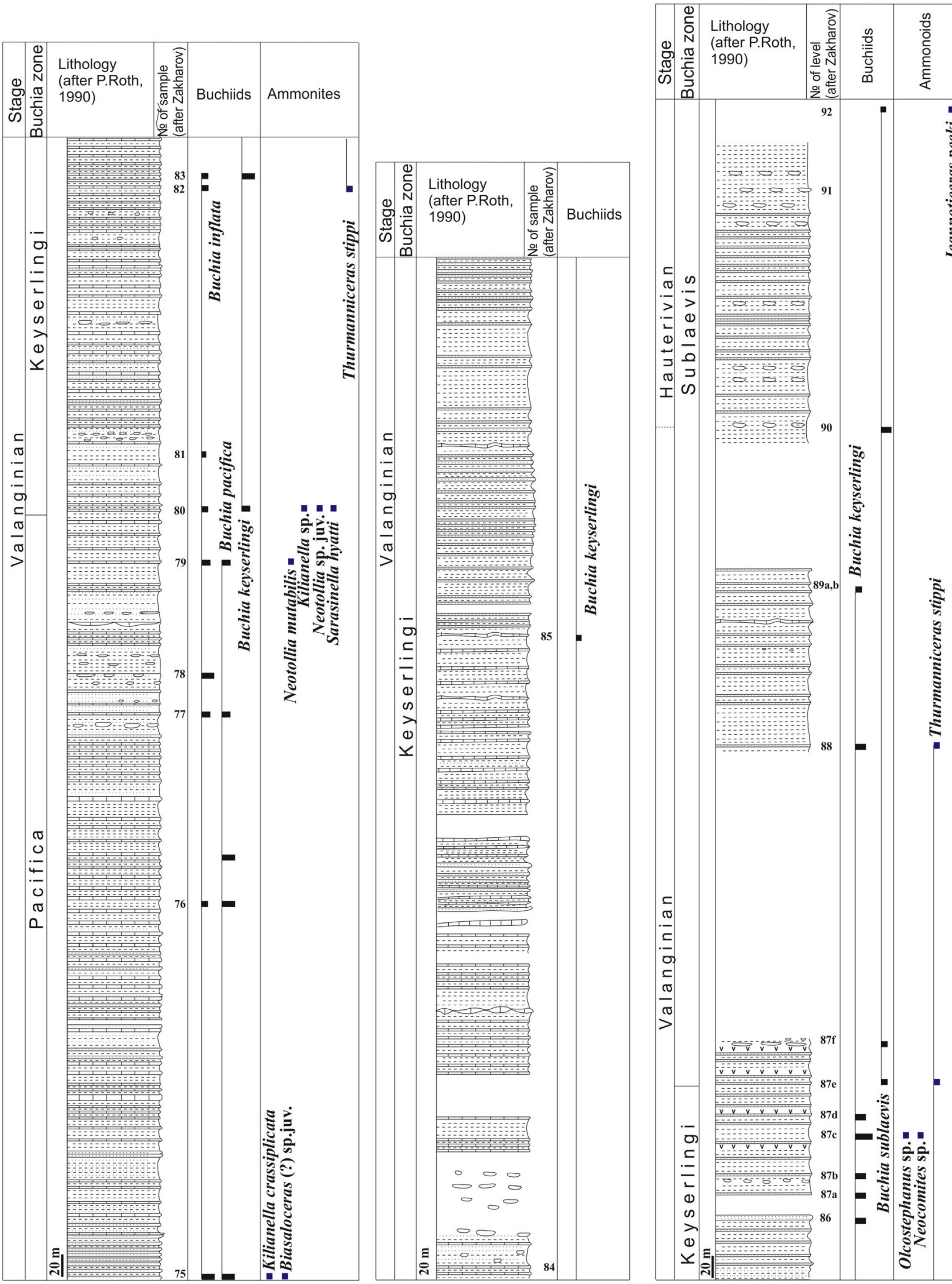
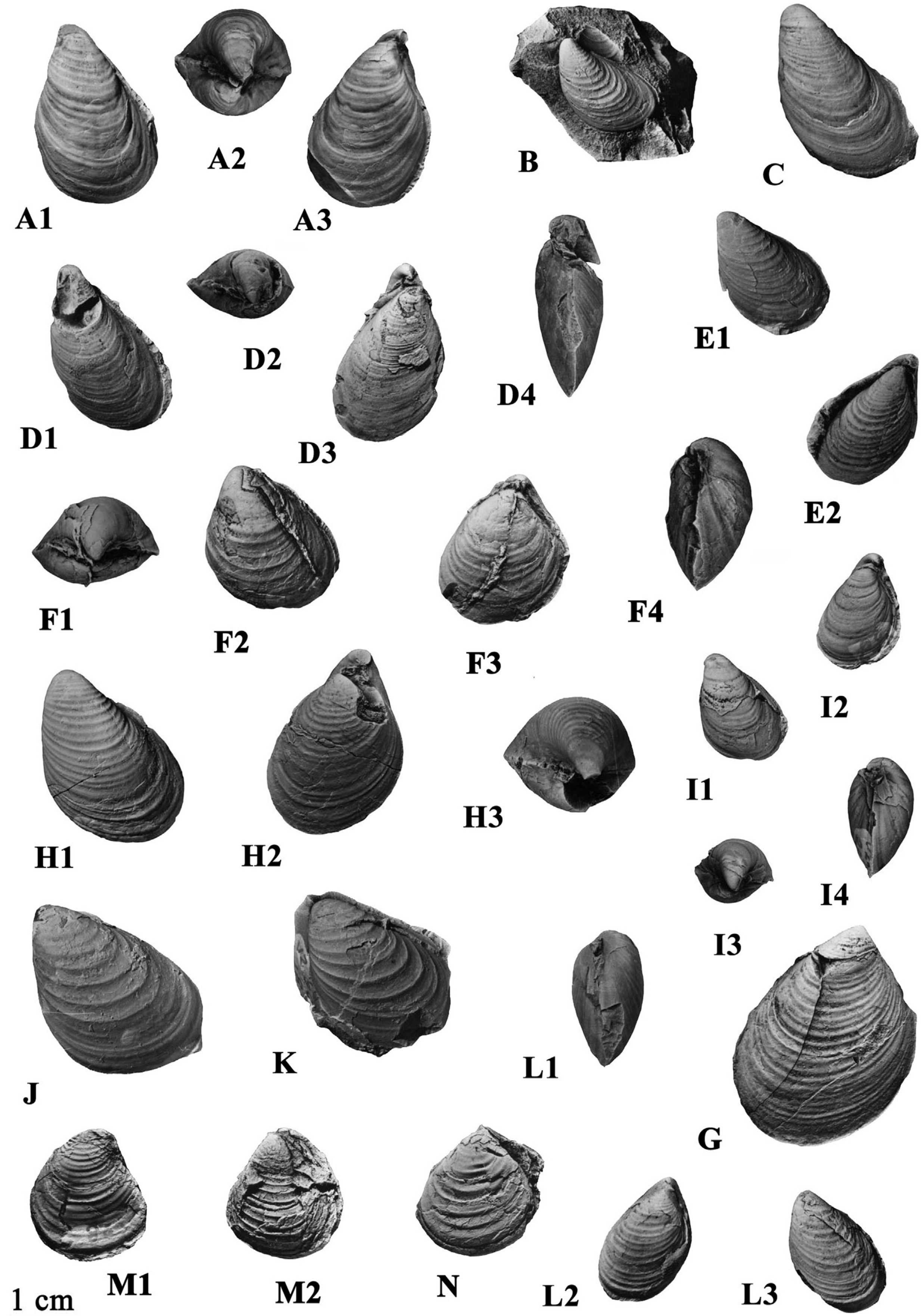


Fig. 3. (*continued*).


A1
A2
A3
B
C
D1
D2
D3
D4
E1
E2
F1
F2
F3
F4
I2
H1
H2
H3
I1
I4
I3
J
K
L1
G
M1
M2
N
L2
L3
1 cm

It should be noted that the rarity of ammonite-bearing levels in the studied succession lead to priority of the *Buchia* zones which were used for the both subdivision and correlation of sections. Only for post-Berriasian strata Imlay (1960; see also Popenoe et al., 1960) proposed a tentative succession of ammonite zones, but relationships between ranges of key ammonite taxa were later revised (cf. fig. 1 in Imlay and Jones, 1970). Furthermore, when the Californian succession was discussed only *Buchia* zones and co-occurrences of ammonites within these zones were considered (Zeiss, 1983; Hoedemaeker, 1987 and numerous later publications). Irregular distribution of ammonites within the *Buchia*-rich sequence prevented recognition of full ammonite zones, but ammonite assemblages or ammonite biohorizons (Rogov et al., 2012), especially those which could be recognized outside the studied area, remain important for interregional correlation and will be discussed further below.

All studied specimens are housed in the Vernadsky State Geological Museum (Moscow, Russia, collection no SGM-1553). Numerous *Buchia* specimens collected during the field works in California were also transferred to the Utah State University.

4. Taxonomic and paleobiological remarks

4.1. Buchia *bivalves*

Buchiids are the most common bivalves occurring in the Jurassic-Cretaceous transitional strata of the Paskenta region. Their succession is very similar to those of northern Siberia and other Boreal areas. However, the individuals of several Upper Tithonian to Valanginian species in northern California, such as *Buchia terebratuloides, B. uncitoides, B. inflata, B. keyserlingi* and *B. sublaevis* are characterized by more convex valves than specimens of the same species from northern Siberia. Specimens of other northern Californian buchias, such as *B. okensis* and *B.* aff. *volgensis* are smaller than northern Siberian members of these species. However, these differences are here ascribed to intraspecific variability, given that these species occur in the same succession as in other parts of the Boreal Realm. The only potential exception is *B.* aff. *volgensis*, which has a stratigraphic range that is significantly different from that of *B. volgensis*. Only *Buchia pacifica* Jeletzky and *B. columbiana* Grey should are here considered as endemic North American species.

The oldest buchiid assemblage, referred by Jones et al. (1969) to the *Buchia elderensis* subzone (or *B. elderensis* zone after Hoedemaeker, 1987), mainly consists of *B. elderensis* (Anderson), a species showing close affinities to the Middle Volgian species *B. russiensis* (Pavlow). Some bivalves ascribed to *B. elderensis* by Jones et al. (1969, pl. 2, figs. 21–24) were even assigned to *B. russiensis* by Zakharov (1981, p. 94). In addition to the index species Jones et al. (1969, p. A6) indicated the presence of a “few specimens of typical *B. piochii*”, but relationships between the First Occurrences (FOs) of *B. elderensis* and *B. piochii* remains unclear, because the precise position of the oldest *B. piochii* record was not indicated, and these specimens were not figured.

Bivalves from the overlying *B. piochii* zone s. str. are represented by numerous specimens of its index species, *Buchia piochii* (Gabb) (Fig. 4B–D), accompanied by *Buchia fischeriana* (d'Orbigny) (Jones et al., 1969, pl. 1, figs. 3, 7-9) in both studied sections. These species show peak abundance in the *piochii* zone but also are known above, although in the Berriasian part of the succession they are less abundant. As a background species, rare specimens of *B. lahuseni* (Pavlow) occur here, and at Grindstone Creek the oldest *B. terebratuloides* (Lahusen) (Fig. 4A) appears near to the top of the *piochii* zone.

Above the *piochii* zone we recognize a new unit, termed *Buchia* aff. *volgensis* – *B. unschensis* beds, which corresponds to the lower part of the aff. *okensis* zone by Jones et al. (1969) (loc. 3047, and possibly 2601–2604 B, C). *Buchia trigonoides* (Lahusen) from the basal part of the former aff. *okensis* zone (loc. 3047 and loc. 28037, Jones et al., 1969, pl. 1, figs. 1, 2, 4–6, 10–17, 23–24) was subsequently assigned to *B. volgensis* by Zakharov (1981, p. 125) and here is re-identified as *B.* aff. *volgensis* (Lahusen).

This stratigraphic interval is characterized by the co-occurrence of *B.* aff. *volgensis* (Lahusen) (Figs. 4 G–I, L and 6C,D), which is distinguished from true *B. volgensis* mainly by its smaller size, *B. unschensis* (Pavlow) (Fig. 4F), as well as *B. piochii* (Gabb) (Fig. 4E), *B. fischeriana* (d'Orbigny) and *B. terebratuloides* (Lahusen) (Fig. 4M–N).

The *B. okensis* zone is characterized by a buchiid assemblage which is very similar to the one of the underlying unit, but is marked by the occurrence of the index species *Buchia okensis* (Pavlow.) (Fig. 5A–E), while *B.* aff. *volgensis* (Lahusen) disappears below the FO of *B. okensis* (Pavlow). Californian specimens of *Buchia okensis* (Pavlow), at first recognized here by Pavlow (1907, pl. I, fig. 10) are showing the typical shell outline and ontogeny of this species, but stay significantly smaller than Siberian specimens of this species. However, the largest specimens from California are comparable in size with the lectotype of this species from the Russian Platform (Pavlow, 1907, pl. I, fig. 11).

The buchiid assemblage of the *uncitoides* zone includes the index species *B. uncitoides* (Pavlow) (Figs. 5 F–I and 6 A–B, G–H), accompanied by *B. jasikovi* (Pavlow) (Jones et al., 1969, pl. 3, figs. 1-13), the last specimens of long-ranging *B. fischeriana* (d'Orb.) and *B. unschensis* (Pavlow), as well as by very rare *B. volgensis* (Lahusen). *B. piochii* (Gabb), *B. terebratuloides* (Lahusen) (Jones et al., 1969, pl. 2, figs. 1–15) and *B. fischeriana* (d'Orbigny) have their last occurrences within this zone. Above this zone buchiid diversity declined, and no more than 2 species co-occur in the overlying strata. *B. uncitoides* (Pavlow) ranges upwards up to the base of the *B. pacifica* zone, and co-occurred with *B. inflata* (Lahusen) (Fig. 7A–D, F–H) throughout the beds with *B. inflata*.

The base of the *pacifica* zone is marked by the appearance of the North American endemic species *B. pacifica* Jeletzky (Jones et al., 1969, pl. 4, figs. 1–19), which shows close affinities with *B. inflata* (Lahusen) (Zakharov, 1981), and co-occurs with the latter species throughout the *pacifica* zone. Jones et al. (1969, pl. 3, figs. 30–33) figured specimens of *B. inflata* (Lahusen) from the upper part of the *pacifica* zone. *Buchia keyserlingi* (Trautschold) (Figs.7E and 8A–E, G) occurs mainly in the *B. keyserlingi* zone; the lowermost part of this zone also yields *B. inflata* (Lahusen).

The uppermost *Buchia*-bearing interval in the Paskenta area is characterized by the occurrence of either *B. crassicollis* (Keyserling) (Jones et al., 1969, pl. 5, figs. 11-11, 16–17) or *B. sublaevis*

Fig. 4. Tithonian and Berriasian buchias of the Paskenta area. A. *Buchia terebratuloides* (Lahusen), etc, Grindstone Creek, upper Tithonian, *piochii* zone, level 38, specimen SGM 1553/1; B-E. *Buchia piochii* (Gabb, 1864), B - McCarty Creek, upper Tithonian, *piochii* zone, level 47, specimen SGM 1553/3; C - McCarty Creek, upper Tithonian, *piochii* zone, level 49b, specimen SGM 1553/4; D - McCarty Creek, upper Tithonian, *piochii* zone, level 49 b, specimen SGM 1553/2; E – Grindstone Creek, Tithonian–Berriasian, beds with *B.* aff. *volgensis* – *B. unschensis*, level 18, specimen SGM 1553/8; F. *Buchia unschensis* (Pavlow, 1907), Grindstone Creek, Berriasian, *okensis* zone, level 29, specimen SGM 1553/5; G-I, L. *Buchia* aff. *volgensis* (Lahusen, 1888), Grindstone Creek, Berriasian, *okensis* zone, G - level 24, specimen SGM 1553/12; H - level 29, specimen SGM 1553/6; I - level 29, specimen SGM 1553/7; L – level 24, specimen SGM 1553/11; J-K. *Buchia okensis* (Pavlow, 1907), Grindstone Creek, Berriasian, *uncitoides* zone, J - level 18, specimen SGM 1553/9; K – level 18, specimen SGM 1553/10; M-N. *Buchia terebratuloides* (Lahusen), etc, Grindstone Creek, Berriasian, beds with *B.* aff. *volgensis* – *B. unschensis*, level 24; M– specimen SGM 1553/13; N – specimen SGM 1553/14.

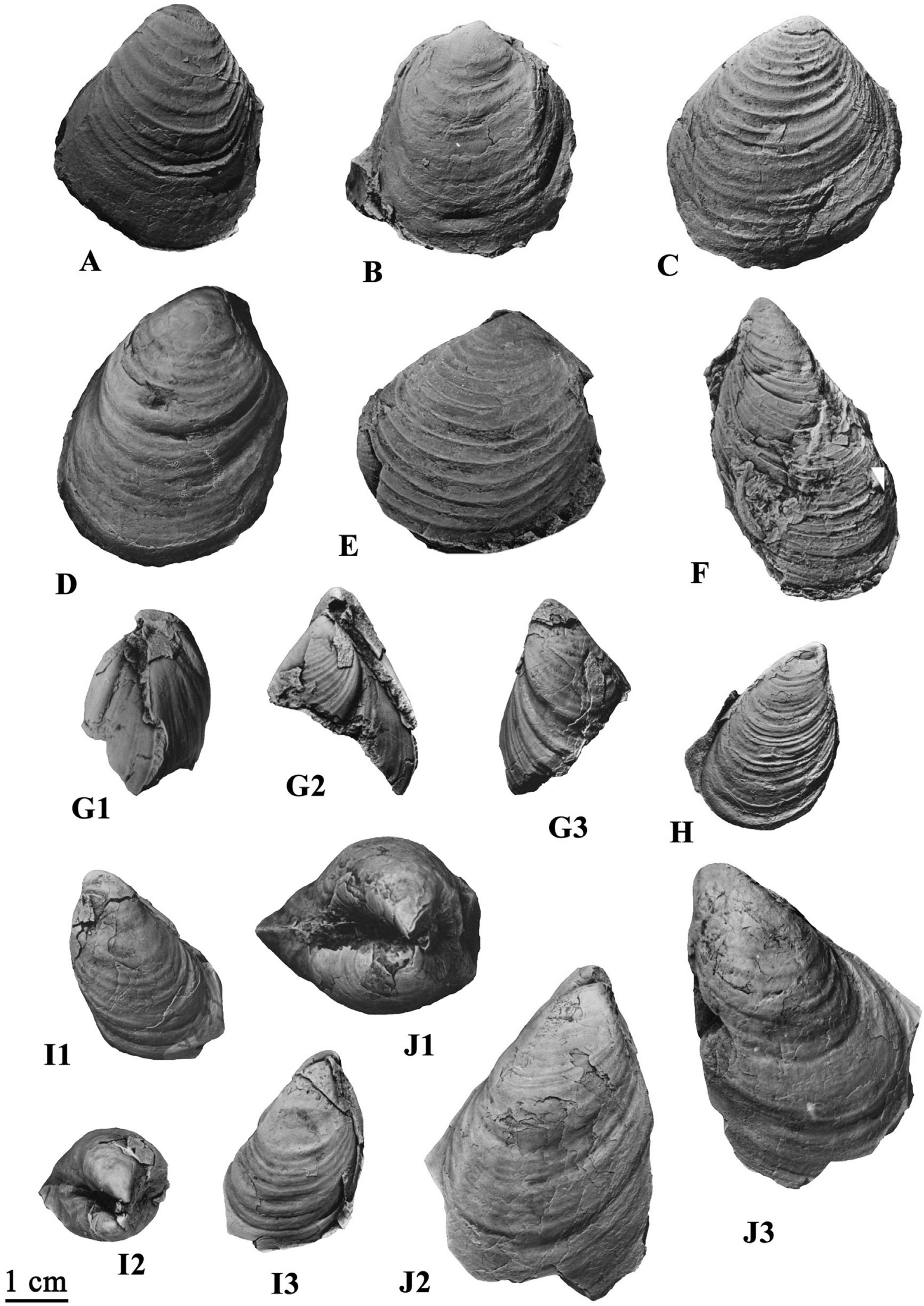


Fig. 5. Berriasian buchias of the Paskenta area. A-E. *Buchia okensis* (Pavlow, 1907), Grindstone Creek, Okensis Zone; A – level 22 a, specimen SGM 1553/15; B – level 22 a, specimen SGM 1553/16; C - level 22 a, specimen SGM 1553/17; D - level 22 a, specimen SGM 1553/19; E – level 22 a, specimen SGM 1553/18; F-J. *Buchia uncitoides* (Pavlow, 1907), *uncitoides* zone; F - McCarty Creek, level 53, specimen SGM 1553/20; G – McCarty Creek, level 55, specimen SGM 1553/21l; H – McCarty Creek, level 55, specimen SGM 1553/23; I - Grindstone Creek, level 14, specimen SGM 1553/22; J – Grindstone Creek, level 14, specimen SGM 1553/25.

