

Invited research papers

Late Valanginian extinction and turnover of Tethyan brachiopods: A signal of the Weissert Event (Bakony Mountains, Hungary)

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ABSTRACT

Brachiopods, together with ammonoids, were collected bed-by-bed from several Lower Cretaceous pelagic sections and localities in the Bakony Mountains (Transdanubian Range, Hungary), dated by detailed ammonoid and nannofossil biostratigraphy. These yielded abundant and diverse brachiopod material (1015 specimens, 25 species), and a possibility to determine the stratigraphic ranges of the brachiopod species. Two sections, including the Berriasian to Hauterivian interval, were studied in detail. In the Hárskút HK-12 section the early late Valanginian Weissert Event was documented previously by stable isotope investigations and it was biostratigraphically correlated with the Édesvíz Key section. The Lower Cretaceous brachiopod record in the Bakony was separated into four assemblages. The abundant early Berriasian brachiopod Assemblage 1 diminished and with a stepwise extinction and partial turnover passed to an impoverished Assemblage 2 in the early Valanginian. These species ultimately disappeared at the early/late Valanginian boundary. This extinction is interpreted as the effect of the global Weissert Event. The extinction horizon is marked by an almost monospecific, dwarf brachiopod fauna (Assemblage 3). In the late Valanginian an abundant and diverse brachiopod fauna appeared, with a complete turnover of species (Assemblage 4). The development of this assemblage in the late Valanginian and Hauterivian was probably controlled by environmental changes, (1) by a switch in palaeoclimate, i.e. by the late Valanginian cooling episode and (2) by the change in the sedimentary environment.

1. Introduction

In the present paper we focus on the stratigraphical distribution of brachiopod taxa in Berriasian to Barremian interval in the Bakony Mts (Hungary) and emphasize the possible effect of the Valanginian Weissert Event (WE). The Berriasian to Barremian strata in the Bakony Mts are rich in brachiopods: more than 1000 specimens were collected from this stratigraphical interval. Two measured sections encompass the whole Berriasian to Hauterivian/Barremian interval, with precise biostratigraphy based on ammonoids and nannofossils, developed in the present project. One of the sections (HK–12) was previously sampled bed-by-bed for stable isotope analyses (Fózy et al., 2010), and showing the presence of the WE. Due to the biostratigraphical correlation between our two measured sections, the temporal and spatial extent of the WE is outlined in the Bakony Mountains. The late Mesozoic time was an overall quiet period in brachiopod evolution. The Early Jurassic “order level” extinction of the Articulata (Rhynchonelliformea) was followed by a diversity maximum in the Middle Jurassic (Vörös et al., 2016, 2019a). Afterwards, due to the differences in

their anti-predatory strategies, the diversity trajectories of the Rhynchonellida and the Terebratulida markedly deviated, and the latter order became dominant in the Cretaceous (Vörös, 2010). Previously, it was demonstrated that long-ranging brachiopod taxa prevailed in the pelagic realm of the western Tethys during the Jurassic-Cretaceous transition (Krobicki, 1996; Vörös et al., 2019b). Here we point out a stepwise extinction, following by a major break of brachiopod development, as a signal of the early late Valanginian WE. We outline four successive brachiopod assemblages in the studied stratigraphical interval. The analysis of this extinction process and its results represent an advance over earlier studies on Early Cretaceous brachiopod evolution.

It has to be mentioned that the WE has not always been regarded as an oceanic anoxic event but definitely linked to a carbon cycle perturbation triggered by a peak of activity of the Parana–Etendeka Large Igneous Province (Erba et al., 2004). Our sections record a sharp lithological change from pure calcareous to more marly at the Weissert level, but anoxic black shales are absent. Therefore, in the present case, it seems advisable to avoid using the expression “Oceanic Anoxic Event”, thus we applied the name “Weissert Event” (WE) in simple form

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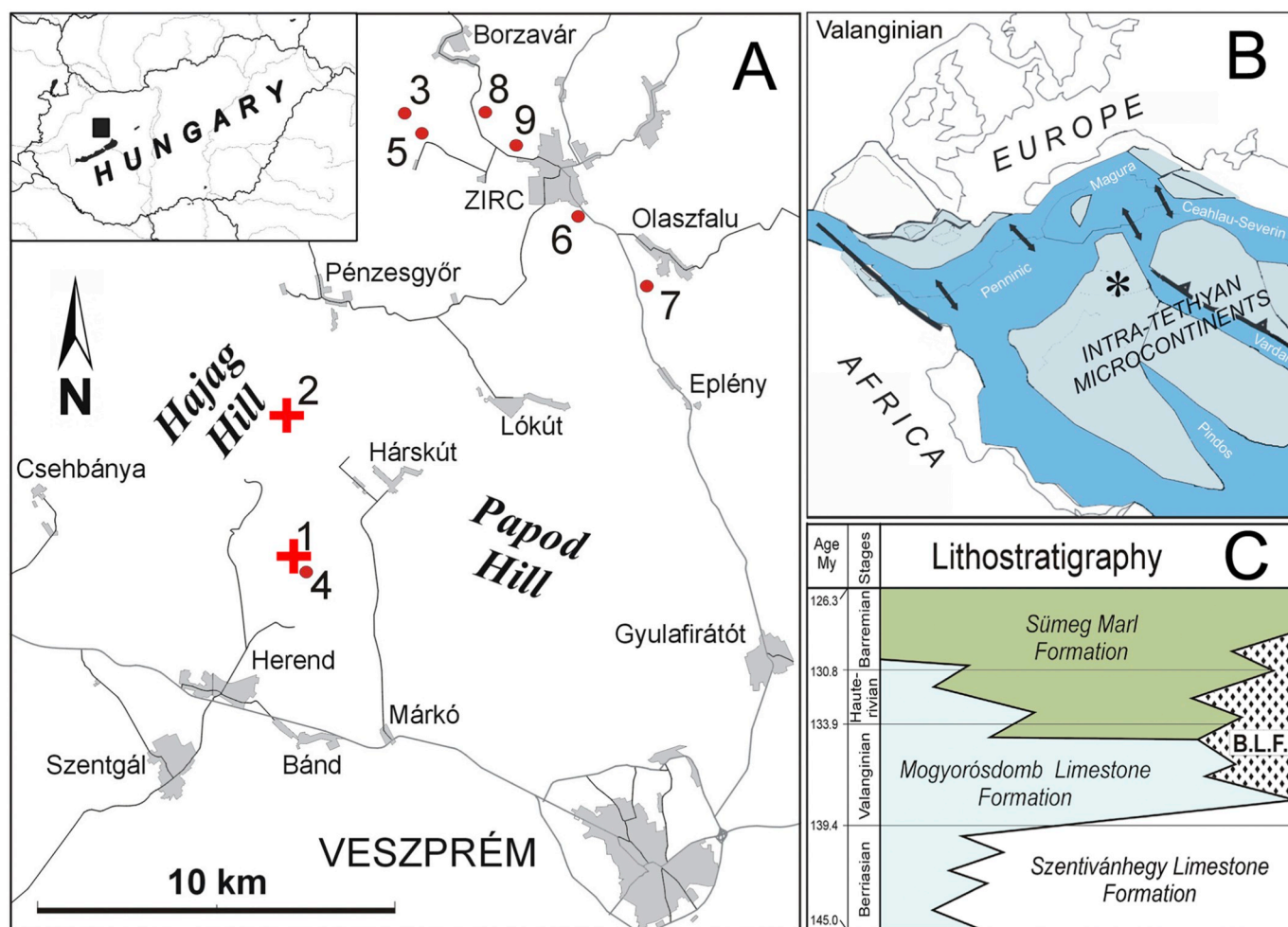


