Integrated isotope and biostratigraphy of a Lower Cretaceous section from the Bakony Mountains (Transdanubian Range, Hungary): A new Tethyan record of the Weissert event

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A B S T R A C T

An integrated stratigraphic subdivision, on the basis of ammonites, belemnites, calpionellids and stable isotope ratios is proposed for the Lower Cretaceous carbonate succession of the Hárskút, Közöskút Ravine (HK-12), (Bakony Mts, Hungary). Abundant and diverse cephalopod assemblages occur in middle and late Berriasian Rossa Ammonitico facies, in a nearly complete sequence spanning the Tirmovella occitanica and Fauriella boissieri Zones. A new belemnite species, Duvalia hungarica, is described from this level. The overlying Lower Valanginian strata are condensed, but also yield rich assemblages of the Thurmanciiceras pertransiens and Busnardoites campyloptous Zones. The cephalopod fauna of the Late Valanginian Saynoceras verrucosum Zone is much less diverse. The overlying 19 m interval of Bianconietype marl yielded no megafossils. The uppermost part of the profile late Haueterivian cephalopods were found. Stable isotope analysis shows a well-defined positive δ13C excursion in the Valanginian strata, identified for the first time in Hungary. Although correlated with a possible anoxic event (known as ‘the Weissert event’), as in many other sections, no black shale or organic-rich level is recorded at Hárskút. © 2010 Elsevier Ltd. All rights reserved.

1. Introduction

To date more than 30 sections are known globally where a significant positive carbon isotope excursion occurs in Valanginian (Lower Cretaceous) strata. The isotope excursion marks the first of several significant carbon cycle perturbations in the Cretaceous and by analogy to younger Cretaceous isotope anomalies, the event may be linked to an oceanic anoxic event (termed the ‘Weissert event’ by Erba et al., 2004). The lack of black shales calls into question the extent of anoxia (Westermann et al., 2010). However, the event is an episode of remarkable change in the Earth system, possibly causally related to the formation of the Paraná-Etendeka large igneous province (Erba et al., 2004).

Here we present, from the Transdanubian Range in Hungary, a new stable carbon isotope stratigraphy integrated with ammonite, belemnite and calpionellid biostratigraphy. The independent biostratigraphic data corroborate the temporal framework and allow a global correlation of the isotope event and biotic change. The Lower Cretaceous formations of the Transdanubian Range have been studied since the mid-19th century, the early period of Hungarian geology (Hantken, 1868). A detailed account on the stratigraphy and palaeontology of the Cretaceous formations of the region was given by Fülöp (1964). It is in this monograph where the outcrop of the Közöskút Ravine near Hárskút was first described as an important Early Cretaceous fossil locality. The biostratigraphic evaluation of the succession was based on a rich invertebrate assemblage, which was collected in 1960–1962. The fauna contains hundreds of megafossils, mainly pelagic cephalopods (ammonites, belemnites and rare nautiloids) but also some benthic elements (brachiopods, crinoids, echinoids, trace fossils, and rare bivalves and gastropods). Although the collection was carried out bed-by-bed, the biostratigraphic assignments and conclusions of Fülöp (1964) were only approximate. No precise boundaries between zones, substages or stages were drawn, and the cephalopods collected from different levels were discussed together. The potential benefits of a modern revision of the fauna are therefore not restricted to a taxonomic

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update but will also make full use of the stratigraphically controlled collection in establishing the biostratigraphic subdivisions within the section.

Therefore, the main aims of this paper are (a) to establish an integrated stratigraphy of the section, with a special focus on the abundant and diverse cephalopod (ammonite and belemnite) fauna, (b) to demonstrate the Valanginian carbon isotope excursion for the first time from Hungary, and (c) to contribute to a better understanding of the Weißert event and its biotic consequences on the basis of our new data.

2. Geological setting

The studied section is situated in the southwestern part of the central Bakony Mts, about 2.5 km east-southeast of the village of Hárskút. The geographical location and geological setting of the studied locality is shown in Fig. 1. The Bakony Mts belong to the Transdanubian Range, representing a key part of the Bakony Unit (Kázmér, 1986), which in turn is part of the AlCaPa composite terrane (Csontos and Vörös, 2004). Together with other units of Austroalpine affinities a Mesozoic stratigraphic sequence deposited on the southern passive margin of the Neotethys ocean is preserved.

The section is located on the northwestern side of a valley called Közöskút Ravine. Geographical coordinates for the section are 47°9’58.17”N, 17°47’11.48”E. The ravine itself provides a classical outcrop of a Lower to Middle Jurassic Rosso Ammonitico-type succession with repeated gaps due to non-deposition (Fülöp et al., 1969; Galácz, 1975). The Upper Jurassic is represented by cherty marls of Biancone-type, of Szentivánhegy Limestone Formation which becomes gradually less continuously passes upwards into the Upper Tithonian Ammonitico-type Pálihálás Limestone Formation. The latter unit (Fülöp et al., 1969; Galácz, 1975) represents a Mesozoic stratigraphic sequence deposited on the southern passive margin of the Neotethys ocean is preserved.

The section is now largely covered by debris and soil. The uppermost part of the trench crosses a forest track, and it ends in a small pit (Fig. 2E), from where poorly preserved latest Hauterivian ammonites were collected. The stratigraphy and the main features of section HK-12 are presented in Fig. 2.

Preservation of the ammonites is varying throughout the section. The lower (Berriasian) beds yielded strongly dissolved internal moulds only, which is typical for the Rosso Ammonitico-type facies. Large-sized, complete specimens and/or fragments of larger ones are common, whereas small-sized forms are missing. In the Valanginian strata the preservation is somewhat different: small-sized forms (including microconchs) are common and bigger specimens are mostly represented by fragments. Bed 10, which is densely fossiliferous, yielded internal moulds and also some exceptionally preserved specimens with perminalized shell remains. Phragmocones and separately preserved body chamber fragments occur together. Many of the ammonites from this level are eroded and only their lower side is preserved. These features suggest a strong condensation for Bed 10. The latest Hauterivian ammonite fauna collected from the marl pit situated at the top of the section comprises poor fragments of dissolved internal moulds only.