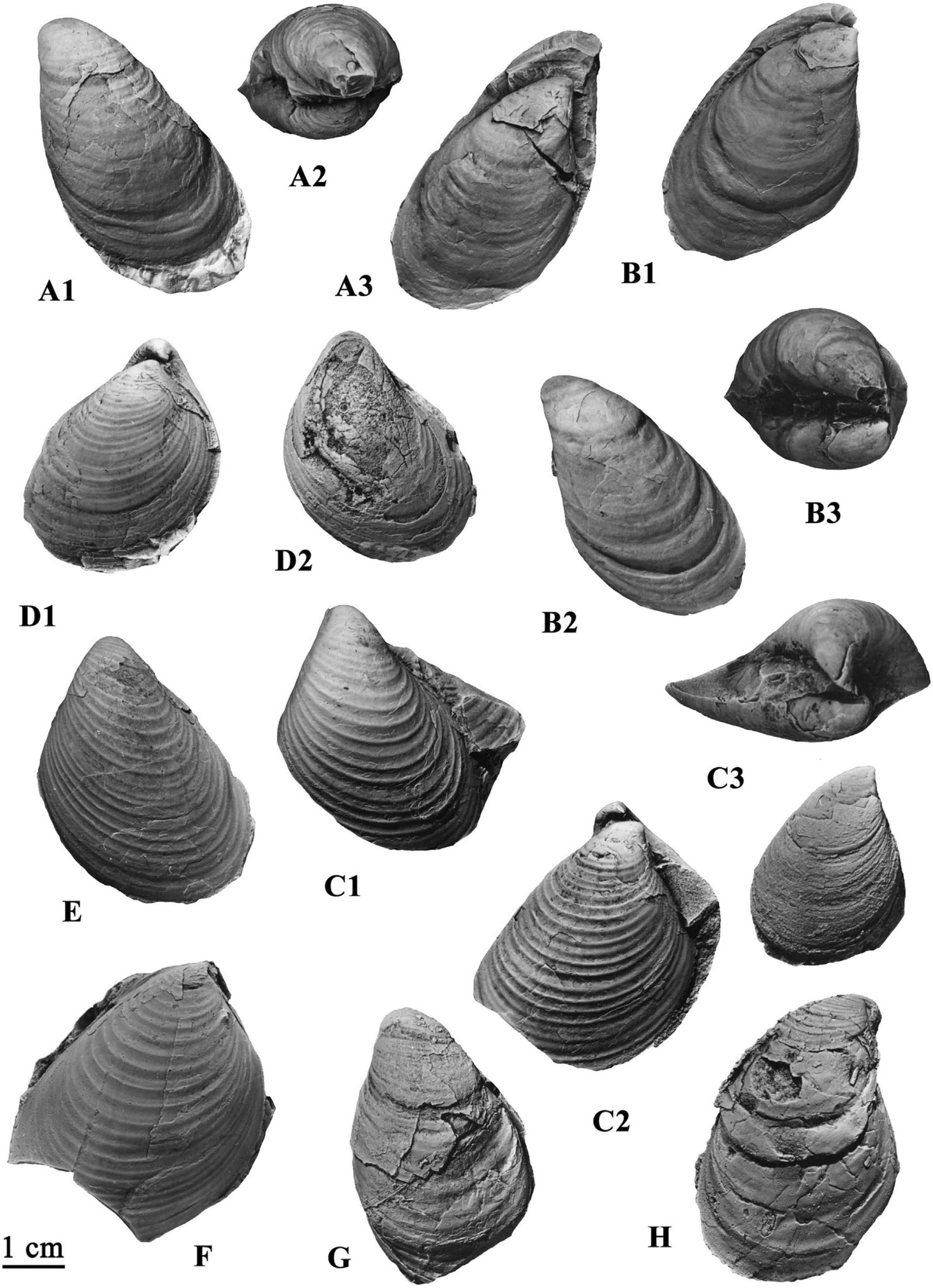


Fig. 6. Berriasian and Valanginian buchias of the Paskenta area. A-B. *Buchia uncitoides* (Pavlow, 1907), Berriasian, *uncitoides* zone, Grindstone Creek, level 14; A - specimen SGM 1553/26; B - specimen SGM 1553/27; C–F. *Buchia* aff. *volgensis* (Lahusen, 1888), Grindstone Creek, *okensis* zone; C - level 33, specimen SGM 1553/31; D – level 31–33, specimen SGM 1553/28; E – level 31a, specimen SGM 1553/29; F – level 31a, specimen SGM 1553/30; G-H. *Buchia uncitoides* (Pavlow, 1907), McCarty Creek; G – level 59, Berriasian–Valanginian, beds with *Buchia inflata*, specimen SGM 1553/32; H– level 61, lower Valanginian, *pacifica* zone, specimen SGM 1553/34.

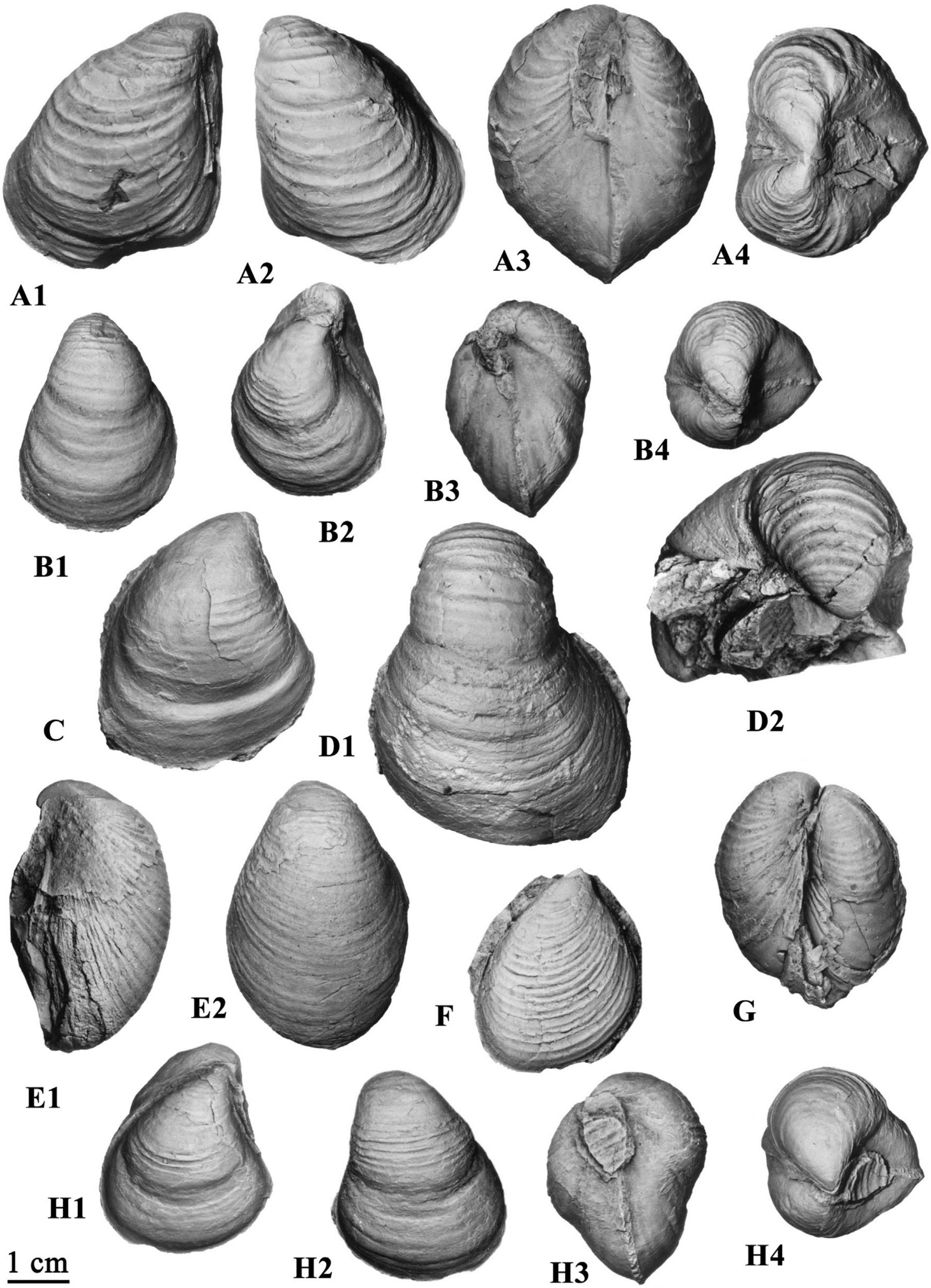


Fig. 7. Valanginian *Buchia* of the Paskenta area. A-D, F—H. *Buchia inflata* (Lahusen, 1888), lower Valanginian, *pacifica* zone; A - Grindstone Creek, level 9, specimen SGM 1553/35; B — McCarty Creek, level 75a, specimen SGM 1553/38; C — McCarty Creek, level 75a, specimen SGM 1553/39; D - McCarty Creek, level 75a, specimen SGM 1553/41; F — McCarty Creek, level 66a, specimen SGM 1553/37; G — McCarty Creek, level 66a, specimen SGM 1553/36; H - McCarty Creek, level 75a, specimen SGM 1553/40; E. *Buchia keyserlingi* (Trautschold, 1868), McCarty Creek, level 87 c, specimen SGM 1553/44.

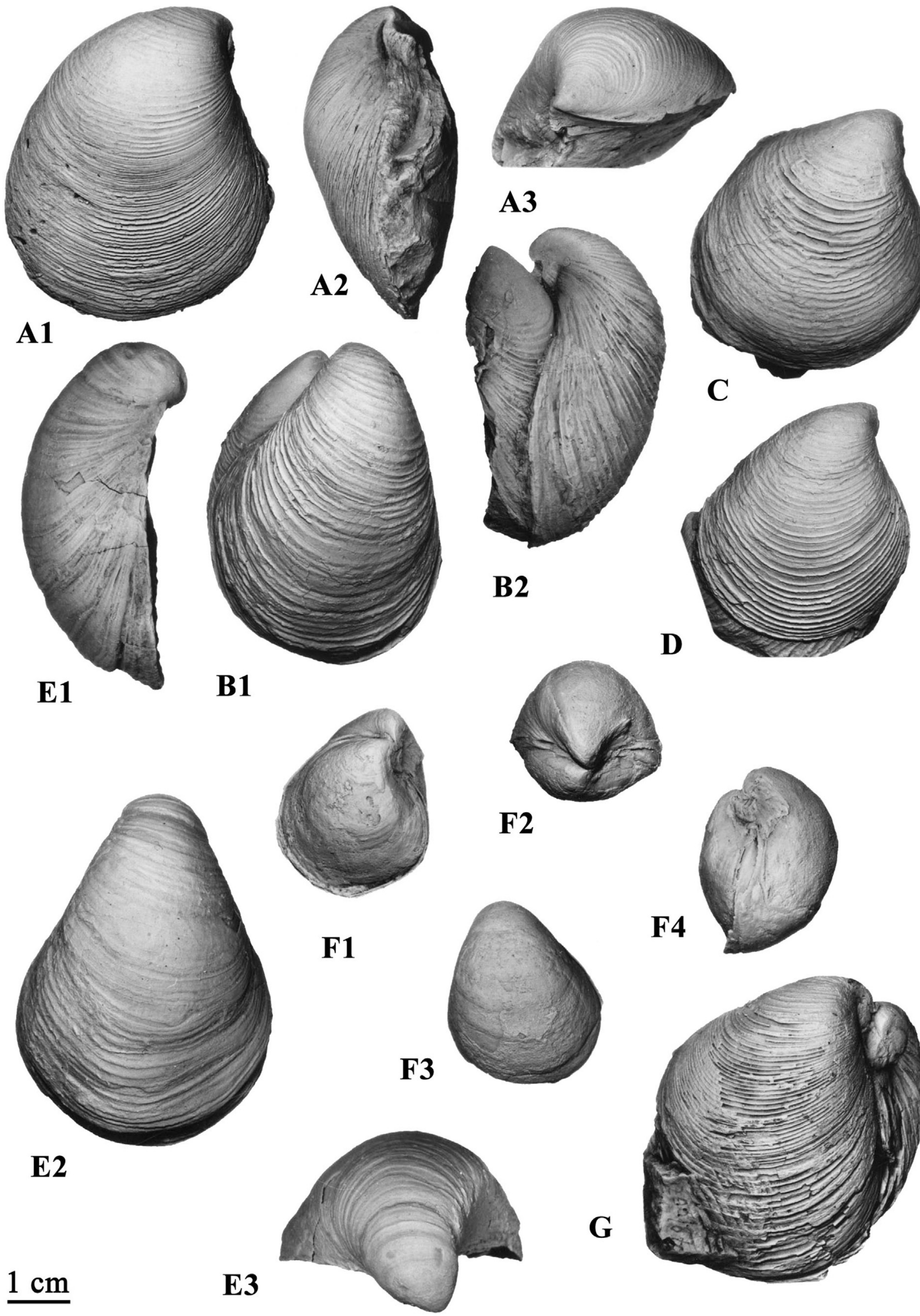


Fig. 8. Valanginian and Hauterivian *Buchia* of the McCarty Creek section. A-E, G. *Buchia keyserlingi* (Trautschold, 1868); A – level 87 a, specimen SGM 1553/42; B – level 87 c, specimen SGM 1553/43; C – level 87 c, specimen SGM 1553/45; D – level 87 c, specimen SGM 1553/46; E – level 87 c, specimen SGM 1553/47; G – level 87 c, specimen SGM 1553/48; F. *Buchia sublaevis* (Keyserling, 1846), level 90, specimen SGM 1553/49.

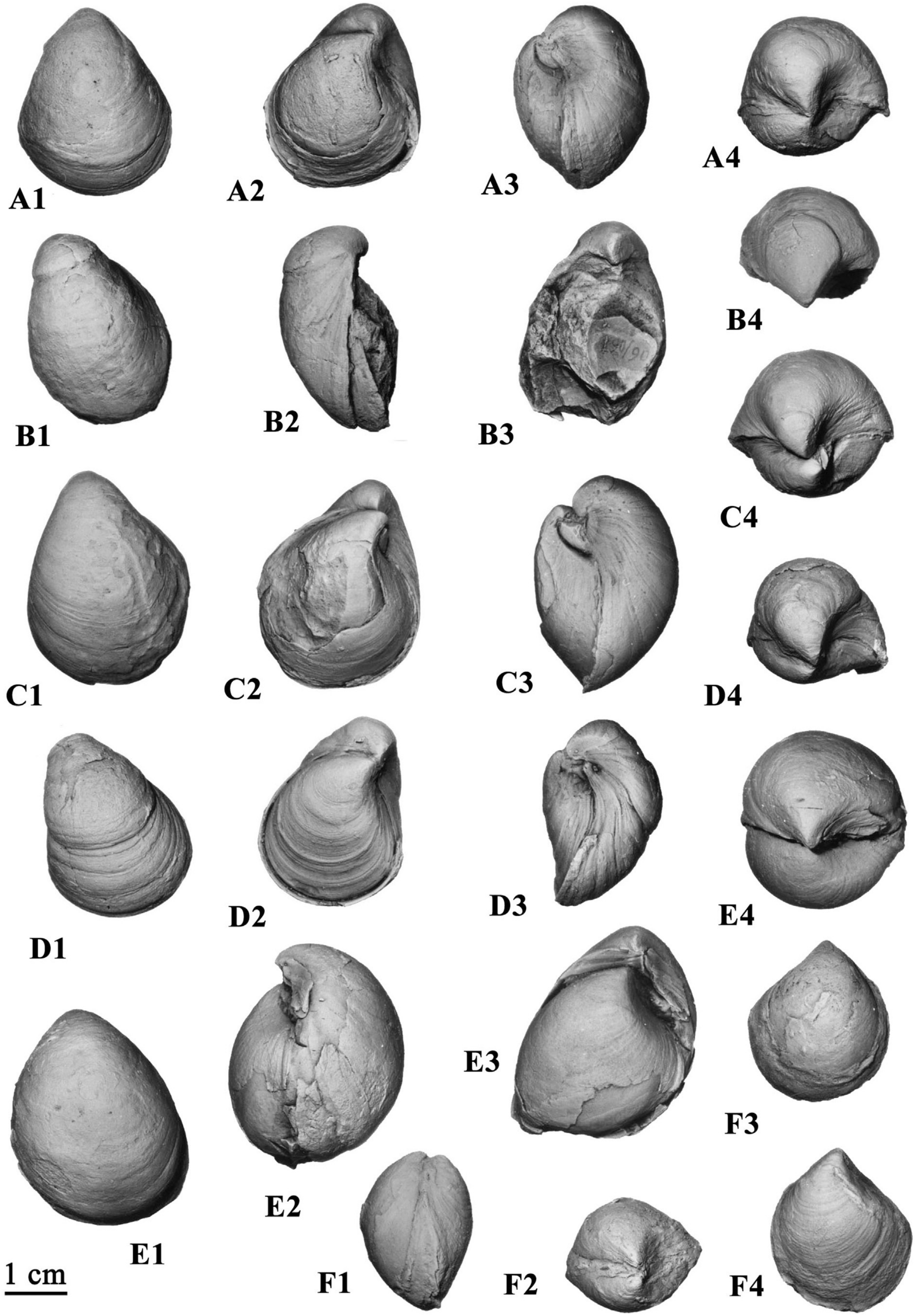


Fig. 9. Hauterivian (*sublaevis* zone) *Buchia* of the McCarty Creek section. A-F. *Buchia sublaevis* (Keyserling, 1846), level 90; A – specimen SGM 1553/50; B – specimen SGM 1553/51; C – specimen SGM 1553/52; D – specimen SGM 1553/53; E – specimen SGM 1553/54; F – specimen SGM 1553/55.