Fig. 1. A, B, C. (A) The geographical setting of the sections and other localities yielding important Berriasian to Barremian brachiopod faunas. 1: Hárskút, HK-12 [and HK-12a], 2: Hárskút, Édesvíz, Key Section [and Édesvíz-major (1961) + Édesvíz-major-27], 3: Borzavár, Szilas Ravine, 4: Hárskút, HK-II, 5: Zirc, Alsó-major, 6: Zirc, Istenes-malom, 7: Olaszfalu, Eperkés Hill, 8: Zirc, Borzavári Quarry, 9: Zirc, Márvány Quarry. The two sections illustrated in details are marked by red crosses. (B) Palaeogeographical setting of the study area in the Valanginian. Dark blue: deep ocean; light blue: submerged continental area. Asterisk indicates the inferred palaeoposition of the Bakony area. (Modified from Csontos and Vörös, 2004). (C) Lithostratigraphical scheme showing the relationship between the Early Cretaceous formations in the Bakony Mountains (modified from Császár, 1996). Geochronology from Ogg et al. (2016). B. L. F.: Borzavár Limestone Formation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

in this paper.

2. Geological setting

2.1. General

The geographical position and the palaeogeographical setting of the studied localities are shown in Fig. 1. The Bakony Mountains as part of the Transdanubian Range and the Pelso tectonic unit (Kovács et al., 2000; Haas, 2001), are considered the southern segment of the Alpine-Carpathian-Pannonian (AlCaPa) composite terrane (Csontos and Vörös, 2004). The Pelso/Bakony unit belonged to a system of intra-Tethyan (or Mediterranean) microcontinents in the Jurassic and Early Cretaceous times (Vörös, 1993, 2016). This submarine area was a pelagic submarine plateau, dissected by deep basins (Fig. 1B). The microcontinent was isolated by deep-sea belts from the main continents, therefore dominantly pure pelagic limestones and other fine-grained sediments were deposited here. Accordingly, the Lower Cretaceous sediments, exposed in our studied sections, are represented mainly by the limestones of the Szentivánhegy and Mogyorósdomb formations (of Biancone type) and the biocalcarenes of the Borzavár Formation. From the Hauterivian the deposition of more clayey and silty Sümege Marl

Formation became prevalent.

The lithostratigraphical formations are defined and described in (Császár, 1996); comprehensive data on the stratigraphy and palaeontology of the Lower Cretaceous formations of the Bakony region were given by Fülöp (1964), and recently by Főzy (2017).

2.2. Localities and sections

The geographical setting of the nine localities yielding important Berriasian, Valanginian and/or Hauterivian brachiopod faunas is shown in Fig. 1A; their chronostratigraphical ranges and/or positions are illustrated in Fig. 2, with indications of the numbers of brachiopod taxa in the respective intervals. Two key sections were studied and discussed in detail in the present paper; both are located near the village Hárskút.

The section Hárskút, HK-12 is situated at the northern edge of the Közöskút Ravine (southern part of the Hajag Hill) (No. 1 in Fig. 1; Geographical coordinates: 47°9'56.97"N, 17°47'8.11"E). It is an artificially enlarged outcrop and a long trench, exposing 30 m of gently dipping Berriasian, Valanginian and Hauterivian strata. The Berriasian part of this section is rather condensed, as the thickness of the fossiliferous Berriasian to lower Valanginian strata (Szentivánhegy and Mogyorósdomb Limestone formations) slightly exceed 3 m. The topmost