The preservation of the belemnites from section HK-12 is generally very good, except for some solution marks. Many of the guards are preserved with a part of their phragmocone. The majority of the guards belong to the family Duvaliidae, dominated by Duvalia ex gr. lata and Pseudobolus ex gr. bipartitus, representing typical off-shore species.

The association described herein consists mostly of mature forms. Juvenile and immature specimens of Duvaliidae, as well as Mesohibolitidae are virtually absent. Occasionally the presence of boring barnacles (Acrothoracica, Cirripedia) (Fig. 7, 8R) is characteristic. The completeness of the material and the presence of alveolar remains would indicate a nearly complete lack of transport.

Other cephalopod remains found in section HK-12 include several aptchi, a few rhyncholiths and two nautiloid internal moulds with shell remains. The fossils from section HK-12 are deposited in the museum of the Hungarian Geological Institute. Most of the specimens which belong to the suborders Phylloceratina and Litoceratina, the representatives of the genus Neolissioceras, and some other Ammonitina specimens were entered into the inventory under the successive inventory numbers K-11326–K-11501. The rest of the stratigraphically useful
Ammonitina and belemnite specimens have successive inventory numbers between K 10.1.1. and K 10.327.1.

3.2. Other macrofauna

The most common benthic fossils are the brachiopods, represented by more than 200 specimens. The majority belongs to the genera *Pygites* and *Triangope*, whereas *Nucleata* is less common. At least two species are distinguished among the more than 30 specimens of irregular echinoids. Bivalves and gastropods are rare; none of the few, poorly preserved internal moulds can be identified. Irregular, branching trace fossils also occur in the section. The only vertebrate remains are isolated teeth of pycnodont and cartilaginous fishes.

3.3. Calpionellids

Calpionellids were studied in thin sections, which were made soon after collecting the samples in 1961. At least one thin section was prepared for each of the 45 beds. Some of the thin sections were made from ammonite internal moulds. When revisiting the section recently, further samples were taken and additional thin sections were prepared from Bed 10 and beds immediately below and above it, in order to better understand the changes of the microbiofacies and calpionellid succession in this critical interval.

3.4. Stable isotope studies

A total of 73 samples were taken from section HK-12. Average spacing of samples was ~0.2 m in the well exposed lower part (Beds 45–10). Above Bed 10, where outcrop conditions were generally poor, samples were obtained from evenly spaced pits, separated by ~0.6 m in stratigraphic thickness. Higher resolution sampling (15 samples over a thickness of 1.35 m) was carried out immediately below, within and above Bed 10, after analyses of the initial suite of samples located a major carbon isotope excursion in this interval. Subsamples, avoiding macrofossils and sparry calcite veins, were then taken for stable isotopic analysis. Carbonate powders were analysed on a VG Instruments Optima Isotope Ratio Mass Spectrometer with a Multiprep Automated Carbonate System (at the University of Plymouth) using 200–300 micrograms of carbonate. Isotopic results were calibrated against NBS-19. Reproducibility for both $\delta^{18}O$ and $\delta^{13}C$ was better than ±0.1‰, based upon duplicate sample analyses.

4. Stratigraphical results

4.1. Ammonites

The stratigraphic distribution of the Berriasian to Valanginian ammonite fauna is given in Table 1. The biostratigraphy is primarily based on the standard Mediterranean ammonite zonal scheme (Reboulet et al., 2009), which is unambiguously applicable owing to the paleobiogeographical affinities of the studied assemblages. Some of the stratigraphically important ammonite taxa of this interval are illustrated in Figs. 3–6.

4.1.1. Berriasian

The Berriasian part of the profile yielded a moderately diverse assemblage of different berriasellids, and representatives of early olocostephanids. The revision of the fossils led to the recognition that the lower part of the section (Beds 45–13) represents a largely complete Middle and Upper Berriasian succession. The zonal indexes for the *T. occitanica* and *Fauriella boissieri* Zones were recognised in numerous successive beds. *T. occitanica* (Fig. 5F,G) is represented by many specimens. Most of them have a larger umbilicus than the type, some of them are extremely loosely coiled. *F. boissieri* (Fig. 4A,B) shows a wide variability in terms of ribbing density and style. It ranges up to the Valanginian as the latest representatives of the species were found in Bed 10. Specimens of the genus *Neolissoceras* (Fig. 5C) are also very frequent.
Haploceras elimatum, which is very common throughout the Tithonian, was also documented from the Middle Berriasian. This confirms the findings of Olóriz (1978) that this species is not restricted to the latest Jurassic.

4.1.2. Valanginian

Beds 12–10 yielded a condensed and rich Early Valanginian ammonite fauna in which Olcostephanus drumensis (Fig. 3C–H) is the most abundant species. Beds 12 and 11 are assigned to the
Thurmanniceras pertransiens Zone whereas the strongly condensed Bed 10, which still contains some elements of the Pertransiens Zone, represents at least some levels of the Busnardoites campylotoxus Zone. The typical Pertransiens Zone ammonites—e.g., numerous specimens of the zonal index (Figs. 3Q and 5D,E,H)—are represented by internal moulds preserved with both sides intact in most cases, while many of the Campylotoxus Zone ammonites occur as eroded specimens, with only their lower part preserved. This taphonomic difference suggests that the fauna of Bed 10 is not mixed but condensed, and the fossils were not separated according to their position within the bed during collection.

Beds 9–1 are assigned to the early Late Valanginian Saynoceras verrucosum Zone. Albeit the index species is missing, the age of these strata is proved by the first appearance of Oosterella (Fig. 3M) and the oldest neocomitids, including various species of Rodighieroites, (Fig. 3L) Sabbaiceras (Fig. 3A) and Neohoploceras. The rich Kilianella assemblage found in the underlying beds is absent here. The change in the olcostephanid fauna is also characteristic: the late Early Valanginian O. drumensis is missing and only O. guebhardi (Fig. 3R) persists. The typical Late Valanginian Valanginites is rare. Although the upper part of the Biancone-type marl contains no megafossils, it is thought to represent the higher part of the Late Valanginian.