(Keyserling) at the McCarty Creek section (Figs. 8F and 9A–F). The total ranges of these two species in California seem to be similar, while variation in occurrences in different sections could be caused by ecological reasons, such as strong competition between these closely related species. Only in the lower part of the *B. crassicollis* (Keyserling) range, the last *B. keyserlingi* (Trautschold) occurs.

Differences in size and inflation between Californian buchiids from the coeval specimen occurred in other Boreal areas are significant for 3 species only. These are *Buchia unschensis* (Pavlow), *B. okensis* (Pavlow) and *B. volgensis* (Lahusen)/*B.* aff. *volgensis* (Lahusen). In contrast with latest (Valanginian–Hauterivian) species these are not so common and missing in the coquina beds. We are unable to find possible explanation of this phenomenon through the analyses of available environmental factors. At least depth of the basin or temperature seems to be insignificant, as the same species are represented by bigger specimens in the both deep and cold Western Siberian basin (Vyachkileva et al., 1990, pl. 25–28) and in shallow-water warm Crimean sea (Yanin, 1970, pl. I, figs. 1-2). Californian-like small-sized and inflated buchiid species are known from the earliest Cretaceous of Southern Primorie (Russian Far East), on the opposite coast of the Pacific Ocean (Sey and Kalacheva, 1999). Here lower Berriasian (lower Ryazanian) *Buchia unschensis* (Pavlow), *B. okensis* (Pavlow) and *B. volgensis* (Lahusen) are nearly two times smaller while compared with their Siberian counterparts.

As in the California, earliest and latest buchiid species here have no differences from the same taxa occurred outside this area (Sey and Kalacheva, 1990, pl. III-IV). However the reasons why south Pacific *Buchia* became small near the Jurassic-Cretaceous boundary became unclear. At least comparison of Californian *Buchia* with specimens from seep carbonates occurred near to the Jurassic-Cretaceous boundary of Spitsbergen have revealed that *Buchia* from Spitsbergen are showing size and inflation typical for other Boreal *Buchia*.

4.2. Ammonites

Ammonites, collected in the Grindstone Creek and McCarty Creek sections, mainly belong to taxa of Mediterranean origin (i.e. Berriasellidae (*Neocosmoceras*), Himalayitidae (*Blanfordiceras*), Neocomitidae (*Kilianella*, *Sarasinella*, *Neocomites*), Olcostephanidae (*Olcostephanus*, *Jeannoticeras*, *Proniceras*, *Paskentites*, *Howarthiceras* gen. nov.). Additionally, there are cosmopolitan phylloceratids and lytoceratids along with locally abundant Boreal ammonites (Craspeditidae (*Neotollia*)). Here we discuss new records, while stratigraphic conclusions based on both previous and new ammonite records are covered in the "Discussion" chapter.

4.2.1. *Craspeditidae (*Neotollia*)*

The genus *Neotollia* was introduced by Shulgina (in Sachs and Shulgina, 1969) with the type species *N. klimovskiensis* (Krymholz), for craspeditid ammonites which differ from the allied genus *Tollia* Pavlow, 1914 by less flattened whorls, narrower umbilicus in *Neotollia* and biplicate ribbing of the early growth stages, usually up to 50–60 mm in diameter for *Neotollia,* in contrast with mainly triplicate ribbing in *Tollia*. "*Tollia mutabilis* (Stanton)", which is the most abundant ammonite species of the study area, representing nearly half of all Tithonian–lower Hauterivian ammonite occurrences in California and Oregon (see Imlay and Jones, 1970), was assigned to the genus *Neotollia* by Shulgina (1985). Imlay and Jones (1970) indicate its mass occurrence in the top of the *pacifica* zone, which is in agreement with our data as many juveniles of *N. mutabilis* (12 specimens, fig. 10 L) were found in the topmost fossiliferous bed of the Pacifica Zone in the McCarty Creek section (level 79, see fig. 2). A single doubtful specimen referred to *Neotollia*? sp. juv. was also recorded from the base of the overlying *keyserlingi* zone (level 80a).

4.2.2. *Berriasellidae (*Neocosmoceras*) and Himalayitidae (*Blanfordiceras*)*

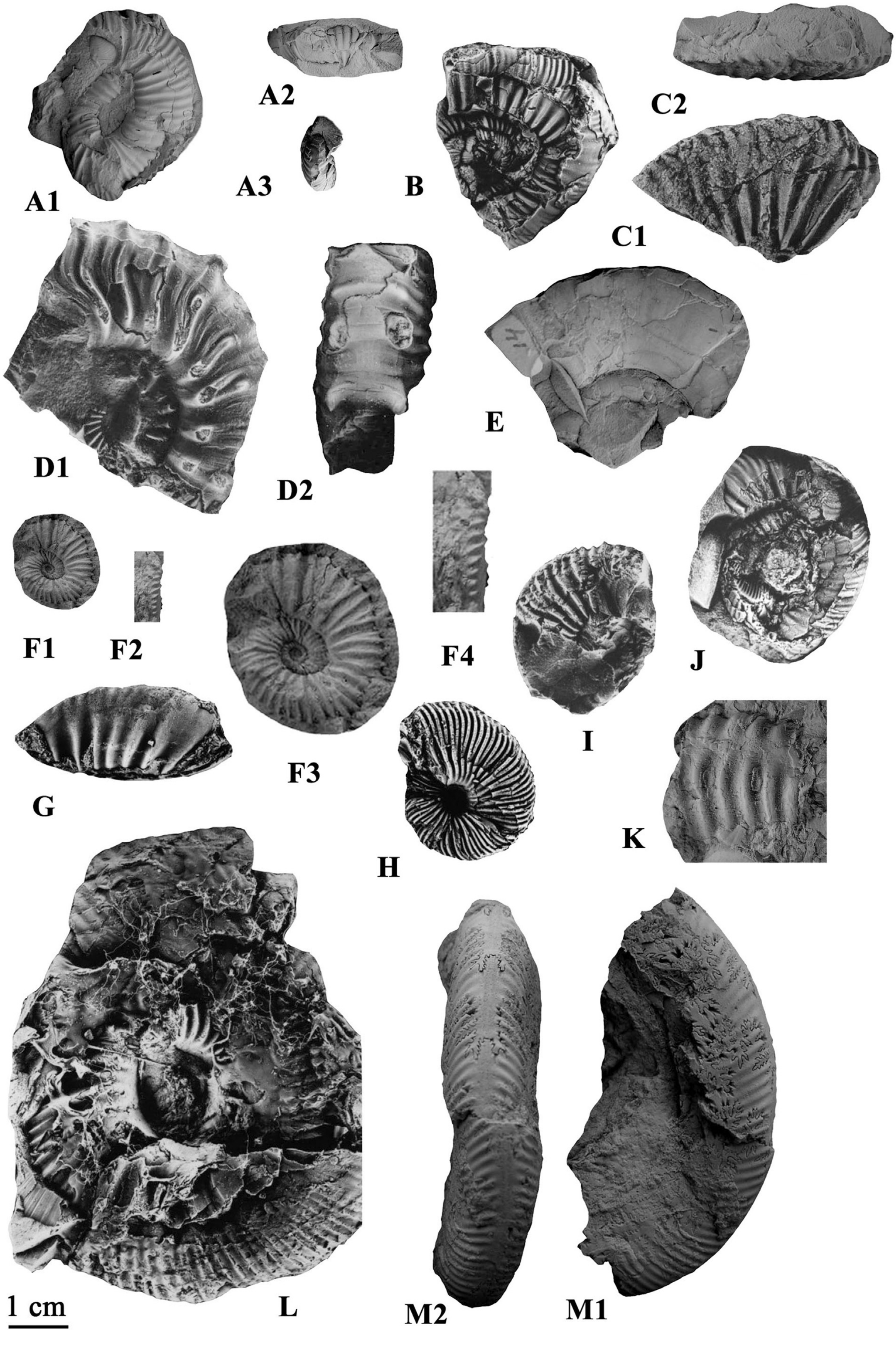
Albeit stratigraphically important, records of *Neocosmoceras* in the Berriasian of California and Oregon are very uncommon (only two specimens were listed as belonging to this genus by Imlay and Jones, 1970). One well-preserved specimen was collected from the *uncitoides* zone (level 55), and is assigned to the *N. euchrense* Imlay and Jones (1970) (fig. 10 D), whose type came from the *uncitoides* zone of Oregon. Even if *Neocosmoceras* should be considered to include *Euthymiceras* and *Transcaspiites* (cf. Arkadiev and Bogdanova, 2009), its stratigraphic range remains relatively small and spans only two standard ammonite zones of the Berriasian, *occitanica* and *boissieri.* This genus is characterized by a very wide geographic distribution and is only absent from the Boreal Realm. Californian *Neocosmoceras* is characterized by the presence of strong spines intercalating on the ventral side with relatively weak ribs. The *Neocosmoceras*-bearing level is also characterized by the occurrence of ammonites, which could be referred to *Blanfordiceras* sp. One specimen is represented by a partial whorl showing slightly curved single and biplicate ribs with some intercalatories, with the rib furcation point positioned at mid-flank (Fig. 10C). These ribs terminate at ventrolateral nodes. A juvenile specimen from the same level (Fig. 10I) is also assigned to *Blanfordiceras.* In the narrow whorls this specimen resembles *Blanfordiceras compressum* Énay (Énay, 2009, pl. 51, figs. 1-3, 5), although the ventrolateral nodes of the Californian ammonite seem to be more pronounced. *Blanfordiceras* strongly resembling the specimen from the Grindstone Creek section are also known from the Berriasian of Chile (Covacevich et al., 1994, fig. 2 b-c). *Blanfordiceras* records from California are also very close to the Argentinian species *B. laxicosta* (Steuer) (cf. Leanza, 1945, pl. VI, figs. 9-10); recently unfigured *B. laxicosta* (Steuer) and *B.* aff. *laxicosta* (Steuer) were mentioned from the middle Berriasian *Argentiniceras noduliferum* zone of Argentina (Parent et al., 2011; Vennari et al., 2014). Younger records of *Blanfordiceras* in Argentina co-occurred with *Neocosmoceras* (Vennari et al., 2014), i.e. their age is the same as for the Californian *Blanfordiceras* occurrence. The Last Occurrence (LO) of this genus in Argentina lies within the *damesi* zone, which nearly corresponds to the *boisseri* zone (Iglesia-Llanos et al., 2017).

4.2.3. *Neocomitidae (*Kilianella*,* Neocomites*,* Sarasinella*,* Thurmanniceras*)*

Neocomitid ammonites are relatively abundant in the Valanginian part of the studied succession, and belong to at least four genera.

The genus *Kilianella* was recorded from the *pacifica* zone (level 65, *Kilianella* sp. juv. (Fig. 10F), level 75 a, *K.* cf. *crassiplicata* (Stanton) (Fig. 10K)) and a dubious specimen from the basal part of the *keyserlingi* zone (level 80a, *Kilianella* sp.). It should be noted that Imlay and Jones (1970) recorded *K. crassiplicata* mainly from the middle part of their *pacifica* zone, which nearly corresponds to beds with *Buchia inflata* and the *pacifica* zone of this paper. These ammonites are characterized by simple and biplicate ribs with prominent nodes at the rib furcation point. These ribs reach the ventrolateral margin where they terminate in nodes (in the inner whorls) or gradually fade out (in outer whorls). As indicated by Imlay and Jones (1970, p. B50), this species is very close to *K. roubaudiana* (d'Orbigny). The latter is a typical lower Valanginian species, ranging through *petransiens* and *neocomiensiformis* zones in the Betic Cordillera (Company and Tavera, 2015), and a similar range for this taxon is reported from South-East France (Reboulet, 1996).

Neocomites, mainly ascribed to the single species "*N.*" *wichmanni* Leanza, were reported by Imlay and Jones (1970) from the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keyserlingi Zone without indication of their precise position within this zone. This species is used as an index for the lower Valanginian in Argentina, which correlates with the *petransiens* zone of the Mediterranean zonation, while *Neocomites* sp. until recently was considered as an index of the uppermost zone of the Argentinian Valanginian (Aguire-Urreta et al., 2007). However, the generic assignment of *N. wichmanni* Leanza remains unclear, and Rawson (1999) pointed out occurrence of *Neocomites* in Argentina in the uppermost Valanginian only, while now these records of the uppermost Valanginian *Neocomites* are re-assigned to the new genus *Decliveites* (Aguire-Urreta and Rawson, 2010).

Our collection includes a single specimen of *Teschenites* sp. (Fig. 11A) from the upper part of the *keyserlingi* zone (level 87c). This is a small fragment (slightly less than half of whorl) with slightly flexuose biplicate to triplicate ribs with variable position of the rib furcation point (mainly at mid-flank, with some ribs branching significantly lower or higher). Semievolute coiling and type of ribbing in this ammonite strongly resemble those in microconchs of uppermost Valanginian *Teschenites* from SE France (Reboulet, 1996, pl.12, figs. 5-6). A very similar ammonite from the Valanginian of the Russian Far East was described as *Teschenites teschenensis* (Uhlig) (Sey and Kalacheva, 2001, pl. 3, fig. 2, refigured here: Fig. 11C).

All records of the genus *Sarasinella* mentioned by Imlay and Jones (1970) were from the basal part of the *keyserlingi* zone, with exception of those from Oregon, which were associated with “larger crushed Buchias which probably belong to *B. pacifica*” (Imlay and Jones, 1970, p. 10). Well-preserved *Sarasinella*, ascribed to *S. hyatti* (Stanton) (Fig. 11 F), was recorded in the McCarty Creek section together with the last *Kilianella* and *Neotollia* at the base of the *keyserlingi* zone. This specimen differs from the type of *S. hyatti* (Stanton) by its well-ribbed body chamber, while the body chamber of the holotype of this species is characterized by weak ribs and becomes nearly smooth near the aperture except rib remains at the mid-flank (Imlay, 1960, pl. 42, fig. 22). By its dense ribbing our specimen resembles the holotype of *S. densicostata* Imlay (Imlay, 1960, pl. 42, fig. 25), but the latter is represented by an immature specimen and could be merely the inner whorls of *S. hyatti.* It is very possible that both the relative rib density and smoothness of sculpture at the final body chamber are highly variable features, as well as final size of this microconchiate species. Imlay (1960, pl. 24, figs. 19, 24) indicated these small microconchs as “micromorphs”. The ammonite genus *Sarasinella* is typical for the Valanginian (Wright et al., 1996), although some species (*S. subdensicostata* Vasicek) are known from the lower Hauterivian (Vašíček, 2009). Our specimen is very close to the specimen from the lower Valanginian of the Amur River ascribed to *S.* cf. *varians* Uhlig by Sey and Kalacheva (2001, pl. 2, fig. 8).

Thurmanniceras occurrences were previously described from the *pacifica* and *keyserlingi* zones of California (Imlay, 1960; Imlay and Jones, 1970). In our collection specimens of this genus are uncommon and were collected from the *keyserlingi* zone only. One piece of relatively evolute neocomitid ammonite, characterized by numerous relatively thin ribs, ascribed to *T.* cf. *californicum* (Stanton), was found at level 88 (fig. 10 M). An additional record of strongly crushed *Thurmanniceras* (*T. stippi* (Anderson), fig. 11 D) was made in the lower part of the *keyserlingi* zone (level 82 b). One further juvenile specimen ascribed to *T. stippi* (Anderson) was found slightly above, at the level 87e (Fig. 11I).