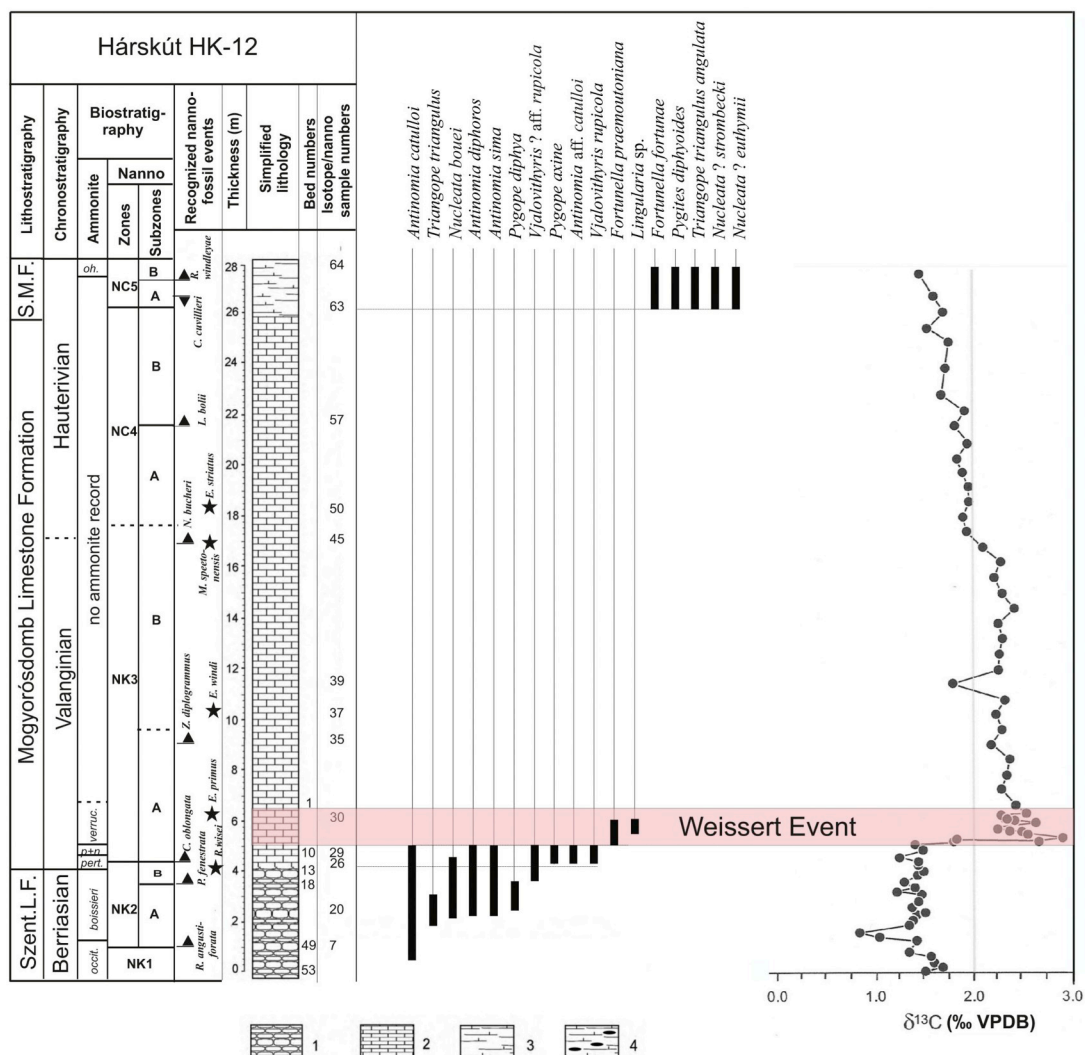


Fig. 3. Lithostratigraphy, chronostratigraphy, simplified lithologic log, ammonite and nannofossil biostratigraphy, recorded nannofossil events and sampling numbers, distribution of the most important brachiopod species and the $\delta^{13}\text{C}$ stratigraphy of the Hárskút, HK-12 section. Ammonite stratigraphy is taken from Főzy et al. (2010). The WE interval marked with pink shaded area. Legend: 1: red or white, mostly nodular limestone, 2: well-bedded siliceous and marly limestone, 3: marl, 4: marl with chert nodules. Abbreviations: Szent. L. F.: Szentivánhegy Limestone Formation, S. M. F.: Sümeg Marl Formation, *occit.*: *occitanica* zone, *pert.*: *pertransiens* Zone, *p + n*: *pertransiens* + *neocomiensiformis* Zones, *verruc.*: *verrucosum* Zone, *oh*: *ohmi* Zone. Asterisks represent single occurrences of stratigraphically important nannofossil taxa. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

abandoned quarry exposed cherty Tithonian limestone and overlying Berriasian to lower Valanginian limestone beds with a few ammonoids and brachiopods (Fülöp, 1964). The uppermost layer of an artificial trench (called Stripe Pit) at Olaszfalu, Eperkés Hill (No. 7 in Fig. 1), dated as late Valanginian (Főzy, 2017), yielded a few but well preserved brachiopods. The abandoned quarries, labelled Zirc, Borzavár Road Quarry (No. 8 in Fig. 1), exposed reddish, cherty crinoidal limestone beds in more than ten metres thickness, containing very rare ammonoids and frequent brachiopods and belemnoids. This type section of the Borzavár Limestone Formation was regarded as representing the whole Valanginian and Hauterivian (Fülöp, 1964). Recent biostratigraphical evaluation pointed to late Valanginian and/or early Hauterivian age (Főzy and Janssen, 2006; Főzy, 2017). An artificial trench named Hárskút, Édesvíz-major (1961) in the close vicinity of the HÉK section (No. 3 in Fig. 1) revealed a few marly layers of Hauterivian age with ammonoids and diverse brachiopods. In another artificial trench named Hárskút, Édesvíz-major-27, also in the close vicinity of the HÉK section (No. 3 in Fig. 1), marly layers were excavated which yielded a few ammonoids and a rather diverse brachiopod fauna. Zirc, Márvány Quarry (No. 9 in Fig. 1). This abandoned quarry exposed a few

metres of Tithonian Szentivánhegy Limestone, overlain unconformably by a very fossiliferous, condensed limestone layer. This less than half metre thick bed, wedging out within the outcrop, was completely destroyed during collection of fossils. The extremely rich ammonoid fauna was considered Barremian by Fülöp (1964); recent biostratigraphical evaluation concluded at a late Hauterivian age (Főzy and Janssen, 2006; Főzy, 2017). The brachiopod fauna is also very abundant and diverse.

3. Material and methods

3.1. Brachiopods

The studied brachiopod material was collected from biostratigraphically well calibrated localities of Berriasian to Valanginian and/or Hauterivian age in the northern Bakony Mountains (see above). The brachiopod material (the fragments below species resolution excluded) is extremely abundant: the 1015 identified specimens came from the Berriasian (236), the Valanginian (138) the Hauterivian (637) and the Barremian (4). Table 1. reports the list of the Berriasian to Hauterivian