4.1.3. Hauterivian

The rich ammonite assemblage collected from a marl pit at the top of the section most probably indicates a latest Hauterivian age. Beside the very common phylloceratids (Fig. 6A,B) and lytoceratids, it contains numerous desmoceratids, crioceratids, hamulinids and ptychoceratids (Fig. 6D). Representatives of Neolissoceras and early pulchelliids (Discoidea spp.) (Fig. 6C) are rare, but their presence also supports the Hauterivian age. Fülöp (1964) assigned the whole assemblage to the Barremian, and listed also Silesites cf. vulpes (a typical early Barremian form) and Spitidiscus sp. (this may refer to an early Barremian holcodiscid ammonite). During our revision of the fauna none of these Early Barremian taxa were recognized, we therefore cannot confirm a Barremian age. On the other hand, some belemnites, like Hibolitites sp. and Duvalia ex gr. grasesiana (Fig. 6G–L) collected from section HK-12 (unfortunately without precise indication of occurrence) may indicate Late Hauterivian or Early Barremian age.

4.2. Belemnites

The stratigraphic distribution of the Berriasian to Valanginian belemnite fauna is given in Table 2. Some of the characteristic taxa of this interval are shown in Figs. 7 and 8. Taxonomic remarks and the description of a new species are given in Appendix 1. Because a widely accepted belemnite-based biozonation is lacking for the Early Cretaceous, the studied section is subdivided into successive local associations of belemnite faunas, the characteristics of which are described herein. These associations are numbered from BA-I (oldest) to BA-VI (youngest) (Table 2), and their age and correlation is discussed below.

BA-I includes Beds 42–19 and is pre-Middle Berriasian to early Late Berriasian in age. It is dominated by Duvalia aff. guillantona (Fig. 8U,V) is recorded in Bed 32, that of Duvalia miraventesis (Fig. 8S,T,Z,W) is in Bed 25. The first occurrence of Pseudobelus bipartitus in Bed 20 indicates the Late Berriasian, possibly the level of Berriasella picteti Subzone (Janssen, 2003, p. 131).

BA-II includes Beds 18–15 and is mid-Late Berriasian in age. This unit commonly yields P. bipartitus, besides other characteristic elements such as Conobelus (?) piradoensis (Fig. 8AA,BB), Conobelus...
Fig. 3. Representative Berriasian and Valanginian ammonites from the Hárskút section (HK-12). (A) Sabbaiceras stefanescui Avram and Gradinaru, 1993 (inventory no: K 10.1.1.) Bed 6, (B) Kilianella roubaudiana (d’Orbigny, 1850) (K 10.2.1.) Bed 10, (C) Olcostephanus drumensis (Kilian, 1910) macroconch (K 10.3.1.) Bed 10, (D) Olcostephanus drumensis (Kilian, 1910) microconch (K 10.4.1.) Bed 11, (E) Olcostephanus drumensis (Kilian, 1910) macroconch, thickly ribbed morphotype (K 10.5.1.) Bed 11, (F) Olcostephanus drumensis (Kilian, 1910) macroconch (K 10.6.1.) Bed 10, (G) Kilianella roubaudiana (d’Orbigny, 1850) (K 10.7.1.) Bed 10, (H) Kilianella roubaudiana (d’Orbigny, 1850) (K 10.8.1.) Bed 11, (I) Kilianiceras gratianopolitense (Kilian, 1890), plasticine mould (K 10.9.1.) Bed 10, (J) Rodighierites belimensis (Mandov, 1976) (K 10.9.1.) Bed 6, (K) Oosterella begastrensis Company, 1987 (K 15223) Bed 6, (L) Kilianiceras gratianopolitense (Kilian, 1890), plasticine mould (K 10.10.1.) Bed 10, (M) "Spiticeras" cf. gevreyi Djezdžić, 1922 (K 10.11.1.) Bed 10, (N) Thurmanniceras pertransiens Sayn, 1907 (K 10.12.1.) Bed 11, (O) Olcostephanus guebhardi (Kilian, 1910) (K 10.13.1.) Bed 10. Scale bar: 10 mm.
Fig. 4. Representative Berriasian and Valanginian ammonites from the Hárskút section (HK-12). (A) (B) *Fauriella boissieri* (Pictet, 1867) (inventory no: K 10.14.1.) Bed 17, (C) *Berriasella privasensis* (Pictet, 1867) (K 10.15.1.) Bed 20, (D) *Kilianella roubaudiana* (d’Orbigny, 1850) (K 10.16.1.) Bed 11, (E) *Neocomites premolicus* Sayn, 1907 (K 10.17.1.) Bed 11, (F) *Busnardoites aff. campylotoxus* (Uhlig, 1902) (K 10.18.1.) Bed 10. Scale bar: 10 mm.
Fig. 5. Representative Valanginian ammonites from the Hárskút section (HI-12). (A) Busnardoites neocomiensiformis (Uhlig, 1902) (inventory no: K 10.19.1.) Bed 10, (B) Busnardoites neocomiensiformis (Uhlig, 1902) (K 10.20.1.) Bed 10, (C) Neolissoceras grasianum (d’Orbigny, 1841) (K 11384) Bed 10, (D) (E) Thurmanniceras pertransiens (Sayn, 1907) microconch (K 11327) Bed 10, (F) (G) Tirnovella occitanica (Pictet, 1867) (K 10.21.1.) Bed 30, (H) Thurmanniceras pertransiens (Sayn, 1907) macroconch (K 11326) Bed 10. Scale bar: 10 mm.
incertus (Fig. 8N,O), Duvalia aff. lata lata and Duvalia hungarica sp. nov.

BA-III includes Beds 14–11, straddling the ammonite-based Berriasian-Valanginian boundary as defined by the first occurrence of the T. pertransiens. Berriasibelus kabanovi (Fig. 7M,N,P,Q) is a common species, whereas the characteristic elements of BA-II are absent. This unit is regarded as a low-diversity transitional interval between two associations with higher diversity, BA-II and BA-IV.

BA-IV comprises the condensed Bed 10 only. The belemnite assemblage contains some conservative faunal elements which persist from older assemblages. The last occurrence of D. ex gr. lata (Fig. 7J,K) is recorded here. This unit also contains the first clear indications of attenuation of the P. bipartitus-stock which continues throughout the succeeding assemblage and the diminishing of previously important taxa such as Berriasibelus.