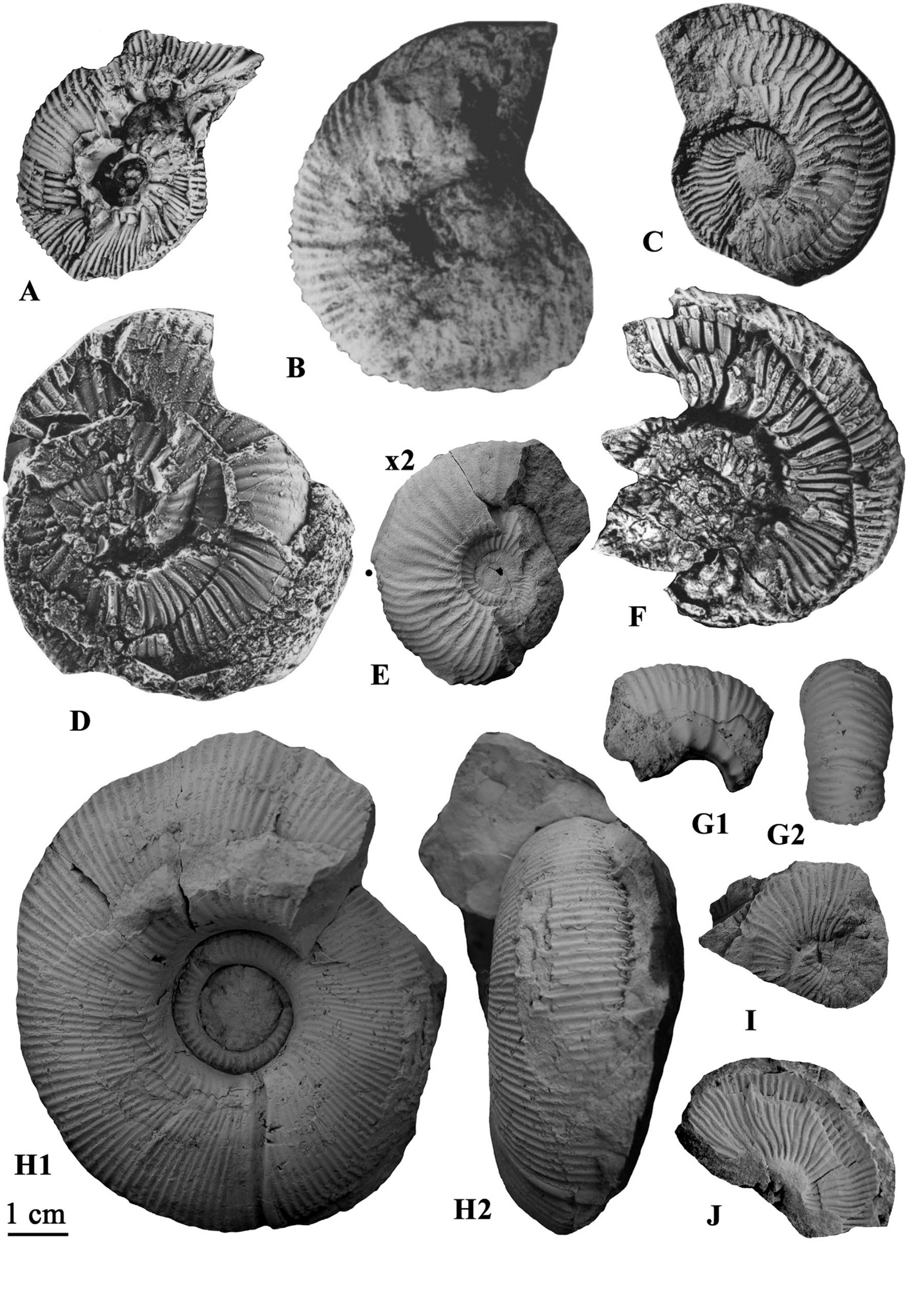
4.2.4. *Olcostephanidae (*Olcostephanus, Jeannoticeras) and Spiticeratidae (Proniceras, Negreliceras, Paskentites

A single small *Olcostephanus* sp. (presumably a microconch) was found in level 87c together with a well-preserved microconch of *Teschenites* (see above) in the middle portion of the *Buchia keyserlingi* zone (Fig. 11A). By its remarkable constrictions, high rib ratio and well-developed periumbilical tubercles this ammonite strongly resembles such species as *Olcostephanus dacquei* (Krenkel) (Krenkel, 1910, pl. III, fig. 6), *O. ventricosus* (Koenen) (Cooper, 1981, fig. 154) and *O. inordinatus* (Tzankov) (Cooper, 1981, fig. 141) as well as *Olcostephanus* sp. from Tibet (He and Xia, 1984, pl. II, figs. 10–24) and some specimens of *O. densicostatus* (Wegener) from SE France (Reboulet, 1996, pl. 30, figs. 3, 9).

The single specimen of *Jeannoticeras pecki* (Imlay) was recorded from the uppermost part of the sequence in McCarty Creek (level 92) within the *Buchia sublaevis* zone (Fig. 11H). Imlay (1960) suggested that *Olcostephanus pecki* represented the uppermost Valanginian in California and Oregon, but in the Submediterranean region of Europe *Jeannoticeras* is typical of the middle part of the lower Hauterivian (*jeannoti* subzone; Bulot et al., 1992, and *jeannoti* horizon, Reboulet et al., 2014), and rare *Jeannoticeras* are also known from a relatively high level in the lower Hauterivian of England (Doyle, 1989). An early Hauterivian age is also suggested for Argentinian (Aguire-Urreta and Rawson, 2001) and Tanzanian (Cooper, 1981) *Jeannoticeras* occurrences, as well as for a single record of this genus from Tibet (Yin, 2016).

Proniceras and *Negreliceras* occurrences in our collection are restricted to the upper part of the *okensis* zone and lowermost part of the *uncitoides* zone. They belong to species well-illustrated and described by Imlay and Jones (1970), i.e. *Proniceras maupinense* Imlay & Jones and *Negreliceras stonyense* (Imlay and Jones). Imlay and Jones (1970) collected approximately 90 specimens of *Negreliceras stonyense*, associated with *Buchia uncitoides* and *B. okensis*, most of them from a single locality. In our collection, this species is represented by a few specimens from the *uncitoides* zone of the Grindstone Creek section (Fig. 2). Specimens of *Proniceras maupinense* Imlay et Jones were collected from both the studied sections. This species occurred in the lower part of the *uncitoides* zone (Fig. 10B and J). It should be noted, however, that taxonomy within the Spiticeratinae is based on the presence and ontogenetic persistence of lateral tubercles. As pointed out by Parent et al. (2011, p.62), “these differences seem to be nothing more than variation based on heterochronic phenotypic plasticity in the developmental pathways”. Recent studies of *Proniceras* by Frau et al. (2016) revealed the occurrence of a thin ventral groove in the inner whorl of *P. pronum* (Oppel) distinguishing it from the Mexican and Californian taxa, which may thus belong to a separate genus. Imlay & Jones (1970) in their description of the new genus *Paskentites* suggested its affinities to the Neocomitidae. However, both the character of the inner whorls (“inner whorls are characterized by

Fig. 10. Tithonian –Valanginian ammonites of the Paskenta area. A. *Howarthiceras* sp., Grindstone Creek, upper Tithonian, *piochii* zone, level 38, specimen SGM 1553/57; B. *Proniceras maupinense* Imlay and Jones et al., 1969, McCarty Creek, Berriasian, *uncitoides* zone?, *maupinense* biohorizon, level 53, specimen SGM 1553/59; C, I. *Blanfordiceras* sp., McCarty Creek, Berriasian, *uncitoides* zone, *euchrense* biohorizon, level 55, C - specimen SGM 1553/61; I – specimen lost; D. *Neocosmoceras euchrense* Anderson (1938); McCarty Creek, Berriasian, *uncitoides* zone, *euchrense* biohorizon, level 55, specimen SGM 1553/60; E. *Biasaloceras* cf. *colusaense* (Anderson, 1938). Grindstone Creek, Berriasian, *uncitoides* zone, level 14, specimen SGM 1553/70; F. *Kilianella* sp. juv., McCarty Creek, lower Valanginian, *pacifica* zone, level 65, specimen SGM 1553/74; G. *Paskentites paskentaensis* Imlay and Jones et al., 1969. McCarty Creek, lower Valanginian, *pacifica* zone, *paskentaensis* biohorizon level 73, specimen SGM 1553/63; H, L. *Neotollia mutabilis* (Stanton, 1895), lower Valanginian, *pacifica* zone, *mutabilis* biohorizon; H - McCarty Creek, level 79, specimen SGM 1553/66; L - Grindstone Creek, level 1, specimen SGM 1553/64; J. *Proniceras maupinense* Imlay and Jones et al., 1969. Grindstone Creek, Berriasian, *uncitoides* zone, *maupinense* biohorizon, level 16b, specimen SGM 1553/62; K. *Kilianella* cf. *crassiplicata* (Stanton, 1895), McCarty Creek, lower Valanginian, *pacifica* zone, level 75a, specimen SGM 1553/75; M. *Thurmanniceras* cf. *stippi* (Anderson, 1938). McCarty Creek, Valanginian, Keyserlingi Zone, level 88, specimen SGM 1553/65.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having high widely spaced primary ribs that bear tiny conical tubercles near the ventral margin. From these pass pairs of much weaker secondary ribs that project strongly forward on the venter"; Imlay and Jones, 1970, p. B47), and the outer whorls which have distinctive perisphinctoid ribbing and weak constrictions, suggest close affinity with the Spiticeratinae. *P. paskentaensis* Imlay and Jones (Fig. 10G) were collected from the *pacifica* zone of the McCarty Creek section. The association of this species with *B. pacifica* Jeletzky was also indicated by Imlay and Jones (1970).

4.2.5. Phylloceratids and lytoceratids

Ammonites belonging to the Phylloceratida and Lytoceratida are relatively scarce (three specimens were found by V. Zakharov, and these groups were also uncommon in material described by Imlay and Jones (1970)). Only one juvenile phylloceratid ammonite (*Euphylloceras*? sp. juv. with a shell diameter of less than 1 cm) was collected in the upper part of the *pacifica* zone of the McCarty Creek section (level 65). One lytoceratid specimen of moderate size was collected from the *uncitoides* zone of the Grindstone Creek section, and is assigned to *Biasaloceras colusaense* (Anderson) herein (Fig. 10E). A second lytoceratid from the Valanginian part of the McCarty Creek succession (level 75, *pacifica* zone) is an indeterminable juvenile.

4.2.6. On the taxonomic position of the American "Kossmatia" and their occurrence in California

Since the publications of Uhlig (1907, 1911) and Burckhardt (1912), the ammonite genus *Kossmatia* is considered typical of the upper Tithonian of Mexico (see Cantú-Chapa, 2006 for a summary). Several upper Tithonian ammonites from Cuba and the USA were also referred to this genus (Uhlig, 1911; Albritton, 1937; Imlay and Jones, 1970; Myczyński, 1989). In California only three specimens assigned to *Kossmatia* were found, all originally described under separate names, and never recorded from outside California (Imlay and Jones, 1970). These ammonites were found within a short stratigraphic interval, and most likely belong to a single variable species. The earliest available name for this species is *Hoplites dilleri* Stanton, 1895 (Stanton, 1895, p. 82, pl. XVIII, figs. 6-7). The genus *Kossmatia* (with the type species *Ammonites tenuistriatus* Gray – see Gray, 1832, pl. 100, fig. 4) was established by Uhlig (1910) for ammonites from the Spiti Shales, NW India. Later, the genus was recorded from different regions of Gondwana, but due to strong faunal provincialism correlation of the *Kossmatia*-bearing beds with the SW European ammonite succession remains unclear. American occurrences of *Kossmatia* were dated rather precisely as Middle (?) Tithonian to Berriasian (von Hillebrandt et al., 1992; Villaseñor and Oloriz, 2019). Differences between American and Himalayan *Kossmatia* were at first emphasized by Énay (1972). A recent revision of the ammonite succession of the Spiti Shales by Énay (2009) has revealed that the age of the *Kossmatia*-bearing beds in the type region of this genus is earliest Tithonian. Age differences, as well as some details of morphology, especially on the ventral surface, which is characterized by common rib interruption in American "*Kossmatia*", but strongly forward projected ribs in typical *Kossmatia*, as well as stronger ribs on the inner whorls of American representatives led Énay (2009) to conclude that these should be considered as separate genera. He suggested that American "*Kossmatia*" could be included in the genus *Fierrites* Cantú-Chapa (Cantú-Chapa, 1993, type: *Perisphinctes Alamitosensis* Aguilera). This assignment seems appropriate for the Californian records. Villaseñor and Olóriz (2019) revised Mexican "*Kossmatia*" and assigned them to the new genus *Burckhardtieia*. However, these authors erroneously considered *Fierrites* as a *nomen nudum*. Moreover, their own new genus has been described without the indication of a type species, which renders *Burckhardtieia* a *nomen nudum*, according to ICZN articles 13.3 and 67.4.1 (see Rogov, 2019 for details). Following Énay's (2009) proposal, the name *Fierrites* is used here for all American "*Kossmatia*". The same approach is used in the recent issue of the Treatise online, devoted to the Perisphinctoidea (Énay and Howarth, 2019).

General features of the genus under discussion are well-described by Villaseñor and Olóriz (2019, as *Burckhardtieia*), and here their diagnosis is accepted for the *Fierrites* genus. Some additional comments should be done about the dimorphism of *Fierrites* and its relationship with true *Kossmatia*.

Énay and Howarth (2019) ascribed genera *Kossmatia* and *Fierrites* to different families (Ataxioceratidae and Neocomitidae respectively). This point of view, emphasizing differences between the discussed genera, can be discussed on the base of their microconchs. The genus *Kossmatia* is characterized by specific type of micrononch aperture, which is characterized by the presence of horn (which is typical for Paraboliceratinae). Microconchiate apertures of *Fierrites* are insufficiently known. Verma and Westermann (1973) although recognized here macro- and microconchs, does not provide any data about ther apertures. Only Villaseñor and Olóriz (2019, fig. 7) has figured microconchiate apertures of the genus *Fierrites*. This genus is sharing the type of aperture with true *Kossmatia*, as horns are relatively well-developed in *Fierrites*, while "lappets" are very small and rather looks as finite aperture curvature of the *Kossmatia* type (Énay, 2009, pl. 25, fig. 2; pl. 26, fig. 2; pl. 27, fig. 4; pl. 28, fig. 2). Thus here the genus *Fierrites* is considered as belonging to Paraboliceratinae.

4.3. Systematic paleontology

Superfamily Perisphinctoidea Steinmann, 1890.
Family Spiticeratidae Spath, 1924.

Genus ***Howarthiceras*** Rogov, gen. nov.

Derivato nominis. After M. K. Howarth, who was the first to suggest that Californian "*Groebericeras*" should be assigned to the separate genus.
Type species. *Groebericeras*? *baileyi* Imlay and Jones, 1970, from the upper Tithonian, *piochii* zone of California.

Diagnosis. Genus represented by the both micro- and macroconchs. Coiling is evolute, cross-section is oval to high oval in outline, with rounded flanks and ventral side throughout the ontogeny. Umbilicus is relatively wide. Inner whorls of macroconch as well as the whole shell of supposed microconch are covered by fairly strong, mostly simple ribs slightly wider than the interspaces, which trend radially on the lower part of the flanks but incline slightly forward on the upper part of the flanks, and arch forward on the venter (cf.

Fig. 11. A. *Olcostephanus* sp., McCarty Creek, lower Valanginian, *keyserlingi* zone, level 87c, specimen SGM 1553/71; B, E. *Neotollia* sp., lower Valanginian; B – Far East, Priokhotie, upper flows of the Tyl' river, specimen lost (photo from the archive of I.I. Sey and E.D. Kalacheva, Saint-Petersburg); E – northern Siberia, Boyarka river, outcrop 13, specimen SGM 1553/75, a dot indicates beginning of the body chamber; C. *Teschenites teschenensis* (Uhlig), upper Valanginian, Russian Far East, Monastyrka River basin, (= Sey and Kalacheva, 2001, pl. 3, fig. 2); D. *Teschenites* sp., McCarty Creek, lower Valanginian, *keyserlingi* zone, level 87c, specimen SGM BX-3/2-28.02.2020; F. *Sarasinella hyatti* (Stanton), McCarty Creek, lower Valanginian, *keyserlingi* zone, level 80, specimen SGM 1553/72; G. *Proniceras* cf. *pronum* (Oppel), Voskresenka, Ryazan region, Ryazanian, *rjasanensis* zone, specimen CNIGR 31–35/623 (= Bogoslowsky, 1896, pl. IV, fig. 5), inner whorls; H. *Jeannoticeras pecki* (Imlay), McCarty Creek, lower Hauterivian, *sublaevis* zone, *pecki* biohorizon, level 92, specimen SGM 1553/73; I-J. *Thurmanniceras stippi* (Anderson, 1938), McCarty Creek, lower Valanginian, *keyserlingi* zone, *stippi* biohorizon; I - level 87e, specimen SGM SGM 1553/77; J - level 82b, specimen SGM 1553/69.

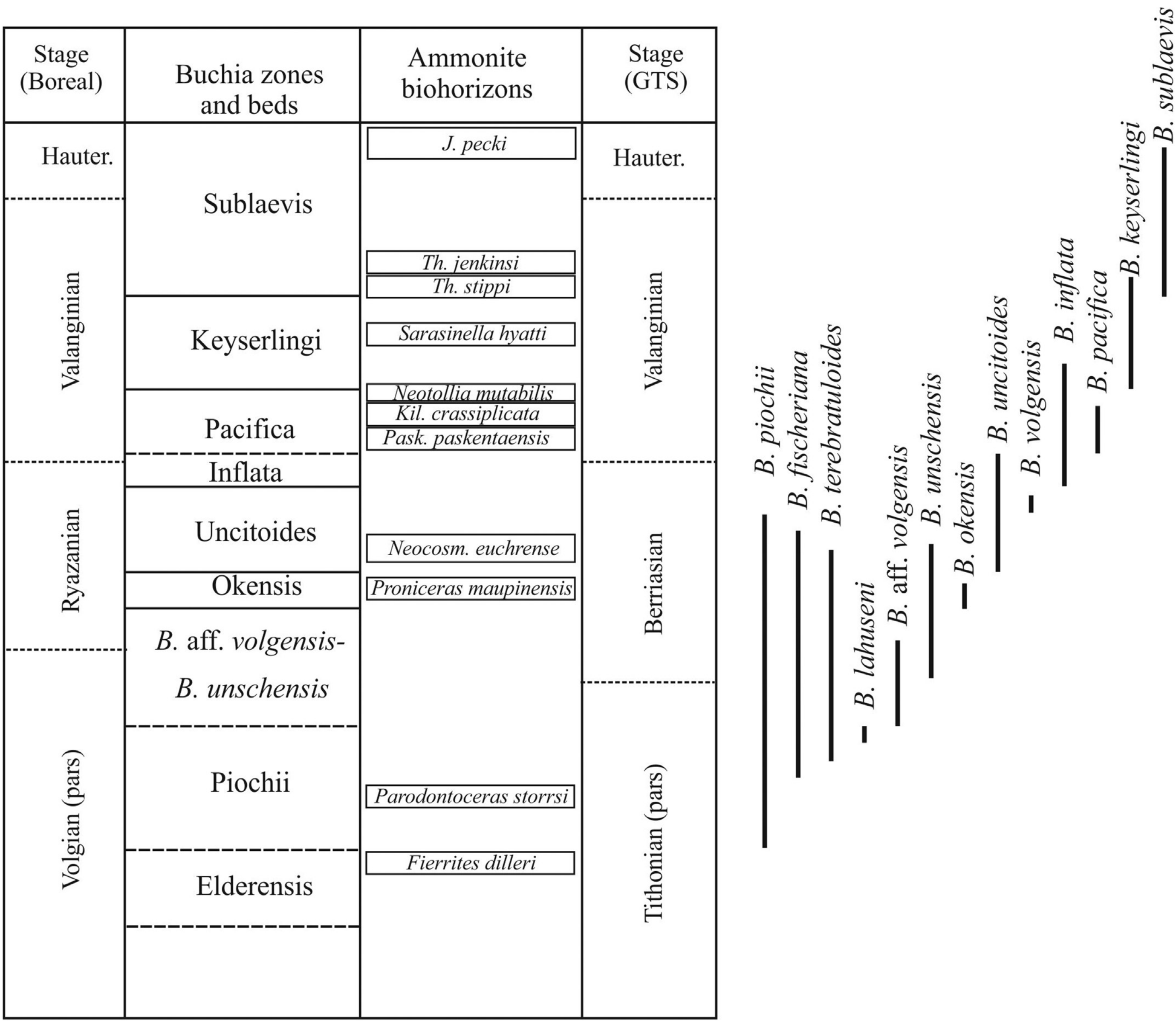

Fig. 12. Biostratigraphic subdivision of the Jurassic–Cretaceous boundary beds of northern California by ammonites and *Buchia*, its correlation with the Siberian succession of *Buchia* zones, and ranges of key *Buchia* species in studied sections.