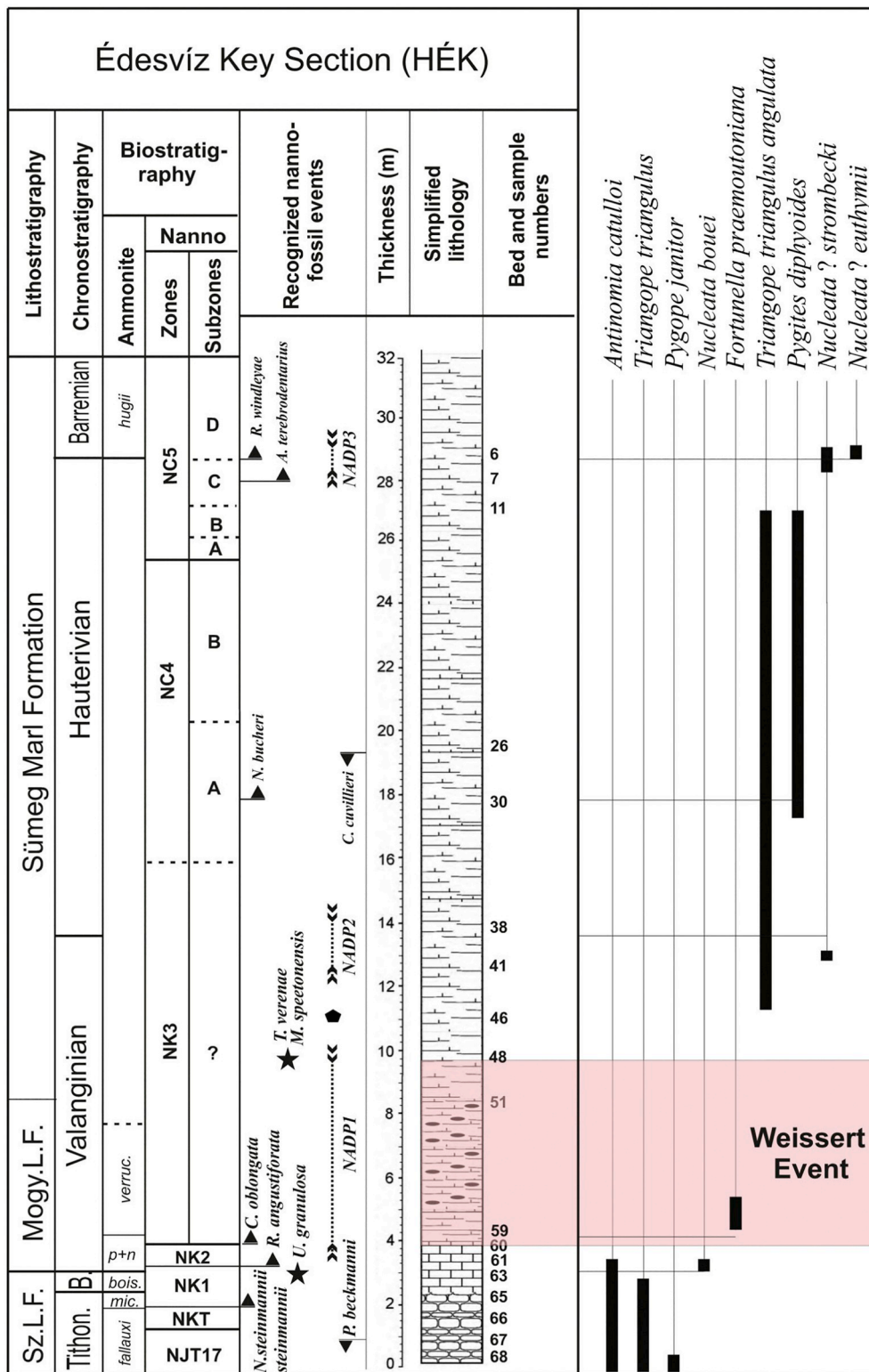


Fig. 4. Lithostratigraphy, chronostratigraphy, simplified lithologic log, ammonite and nannofossil biostratigraphy, recorded nannofossil events, sample numbers, and distribution of the most important brachiopod species in the Hárskút, Édesvíz, Key Section. The inferred interval of the Weissert Event is shaded. Legend: same as in Fig. 3. Abbreviations: Sz. L. F.: Szentivánhegy Limestone Formation, Mogy. L. F.: Mogyorósdomb Limestone Formation, Tithon.: Tithonian, B.: Berriasian, mic.: microcanthum Zone, bois.: boissieri Zone, p + n: pertransiens + neocomiensiformis Zones, verruc.: verrucosum Zone. NADP1, 2, 3: Nannofossil Abundance and Diversity Peak intervals. Asterisks represent occurrences of stratigraphically important nannofossil taxa, polygon represents the only barren sample.

brachiopod taxa of the Bakony Mountains and the number of specimens at the respective sections and localities. The four Barremian brachiopod specimens (from the HÉK section) are also included into Table 1.

The Berriasian to Barremian brachiopod fauna of the Bakony Mountains is very diverse taxonomically: the 1015 specimens represent 25 species of 12 genera (Table 1). The overwhelming part belongs to the Pygopidae (658 specimens); the most abundant genera of the family are: *Triangope* (336), *Pygites* (141), *Antinomia* (134) and *Pygope* (47).

The family Nucleatidae is represented by 165 specimens and 5 species; rhynchonellides are also diverse (172 specimens; 5 species); other taxa are subordinate. It is worth mentioning that the brachiopod fauna of the HK-12 section is by far the most abundant and diverse (319 well-identified specimens, 18 species); the fauna of the HÉK section is also abundant but less diverse (219 specimens, 9 species); moreover, the Szilas Ravine section yielded a less abundant but rather diverse fauna (71 specimens, 12 species). In the brachiopod taxonomy we largely

Table 1
The Berrisian to Barremian brachiopod taxa of the Bakony Mountains and the numbers of specimens at the respective sections and localities.

Sections and other localities	<i>Lingularia</i> sp.	<i>Monticlairella? tarica</i> (Zejszner, 1846)	<i>Monticlairella? agassizi</i> (Zejszner, 1846)	<i>Fortunella mouzoniana</i> (d'Orbigny, 1847)	<i>Fortunella fortuneae</i> Calzada, 1985	<i>Fortunella toniana</i> Sulser & Calzada, 1991	<i>Svaljaviathyris bilimeki</i> (Suess, 1858)	<i>Pygope diphyia</i> (Buch, 1834)	<i>Pygope axine</i> (Zejszner, 1846)	<i>Pygope janitor</i> (Pictet, 1867)	<i>Antinomia cautiloi</i> (Pictet, 1867)	<i>Antinomia diphoros</i> (Zejszner, 1846)	<i>Antinomia sima</i> (Zejszner, 1846)
Zirc, Márvány Quarry				120						8			
Hárskút, Édesvíz, Key Section						6							
Hárskút, Édesvíz-majior (1961)													
Hárskút, Édesvíz-majior-27 (1963)					15	19		2	2		74	3	8
Hárskút, HK-12	4	1		8									
Zirc, Borzavár Road Quarry				1							1		
Hárskút, Rend-kő Olaszfalu, Eperkés Hill, Stripe Pit, Bed 1													
Zirc, Istenes-malom													
Zirc, Alsó-majior		2	2				4	33	1	2	2	1	1
Borzavár, Szilas Ravine								1	3	1	5	12	
Hárskút, HK-II								5		7	1		
Hárskút, HK-12/a	4	2	2	1	144	25	4	41	6	1	98	17	8
Sections and other localities	<i>Antinomia aff. cautiloi</i>	<i>Pygites diphyoides</i> (d'Orbigny, 1849)	<i>Triangulus triangulus</i> (Valenciennes in Lamarck, 1819)	<i>Triangope triangulus angulata</i> Vigh, 1981	<i>Triangope? aff. triangulus</i>	<i>Sphenope bifida</i> Vörös, 2013	<i>Nucleata bouei</i> (Zejszner, 1846)	<i>Nucleata strombecki</i> (Schloenbach, 1867)	<i>Nucleata? euthymi</i> (Pictet, 1867)	<i>Vjalovityris rupicola</i> (Zittel, 1870)	<i>Vjalovityris aff. rupicola</i> (Zittel, 1870)	<i>Oppeliella pingicula</i> (Zittel, 1870)	Sum
Zirc, Márvány Quarry	19	37	4	4				42					222
Hárskút, Édesvíz, Key Section	28	140	3	3		1		6	1				221
Hárskút, Édesvíz-majior (1961)	5	32	5	5				14	1				57
Hárskút, Édesvíz-majior-27 (1963)	3	16	1	1				3					23
Hárskút, HK-12	51	54	8	35				8	2	7	16	1	319
Zirc, Borzavár Road Quarry	32	1	14	14				14					56
Hárskút, Rend-kő Olaszfalu, Eperkés Hill, Stripe Pit, Bed 1	2	2	4	4				4					6
Zirc, Istenes-malom						2					8		8
Zirc, Alsó-majior						2							11
Borzavár, Szilas Ravine					4	2				1			6
Hárskút, HK-II		2				2							71
Hárskút, HK-12/a		1				2							9
Hárskút, HK-12/a	13	286	13	42	4	42		91	4	8	24	1	1015
sum	140	36	4	4	4	4	4	91	4	8	24	1	1015

followed the revised volumes of the “Treatise” (Savage et al., 2002; Lee et al., 2006) with a few exceptions. The generic name *Vjalovithyris* Tkhorshzhevsky, 1989 (synonymized with *Nucleata* in the Treatise) was retained for the species *V. rupicola* (Zittel, 1870) with laterally lobate shell. On the other hand, the more or less globose species *bouei* (Zejszner, 1846) and *strombecki* (Schloenbach, 1867), were arranged to *Nucleata* Quenstedt, 1868. The genus *Pygope* Link, 1830, in our opinion, was too widely interpreted in the revised Treatise (Lee et al., 2006). Here we used the narrower interpretation of the previous Treatise (Muir-Wood, 1965) and Buckman (1906), and restrict *Pygope* to the perforate or bifidate forms with straight lateral commissures, without beak ridges and planareas. In this concept, the species *diphya* (Buch, 1834), *axine* (Zejszner, 1846) and *janitor* (Pictet, 1867) belong to *Pygope*. Moreover, here we use again the generic name *Antinomia* Catullo, 1851, following Buckman (1906) and Muir-Wood (1965), for the perforate and bifidate forms with arched or sinuous lateral commissures and well developed planareas. The species *catulloi* (Pictet, 1867), *diphoros* (Zejszner, 1846) and *sima* (Zejszner, 1846) are ranked here to *Antinomia*.