BA-V is restricted to Bed 9 and possibly Bed 8. It is characterised by the last occurrence of Duvalia lata, Berriasibelus, Castellanibelus (Fig. 7C,D). Duvalia emericii and Pseudobelus sp. 2 are confined to this unit.

BA-VI includes Beds 6 and 5. In the studied section this is a monospecific association of Pseudobelus sp. 1 (Fig. 8A–C). Elsewhere, this species is known to occur in low diversity and high abundance faunas, associated with Duvalia ex gr. binervia and Hibolithes jaculoides (Janssen and Clément, 2002, fig. 3).

4.3. Calpionellids

More than 20 calpionellid taxa have been identified from section HK-12, allowing an independent biostratigraphic subdivision, where calpionellid distribution serves as the basis of correlation using the zonal scheme of Remane et al. (1986) which superseded that of Allemann et al. (1971), or one of the more recently published, refined zonations (Grünn and Blau, 1997; Pop, 1994, 1997; Reháková and Michalík, 1997). The most characteristic calpionellid taxa of the section are shown in Fig. 9. Calpionella elliptica (Fig. 9U), represented by specimens of varying size, is the most abundant species in the lowermost interval of Beds 44–41. Small forms of the Calpionella alpina group and Remaniella colomi are also common, whereas Remaniella cadischiana (Fig. 9K) and Tintinnopsis longa (Fig. 9Q) are rare, but their occurrence is stratigraphically important. These strata are assigned to the Calpionella Zone. At the subzone level, correlation with the C. elliptica Subzone (Reháková and Michalík, 1997), T. longa Subzone (Pop, 1994, 1997) or the Remaniella cadischiana Subzone (Grünn and Blau, 1997) is justifiable, suggesting a Middle Berriasian age of these beds.

The overlying interval of Beds 40–11 is correlated with standard Calpionellopsis Zone (or Zone D in the older terminology), based on the common, or at some levels predominant, occurrence of the
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genus *Calpionellopsis*, which suggests a Late Berriasian age. Further subdivision at the subzone level is also possible. Beds 40–34 are assigned to the *Calpionellopsis simplex* Subzone (previously referred to as Subzone D1), well-established in all subzonal schemes, on the basis of the range of its index species. Several forms, including *C. elliptica*, persist up to here from the underlying unit. Beds 33–19 are assigned to the *Calpionellopsis oblonga* Subzone (sensu Pop, 1994, 1997; Reháková and Michalík, 1997) or Subzone D2, where the index species is rare in the lower beds and is accompanied by *Lorenziella plicata* in the uppermost bed of this interval. Beds 18–11 are best assigned to Subzone D3, using the original standard zonation of Allemann et al. (1971). Diagnostic is the first occurrence of *Lorenziella hungarica* (Fig. 9F). There is a general decrease in calpionellid abundance from Bed 13 upwards, with the decline of *Tintinnopsella* and *Remaniella* being especially noticeable. Neither *Praecalpionellites murganau*, nor *P. dadayi* is recorded in our

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*Fig. 7.* Representative Berriasian and Valanginian belemnites from the Hárskút section (HK-12). (A), (B) *Duvalia lata lata* (de Blainville, 1827). (Inventory no: K 10.29.1.) lateral and dorsal views, respectively Bed 9, (C), (D) *Castellanibelus aff. orbignyanus* (Duval-Jouve, 1841) (K 10.30.1.) dorsal and lateral views, respectively Bed 9, (E), (F) *Hibolithes laryi*? (Mayer, 1866) (K 10.31.1.) lateral and ventral views, respectively Bed 9, (G) *Pseudobelus* cf. *bipartitus* de Blainville, 1827. (K 10.32.1.) lateral view of alveolar part only, Bed 11, (H), (I) *Duvalia hungarica* sp. nov. (holotype), (K 10.33.1.) dorsal and lateral views respectively, Bed 15, (J) *Berriasibelus gr. conicus* (de Blainville, 1827) with *Acrothoracica* pits (K 10.34.1.) dorsal view, Bed 10, (K), (L) *Duvalia emericci* (Raspail, 1829) (imm.) (K 10.35.1.) lateral and dorsal views, respectively Bed 9, (M), (N) *Berriasibelus* kabanovi Weiss, 1991 (K 10.36.1.) internal lateral and dorsal views, respectively Bed 10, (O) *Duvalia emericci* (Raspail, 1829) (K 11716) lateral view, Bed 9, (P), (Q) *Berriasibelus* kabanovi Weiss, 1991 (K 10.37.1.) dorsal and lateral views, respectively Bed 14, (R), (S) *Duvalia hungarica* sp. nov. (paratype) (K 10.38.1.) dorsal and ventral views, respectively Bed 15. Scale bar: 10 mm.
Fig. 8. Representative Berriasian and Valanginian belemnites from the Hársikút section (HK-12). (A) Pseudobelus sp. 1 (=jantikensis? Nerodenko, 1986). (Inventory no.: K 10.39.1.) lateral view, Bed 5, (B), (C) Pseudobelus sp. 1 (=jantikensis? Nerodenko, 1986) (K 10.40.1.) lateral and dorsal views, respectively Bed 5, (D), (E) Pseudobelus sp. 2 (imm.) (=? sultanovkaensis Nerodenko, 1986; = gr. bipartitus) (K 10.41.1.) dorsal and lateral views, respectively Bed 9, (F), (G) Pseudobelus sp. 3. (K 10.42.1.) lateral and dorsal views, respectively Bed 9, (H), (I) Pseudobelus sp. 2 (=? sultanovkaensis Nerodenko, 1986; = gr. bipartitus) (K 10.43.1.) lateral and dorsal views, respectively Bed 9, (J), (K) Duvalia aff. lata consticta Uhlig, 1902 (K 17715) dorsal and lateral views, respectively Bed 10, arrow indicates the length of the groove, (L), (M) Duvalia cf. lata consticta Uhlig, 1902 (K 10.44.1.) dorsal and lateral views, respectively Bed 16, (N), (O) Conobelo us incertus Weiss, 1991 (K 10.45.1.) dorsal and lateral views, respectively Bed 18, (P), (Q) Duvalia lata consticta Uhlig, 1902 (K 10.46.1.) dorsal and lateral views, respectively Bed 25, (R) Berriasibelus gr. conicus (de Blainville, 1827) with Acrothoracia pits (K 10.47.1.) dorsal view, Bed 10, (S), (T) Duvalia miravetesensis? Janssen, 2003 (juv.) (K 10.48.1.) dorsal and lateral views, respectively Bed 25, (U), (V) Duvalia aff. guillantona Besairie, 1930 (K 10.49.1.) lateral and dorsal views, respectively Bed 32, (W), (X) Duvalia miravetesensis janssen, 2003 (K 10.50.1.) lateral and dorsal views, respectively Bed 19, (Y), (Z) Duvalia miravetesensis janssen, 2003 (K 10.51.1.) lateral and dorsal views, respectively Bed 25, (AA), (BB) Conobelo us (T) pseudoboraeus Janssen, 2003 (K 10.52.1.) dorsal and lateral views, respectively Bed 18, (CC), (DD), (EE) cross-sections through Duvalia hungarica sp. nov. (holotype) Bed 15, (FF), (GG), (HH) idealised cross-sections through Duvalia lata consticta. Scale bar: 10 mm.
samples, thereby the topmost subzones of the Calpionellopsis Zone cannot be identified using their index species in the zonation of Pop (1994, 1997), Reháková and Michalík (1997) and Grün and Blau (1997).