Imlay and Jones, 1970). Further ornamentation gradually became relatively smooth, but it is still visible at the largest known outer whorls. Septal suture is unknown.

Discussion. The genus is very rare; with only two specimens known to date: a macroconch figured and described by Imlay and Jones (1970, p. 35, pl. 5, 15; pl. 6, figs. 1,2,5,6, 8-11) and a supposed microconch collected by V.A. Zakharov in the *piochii* zone of the McCarty Creek section (Fig. 10A). When describing species *Groebericeras*? *baileyi*, Imlay and Jones (1970, p. 37) indicated that this species “shows more resemblance to *Groebericeras* than to other taxa… A positive generic determination is not possible, however, because *Groebericeras* is to date represented only by a single species whose immature growth stages have not been illustrated and whose range of variation is unknown.” Today, we have much more information about the ammonite genus *Groebericeras*, which is well-illustrated and described from Argentina (Aguire-Urreta and Alvarez, 1999; Parent et al., 2011) and Iraq (Howarth, 1992). The new genus shows some resemblance to the Argentinian *Groebericeras* in the ribbing of the inner whorls, but it is characterized by much more strongly developed ribs than any figured *Groebericeras.* Howarth (1992) considered *G. bifrons* Leanza, the type species of *Groebericeras*, as a junior synonym of *G. rocardi* Pomel, originally described from Algeria. However, Aguire-Urreta and Alvarez (1999) indicated that within the limited variability of both species, Argentinian specimens are more evolute and strongly ribbed, and lack tubercles. Recently Cantú-Chapa (2012) on the basis of the septal suture pattern of the outer whorls, erected the new genus *Kurdistanites* (with *Ammonites rocardi* Pomel as the type) within a new subfamily, Groebericeratinae. However, a high variability of septal sutures of the outer whorls is well-known for many ammonoids (de Baets et al., 2015), and the introduction of both the new genus and subfamily is regarded as unnecessary here.

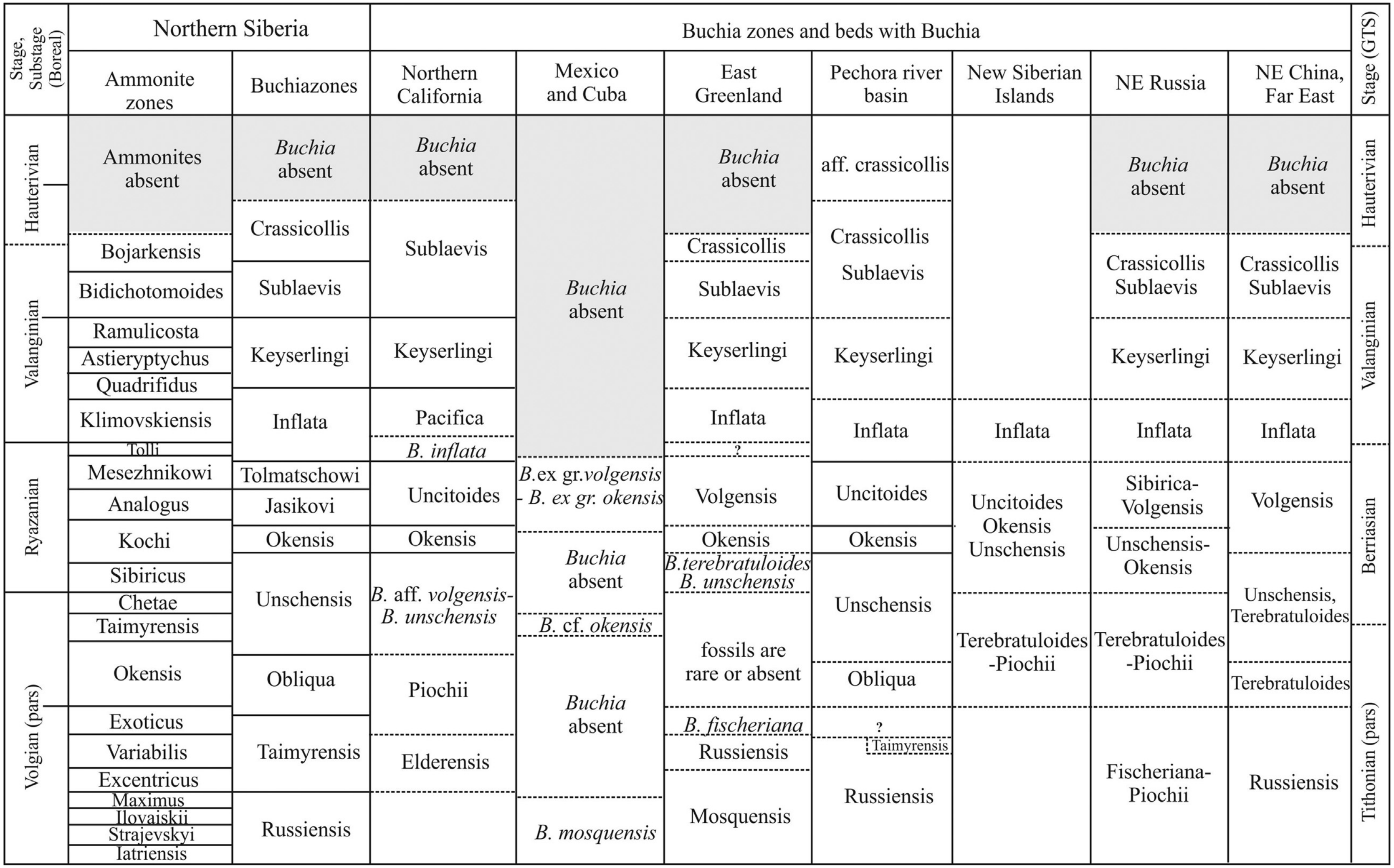

Fig. 13. Panboreal correlation of *Buchia* zones from the Middle Volgian to Hauterivian. The following papers should be used as a reference for this figure: northern Siberia, ammonite zones – Baraboshkin (2004); Rogov and Zakharov (2009); northern Siberia, *Buchia* zones – Zakharov (1981), 1987; California – this paper; Mexico and Cuba: beds with *Buchia* are proposed herein for the first time, based on *Buchia* records from Myczyński (1977), 1989, 1999; De la Mora et al. (2000); East Greenland – Surlyk and Zakharov (1982), with additions based mainly on re-interpretation of ammonite record by Alsen (2006); Rogov and Zakharov (2009); Pechora basin – Zakharov (1981), with minor corrections; New Siberian Islands – Kuzmichev et al. (2009); North-East Russia – Paraketsov and Paraketsova (1989), with minor corrections; NE China, Far East – Sha and Fürsich (1993); Urman et al. (2014).

5. Discussion

5.1. Comments on buchiid zonation and its Panboreal correlation

The significance of the *Buchia* faunas for the subdivision of the Jurassic-Cretaceous transitional strata of the Great Valley Group became clear since the pioneering papers studying this succession (Diller and Stanton, 1894; Stanton, 1895). Later the importance of the *Buchia* sequence was recognized by Anderson (1938), and Jones et al. (1969) introduced the succession of *Buchia* zones for this area, which is used as a primary zonal succession in all further studies.

Buchia zones can be considered as interval zones, since zonal boundaries are rarely defined by the FO and LO of the index species (exceptions are the Siberian *B. taimyrensis* and *B. tolmatschowi* zones; see Zakharov, 1987, Table 2; Hoedemaeker, 1987, fig. 10). Usually, the lower boundary of the zone is marked by the FO of its index species, which also ranges into the successive zone, or (as in the case of the *B. unschensis* zone of Siberia *and B. uncitoides* zone of California) the zonal boundaries are drawn at the start and end of a mass occurrence of its index species, which is also rarely occurring in the underlying and overlying units (Fig. 12).

5.1.1. Buchia elderensis *zone*

The *B. elderensis* zone was originally considered as a separate zone by Hoedemaeker (1987). It is defined by the full range of its index species, while the base of the overlying *piochii* zone is marked by numerous occurrences of *B. piochii.* However, the precise ranges of *B. elderensis* (And.), *B. russiensis* (Pavlow) and *B. piochii* (Gabb) within the *elderensis* zone of California are unknown. Taking into account available data concerning the range of the *B. russiensis* (Pavlow), which is common in the Middle Volgian but which also occurs in the lowermost Upper Volgian (Zakharov, 1981, 1987), the *elderensis* zone should be Tithonian in age. Additional evidence for the age of the basal part of the buchiid succession in California can be derived through the analysis of belemnite data, as Californian belemnite species *Lagonibelus napaensis* (Anderson) and *Arctoteuthis porrectiformis* (Anderson), at Nordvik (northern Siberia) appear in the upper part of the Middle Volgian, which corresponds to the upper Tithonian M20 magnetozone (Dzyuba, 2012).

5.1.2. Buchia piochii *zone*

The *Buchia piochii* zone is one of the oldest biostratigraphic units recognized in this region (Diller and Stanton, 1894). In contrast to nearly all other Californian *Buchia* zones, whose lower boundaries are marked by the FO of the index species, the lower boundary of the *piochii* zone (= *fischeriana* subzone of Jones et al., 1969) is unclear in some points. There are three possible events which can be used for delineation of this level: 1) disappearance of *B. elderensis* (Anderson); 2) appearance of *B. fischeriana* (d'Orbigny) and 3) mass occurrences of *B. piochii* (Gabb). Unfortunately, the lower boundary of the *piochii* zone *s. str.* was not studied by us, while data by Jones et al. (1969) cannot be used in support of any event. The only point, which should be taken into account, is a long stratigraphic range of *B. fischeriana* (d'Orb.), which appears in the Middle Volgian and disappears during the Berriasian, thus the second event seems to be not very good. The *piochii* zone lacks age-diagnostic ammonites, and conclusions about age of the *piochii* zone are based on indirect evidence. *Buchia piochii* (Gabb) is mainly recorded from the Pacific region. However, its occurrences are known from the Upper Volgian *Garniericeras catenulatum* zone of the Volga area (Gerasimov, 1955, pl. XIV, figs. 6, 7; Gerasimov, 1969, pl. VII, figs. 3, 5). Based on magnetostratigraphic data, this zone is correlated with the upper Tithonian (Rogov, 2014). The FO of *Buchia terebratuloides* (Lahusen), which appears at Grindstone Creek in the upper part of the *piochii* zone, is reported from the uppermost Middle Volgian with abundant records in the Upper Volgian (Zakharov, 1987). Taking into account the appearance of *B. unschensis* (Pavlow) (index species of the *unschensis* zone, which is mainly correlated with the lowermost Berriasian) above the *piochii* zone in California, a Tithonian age for this zone seems to be very possible.

5.1.3. Beds with Buchia *aff.* volgensis − B. unschensis

Beds with *Buchia* aff. *volgensis* − *B. unschensis* here are recognized for the first time, with Grindstone Creek as a type section (interval between levels 23 and 28, see Fig. 2). This unit corresponds to the lowermost part of the aff. *okensis* zone of Jones et al. (1969), as "*B. trigonoides* (Lahusen)" of these authors from the basal part of the former aff. *okensis* zone here is re-considered as *B.* aff. *volgensis* (Lahusen). This stratigraphic interval approximates to the *unschensis* zone of northern Siberia, which is characterized by mass occurrences of the type species associated with *B. terebratuloides* (Lahusen) and *B. fischeriana* (d'Orbigny). All these species occur also in the beds with *Buchia* aff. *volgensis* − *B. unschensis* of California. The lower boundary of the *unschensis* zone in northern Siberia lies a little below the J/K boundary. As has been shown by Zakharov (1990, fig. 4), mass occurrences of *B. unschensis* (Pavlow) at Nordvik are known from the lower part of the member VII, i.e. from the uppermost part of the *Craspedites okens*is ammonite zone. Hence in the studied Californian sections the Tithonian−Berriasian boundary is tentatively drawn within the beds with *Buchia* aff. *volgensis* − *B. unschensis.* It should be noted that the buchiid assemblage is very similar to those of California and is known also from the Far East (Sey and Kalacheva, 1999). Here *B. piochii* (Gabb), *B. terebratuloides* (Lahusen), *B.* aff. *volgensis* (Lahusen), *B. fischeriana* (d'Orb.) and *B. unschensis* (Pavlow) co-occurred throughout the Chigan Fm, the upper part of which is characterized by the presence of lower Berriasian ammonites.

5.1.4. Buchia okensis *zone*

The *Buchia okensis* zone at first was assigned by Jones et al. (1969) and Imlay and Jones (1970) to the Tithonian, mainly because of the unclear position of the Tithonian/Berriasian boundary in Tethys, although later Imlay (1980) still considered this zone as belonging to the Tithonian stage. On the other hand, the Berriasian age of the *Buchia okensis* zone was clearly shown by Zakharov (1981, 1987). In California as well as in other Boreal areas, the lower boundary of this zone is marked by the FO of the *B. okensis* (Pavlow). Ammonites from the *okensis* zone (see below) are also without any doubt Berriasian, and the age of this zone was also confirmed based on nannofossils by Bralower (1990). This is one of the best traced and shortest *Buchia* zones, which can be recognized in the nearly all Boreal areas. At the McCarty Creek section *B. okensis* zone was confirmed for the single bed only, while its lower part is perhaps corresponding to the observational gap, as follow from the measured thickness of this zone shown by Bralower (1990, fig. 8).

5.1.5. Buchia uncitoides *zone*

The *uncitoides* zone of California corresponds to the *jasikovi* and *tolmatschowi* zones of northern Siberia and is probably late Berriasian in age, as indicated by co-occurring ammonites. Such correlation of *Buchia* zones is supported by their relative position between the *okensis* and *inflata* zones, as well as by the presence of *B. jasikovi* (Pavlow) in the *uncitoides* zone of California, and rare occurrence of *Buchia* close to *B. tolmatschovi* (Sokolow) (*Buchia* ex gr. *uncitoides* - *tolmatschowi*) in the lowermost part of the beds with *Buchia inflata*. Both *B. uncitoides* and *B. jasikovi* shows their first occurrence in the upper part of the underlying *okensis* zone, and the lower boundary of the *uncitoides* zone is drawn by the mass occurrence of this species.

5.1.6. Beds with Buchia inflata

Beds with *Buchia inflata* are recognized in California for the first time (with McCarty Creek as the type section, between levels 57 and 61), their lower boundary is marked by the FO of *Buchia inflata* (Lahusen), while the upper boundary is defined by appearance of *B. pacifica* Jeletzky, although *B. inflata* (Lahusen) is also common in the *pacifica* zone. Beds with *Buchia inflata* of this paper correspond to the lower part of *pacifica* zone sensu Jones et al. (1969), and the lower part of the Siberian *inflata* zone. These beds lack age-diagnostic ammonites, and their age is unclear. The presence of the Valanginian ammonites (*Kilianella)* in the lowermost part of the overlying *pacifica* zone as well as a Berriasian age of the lower part of the former *pacifica* zone confirmed by calcareous nannofossils (Bralower, 1990) suggest that beds with *Buchia inflata* should be latest Berriasian or latest Berriasian to earliest Valanginian in age.

5.1.7. Buchia pacifica *zone*

The *pacifica* zone is characterized by occurrences of the index species, *Buchia pacifica* Jeletzky (its lower boundary is marked by the FO of the index species), and *B. inflata* (Lahusen). This zone is characterized by a relatively rich ammonite assemblage, which includes endemic taxa (*Paskentites)* along with typical early Valanginian genera (*Kilianella, Neotollia*), and an early Valanginian age of this zone is clearly confirmed by ammonites (see below).

5.1.8. Buchia keyserlingi *zone*

In contrast to North American endemic *Buchia pacifica* (Jeletzky), the index species of the overlying *keyserlingi* zone, *Buchia keyserlingi* (Lahusen), is widespread throughout the Panboreal Superrealm (sensu Westermann, 2000), and ranges from Valanginian to at least the lower Hauterivian. The lower boundary of the *keyserlingi* zone lies in the lower Valanginian, while the position of its upper boundary remains unclear. In northern Siberia the base of the overlying *sublaevis* zone is drawn approximtely at the lower/upper Valanginian boundary (Zakharov, 1981). The lower boundary of the *keyserlingi* zone in northern Siberia is corresponding to the mass occurrences of its index species, while the FO of *B. keyserlingi* in this region nearly coincides with FO of *B. inflata* (Lahusen). However, in California FO of these species are strongly diachronous, and here the lower boundary of the *keyserlingi* zone is marked by appearance of its index species.

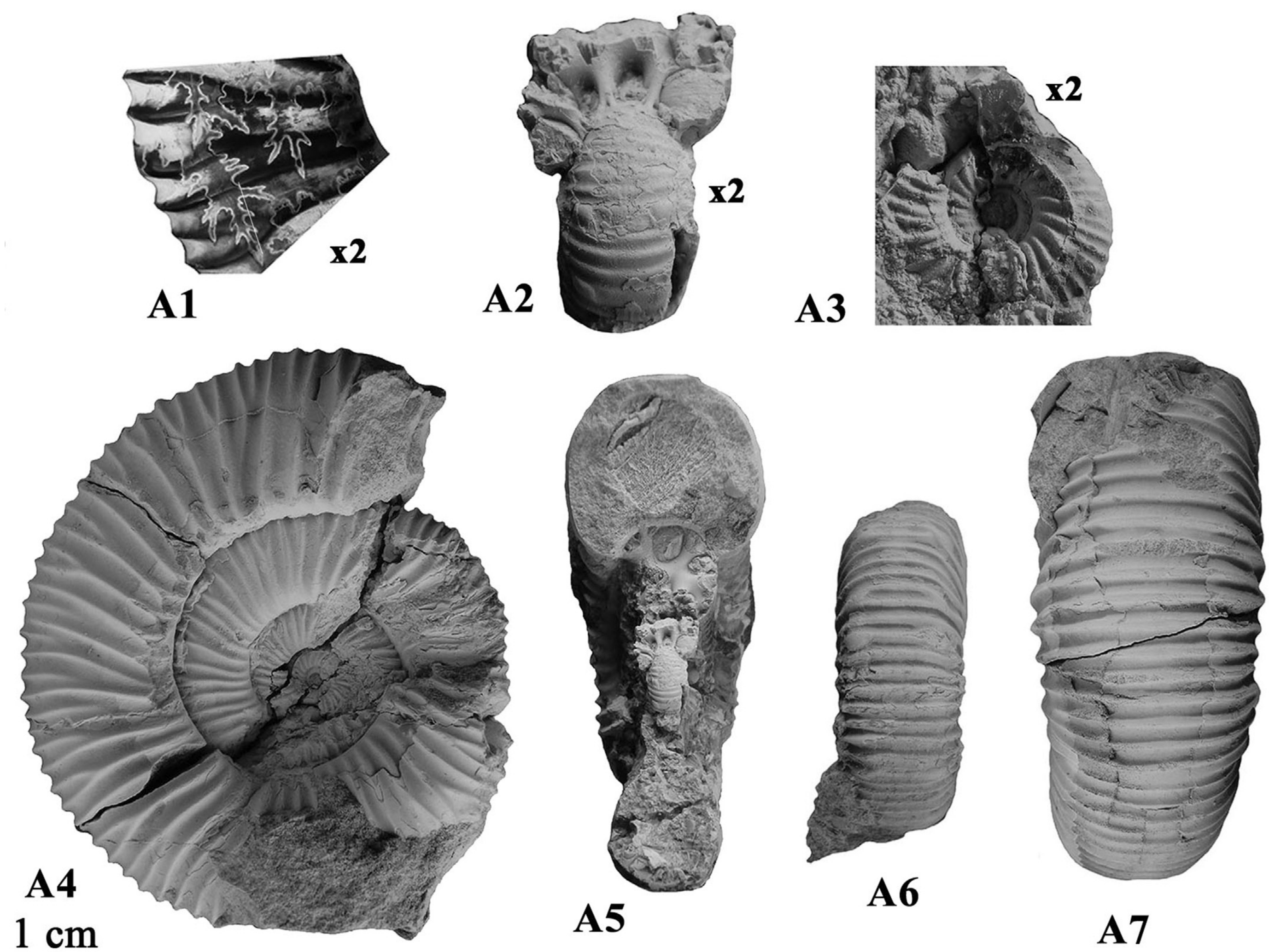

Fig. 14. A - Himalayitidae gen. nov.?, northern Siberia, Kheta river, outcrop 20, loose block of the Middle Volgian *Dorsoplanites maximus* zone, specimen SGM BX-3/1-28.02.2020 (see Supplement 2 for further information concerning localities).