3.2. Ammonoids

The majority of the rich brachiopod fauna, alongside ammonoids, was collected bed-by-bed from different sections around Hárskút in the early 1960s. The successive collecting campaigns in the sections Hárskút-12, Hárskút-12/a, Hárskút-II and HÉK were supervised by Prof. József Fülöp, that time general director of the Hungarian Geological Institute. Another important profile is the Szilas Ravine Section, which was sampled in the 1980s under the supervision of Prof. Géza Császár.

Apart from these well documented sections, which contain numerous layers and offer a broad stratigraphic context for the benthic faunal elements, some sections are restricted to a few layers only (like the uppermost, Valanginian part of the Eperkés Hill Section), and occasionally even the precise location of the sections is unknown (e.g. Hárskút, Édesvíz-major-27 and Édesvízmajor (1961)), thus serve only additional information of less importance. Further subsidiary brachiopod faunas were available in museum collections obtained from some other outcrops (like Borzavár Road Quarry, Zirc Istenes-malom, and Alsó-major) where no succession was recognized, but the few accompanying cephalopods still provide useful age control. In case of the Márvány Quarry Section brachiopods came from a thin and condensed limestone which contains a rich ammonite fauna, but no succession was documented.

The mentioned collecting activity yielded hundreds to thousands of ammonites from each of the main sections, collected bed-by-bed, and dozens of specimens from the auxiliary profiles which gave a precise age constrain for the accompanying brachiopod fauna. The overwhelming part of these ammonites is Tithonian, Berriasian and Hauterivian in age; a few sections also yielded Kimmeridgian and/or Barremian cephalopods as well (Főzy, 2017). The faunal turnover just around the WE, which is the strict focus of the present paper, happened in the late early Valanginian, within a time interval represented only in two of the sections (i.e. Hárskút, HK-12 and HÉK section).

Preservation of ammonites is variable: most of them are moderately eroded internal moulds, occasionally only one side preserved. In case of the condensed lower Valanginian of the Hárskút, HK-12 Section, and in the similarly condensed Márvány Quarry Section, many of the specimens are better preserved, partly with permineralized shell.

The majority of the ammonites belong to long ranged taxa (i.e. phylloceratids and lycoceratids), which implies Mediterranean affinity, and also the age diagnostic Ammonitina species are characteristically Mediterranean taxa. For this reason the ammonite zonation developed for the Tethyan palaeogeographical realm (Ogg et al., 2016 with further references) was used.

3.3. Nannofossils

From the Hárskút HK-12 section, 64 nannofossil samples (HK 1–64) were collected in 2009 and additional sampling in the interval HK 26–31 was carried out in 2010. Exactly the same rock pieces were analysed for stable isotopes and nannofossils.

The abandoned trench of the HÉK section is presently almost inaccessible, therefore nannofossil samples were taken from ammonite internal moulds that were collected bed-by-bed in the 1960's. Some additional samples were taken from rock pieces accompanied the ammonite material.

For smear-slide preparations, uniform amounts of rock were powdered, diluted and boiled in uniform amount of distilled water. After 1 min boiling, a smear slide is prepared with sterile equipment. Total of 16 samples were investigated from HK-12, and 21 samples from HÉK sections for nannofossil biostratigraphy with Nikon Eclipse 50i Pol polarizing light microscope at 1250× magnification using oil immersion objective 100×, 1.25 numerical aperture. Images were taken in cross polarized light (XPL) or plane polarized light (PPL), or with gypsum plate if needed, with TouPCam digital camera and its software.

In order to obtain precise stratigraphic data, at least 500 field of views in longitudinal traverses were investigated for each sample, one field of view is $2.37 \times 10^2 \text{ mm}^2$ (Aguado et al., 2018). To record rare specimens, random traverse settings were also searched.

Tethyan nannofossil biostratigraphic framework of Bown et al. (1998) and Bralower et al. (1995) is used here. Related to first- and last occurrences of certain taxa or any other nanno-events recognized in this paper are also relied on Bralower et al. (1989), Casellato (2010) and Elbra et al. (2018) for the Tithonian/Berriasian boundary, and on Kenjo (2014) for the upper Berriasian. Related to the WE, works of Erba and Tremolada (2004), Barbarin et al. (2012), Aguado et al. (2018), Mattioli et al. (2014) and Bottini et al. (2018) were also considered.

All smear slides were prepared and kept in inventory at the Hungarian Natural History Museum Budapest, at the Department of Palaeontology and Geology.

4. Results

4.1. Ammonoids

The range chart of the Lower Cretaceous ammonites of the HK-12 section, alongside with the illustration of the most important ammonites were published by Főzy et al. (2010) and here indicated in Fig. 3.

For the previously unpublished HÉK section biostratigraphic subdivision is given below. For the lowermost three beds of the section yielded a diverse ammonite fauna of lower Tithonian *fallauxi* Zone. A single bed (Bed 65) containing some perisphinctid ammonites may represent the lower part of the upper Tithonian *microcanthum* Zone. Upwards in the section berriasellids, including *Fauriella boissieri* (Pictet, 1867) and poorly preserved olcostephanids occur. These beds (Beds 64–62) were assigned into the upper Berriasian *boissieri* Zone; however they may encapsulate the recently introduced *alpillensis* Zone of Reboulet et al. (2018) as well. Beds 60–61 yielded specimens of *Kilianella* and *Neocomites*, thus representing the lower Valanginian; probably the *pertransiens* and/or *neocomiensiformis* Zone(s). *Karakaschiceras* was not found; therefore the *inostranzewi* Zone cannot be documented. From bed 59 and above, representatives of genera *Oosterella* and *Valanginites* were found, which mark the beginning of the Late Valanginian *verrucosum* Zone. Upsection ammonites become scarce and for this reason stratigraphic subdivision on zonal level is highly difficult. Thus the lower boundary of the stage can tentatively be drawn by the appearance of the first *Crioceratites* in Bed 38. Numerous subsequent beds upward yielded a typical Hauterivan, but poorly preserved ammonite assemblage. They may represent several ammonite zones, but their boundaries cannot be drawn precisely. From Bed 7, alongside many desmoceratids the first representatives of pulchellids (*Discoidella*) and

also *Paraspticer* specimens were collected. This fauna is characteristic for the latest Hauterivian and earliest Barremian age. The base of the latter stage was drawn by the appearance of the first holcodiscids in Bed 6. Higher beds still contain lowermost Barremian (*hugii* Zone) ammonites only.