Bed 10, where condensation is suspected on the ground of macrofossils, has been sampled at higher resolution. The lowermost part of the layer is rather poor in calpionellids. Abundance and diversity increases higher up, where Calpionellites darderi (Fig. 9A, B), Calpionellites aff. uncinata, Calpionellopsis oblonga, Praecalpionellites dadayi (Fig. 9C), P. murgeanui (Fig. 9D), C. alpina, T. longa and Lorenziella occur together. This assemblage is assigned to the Calpionellites darderi Subzone of the standard Calpionellites
Zone (or Zone E in the older terminology), suggesting the Early Valanginian. The subzonal index species is rare near the base of the bed but becomes common in higher samples.

The topmost few centimeters of this layer, labelled for sampling as Bed 10d, differs in containing scarce calpionellids only, including Lorenziella spp., Tintinnopsella carpathica and T. laticarpathica and Remaniella cadischiana. This assemblage is assigned to the Calpionellites hungarica Subzone (Grün and Blau, 1997) of the standard Tintinnopsis Zone (or Zone F in the older terminology), corresponding to the early Late Valanginian.

No calpionellids have been found in any of the higher samples from Beds 9–1, even though their microfacies is otherwise similar to the underlying Bed 10 in containing planktic foraminifers, stromiospheres and biodetrital grains.

4.4. Stable isotopes

Measurement of carbon isotope composition of bulk carbonate yielded positive $\delta^{13}C$ values throughout the section examined (Figs. 10–12). Values around $1.4\%_o$ characterise the lower part of the section, before a rapid $1.6\%_o$ positive shift, reaching a maximum of

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**Fig. 10.** Simplified sedimentary log of HK-12 section, showing the $\delta^{13}C$ vs. $\delta^{18}O$ stratigraphy. EV = Early Valanginian, P + C. = Pertransiens and Campylotoxus; Pert. = Pertransiens, Bois. = Boissieri.
Fig. 11. Simplified sedimentary log and integrated biostratigraphical results for the lower, cephalopod rich part of the HK-12 section, showing the δ13C stratigraphy. Abbreviations as for Fig. 10. Calpionellid biostratigraphical schemes after (1) Remane (1963), (2) Grün and Blau (1997), (3) Allemann et al. (1971). Scale does not permit to show Zone F which is restricted to the topmost centimeters of Bed 10, above Zone E.
3.0‰. Following this event a return towards more negative values is observed. Hence at the top of the section a carbon isotope value of 1.4‰ is once again recorded.

Detailed sampling around the positive shift revealed that the excursion steady-state values (between 1.2 and 1.5‰) persist into the lower part of Bed 10, increasing to 1.8‰ in the topmost 15 cm of Bed 10, before jumping to values up to 3.0‰ but typically between 2.4 and 2.7‰ in the first meter of sediments above Bed 10.

For the examined interval, a number of works provide more than 30 comparable δ13C curves from various Early Cretaceous basins (e.g. Föllmi et al., 1994; Gröcke et al., 2005; Hennig et al., 1999; Weissert et al., 2009; Duchamp-Alphonse et al., 2007). The overall fit of the Hárskút data with existing curves is remarkable. The well-defined positive shift can be unequivocally correlated with the Valanginian event. Minor but significant differences seen are that the positive excursion at Hárskút has a sharp base and the following platform possibly suppressed reflecting either a hiatus or some degree of stratigraphic condensation, as independently suggested by ammonoid biostratigraphic and taphonomic evidence.

The oxygen isotope data vary from ~−0.2 to −3.2‰. The most negative δ18O values are seen within the middle part of the section above the positive carbon isotope event. Although showing a degree of scatter, isotope values become increasingly more positive, reaching a value of ~−0.8‰ towards the top of the section. Fluid-rock interactions during diagenesis commonly result in decreasing δ18O_carbon values (Hudson, 1977). A diagenetic overprint affecting the samples analysed cannot be excluded, hence the oxygen isotope profile is not examined any further. However, the preservation of primary δ13C values during diagenesis is quite typical, and is likely due to the buffering effect of carbonate carbon on the diagenetic system, as this is the largest carbon reservoir.

Given the relative abundance of belemnites it was hoped that via isotope analyses further details regarding the palaeoenvironmental conditions at Hárskút could be obtained. The oxygen isotopes of the belemnite rostra (n = 10) (Duvallia cf. luta constricta and Pseudobelus sp.) show only modest variability ranging from −0.75 to 0.96 ‰ (V-PDB), whilst carbon isotopes ranged from −2.05 to 1.78 ‰ (V-PDB). The major potential process that may destroy a primary isotopic signature is diagenetic alteration. Trace elemental analysis (determined using an ICP-AES) revealed modest Fe (10–1100 ppm) and Mn (5–300 ppm) concentrations within the belemnite rostra which indicates, however, a generally poor state of preservation of these fossils (cf. Price and Mutterlose, 2004; Price et al., 2009). The presence of high levels of Fe and Mn is used as indicator of diagenesis and therefore our preliminary isotope analysis of the belemnites does not provide any further data regarding the palaeoenvironmental setting.