5.1.9. Buchia sublaevis *zone (=* B. crassicollis *zone)*

The biostratigraphic unit with *Buchia crassicollis* (Keyserling) was among the first Lower Cretaceous intervals recognized in California (Diller and Stanton, 1894), and later (as *Buchia crassicollis solida* zone) where it was used by Jones et al. (1969) and Imlay and Jones (1970). In contrast to these studies, no specimens of *Buchia crassicollis* were recorded during the field works by Roth and Zakharov, but instead the uppermost part of the succession was crowded by a closely related species, *Buchia sublaevis* (Keyserling). Thus here we recognize the *Buchia sublaevis* zone (with McCarty Creek as the type section, between levels 87 and 92), which is nearly equivalent of the *Buchia crassicollis* zone of our forerunners. In other Boreal areas these species mainly occur in succession, with *B. sublaevis* below and *B. crassicollis* above (see Zakharov, 1981). However, in northern California some sections show records of *B. sublaevis*, while others are characterized by *B. crassicollis* occurrences. The age of the *sublaevis* zone based on Siberian and Californian data is spanning the early Valanginian to early Hauterivian. The uppermost reported records of the index species which correspond to the *jeannoti* subzone of the lower Hauterivian *loryi* ammonite zone, as follow from the *Jeannoticeras* occurrences (Imlay, 1960; see also below additional comments about ammonite succession). In England *B. sublaevis* appears in the lower Hauterivian (Ke1ly, 1990).

5.1.10. *Panboreal correlation of* Buchia *zones in the Middle Volgian (Tithonian) -Hauterivian*

Panboreal correlation of the Volgian *Buchia* zones has recently been published by Rogov and Zakharov (2009). Some minor revisions here concern the boundaries of the zones in selected areas. In the north Siberian succession the lower boundary of the *Buchia obliqua* zone and its correlatives, which previously were considered to coincide with the Middle—Upper Volgian boundary, is placed within the uppermost Middle Volgian *Praechetaites exoticus* zone, as in the Kheta river reference section where the FO of *B. obliqua* occurs in the upper part of the *P. exoticus* zone (Zakharov, 1990, fig. 2). As the mass occurrence of *B. unschensis* (Pavlow) appears in the lower part of the member VII at Nordvik (Zakharov, 1990, fig. 3), the lower boundary of the *unschensis* zone is placed in the uppermost part of the *Craspedites okensis* ammonite zone (Rogov et al., 2015). The rest of the Siberian succession remains unchanged. The precise age of the Tithonian *Buchia*-bearing beds in Mexico is unclear. De la Mora et al. (2000) indicated presence of *Buchia* throughout the lower Tithonian s.l. The only specimen of *B. mosquensis* (Buch) from the upper part of the lower Tithonian was figured (de la Mora et al., 2000, figs. 3—10.8), while other numerous species (including mix of Volgian, Ryazanian and Valanginian taxa) remain unfigured. Thus the unit with *B. mosquensis* (Buch) in the lower Tithonian can be tentatively recognized here (Fig. 13).

Next level with *Buchia* occurs at the Tithonian-Berriasian boundary of Cuba. Here *Buchia* cf. *okensis* (Pavlow) (Myczyński, 1989, pl. VII, fig. 6; pl. X, fig. 7) was found in association with *Salinites* spp., *Fierrites*, and other taxa, indicative of the Jurassic-Cretaceous transition, while small-sized juvenile *B. terebratuloides* (Lahusen) (Myczyński, 1999, figs. 4.3,5) occurred in the adjacent interval, between records of *Fierrites* and *Proniceras.* Above these records Myczyński (1977) recorded large-sized *Buchia*, which resemble upper Berriasian taxa, such as *B. volgensis* (Lahusen) (Myczyński, 1977, pl. 8, fig. 6) and *B. okensis* (Pavlow) (Myczyński, 1977, pl. 8, fig. 7), but he did not provide the stratigraphic position of these occurrences, indicating only the formational unit (Polier Fm, Valanginian - Barremian). These records are tentatively ascribed to beds with *B.* ex gr. *volgensis - B.* ex gr. *okensis.* Taking into account that beds with *Praechetaites tenuicostatus* of East Greenland now are considered as uppermost Middle Volgian instead of Upper Volgian (Rogov and Zakharov, 2009), *Buchia fischeriana* beds of this region also become uppermost Middle Volgian, while the *B. terebratuloides — B. unschensis* beds are transferred to the lowermost Ryazanian. The position of the *volgensis* zone upper boundary in East Greenland is unclear; the uppermost occurrences of *B. volgenis* (Lahusen) were referred to the *mesezhnikowi* ammonite zone by Surlyk and Zakharov (1982), but later Alsen (2006) recognized above this zone the *albidum* zone. The recognition of the *albidum* zone was based on re-determination of ammonites figured as *Bojarkia mesezhnikowi* Schulgina by Surlyk (1978, pl. 7, figs. 2-3). However, in our opinion these ammonites should be ascribed to *Bojarkia krimholtzi* Alekseev of the *mesezhnikowi* zone, but the presence of the *Tollia* ammonite zone in the eastern Greenland can be proven by *Tollia* records. In the succession of the Pechora River region the level with *B. taimyrensis* Zakharov is proven for the Volonga River section only, in which this species is associated with *B. russiensis* (Pavlow). Perhaps a small regional gap occurs here at the Middle—Upper Volgian boundary beds. Above the *B. obliqua* and *B. unschensis* zones are clearly recognized. This area is especially interesting because latest occurrences of *Buchia* here are known in association with upper Hauterivian ammonites *Speetoniceras* (Zakharov, 1981). The Volgian—Valanginian succession of the New Siberian Islands is almost lacking any ammonites except *Boreophylloceras*, and its stratigraphic subdivision is based solely on buchias (Kuzmichev et al., 2009). In contrast with other Siberian successions here the typical Pacific species *Buchia piochii* (Gabb) occurs. The Jurassic—Lower Cretaceous of North-East Russia also shows very uncommon ammonite records, while the buchiid succession permits only tentative recognition of substages. It should be noted also, that here *B. tenuicollis* sensu Paraketsov and Paraketsova is re-determined as *B. piochii* (Gabb), thus upper Volgian unit became re-assessed. The total range of the *B. piochii* (Gabb) in this region is unclear. Although Paraketsov and Paraketsova (1989) reported the presence of this species even in the Lower Volgian, precise stratigraphic position of figured specimens (Paraketsov and Paraketsova, 1989, pls. VII and VIII) even at the substage level is insufficiently known. The proposed succession of zones for the Far East is based on newly published study of the Komsomolsk section (Urman et al., 2014), while data from NE China (Sha and Fürsich, 1993) are partially corrected, as the specimen figured by the aforementioned authors as "*B. pacifica* Jeletzky" (Sha and Fürsich, 1993, fig. 3, k-m) in our opinion should be ascribed to the upper Valanginian *B. sublaevis* (Keyserling).

5.2. *Ammonoid succession of the Jurassic—Cretaceous boundary beds in northern California and its significance for Boreal-Tethyan correlation*

The ammonite records from the uppermost Jurassic and lowermost Cretaceous of northern Californian are important for inter-regional correlation (cf. Zeiss, 1983; Hoedemaeker, 1991). However, many species are represented by their types only, and both their total stratigraphic ranges and morphological variability are unknown.

Our data on ammonite distribution through the *Buchia* zones in California accompanied by those summarized by Imlay and Jones (1970) permits us to recognize the following tentative sequence of biohorizons (5.2.2—5.2.11):

5.2.1. Fierrites dilleri *horizon*

Imlay (1961) recognized beds with *Durangites* and *Kossmatia* [*Fierrites*] *dilleri* in the upper Tithonian of California (*Kossmatia — Durangites* assemblage in Imlay, 1980). Although the age of *Fierrites* in Mexico is unclear in some aspects (cf. Adatte et al., 1993; Stinnesbeck et al., 1993; Cantú-Chapa, 1993, 2006; Villaseñor et al., 2012; Riccardi, 2015; Villaseñor and Oloriz, 2019), it ranged from Middle Tithonian to Berriasian. von Hillebrandt et al. (1992) recorded two separate levels with *Fierrites* ("*Kossmatia*") in Mexico (faunas M16 *"K". victoris* and M19 *"K." exceptionalis*, although they also mentioned "*Kossmatia*" in faunas M14, M15 and M18). A provisional *dilleri* horizon can be recognized in the upper Tithonian of California at the base of the former "*Kossmatia*" records which were summarized by Imlay and Jones (1970). Due to insufficient knowledge of the age of *Fierrites* in Mexico as well as the absence of other age-diagnostic ammonites recorded from the same interval as *Fierrites* in California, its correlation is unclear. Juvenile "*Durangites*" was figured from near this stratigraphic interval in Paskenta (Anderson, 1945, pl. 2, figs. 4a, b), but this specimen is now lost (Imlay and Jones, 1970, p. B11), and its identification as *Durangites* is doubtful (Frau et al., 2015, p.121). The *dilleri* horizon perhaps corresponds to the level with *Fierrites aguilerai* (Cragin) and *F. zacatekanum* (Burckhardt) in the Malone Mountains, Texas, which lies at the top of the Malone Formation of this region (Albritton and Smith, 1965). Imlay (1980, p. 35) also reported here *F. rancheriasensis* (Imlay), which was previously described by Imlay (1943) from eastern Chihuahua, Mexico. However, it should be noted that Berriasian to Valanginian calpionellids were recorded below beds containing ammonites of *Kossmatia-Durangites* assemblage in San Pedro del Gallo (Mexico) (Pessagno et al. (2009, p. 197). The type locality of the *dilleri* horizon is USGS Mesozoic loc.666 (Imlay and Jones, 1970).

5.2.2. Parodontoceras storrsi *horizon*

Stanton (1895, p. 16) suggested that his *"Hoplites storrsi"* occurred nearly 1000 feet (~304 m) below the *"Hoplites dilleri"*, but later relationships between ranges of these taxa were re-assigned (Imlay and Jones, 1970). This species is missing in our collection, and as well as *Fierrites* occurs rarely in the Californian succession, as Imlay and Jones (1970) mentioned only nine specimens belonging to the genus under discussion, while *Paradontoceras storrsi* was represented by the holotype only. The latter co-occurred with the holotype of *Pseudophylloceras knoxvillensis* (Stanton) and *Aulacosphinctoides* sp. juv. (Imlay and Jones, 1970, pl. 12, figs. 1-2). *P.* cf. *storrsi* (Imlay, Jones, 1970, pl. 12. fig. 7, 8, 10) occurred significantly higher in the succession and could represent a separate species. The *Storrsi* biohorizon could be tentatively correlated with a level within the *alternans* zone of Argentina (Cerrito Caracoles section), which contains *Parodontoceras* cf. *storrsi* (Parent et al., 2013, fig. 21B). Recent advances in magnetostratigraphy of the Jurassic–Cretaceous boundary beds in Neuquén Basin (Iglesia-Llanos et al., 2017) revealed that based on magnetostratigraphic evidence the *alternans* zone of the Neuquén Basin corresponds to the interval spanning the upper part of the *microcanthum* zone and "Durangites" (=Andreaei) zone of the Standard Tethyan succession.

In Peru *Paradontoceras* sp. was mentioned from the upper Tithonian unit containing *Microcanthoceras* and *Substeuroceras* (Énay et al., 1996), thus age of these occurrences seems to be close to those in Argentina and California. Occurrences of *Parodontoceras* in British Columbia came from the upper part of the *Terebratuloides* zone, which corresponds to the uppermost Tithonian to lower Berriasian (Jeletzky, 1984). Sey and Kalacheva (2001) described and figured a single specimen of *Parodontoceras* from the Far East. They suggested an early Berriasian age to this ammonite, but as this specimen was found during the geological mapping without any co-occurring age-specific fossils, its age remains unclear.

5.2.3. Proniceras maupinense *horizon*

While describing *Proniceras maupinense*, Imlay and Jones (1970) indicated that all six specimens ascribed to this species came from the *Buchia* aff. *okensis* zone. However, *P. maupinense* (Imlay and Jones) was found in the *uncitoides* zone of the studied sections (Fig. 5N). Thus this biohorizon may correspond to the *okensis* – *oncitoides* boundary beds. On the other hand, the zonal boundary here was drawn based on 'negative' evidence, i.e. absence of *Buchia* aff. *okensis* (Pavlow). The genus *Proniceras* after Hoedemaeker et al. (2016) is restricted to the upper Tithonian – lowermost Berriasian (lower subzone of the *jacobi* zone). The stratigraphic position of the *maupinense* horizon within the *okensis* zone strongly contradicts such correlation, as from the both magnetostratigraphic (Houša et al., 2007; Bragin et al., 2013) and biostratigraphic (Shurygin and Dzyuba, 2015) lines of evidence the *okensis* zone and *kochi* ammonite zone correspond to a much higher level within the Berriasian. However, it should be noted that the generic assignment of at least Mexican *Proniceras* remains unclear. Parent et al. (2011) recently re-figured lectotype of *Proniceras pronum* (Oppel) (Parent et al., 2011, fig. 28 A), the type species of the genus *Proniceras*, and indicated that in contrast with its diagnosis published by Wright et al. (1996) this ammonite "shows the development of stout, rounded moderately elongate umbilical tubercles from about D = 15 mm, which are retained up to the end of the last preserved whorl without signs of any kind of lateral tubercles" (Parent et al., 2011, p. 62). Periumbilical tubercles are lacking in *"Proniceras" maupinense* (cf. Imlay and Jones, 1970, p. B32), which shared this feature with some other *"Proniceras"*- like spiticeratins, such as *"P." jacobi* (Djanelidze) (cf. Djanélidzé, 1922, pl. 1, figs. 5-9, pl. 14, fig. 6; Vašíček et al., 2018, p. 198, fig. 6 D-E) from the Jurassic–Cretaceous boundary beds.

It should be noted that *Proniceras* cf. *pronum* (Oppel) was previously reported from the type region of the Ryazanian Stage Bogoslowsky (1896), p. 72, pl. IV, fig. 5, re-figured herein (Fig. 11G), indicating that the lower boundary of the Ryazanian lies somewhere within the *jacobi* zone of the Mediterranean succession. This unique specimen came from the abandoned section located near to Voskresenka settlement, where a Ryazanian sandstone bed (0.5 m in thickness) overlies Oxfordian or Callovian black clays (cf. Bogoslowsky, 1896, p. 40). Such a conclusion is also supported by recent finds of ammonite genera *Riasanella* (badly preserved and doubtful) and *Riasanites* (much better preserved) in the famous Stramberg succession, in which these ammonites, typical for the Ryazanian Stage, were recorded in association with typical assemblage of the *jacobi* zone (Vašíček and Skupien, 2016; Vašíček et al., 2018). However, taking into account appearance of first *Riasanites* and *Riasanella* in the Russian Platform above oldest *Hectoroceras* (cf. Mitta, 2008, 2011), these biostratigraphic data contradicts with results of magnetostratigraphic correlation, and we need more solid magnetostratigraphic data from fossil-rich Boreal sites for further confirmation of interregional correlation. It should be noted that a poorly preserved ammonite referred to *Riasanella* was found in the lowermost part of the *jacobi* zone, which is corresponding to the M18r magnetozone (Vaňková et al., 2019) and thus to the uppermost Upper Volgian. *Riasanites* was found in old museum collection. Its precise stratigraphic position and locality remains unclear. However, this ammonite is co-occurred with lower Berriasian calpionellids *Calpionella alpina* and *Crassicollaria parvula* (Vašíček et al., 2017).

Rare occurrences of himalayitid ammonites in northern Siberia although very important for palaeobiogeography cannot be used for improving Boreal-Tethyan correlation as they show some differences from their Pacific or Tethyan counterparts. These are *Sachsia sachsi* Shulguna from the *Chetaites sibiricus* zone (see Shul'gina, 1975, p. 186, pl. XV, fig. 1 (figured as *Argentiniceras* sp. nov.) and Shulgina, 1985, p. 24), and Himalayitidae gen. nov. ? (Fig. 14), which was found loose but from analysis of lithologies and associated microfossils (provided by A.A. Feodorova and O. V. Shurekova), it probably came from the Middle Volgian *Dorsoplanites maximus* zone. The latter ammonite shows resemblance to some Argentinian himalayitids (such as *Catutosphinctes* or *Krantziceras*), but characterized by occurrence of ventrolateral nodes.

5.2.4. Neocosmoceras euchrense *horizon*

Neocosmoceras euchrense is a rare species, which previously was known by its holotype only (Imlay and Jones, 1970), which was found together with abundant *Buchia uncitoides* in locality 2074 (Oregon). One more specimen from McCarty Creek (Fig. 4V) came from the middle part of the *uncitoides* zone, where it co-occurs with *Blanfordiceras* (Fig. 4W). It could be synonymous with *N. crossi* (Anderson), whose holotype is represented by small fragments found by C. M. Cross and J. A. Taff at McCarty Creek. However, the latter species is badly preserved and cannot be determined through its type specimen (the only known specimen referred to this species). Taking into account the range of *Neocosmoceras* in other American successions (see discussion above, in the palaeontological part of this paper), this biohorizon could correspond to the upper *occitanica* to lower *boissieri* standard ammonite zones.