The sections HK-12 and HÉK are about 4 km from each other, yet they show differences from the point of view of ammonite biostratigraphy. In general terms, HK-12 provided much larger and better preserved fossil assemblage. The Berriasian is well documented at HK-12, and poorly at HÉK. Lower Valanginian was documented in both sections, but HK-12 yielded more and better preserved fossils. The *verrucosum* Zone is rich at HK-12, but also inferred at HÉK. At HK-12 only the uppermost Hauterivian was proved, while more, but poorly preserved Hauterivian ammonites were found at HÉK. Barremian ammonites were found only at HÉK. In spite of these differences, the biostratigraphical correlation between the two sections is feasible.

4.2. Nannofossils

The present research resulted in an advanced calcareous nannofossil biostratigraphy of the HK-12 section and the HÉK section (Figs. 3 and 4). The nannofossil biostratigraphy of HK-12 section has been revised here, while nannofossil zonation for the HÉK section is established here for the first time. These data may serve as an excellent stratigraphical control where stratigraphy is based on ammonites (Főzy et al., 2010), and may give new results where absence of ammonoids could not provide exact age reference.

In Hárskút HK-12, the nannofossil biostratigraphic framework of the upper part of section was revised on the basis of 16 samples. Throughout the section, calcareous nannofossil preservation is good to moderate. No barren samples were detected, although nannofossil absolute abundance shows wide differences between samples.

Nannofossil events revealed that exact stratigraphic range of the section is from middle Berriasian to uppermost Hauterivian. The significant first occurrence (FO) and last occurrence (LO) events at the respective beds/samples of the section are well documented. Presence of nannozones NK1 (samples 1–7), NK2 (samples 8–?26), NK3 (samples? 26–?47), NC4 (samples? 47–63) and NC5 (sample 64) were pointed out. Calcareous nannofossil bioevents calibrated with chemostratigraphy and ammonite zonation and other bioevents recorded at Hárskút HK-12 section, and the assumed extent of the WE are shown in Fig. 3.

From HÉK section, 21 nannofossil smear slides were prepared to establish the microbiostratigraphic framework supporting macrofossil data but without performing quantitative investigations. Throughout this section, calcareous nannofossil preservation is good to moderate. One almost barren sample was detected (sample 46). Documented nannofossil events revealed the exact stratigraphic range of the section which expands from upper Tithonian to lowermost Barremian showing a condensation of the lower part. The major first occurrence (FO) and last occurrence (LO) nannofossil events are well documented (Fig. 4). Some important nannofossil events were not satisfactory detected, or not detected at all. For example, *Rucinolithus wisei*, which is an important biostratigraphic marker (Bralower et al., 1989) but rather rare in Tethyan sections (Bottini et al., 2018), was not found. Presence of nannozones NJT17 (samples 68–67), NKT (sample 66) and NK1 (samples 65–62), NK2 (sample 61), NK3 (samples 60–38), NC4 (samples 30–9), NC5 (samples 7–6) were pointed out. Considering the important nannofossil abundance and diversity peak (NADP1) interval between samples 60 and 48, in the lower part of NK3A nannofossil subzone, we assume that this interval may correspond to the WE which is more extended here than in the HK-12 section. Calcareous nannofossil bioevents calibrated with ammonite zonation and other bioevents recorded at HÉK section are portrayed in Fig. 4.

4.3. Brachiopods

Brachiopod range charts, based on the above biostratigraphical results, have been constructed for the HK-12 and the HÉK sections, with the indication of the occurrences of species in the respective beds and/or intervals of the sections (Figs. 3 and 4). The rather abundant and diverse Berriasian brachiopod assemblage of the HK-12 section was followed an even more diverse fauna in the early Valanginian (Fig. 3). The lower Valanginian condensed and pure limestone beds (Beds 10, 11) are overlain by thin bedded, marly limestones with clayey interlayers (Beds 6–9) representing the upper Valanginian *verrucosum* Zone. These beds record a sharp change in the brachiopod fauna: the previous, diverse assemblage is replaced by an almost monospecific fauna, with small sized *Fortunella praemoutoniana* and a few minute *Lingularia* sp. specimens. Particularly the Lingulidae are widely considered as “disaster taxa” (Hallam and Wignall, 1997; Rodland and Bottjer, 2001; Petsios and Bottjer, 2016), thus our present record seems to correspond to the sharp excursions in the of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ curves indicating the WE (Főzy et al., 2010). The next, rather thick part of the section HK-12 was sampled only for microfossils and geochemistry. Based on nannofossil biostratigraphy and chemostratigraphy, this part of the section is considered late Valanginian to early Hauterivian in age. In the top of the section an abundant and rather diverse assemblage of fossils was collected. The ammonoids point to a late Hauterivian age (I. Főzy, this paper). The composition of the brachiopod fauna is entirely different from that recorded in the lower Valanginian; the appearance of *Pygites diphyoides*, *Triangope triangulus angulata*, *Nucleata? strombecki* and *Nucleata? euthymi* is particularly remarkable. The brachiopod record of the HÉK section is more continuous with respect to section HK-12, even though the bulk diversity is lower. The species characterizing the Berriasian, occur also in the lower Valanginian. The lowermost beds (56–58) of the upper Valanginian (probably *verrucosum* Zone) yielded exclusively the small sized *Fortunella praemoutoniana* specimens. This level, despite the absence of Lingulidae, are considered equivalent to the Beds 6–9 of the HK-12 section. After a dozen layers free of brachiopods, *Triangope triangulus angulata* and *Nucleata? strombecki* appear in the uppermost part of the upper Valanginian. This association is augmented with *Pygites diphyoides* in the lower to upper Hauterivian, and with *Nucleata? euthymi* in the lowermost Barremian. Importantly, the brachiopod record of the HÉK section documents the abrupt turnovers in the earliest late Valanginian (prior to and following the *verrucosum* Zone), coeval with the WE. The representative elements of the studied Berriasian to Barremian brachiopod fauna are illustrated in Fig. 5.