5. Discussion

5.1. Biostratigraphic correlation

5.1.1. Ammonites

The ammonite assemblages are composed exclusively of Mediterranean forms. The dominance of suborders Phylloceratina and Lytoceratina is conspicuous. In Bed 10, the most fossiliferous layer in the section, nearly 50% of the specimens belong to these two groups. The faunal succession agrees well with those known from the other parts of the Mediterranean Province, e.g. the Subbetic in Spain (Aguado et al., 2000; Company, 1987) and Morocco (Wippich, 2003), therefore the standard ammonite zonal scheme (Reboulet et al., 2009) was followed.

The Middle and Late Berriasian fauna can be characterized by a moderately diverse assemblage of representatives of the following genera: Berriasella, Malbosiceras, Euthymiceras, Tirmovella, Fauriella, Dalmasciceras, Kilianiceras and Spiticeras. Many of the species belonging to these ammonite genera are little known and the their stratigraphical distribution is uncertain, since most of them are known from the classical monographs only. A thorough revision of these groups — especially the genus Spiticeras, which is very common in Hárskút — is badly needed.

T. pertransiens is represented by dozens of well preserved specimens. Both micro- and macroconchs were found and the assemblage shows great variability in coiling and ornamentation which was already demonstrated by Company (1987). According to Wippich (2003), the first appearance of Neoconites premolicus is simultaneous with that of T. pertransiens, therefore it can be used as an alternative index for the zone. N. premolicus (Fig. 4E) is also present in section HK-12. It appears in Bed 11, whereas the first occurrence of T. pertransiens is in Bed 12.

The Pertransiens Zone also contains the latest representatives of Kilianiceras gratianopolitense (Fig. 30), and a rich Olistostephanus fauna. O. drumensis is very common. The distinctive, depressed, small-sized Olistostephanus stephanophorus (Fig. 3J, K) is represented by a single specimen. This taxon was chosen by Bulot and Thieuloy (1995) as the index for the interval between Pertransiens and Inostranzewi Zones. According to Bulot and Thieuloy (1995), the latter zone contains three horizons, including the topmost B. campylotoxus Horizon. On the other hand, according to one of us (N.J.) the first appearance of O. stephanophorus in the Vergol section (France) (V43-44 and V45-46) is in the Pertransiens Zone, consequently it cannot mark the beginning of a distinct, subsequent zone. O. stephanophorus — although not well known outside SE France and Switzerland — was figured also from Baluchistan (Fatmi and Rawson, 1993), suggesting a wide geographical range.

The diverse forms assigned to Kilianella include some large-sized, coarsely ribbed, poorly known macroconchs in the Lower Valanginian beds which resemble those reported from Morocco by Ettachfini (2004). The most distinctive feature of Bed 10 is the well preserved Neocomitidae fauna, which contains some little known forms and new taxa. Some specimens are identified as B. campylotoxus, and many others as Busnardoites neocomiensiformis (Fig. 5A, B). The latter species has been misinterpreted by nearly all ammonite workers (for details see Klein, 2005, p. 323) since it was first described.
by Uhlig (1902). The species was chosen as the type species of the Early Hauterivian subgenus Neocomites (Teschenites) by Thieuloy (1971). Recently Busnardo et al. (2003) proposed a new type species (Teschenites fluitculus Thieuloy, 1977) for the Hauterivian taxon, and applied the name *Neocomiensiformis* for the Valanginian forms which are restricted to the Campylotoxus Zone. This view was accepted by Klein (2005) and is also followed herein.

A few specimens from Bed 10 are referred here as *Busnardoities* aff. *campylotoxus* (Fig. 4F), representing little known adult macroconchs, in which the part of the body chamber is also preserved. These forms are close to those described by Uhlig (1902) under the name *Protacantodiscus*.

### 5.1.2. Belemnites

In the studied section HK-12, the lowermost belemnite association (BA-I) contains some characteristic belemnites that previously were only known from southeast Spain (Janssen, 2003), where they were collected from strata from the Malbosiceras paramimonum Subzone up to the base of the Alpillensis Ammonite Subzone. BA-II contains belemnites (e.g. *Conobius* (piradoensis) that were previously described from the Berriasella alpillensis Subzone in southeast Spain, and also from Morocco (described as Hibolithes in section HK-12, in Mutterlose and Wiedenroth, 2008, p. 817, 822). BA-III contains *B. kabanovi* which occurs from the latest Alpillensis Subzone to the Pertransiens Zone. The condensed Bed 10 represents BA-IV; it contains *Duvalia* aff. *lata constricta* (Fig. 8J,K). The latter species typically occurs in the Vocontian Basin in the younger part of the Pertransiens Zone (beds with *Barronites hirsutus*) and the boundary levels between the Pertransiens and the Campylotoxus Zones.

Bed 9 yielded *Duvalia emercii* (Fig. 7K,LO) which is elsewhere characteristic to the top of the Campylotoxus Zone and the base of the Verrucosum Zone. The last occurrences of *D. ex gr. lata, Berriasibilus* and *D. emercii* characterise the so-called Verrucosum event, the disappearance of almost all early Valanginian belemnite species and genera (Janssen and Clément, 2002) just above the Verrucosum Horizon (= basal part of the Verrucosum Subzone). *Pseudobolus* sp. 1 is a typical post-Verrucosum event element. *Pseudobolus* sp. 2 (Fig. 8D,E,H,I) is common in the Early-Late Valanginian boundary strata and evolves into *Pseudobolus* sp. 1 in the middle part of the Verrucosum Subzone. The beds above did not yield any belemnites.