5.2.5. Paskentites paskentaensis *horizon*

Paskentites paskentaensis Imlay and Jones was represented in the collection of Imlay and Jones by eight specimens from the middle third of the *pacifica* zone. This level marks the position of the *Paskentites paskentaensis* biohorizon, with McCarty Creek as the type section. Correlation of this biohorizon with other ammonite successions is unclear, as the genus under discussion is a Californian endemic which was not found outside this region. However, its occurrence in the *pacifica* zone within the range of *Kilianella* and below FO of *Neotollia* suggests an earliest Valanginian age for this biohorizon.

5.2.6. Kilianella crassiplicata *horizon*

Imlay (1960, p. 171) recognized the "*Kilianella crassiplicata* provisional zone" in the lower Valanginian of northern California. Recognition of this unit was based on the study of three collections, one of which was described from McCarty Creek, the type section of the species under discussion, by Stanton (1895). The type specimen of *Kilianella crassiplicata* was found together with an unfigured specimen of *"Hoplites dilleri"* (cf. Stanton, 1895), which later was not mentioned by Imlay and Jones (1970) and whose assignment remains unclear. Distribution of the genus is restricted to the upper Berriasian to lower Valanginian. An early Valanginian age of the *crassiplicata* horizon fits well with other ammonite data from the Paskenta area (see below).

5.2.7. Neotollia mutabilis *horizon*

The craspeditid *Neotollia* is among the most typical early Valanginian genera in western and northern Siberia (Bogomolov, 1989; Vyachkileva et al., 1990; Shulgina et al., 1994, see Fig. 9E and F). This genus ranged from the base of Valanginian to upper part of the lower Valanginian, but disappears below the lower/upper Valanginian boundary (Bogomolov, 1989; Shulgina et al., 1994). Occurrences of this genus are also known from the Russian Far East (Fig. 9B), but the latter records were collected during geological mapping and their statigraphic position within the succession remains unclear. In California occurrences of *N. mutabilis* (Stanton) are restricted to the topmost part of the *pacifica* zone, while badly preserved *Neotollia* sp. also occurred in the lowermost *keyserlingi* zone. Imlay (1960) used this species as an index of the provisional "*Homolsomites mutabilis* zone". However, the rare ammonite occurrences and narrow stratigraphic ranges of taxa proposed as zonal indexes rather permits recognition of biohorizons not zones.

5.2.8. Sarasinella hyatti *horizon*

Sarasinella hyatti was described from Oregon only. However, its range remains poorly understood, as both the type specimen and another conspecific ammonite (Imlay, 1960, pl. 42, figs. 22, 24) came from imprecisely dated horizons, while specimens collected some 500 feet below the *mutabilis* horizon in localities 2154 and 4390 were unfigured. Thus, although Imlay (1960) suggested the range of *S. hyatti* lies between ranges of *K. crassiplicata* and *N. mutabilis*, this statement remains insufficiently proven. Here the *hyatti* horizon is tentatively proposed on the basis of the occurrence of the single specimen of species under discussion in the base of the *keyserlingi* zone of the McCarty Creek section.

5.2.9. Thurmanniceras stippi *horizon*

The interval from the middle part of the *keyserlingi* zone to basal part of the *sublaevis* zone of the McCarty Creek section is mainly characterized by occurrences of *Thurmanniceras stippi*/cf. *stippi* (Anderson). This is the type section for *T. stippi*, described by Anderson (1938) from upper part of the '*Aucella crassicollis* zone'. The holotype of *T. stippi* was found here some 1000 feet below the type specimen of *T. jenkinsi* (Anderson, 1938, p. 166). The same stratigraphic relationships between *T. stippi* and *T. jenkinsi* were reported by Imlay Imlay (1960), p. 216; Imlay and Jones (1970, p. B48).

5.2.10. Thurmanniceras jenkinsi *horizon*

Although this species was not found during our study of the McCarty Creek section, the presence of the separate level with *T. jenkinsi* (Anderson) in this section and other Californian localities was clearly shown by Imlay (1960; Imlay and Jones, 1970, see above). In California and Oregon the occurrence of this species is restricted to the *keyserlingi* zone, significantly below the *Jeannoticeras* occurrences (Imlay and Jones, 1970, p. B49). Correlation of this biohorizon with the standard Mediterranean scale remains unclear. The genus *Thurmanniceras* in Europe is mainly restricted to the lower Valanginian (Company, 1987), but at the McCarty Creek section (Fig. 3) the LO of *Thurmanniceras* lies close to occurrence of the typical upper Valanginian *Teschenites.*

5.2.11. Jeannoticeras pecki *horizon*

This species described by Imlay (1960) from Oregon and northwestern Washington as *Olcostephanus* was an index of the upper Valanginian. This species was reported as co-occurring with the latest buchiid species in the North American succession, *Buchia crassicollis* (Keyserling). In Russian sections the latter species is known from the Valanginian – Hauterivian transitional beds (*bojarkensis* zone, see Zakharov, 1981), as well as *B. sublaevis* (Keyserling), which is used herein as an index species for the Californian succession. Here *J. pecki* (Imlay) is recognized in California for the first time. As has been noted by Imlay (1960), *J. pecki* is very similar to *J. jeannoti* (d'Orbigny), the index species of the *jeannoti* subzone (upper subzone of the lower Hauterivian *Crioceratites loryi* zone) of standard Mediterranean succession (Reboulet et al., 2014, 2018). That is why we correlate the *pecki* horizon with the *jeannoti* subzone. However, the position of the Valanginian–Hauterivian boundary in the studied succession cannot be precisely determined. *Buchia sublaevis* (Keys.) co-occurred with *J. pecki* (Imlay), and is known from both the uppermost Valanginian and lowermost Hauterivian of the Siberian succession, and the discussed boundary possibly lies within this zone.

6. Conclusions

For the first time detailed data concerning ammonite and *Buchia* ranges through the key sections across the Jurassic–Cretaceous boundary of California are presented. The recognized buchiid succession (including newly proposed units) can be directly correlated with *Buchia* zones throughout the Panboreal Superrealm, providing good biostratigraphic background. As has been noted previously, ammonites in the studied succession are relatively uncommon and are known from some thin intervals only, thus early attempts to propose a succession of ammonite zones (Imlay, 1960) were later replaced by assigning ammonite occurrences to *Buchia* zones (Imlay and Jones, 1970). However, such a punctuate ammonite distribution permits the recognition here of a succession of infrazonal ammonite-based units, biohorizons, some of which provide direct correlation with European or South American ammonite successions.

CRediT authorship contribution statement

V.A. Zakharov: Writing - original draft, Writing - review & editing. **M.A. Rogov:** Writing - original draft, Writing - review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cretres.2020.104422.

Supplementary material

Supplement 1

Detailed description of the Grindstone Creek and MacCarthy Creek sections (by Peter Roth and Victor Zakharov)

Descriptions given below are based mainly on field determination of fossils, as only some specimens (nearly all ammonites but only part of buchiids) were transferred to the Geological Institute of RAS after the field works and now stored in the Vernadsky State Geological Museum (SGM, Moscow, Russia).

The following acronyms are used for determination of the bivalve abundance:

Abundant (A)

Very common (VC)

Common (C)

Very numerous (VN)

Numerous (N)

Rare (R)

Very rare (VR)

<u>Grindstone Creek Section</u>

Pacifica zone

<u>Points VZ90/07-01</u>

Detailed description is missing; this zone has been studied during the first days of works at this section and instead field notebook information concerning succession of beds was available as audio record (made by Peter Roth) only. At the lithological column succession of strata belonging to Pacifica zone was prepared by P. Roth. Description is given from youngest to oldest beds.

Pacifica zone (here and above)

<u>*Points VZ90/ 10-08*</u>

(8) This level is located in 10-15 m above the concrete dam upstream of the creek under the oak and farmer's buildings. Total thickness of rocks here is 6-7 m, they are represented by black shales (greenish when weathered) with rare limestone nodules (up to 20 cm in thickness and 50 cm in length). Very numerous shells of *Buchia pacifica* Jel. are equally scattered or form clusters; nests consists from dozens of valves showing different ontogenetic stages are presents. Shells preserved in shales are flattened, while those preserved in concretions are commonly well-preserved, albeit flattened valves are lies parallel to bedding. Numerous "humpback" buchiids, typical for *B. pacifica* species are occurred here, but typical *B. inflata* were also recorded. Coarse-ribbed buchiids are uncommon. Sometimes big convex valves are lies at the beaks; perhaps they are preserved at lifetime position.

Inflata zone

(9) Shales same as at the point 8. Limestone coquina bed (0,8 m in thickness) has been tectonically moved as far as 3 m. *Buchia pacifica* Jel. are very abundant, shells with coarse ribs are numerous. The following succession is observed here: 0-3 m - clay with very abundant *Buchia pacifica* and scarce *B. inflata*; 3-5 m – greenish-grey clay with 4 tuff horizons (1-3 cm in thickness). Fragments of a big inoceramid bivalve occurred at 20 m, and indeterminate belemnite guard at 5 m; 5-15 m – intercalation of clay and sandstone bands (1-2 cm in thickness), latter with lenses filled by buchiid valves (*B. inflata* and, possibly, *B.* cf. *pacifica*; occasionally *B. uncitoides* perhaps were also found here).

(10) Clays close to those from points 8 and 9, with very abundant *B. inflata* and rare *B.* cf. *uncitoides*. It should be noted, however, that juveniles of *B. inflata* were in field determined to as *B.* cf. *uncitoides*; big shells of *B. uncitoides* are missing here. At the level 15 m numerous *Buchia inflata* (as well as *B. uncitoides* ?) valves and fragmented valves covered bedding plane. Such mass occurrence of buchiids could be considered as connected with diastema.

Uncitoides zone

<u>*Points VZ90/17-11*</u>

(11) Clays similar to those in point 10, but without limestone bands, intercalated with light-greenish to greyish sandstone. Two lowermost sandstone bands had thickness 20 and 25 cm, respectively. Very abundant *B. uncitoides* were found just above the 1st sandstone band. Below this level *B. uncitoides* were found at each meter of the section, but they are especially abundant at the level 35 m.

(12) Intercalation of limestone and clay with egg-like cleavage. Buchiid shells and their fragments are crushed. All taxa found here are determined in open nomenclature only; these are *B.* cf. *piochii* (numerous within nests), *B.* cf. *uncitoides* (VC).

(13) Black dense, conchoidal shales. *B. uncitoides* (common in concretions) and *B.* cf. *fischeriana* (VR) are scarcely scattered throughout the bed as solitary shells without shell concentrations; big shells are absent, all small-sized. Juvenile *Euphylloceras* sp. juv. was found here. At 5.0- 15.0 m intercalation of clay and greenish-grey sandstone is well-visible; thickness of clayey bands is nearly 20 cm, sandstones are 5-10 cm in thickness.

(14) At the 15-30 m interval intercalation of clay and limestone (limestone beds are dominated). Among the buchiids very numerous *B. uncitoides* are encountered (including elongated and *B. terebratuloides*-like morphotypes within the single nest); *B. fischeriana* are also known from here. At 35-45 m thickness of sandstone bands and their frequency are gradually growing. Sandstones (which are possibly tuffaceous) here are represented nearly 50% of rock types. At 45 m within the sandstone band coquina consists from the complete and fragmented valves of *B. uncitoides* was found. Ammonites: *Negreliceras* cf. *stonyense*, *Biasaloceras* cf. *colusaense*.

(15) At the interval 0-24 m thick bands of sandstone are strongly prevailed, they are intercalated with sandy clays. Buchiids encountered here are varied strongly in form and size. *B. uncitoides* (VC) and *B. fischeriana* (VR) were found throughout the clays and sandstones, but coquinas are

presented in sandstones only. 10 m of the section is covered by the talus; beginning of this point is well-marked by cotton wood.

(16b) Sandstones here changes to sandy clays. Slopes of the Grindstone Creek valley are strongly grassed here, which is possibly caused by changes of prevailing rock types. Above black clays with limestone septarians (which are especially numerous at 10 m) occurred. Numerous strongly deformed fossils (ammonites and buchiids *Buchia terebratuloides* (C), *B.* sp. juv. cf. *uncitoides* (A)) were gathered in these limestone concretions. Buchiids are mainly represented by imprints of isolated valves; such juvenile buchiids are hardly determinable and they could belong to *B. terebratuloides*. Ammonites: *Negreliceras* cf. *stonyense*, *Proniceras maupinense.*

(16a) two meters below the 16 b. Septated limestone, with possible presence of siderite in its central part.

(17) Black shales with occasionally limestone concretions, which are sometimes visible under the grass. *B. fischeriana* and *B.* cf. *uncitoides* were collected at the level 25 m

Okensis zone

<u>Points VZ90/18-22, 28-34</u>

(18) Clay small-dustless, with uncommon concretions of aphanitic limestone septarians. Buchiids *B. uncitoides* (VC), *B. okensis* (C), *B. piochii* (VR)) were found in two of these concretions

(19) Dark clay in the lower part of the interval, with lenses of dark-grey limestone septarians at some levels. These lenses are up to 0,5-1 m in length and 0,2-0,25 m in height; they were not characterized by fossils. *B. terebratuloides* (VC) were found only at the 70 m within small concretions of soft limestone.

(20) Limestone at the level 80 m; its visible length is 0.5 m and height is 0,25 m. Buchiids (*B. terebratuloides* (N), *B. okensis* (VR) and *B. uncitoides* (VR) were encountered at the peripheral

parts of this limestone body only. They are preserved as separate valves and (uncommon) well-preserved articulated shells.

(21) At the 90 m limestone boulder (0,5x0,3 m), covered by the moss, is occurred. It is containing common *B. terebratuloides*.

(22) Continuous succession of rocks is missing. Some pieces and boulders of limestone are scattered between 90,0 and 105,0 m. Point 22 is at the 100 m level; 2 m below (point 22a) coquina with *B. okensis* (A), *B. terebratuloides* (C), *B.* aff. *fischeriana* (C), *B.* aff. *unschensis* (R), *B. volgensis* (R) is occurred. Dense aphanitic limestone concretion (0,7x0,1 m) has been found at p. 22. Peripheral parts of the concretion yields *B. terebratuloides* (common), *B. okensis* (very rare), preserved as separate valves.

(35) Limestone boulder at the top of the ravine (not in situ) contains *B. terebratuloides* (VC) and *B.* ex gr. *okensis* (VR). Articulated specimens are numerous, including big-sized well-preserved ones.

(34) Above the limestone (p. 33) nearly 10 m of the section is covered by the talus. Possibly here could be fractional zone. Above this interval limestone concretion with *Buchia terebratuloides* (C) and *B. okensis* (VR) has been found at the slope.

(33) 3 limestone concretions (0,25 m in thick) are exposed at the 10 m of the section. These concretions are containing *B. terebratuloides* (VC), *B.* aff. *volgensis* (C), *B.* ex gr. *okensis* (VR).

(32) Nearly 2 m above the p.31 a lens of the dense grey limestone with *B. terebratuloides* (N), *B.* aff. *volgensis* (R), *B. piochii* (VR) and *B.* ex gr. *okensis* (VR) is occurred.

(31) located at 7 m above the p. 30. Beaded limestone band with *B. terebratuloides* (N) and *B.* aff. *volgensis* (VC). Buchiids are mainly preserved as mould of articulated shells and well-preserved separate valves.

(30) Dense limestone with *Buchia terebratuloides* (VC) in nests and *B.* aff. *volgensis* (juv.)

(29) Lenses of strongly cleavaged limestone with nest-like accumulations of *Buchia unschensis* (R) and *B. terebratuloides* (VN).

Between point 29 and 30 ~ 4 m of the badly exposed mudstone.

(28) located 6,5 m above the p.27. Thin band of the limestone with poorly preserved shells of *Buchia unschensis* (R), *B. terebratuloides* (C), *B.* aff. *volgensis* (one specimen) and *B.* ex gr. *okensis* (3 valves).

Beds with *B.* aff. *volgensis - B. unschensis*

Points VZ90/23-27

(27) Between points 26 and 7 badly exposed black clays could be observed. *B. terebratuloides.*

(26) B. terebratuloides (VC) collected from “soft” limestone, in which bivalves are scattered or forming nests.

(25) Limestone band (0,25 m x ~ 3 m) is exposed at the left slope of the ravine. *B.* aff. *volgensis* are hardly to knock out as their relatively big valves are scale off. Bivalves are mainly preserved as separate well-preserved valves at the different growth stages.

(24) Light-grey dense limestone (0,25x1,5 m) with numerous buchiids *B.* aff. *volgensis* (C) and *B. fischeriana* (C) preserved as separates valves and (rarely) as full shells at the different growth stages.

(23) Concretionary band of the “uliginous” limestone (0,3x2 m). All buchiids are collected from the thin level. The are represented by *B. piochii* (VC), *B. fischeriana* (C), *B. terebratuloides* (C), *B.* cf. (aff.) *volgensis* (VR).

Piochii zone

Points VZ90/45-36

(36) Two lenses of grey soft limestone within the black shales, with *B. piochii* (C).

(37) Two small concretions of grey dense limestone within the black shales, with *B. piochii* (VC)

(38) Big fractured concretions of grey dense limestone with *B. piochii* (N) and *B. terebratuloides* (R).

(39) Limestone concretion, conchoidal at the outer part. In its inner part *Anopaea* (?) sp., *Howarthiceras* sp. juv. and buchiids *B. piochii* and *B. fischeriana* were found.

(40) At the 19.0- 28.0 m for the first time thin sandstone band (0,05 m, at the level 19 m) and sandstone member (2m5 m in thickness, at 24-27 m) are occurred. At 31-32 m two thin nodular bands of sandstone and limestone are occurred, with nests containing *B. terebratuloides*.

(41) Dense intercalation of sandy (1-2 cm) and clayey (3-5 cm) interbeds with thick limestone band, containing numerous fossils: *B. piochii* (A), *B. fischeriana* (R), *Pleuromya* sp. (one specimen), Heterodonta gen. et sp. indet. (one specimen).

(42) Big limestone band with *B. piochii* (VN) and *B. fischeriana* (VC), represented by nests consists from fragmented valves and uncommon articulated specimens at the different growth stages.

(43) Sandstone member it the right border of the creek, nearly 8 m in thickness, with limestone (0,3 m thick) in the middle part. Limestone containing nests with *B. piochii* (R) and *B. fischeriana* (C).

(44) Sandstone member with nearly 20 sandstone bands (0,5-10 m thick) within shales with rare limestone bodies (up to 0,2 m), latter with *B. piochii* (VC in nests) and *B. fischeriana* (R).