(1) *Fortunella fortuneae* Calzada, 1985, (INV 2020.1.), Hárskút, Rendkő, Bed 35, Hauterivian, a: dorsal view, b: lateral view, c: anterior view. (2) *Pygites diphyoides* (d'Orbigny, 1849), (INV 2020.2.), Hárskút, HÉK section, Bed 12, upper Hauterivian, a: dorsal view, b: lateral view. (3) *Pygites diphyoides* (d'Orbigny, 1849), (INV 2020.3.), Hárskút, HÉK section, Bed 22, upper Hauterivian, plaster cast of a sectioned specimen, dorsal view. (4) *Triangope triangulus angulata* Vigh, 1981, (INV 2020.4.), Hárskút, HÉK section, Bed 41, upper Valanginian, dorsal view. (5) *Triangope triangulus angulata* Vigh, 1981, (INV 2020.5.), Olaszfalu, Eperkés Hill, Stripe Pit, Bed 1, upper Valanginian, a: dorsal view, b: lateral view. (6) *Triangope* aff. *Triangulus* (Lamarck, 1819), (INV 2020.6.), Hárskút, Édesvíz-major (1961), Bed 5, upper Hauterivian, a: dorsal view, b: lateral view. (7) *Nucleata? euthymi* (Pictet, 1867), (INV 2020.7.), Hárskút, HÉK section, Bed 6, Barremian, a: dorsal view, b: anterior view. (8) *Fortunella praemoutoniana* Sulser & Calzada, 1991, (INV 2020.8.), Hárskút, HÉK section, Bed 58, upper Valanginian, a: dorsal view, b: anterior view. (9) *Lingularia* sp. (INV 2020.9.), Hárskút, HK-12 section, Bed 6, upper Valanginian, external view. (10) *Lingularia* sp. (INV 2020.10.), Hárskút, HK-12 section, Bed 6, upper Valanginian, external view. (11) *Lingularia* sp. (INV 2020.11.), Hárskút, HK-12 section, Bed 6, upper Valanginian, external view; (12) *Antinomia* aff. *catulloi* (Pictet, 1867) (INV 2020.12.), Hárskút, HK-12 section, Bed 11,

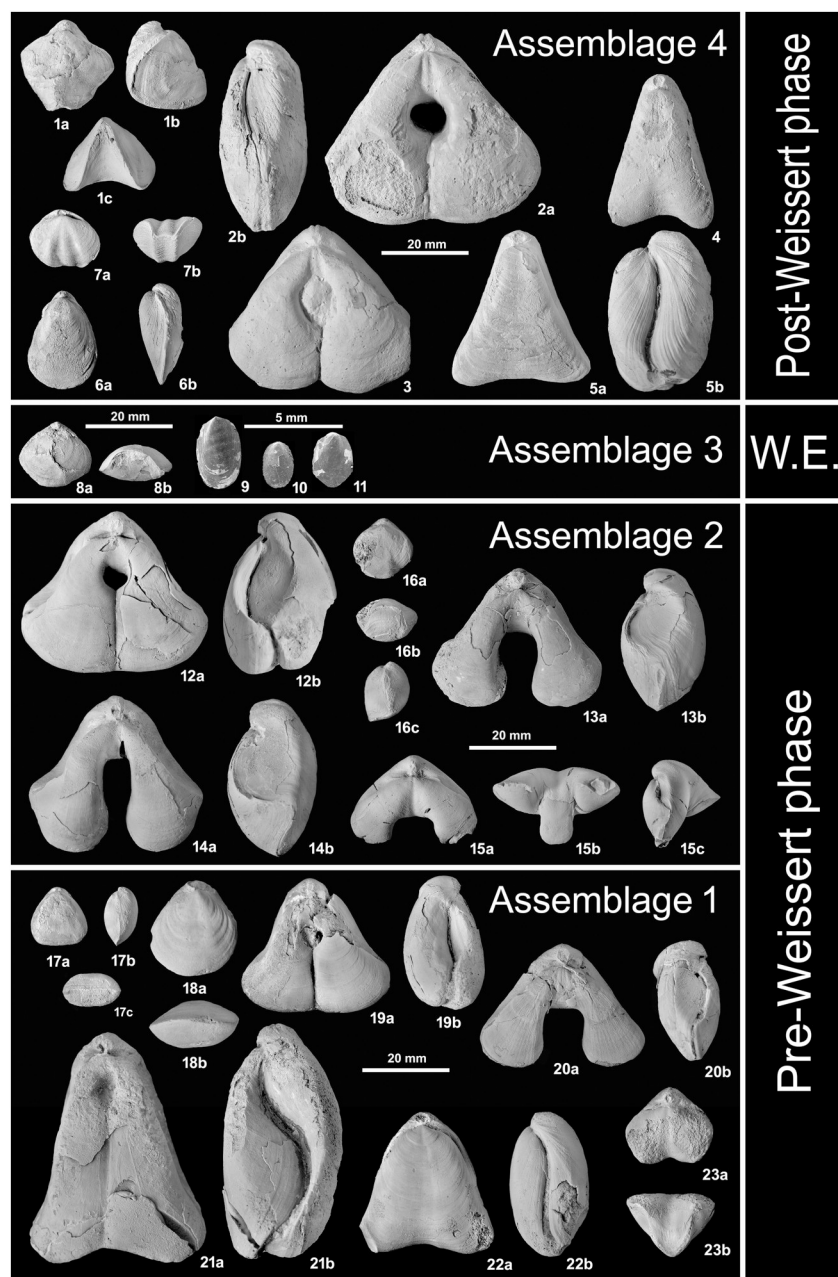


Fig. 5. Representative species of the examined Berriasian to Barremian brachiopod fauna and their turnover across the earliest late Valanginian extinction horizon (WE). Specimens have been coated with ammonium chloride before photography. Specimens are deposited in the collection of the Department of Palaeontology and Geology of the Hungarian Natural History Museum (Budapest), under the inventory numbers prefixed by M., or INV and/or in the palaeontological collection of the Mining and Geological Survey of Hungary (MGSZ) under the inventory numbers prefixed by K. Scale bar = 20 mm, except 9–11, where the scale bar = 5 mm. Assemblage 1: early Berriasian species; Assemblage 2: late Berriasian to early Valanginian species, disappeared prior to the WE; Assemblage 3: species restricted to the extinction horizon; Assemblage 4: species appeared after the WE.

lower Valanginian, a: dorsal view, b: lateral view. (13) *Antinomia diphoros* (Zejszner, 1846) (INV 2020.43.), Hárskút, HK-12 section, Bed 21, upper Berriasian, a: dorsal view, b: lateral view. (14) *Antinomia sima* (Zejszner, 1846) (INV 2019.62.), Hárskút, HK-12 section, Bed 18, upper Berriasian, a: dorsal view, b: lateral view. (15) *Vjalovithyris* aff. *rupicola* (Zittel, 1870), (K 11503), Hárskút, HK-12 section, Bed 10, lower Valanginian, a: dorsal view, b: anterior view, c: lateral view. (16) *Oppeliella pingucula* (Zittel, 1870) (INV 2019.67.), Hárskút, HK-12 section, Bed 21, Upper Berriasian, a: dorsal view, b: anterior view, c: lateral view. (17) *Monticlarrella? agassizi* (Zejszner, 1846) (INV 2019.53.), Lókút, Key Section, Bed 4., upper Tithonian, a: dorsal view, b: lateral view, c: anterior view. (18) *Svaljavithyris? bilimeki* (Suess, 1858) (INV 2020.44.), Borzavár, Szilas Ravine, Bed 37, Berriasian, a: dorsal view, b: anterior view. (19) *Pygope diphya* (Buch, 1834) (INV 2019.55.), Borzavár, Szilas Ravine, Bed 41, Berriasian, a: dorsal view, b: lateral view. (20) *Antinomia diphoros* (Zejszner, 1846) (INV 2019.61.), Borzavár, Szilas Ravine, Bed 39, Berriasian, a: dorsal view, b: lateral view. (21) *Antinomia catulloi* (Pictet, 1867) (INV 2019.59.), Hárskút,

HK-12 section, Bed 18, upper Berriasian, a: dorsal view, b: lateral view. (22) *Triangope triangulus* (Lamarck, 1819) (M.87.069.), Borzavár, Szilas Ravine, Bed 41, Berriasian, a: dorsal view, b: lateral view. (23) *Nucleata bouei* (Zejszner, 1846) (INV 2019.65.), Borzavár, Szilas Ravine, Bed 31, Berriasian, a: dorsal view, b: anterior view.