### 5.2. Carbon isotope excursion

The Valanginian carbon isotope excursion is a pronounced excursion in marine carbonate, and marine and terrestrial organic carbon-isotope records (e.g. Gröcke et al., 2005; Lini et al., 1992; Weissert et al., 1998; Duchamp-Alphonse et al., 2007). It has been identified throughout the Tethyan area, and has subsequently been located in many other regions of the Northern Hemisphere (e.g. western North Atlantic: Adatte et al., 2001; Bornemann and Mutterlose, 2008; Central Pacific: Erba et al., 2004; Boreal Arctic basin: Price and Mutterlose, 2004) and more recently in the western North Atlantic: Adatte et al., 2001; Bornemann and Mutterlose, 2008; Central Pacific: Erba et al., 2004; Boreal Arctic basin: Price and Mutterlose, 2004; Pucéat et al., 2003).

The Valanginian carbon isotope event has been interpreted as the expression of a global perturbation of the carbon cycle, resulting in a crisis of carbonate-producing biota (Lini et al., 1992; Erba et al., 2004; Duchamp-Alphonse et al., 2007). Many triggering processes have been proposed to explain this change in the carbon cycle, such as an increase in CO₂ input into the atmosphere due to the emissions of the Paraná–Etendeka large igneous province (Lini et al., 1992; Erba et al., 2004), leading to warming which enhances continental weathering, increases in marine primary productivity and increased storage of organic matter and the drawdown of atmospheric CO₂, which lead to subsequent cooling (Föllmi et al., 1994). Indeed, different lines of evidence suggest that climate may have become cooler during the Valanginian δ¹³C event (Brassell, 2009; McArthur et al., 2007; Price and Mutterlose, 2004; Pucéat et al., 2003).

### 5.3. Connection of the Weissert event and the sedimentary and faunal changes

The start of the positive carbon isotope excursion in the studied section coincides with a horizon of stratigraphic condensation, possibly followed by a gap. Bed 10 represents both the Pertransiens and Campylotoxus Zones and calpionellid zones E and F. There is evidence that the younger zones are confined to the topmost layer within this bed. The sudden jump to peak positive values in the overlying beds in the Verrucosum Zone differ from the shape of the carbon isotope curve in complete stratigraphic sections elsewhere (e.g. Duchamp-Alphonse et al., 2007), but the ammonite biostratigraphic resolution does not permit estimation of the gap. Astrochronological constraints from the Chiaserna Monte Acuto section in the Appenines (Sprovieri et al., 2006) suggest a nearly 1 Ma duration for the steep positive excursion on the curve, thereby the hiatus above Bed 10 at Hárskút may...
represent several hundred thousand years. It is interesting to note that the Campylotoxus Zone is also condensed to a single, richly fossiliferous ammonite-bearing bed in the Kacha River section in Crimea, below the start of the isotope shift (Gröcke et al., 2005). A condensed phosphatic interval is also found on the northern Tethyan margin in platform sediments of the Helvetic Alps (Föllmi et al., 2007). In the Southern Carpathians, a more extensive gap exists between the uppermost Berriasian to the mid-Valanginian, thought to be related to the nutrification crisis related to the Weissert event (Barbu and Melinte-Dobrinescu, 2008). A decline in abundance of nannoconids and other changes in the nannofossil assemblages point to a mid-Valanginian fertilization episode as a manifestation of the Weissert event (Erba et al., 2004). We speculate that condensation and hiatus at Hárskút may reflect the nutrification and calcification crises observed elsewhere. If volcanic activity indeed contributed excess amounts of CO2 to the atmosphere–ocean system, then rising volcanic CO2 pulses may have caused a decrease in pH and carbonate ion concentration of surface waters (Weissert and Erba, 2004). Related changes in shallow marine environments include widespread platform drowning (Föllmi et al., 1994; Weissert et al., 1998).

In contrast to other Cretaceous OAEs, marine sediments deposited during the Valanginian carbon isotope event lack the widespread occurrence of well developed organic–carbon rich levels. Organic-rich deposits are limited to only a few localities (e.g. Bersezio et al., 2002). As with many other sections, no black shale or organic-rich level is recorded at Hárskút. Geochemical evidence gathered by Westermann et al. (2010) casts further doubt at the veracity of an OAE during the Valanginian.

Although the Weissert event is not associated with a mass extinction, the attendant environmental changes did influence the biota. In the Hárskút section we note that the disappearance of calpionellids is synchronous with the onset of the carbon isotope excursion. Although it is not the case everywhere, there are many other localities where a significant calpionellid extinction appears to be related to the Weissert event (e.g. Erba et al., 2004). Belemnite faunas locally also show a major turnover and decline above Bed 10 (unit BA-IV). This pattern corresponds to a major belemnite extinction observed in the Verrucosum Zone in the Vocontian Basin and Betic Cordillera (Janssen and Clément, 2002), possibly also causally related to the Weissert event. An early Late Valanginian crisis is also noted in the bryozoan faunas in the Jura Mtn. (Walter, 1989).

6. Conclusions

The Hárskút HK-12 section exposes 28 m of Lower Cretaceous pelagic carbonates which comprise Rosso Ammonitico facies passing upwards into Biancone facies, overlain by marlstones. The locality is within the Bakony Unit of the AlCaPa terrane, its
sedimentary sequence was deposited in deep water environments on the southern margin of the Neotethys. Fossiliferous strata in the lower part of the section contain abundant ammonites and belemnites, whereas its microfauna includes calpionellids. The lithology is amenable to bulk carbonate stable isotope analyses.

The key results of our integrated stratigraphic study are the following:

1) The succession of 76 ammonite taxa permits the use of the Mediterranean standard ammonite zonal scheme (Reboulet et al. 2009). The basal 6.5 m is subdivided into five zones, from the Middle Berriasian Occitanica Zone to the Upper Valanginian Verrucosum Zone. Beds 12–10, representing the Pertransiens and Campylotosus Zones are condensed, especially Bed 10 which contains taphonomically distinct ammonites of the Campylotosus Zone only in its upper part. Above an unfossiliferous interval, the top of the section yielded a Late Hauterivian assemblage.

2) More than 100 belemnite specimens from the lowermost &gt;6 m are assigned to 20 taxa. Their stratigraphic distribution permit the recognition of six local belemnite associations, the lowermost of them is further subdivided into four subunits. Calibration of belemnite biostratigraphic units with co-occurring ammonite faunas confirm that the lower part of Harsküt section spans the Middle Berriasian through Upper Valangian interval. Notably, belemnite-based correlation of the condensed Bed 10 supports its assignment to the Pertransiens and Campylotosus Zones.