(45) Intercalation of sandstones, limestones and shales. *Buchia piochii* (VN in nests), *B. fischeriana* (VR), *B. lahuseni* (the same as in the p. 49b) were found in the limestone band only (0,2 m in thickness).

Points 43-45 are exposed at the Grindstone spring. Within the interval between points 45 and 36 two buchiid species are mainly encountered, *B. piochii* (A or C) and *B. fischeriana* (R)

<u>MacCarthy Creek section</u>

This section has been described at the base of observation at different localities (not in a single section). Field description (by V.A. Zakharov) and field figure (by P. Roth) of this section are revealing significant differences in thickness of units and / or distance between adjacent levels while compared. Currently we are unable to fix these inconsistences, and both figure and description are given ‘as is’.

Piochii zone

<u>*Points VZ90/46-52*</u>

(46) Situated near to the Pellows Road, Gold Canyon. Here there is an outcrop 10-12 m in length and 3 m in high, with intercalation of thin (3-5 cm) layers of sandstones and shales. Few limestone intercalations with buchiid shells in nests (with *Buchia* cf. *piochii* (VC) and *B.* cf. *fischeriana* (R)) are also present here.

(47) Located 500 m southwards from the point 46, at the right border of a creek. Shaly member with some sandstone intercalations, with limestone band (10 m in length and 0,2 m high), containing *B. piochii* (C).

(48) Located 1 km eastwards from the p. 47, at the base of the Wheack, quadrangle 19; SE corner of the McCarty Creek between Kelly Road and Pellows Road. At the creek course dense grey limestone and shales are exposed; nests with *B.* cf. *piochii – fischeriana* occurred in shales.

(49) 49a located 300-400 m eastwards from p. 48. Conglomerates and gravel, with *B.* cf. *piochii* (A); *49b* is located 40 m above the *49a*. Sandy shales, with nodules and lenses of limestone (with nests, containing *Buchia* ex gr. *fischeriana-lahuseni-piochii*)

(50) Located at the crossing of three ravines, which merged with McCarty Creek. Flyshoid intercalation of siltstone (5-10 cm) and clayey (10-15 cm) bands. Buchiid valves - *B. uncitoides* (R), *B. terebratuloides* (?) are scattered through the bedding planes.

(51) Located 40 m above the p. 50. The same rocks as in p.50, but with limestone bands.

B. terebratuloides (from limestone), *B.* cf. *uncitoides* (VR). Specimen *51b* – collected not in situ.

Okensis zone

(52) Located 50 m above the p.51. Flyshoid rocks. All buchiids, ascribed to as *B. unschensis, B.* aff. *okensis, B. terebratuloides, B. fischeriana* are collected from marlstone bed.

Uncitoides zone

<u>*Points VZ90/53-63*</u>

(53) located 200 m downstream from the fence. Black shales with limestone lenses. One of the limestone unit contained *B. uncitoides* (N), B. cf. *fischeriana* (small-sized) and ammonite *Proniceras maupinense*. Small-sized concretions with bivalved shells of *B. uncitoides* are found in talus. Nearly 20 m above limestone lenses with abundant *B. uncitoides* were encountered.

(54) Located 200 m downstream from the p. 53. Intercalation of shales and limestone bands, with uncommon sandstones. *B. uncitoides* (A), preserved mainly as separate valves were collected from limestone bodies.

(55) located 400 m downstream from the p. 54, near the gate and the road. Black shales with limestone concretions, containing numerous *B. uncitoides* (VN) and ammonites *Blanfordiceras* sp., *Neocosmoceras euchrense*.

(56) located 500 m downstream from the p. 55. Intercalation of black shales/clays with sandstones and limestone lenses. *B. uncitoides* (VN), *B.* ex gr. *volgensis* (VR) and *B.* ex gr. *unschensis* (VR) were collected from limestones and black clays. Buchiids preserved in nests and thin layers.

Beds with *Buchia inflata*

Points VZ90/57-61

(57) located 30 m stratigraphically above the p. 56. Few dozens of limestone, black shale and sandstone bands are located between the p. 56 and the p. 57, with *B.* ex gr. *inflata* and *B. uncitoides* (VR). FAD of *B. inflata* (R), occurred in 1m-thick sandstone bed. 18 m-thick member exposed here containing 4-6 thick sandstone beds, which crossed the creek and goes to nearby road.

(58) located 100 m above the p. 57. Limestone with *B. uncitoides – tolmatschowi.*

(59) Located at the left bank of the McCarty Creek, just at the mouth of deep ravine with metal pipe behind the farmer's shed; the succession described herein is ~ 30-35 stratigraphically above the point 58. Numerous *B. uncitoides* and *B. inflata* were collected from limestone concretions.

However, big-sized *B. uncitoides* shells are easily cracked, and well-preserved specimens are hard to gather.

(60) Soft limestone with band of carbonate sandstone, containing *B. uncitoides* (R) and *B. inflata* (C).

Pacifica zone

<u>*Points VZ90/61-83*</u>

(61) Located 8 m above the p. 60. Thin sandstone band below the limestone including a lens of buchiid coquina with *B. uncitoides*, *B. pacifica* and belemnite phragmocone.

(62) located 20 m above the p. 61. 20 cm-thick limestone band with *B.* cf. *uncitoides* (VR) and *B. inflata* (VR), located in the creek channel, at ravine's curve below the shed.

(63) located 30 m stratigraphically above the p.62. Intercalation of limestone lenses and black shales. Buchiids *B. uncitoides* juv. (VR) and *B. inflata* (VC) were found in limestone.

(64) located 50 m stratigraphically above the p.63. Intercalation of thin beds of black shales (15-50 cm), limestones (5-20 cm) and sandstones (20-93 cm). *B. pacifica* (VN) and *B. inflata* (VN), were collected from the lens of coquina sandstone 3-4 cm in thickness. At the left border of the creek shales also containing bivalved shells of *B. pacifica* (R).

(65) located 25 m stratigraphically above the p.64. Between p. 64 and p.65 at the left border of the creek thick siltstone beds intercalated with thin sandstone (10-20 cm) and limestone (20-25 cm) beds. *B. pacifica* (C) occurred in all rock types. In shales buchiid valves are equally scattered or occurred in small accumulations (2-3 specimen). In limestones buchiids are mainly occurred in nests, in sandstones – as coquinas. In concretion of yellow-orange limestone ammonites (*Euphylloceras* sp. and *Kilianella* sp.juv.) were found. 10 m stratigraphically above the p. 65 below the thick sandstone bed lens of carbonate sandstone containing separate valves of *B. pacifica* (A).

(66) located at the right border of the creek, nearly 20 m stratigraphically above the p. 65. Intercalation of black shales, limestones and sandstones. Buchiids *B. inflata* (VN) и *B. pacifica*

(VN) occurred in limestones (as nests), sandstones (lenses) and shales (uncommon scattered valves and small groups). They are represented by specimens at the different stages of development. Very big and very small specimens are uncommon, middle-sized ones are prevailed. Bivalved specimens are rare.

(67) located 20-25 m stratigraphically above the p.66. Between the p. 66 and p. 67 intercalation of black shales, sandstones and limestones is exposed. *B. inflata* (A) were collected in coquina sandstone lens below the sandstone lacking fossils. Buchiids occurred in the nearly all beds. I limestones they are well-preserved, while in black shales are crushed, usually in thin coquina layers.

Points described below occurred mainly at the left border of the creek.

(68) between the points 67 and 68 (~ 25 m in thickness) intercalation of black shales, greenish-grey sandstones and limestones (orange if weathered and grey inside) is exposed. *B. inflata* and *B. pacifica* (A) occurred in accumulations through the whole interval in members 3-4 m thick, subdivided by thin beds without buchiids (20-25 cm).

(69) located 18-20 m stratigraphically above the p.68; lithologies generally are the same (black shales, sandstones and limestones). Limestone beds here are thicker compared with part of the section described above. Three thin beds (10, 5 and 3 cm) of tuff occurred above the coquina bed. Buchiids *B. inflata* - *B. pacifica* (A) are very numerous, but bivalved specimens are uncommon.

(70) located 50 m stratigraphically above the p.69, at the left border of the creek 10 m from the column with inscription "15MPH on Bridge for trucks & busses". Intercalation of black shales and sandstones with rare limestone bands with *B. pacifica* (VC in black shales and A in coquinas).

(71) located 45-50 m stratigraphically above the p.70. Between points 70 and 71 intercalation of black shales, sandstone (10-25 cm kin thickness) and limestones (mainly in the lower part of this interval). *B. pacifica* (A) occurred in sandstone coquinas and in sandstones, relatively uncommon

in black shales and rare in limestones. This interval includes 5 thin layers (2-5 cm), consists from buchiid valves. Bivalved shells are rare; big and small-sized shells are also uncommon. “Curved” shells with widely ranged concentric folds are typical for these strata. Unfortunately, all shells are crushed.

(72) located 20-22 m stratigraphically above the p.71. Relatively thick sadstone bed (0,5 m), followed by few thinner sandstone beds is exposed at the creek’s channel and at the its left borde. Nearly 5 m above the next unit with 5 sandstone beds s located. *B. pacifica* (VN) represented by typical high and curved forms with attenuated near-beak part of the shell. Buchid remains occurred in coquinas above the thick sandstone bed, within the thinner sandstone bodies.

(73) located ~50 m stratigraphically above the p.72. Here few sandstone beds are exposed, with additions of limestone. *B. pacifica* (A) occurred in the both sandstones and limestones, their shells are mainly preserved as slightly crushed separate valves. Between points 72 and 73 some additional beds with buchiids could be recognized; thus, ~10 m below p.73 sandstone with buchiid coquina (30 cm) with ammonite remains is occurred.

(74) located 50 m stratigraphically above the p.73 (296 m below the lower boundary of the Keyserlingi zone). Black shales intercalated with sandstones and rare limestones. Coquina beds occurred each 2-3. *Buchia inflata - B. pacifica* (mix, A) collected at the level 296+-5 m. *(75*) located ~60 m stratigraphically above the p.74 (240 m from the Keyserlingi zone lower boundary). Between the points 74 and 75 intercalation of black shales and sandstones is exposed, while limestones are rare. *Buchia inflata - B. pacifica* (mix, A) occurred through the whole interval, with coquinas in each 5-10 m. Well-preserved *Buchia* were collected at the left border of the creek; they are resembling *B. inflata* rather than *B. pacifica.* Ammonites: *Kilianella crassiplicata*, *Biasaloceras* sp.juv.

(76) located ~105-110 m stratigraphically above the p.75. At the left border of the creek an outcrop 30-35 m in length and 4 m high is studied. Bed thickness here is 20-25 cm in average. Lens with buchiids is occurred in the bottom of the section, but here shell detritus (from

ammonites too) and broken shells are dominated. 1 m higher in sandy limestone bivalved buchiid shells showing different stages of the developments occurs; middle-size shells are prevailed here, but small (2-3 cm high) are also known, while very big ones (up to 5-6 cm) are very rare. Preservation of buchiids in limestone is generally poor and species hard to determine; Abundance of the both *B. inflata* and *B. pacifica* decreased. 45 m above the point 76 carbonate coquina sandstone (15-25 cm in thickness), filled by *B. pacifica* (A) occurred. Thin intercalations of shell detritus (0,5 cm) occurred. Valves of the small and middle size are dominated, while big shells are very rare.

(77) located ~105-110 m stratigraphically above the p.76 and 15 m above the coquina sandstone. Intercalation of black shales and greenish-grey sandstone with some limestone lenses is exposed here. Height of the exposed part of the section ~10-12 m. *B. inflata - B. pacifica* (VC) occurred throughout within the thin coquina beds, consists from valves and shell detritus, nests in limestone and crushed valves (or sometimes bivalves shells) in black shales.

(78) located 20 m stratigraphically above the p.77, and generally characterized by the same lithologies. *B. inflata - B. pacifica* (A) collected from the coquina bend within the sandstone (0,8 m thick). Shell detritus is dominated, while bivalve valves are less numerous; bivalved shells are missing. Observation on the 100 valves belonging to *B. inflata - B. pacifica* has shown that there are no trend in their distribution. Typical *B. pacifica* are slightly less numerous, while ribbed *B. pacifica* resembling *B. inflata* are numerous; from the other hand, nearly all specimens are crushed and some of them cannot be properly identified

(79) located 20 m stratigraphically above the p.78. Limestone bed exposed in the spring is in the highest part of the section. *B. inflata - B. pacifica* (VN) are preserved as separate valves. Neatly all types of shells typical for these species were found, without any trends in intraspecific variability. Ammonites are small but very common. This is the uppermost point containing *B. pacifica*.

Keyserlingi zone

Points VZ90/80-87f

(80) located 15-16 m stratigraphically above the p.79. Between the points 78 and 79 succession is poorly exposed, and only some ridges composed from limestone and sandstone occurred in the creek. *B. inflata* (VC) and *B.* cf. *keyserlingi* (C) collected from the concretions of sandy limestone. Small-sized specimens are dominated, along with middle-sized valves are.

(81) located 40 m stratigraphically above the p.80. Section at the left border of the creek ~ 20 m length and 2-3 m high consists from black shales with sandstone bands and rare limestone lenses. 20-40 m above some ridges of sandstone and limestone occurred with two *Buchia*-bearing units. 10 valves collected in one bed and one valve 15 m above. Among the collected specimens high and ovale – valved *B. inflata* could be determined.

(82) located 75-80 m stratigraphically above the p.81. At the right border of the creek the section ~ 50 m length and 2-10 m in high is exposed, with intercalation of black shales and sandstones with limestone lenses. Two smooth valves of *B.* ex gr. *inflata* were found in the limestone lense, and nest consists from 5-6 valves of the same species has been found in black shales.

(83) located 3 m stratigraphically above the p.82. Limestone lens (5-10 cm in thickness) containing numerous fragments of smooth *B.* ex gr. *inflata* shells and small piece of ammonite. Here and above buchiids, remaining *B. pacifica* are disappeared.

(84) located 17 m stratigraphically above the p.83. *B.* ex gr. *keyserlingi* (N) collected from sandstone and limestone concretions. Buchiids collected here are characterized by dense concentric folds, typical for *B. keyserlingi,* while ontogeny of the right valve of these specimens resembling those of *B. inflata.* Nearly 70 m above are covered by grass. Above this interval at the right border of the creek ca. 15 m of intercalation of black shales and sandstones with some limestone bands is well-exposed. Left valve of *B.* cf. *keyserlingi* has been collected from sandstone bed at the 10 m above the bottom of the section. 25-30 m downstream after the interval covered by vegetation sandstone ridges appear at the bottom of the creek. Thickness of these rocks is nearly 25 m. Section at the left border if the creek is nearly 50 length and 3-4 m

high. It is composed mainly by black shales with numerous sandstone bands and limestone lenses.

(85) located 190-200 m stratigraphically above the p.84. 15 m above the base of the section buchiids were collected below the “folded” limestone (~ 10 m from the oak). Downstream from the during the nearly 30 m some rocks are exposed at the creek bottom, while next 60 m are covered by vegetation, and afterwards some exposures at the left border of the creek. Total thickness of rocks exposed here is nearly 40 m. Black shales with intercalations of green sandstone are dominating rock types; thin limestone lenses are also present. *B.* ex gr. *keyserlingi* (C), preserved as separate average-sized valves, were found in the uppermost sandstone band only.

(86) located 130 m stratigraphically above the p.85. Here at the right border of the creek section 60-70 m length and 10-12 m high is occurred. Near to a bridge during the joint visiting of the section with D. Jones we have found *Buchia keyserlingi.* These specimens however, are differ from the typical specimens of this species by elongated shell and narrow near-beak part, while ontogeny of the right valve of these specimens resembling those of *B. inflata* or *B. pacifica.* Local *B. keyserlingi* distinguished from the typical *B. keyserlingi* by the same features as differ *B. pacifica* from *B. inflata.*

(87) located at the right border of the creek near to bridge. First buchiid assemblage has been collected 10-12 m above the p. 86. All sections could be traced ~ 100 m, and their height is up to 20 m. Additional localities are also present above the road. Fossils from separate levels are indicated by using letters a, b, c, d, e, f. Taphonomy of all buchiids collected here is identical.

(87a) (12 m above p.86) *B.* ex gr. *keyserlingi* (VC)

(87b) (6 m above p.87a) *B.* ex gr. keyserlingi (VC)

(87c) (5 m above p. 87b) *B.* ex gr. *keyserlingi* (VN); ammonite

(87d) (6 m above p. 87 c) *B.* ex gr. *keyserlingi*

Sublaevis zone

Points VZ90/87e-92

(87e) (15 m above p. 87d) *B.* ex gr. *sublaevis – crassicollis* Keys. 5 m below this point and 6-7 m above small juvenile buchiids were found.

(87f) (10 m above p. 87e). Ammonite from limestone concretion.

Above the point 87 f there is a little gap in the section located at the right border of the creek; but corresponding units could be found in the ravine in the left border of the creek.

(88) located in the deep ravine, inflow from the left side to the McCarty Creek in 50-60 m downstream the bridge. Here limestone lens with *B.* ex gr *keyserlingi* (A) and ammonite piece were found. These rocks have nearly the same age as those marked here to as 87 b, c, d, e

(89) subdivided on two subpoints.

(89a) big locality at the left border of the creek, 25-30 m above the p. 87f. Two belemnite rostra and one phragmocone were found here.

(89b) located 3 m below the p. 89a. Black shales with nest of *Buchia*; one specimen of *B.* ex gr. *keyserlingi* has been collected.

(90-91) Very big section at the left border of the McCarty Creek, composed from intercalation of black shales with sandstones and limestones. It is located nearly 500 m downstream from the bridge. Thickness of separate beds could not be precisely determined here. Thickness of rocks exposed between points 90 and 91 is nearly 150 m.

(92) Above the point 91 an assemblage consists from *Buchia sublaevis* and *Jeannoticeras pecki* has been found.

Succession of *Buchia* zones, exposed along the McCarthy Creek:

Piochii Zone (points 46-52)

Uncitoides Zone (points 53- 63)

- Uncitoides – Tolmatschowi Subzone (points 55-58)
- Uncitoides – Inflata Subzone (points 59-63)

Pacifica – Inflata Zone (points 64 – 84)

Keyserlingi Zone (points 85- 87d)

Sublaevis Zone (points 87e - 92)

Supplement 2

Coordinates of sections which not shown in map:

Boyarka river, outcrop 13, northern Siberia 70.617856 N, 97.341371 E

Kheta river, outcrop 20, northern Siberia, 70.532090 N, 95.445537 E

Monastyrka River basin, Far East, 44.337473 N, 135.737793 E

Nordvik, northern Siberia 73.941438 N, 112.944362 E

Upper flows of the Tyl’ river, Far East, Priokhotie, 54.162462 N, 135.071419 E

Voskresenskoe, Ryazan region (now - Voskresenka), 54.232226 N, 39.455905 E