3) Distribution of over 20 calpionellid taxa is restricted to the lower part of the section, up to Bed 10. These strata are assigned to calpionellid zones C through F. Six subzones of the more detailed schemes are also recognized. The Berriasian-Valangian boundary falls within Subzone D3. The lower part of condensed Bed 10 belongs to the darderi Subzone of Calpionellities (=E) Zone, implying that the D–E zonal boundary falls within the Pertransiens Zone. The topmost part of Bed 10 is assigned to the hungarica Subzone, the second subzone of the Tintinnopella (=F) Zone, correlated elsewhere with the Verrucosum Zone. Thus calpionellid biostratigraphy also indicates a significant condensation in Bed 10.

4) Carbon isotope ratios measured in bulk carbonate show a near-stage evolution throughout the section. Nearly constant positive values of &gt;1.3‰ persist up to the Pertransiens Zone, jump rapidly up to 3‰ across a few centimetre thick condensed interval of the late Early Valangian Campylotosus Zone and the lowermost layers of the overlying early Late Valangian Verrucosum Zone, positive values above 2.5‰ are maintained across a narrow interval before a long and gradual decline approximates pre-excursion values by the Late Hauterivian. This carbon isotope curve is conformed with other carbon isotope records, deviating from its well-established pattern only in the highly condensed nature of its rising segment. Oxygen isotope data obtained from both bulk carbonate and belemnite calcite do not reflect primary values.

5) The condensation of the Campylotosus Zone and the hiatus at the base of Verrucosum Zone at the onset of the carbon isotope excursion is regarded as the unique local manifestation of the Weissert event. It might be causally related to the calcification crisis and nutrification event reported from elsewhere. Disappearance of the calpionellid fauna and the major turnover and decline in belemnite associations are also thought to reflect the local biotic response to the cascade of environmental changes that characterize the Weissert event (Fig. 13).

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Appendix. Taxonomic remarks on selected belemnites with description of a new species (by N.M.M. Janssen)

Family Duvaliidae Pavlov, 1914

Genus Castellanibelus Comboni, 1972

Castellanibelus aff. orbignyanus (Duval-Jouve, 1841): a species which differs from the nominal one, due to its strong dorso-ventral compression.

Genus Duvalia Bayle, 1878

Duvalia aff. guillantona Besairie, 1930 (cf. Janssen, 2003, pl. 6, figs 10 and 11): a laterally very compressed medium-sized species with a deep alveolus and very long alveolar groove. It is morphologically close to certain belemnites from the southeast France (Tournaisian) which show the same morphology. Both these species are described as new species (by N.M.M. Janssen) in a paper which is in preparation.

Family Spongoleiidae

Genus Pseudobelus Kuhn, 1964


Pseudobelus sp. nov. (see below): previously, this new species was known only from the southeast Tethyan margin (not in the western Tethys) as a species only described from the southeast France (Tournaisian) which show the same morphology. Both these species are described as new species (by N.M.M. Janssen) in a paper which is in preparation.

Pseudobelus lata (Kuhn, 1964), (cf. Janssen, 2003). The species described from the southwest Tethyan margin.

Pseudobelus sp. 2, the last of the so-called “western Tethyan” group of belemnites found in the Tethyan margin.

The latter author provisionally placed this species in the Mesobiolitidae. The material from the Tethyan margin is only small fragments and it is difficult to place this species in a more specific group. The material from the Tethyan margin is only small fragments and it is difficult to place this species in a more specific group.

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Family Duvaliidae, Pavlov, 1914
Genus Duvalia Bayle, 1878
Duvalia hungarica sp. nov.
Figs. 7H,I (holotype), 7R,S (paratype), 8CC–EE.


Derivation of name. The species is named after the country where the most complete material originates from.

Holotype. The specimen (K 10.33.1.) collected from the Hárskút (HK-12, Bed 15) is stored in the Geological Institute of Hungary (Budapest). A cast of it is stored in the collection of Naturalis (Leiden).

Paratypes. One specimen (K 10.38.1.) from the same section and same bed as the holotype, stored also in the Hungarian Geological Institute. A cast of it is stored in Leiden. Two further, incomplete specimens from Río Argos section (Spain) stored also in Leiden.

Type locality. Section HK-12, Hárskút, Közöskút Ravine, Bakony Mts, Hungary.
Stratigraphic horizon. The holotype and the paratypes were collected from a HK-12, Bed 15, which was assigned to the upper part of the Late Berriasian Bossieri Zone. The Spanish specimens were obtained from beds belonging to the Alpillensis Subzone.

Diagnosis. Medium-sized, rather robust latatoid rostrum with characteristic hexagonal to octagonal cross-sections.

Description. The alveolar groove is relative short and running into a characteristic flattened area, not known from other species of the Duvalia lata-group. Lateral expulsions are well developed and shifted towards the dorsal (alveolar) side (Fig. 8CC,DD). The apex appears pointed to blunt and orientated at the dorsal side. The alveolus is very shallow, not reaching beyond the length of the alveolar groove. Both dorsal and ventral side appear to be near parallel for most part, and do not show a constriction towards the alveolar region.

Remarks. Reminiscent of Duvalia deeckei Kilian, 1889. The latter species was described from a lithostratigraphical unit in the southeast of Spain that straddles the Jurassic-Cretaceous boundary. It is a junior synonym of Duvalia tithonia (Oppel, 1865). The latter shows a comparable dorsal groove but not the flattened area on the dorsal side, nor the irregular outline in lateral view, nor reaches it the size of the new species. The closely related, and probable ancestor D. lata constricta (Fig. 8P,Q) never shows a hexagonal to octagonal outline but is always rounded, with a well developed alveolar groove but no characteristic flattened dorsal area.

Geographical distribution. The species is known from the Mediterranean Realm, from the territory of Hungary and Spain.

Associated belemnites. The new species occurs with Duvalia gr. lata and Pseu-dobelus bipartitus. Less common species, including Conobelus incertus and Conobelus (?) piradoensis, occur in the same stratigraphical interval.