The stratigraphical ranges of the brachiopod taxa, recorded in the well-dated Berriasian to Barremian sections and localities in the Bakony Mts, are shown in Fig. 6.

Seven (mostly pygopide) species range up from the early Berriasian, to the late Berriasian and five species disappear and three species appear at this boundary. Seven late Berriasian species pass to the early Valanginian where three species disappear (Assemblages 1 and 2 in Figs. 5 and 6). The eight species persisting to the early Valanginian disappear at the lower boundary of the upper Valanginian. The beginning of the late Valanginian (*verrucosum* Zone) is seen as a sharp break, with the transient appearance of *Fortunella praemoutoniana* and *Lingularia* sp. (Assemblage 3 in Figs. 5 and 6). Shortly after, a complete turnover of brachiopod taxa is recorded, most markedly among the

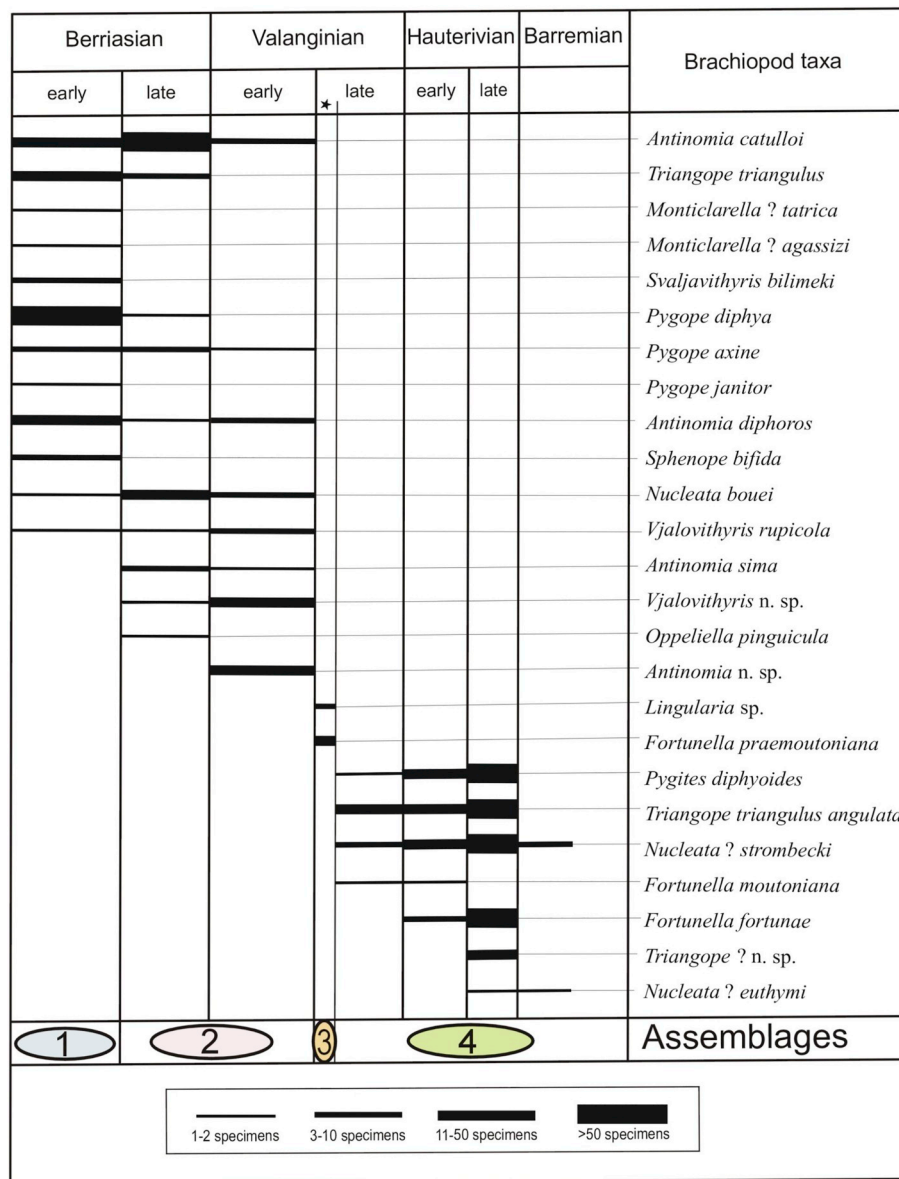


Fig. 6. Stratigraphical ranges and relative abundance of the brachiopod species recorded in the well-dated sections (Hárskút, HK-12, HK-12a, HK-II, Édesvíz, Édesvízmajor (1961), Édesvízmajor-27, Borzavár, Szilas Ravine, and localities Zirc, Alsó-major, Istenes-malom, Borzavár Road Quarry, Márvány Quarry, Olaszfalu, Eperkés Hill, Stripe Pit 1) through the Berriasian to Barremian interval and the four Assemblages. Asterisk indicates the *verrucosum* Zone (~ WE).

Pygopidae. The genera *Pygope* and *Antinomia*, with all species, totally disappeared at the end of the early Valanginian, whereas the genus *Pygites*, as an entirely new element, appeared in the late Valanginian. *Triangope triangulus*, dominant in the Berriasian, was substituted by *Triangope triangulus angulata* in the late Valanginian to the Hauterivian (Assemblage 4 in Figs. 5 and 6).

5. Discussion

5.1. The presumed extent of the Weissert Event in the Bakony Mountains

The nannofossil bioevents, calibrated with ammonite zonation, and the brachiopod bioevents give support to an improved correlation between the HK-12 and HÉK sections, even in the absence of $\delta^{13}\text{C}$ data in the latter section. Both at Hárskút HK-12 and HÉK sections, abrupt lithologic changes from pure pelagic limestones to hemipelagic marly sediments can be visible at the base of the upper Valanginian, which reflect a major environmental change discussed and correlated to the WE by several authors (Mattoli et al., 2014; Bottini et al., 2018;

Martinez et al., 2013, 2015; Charbonnier et al., 2016, 2020; Aguirre-Urreta et al., 2019; Ray et al., 2019). At Hárskút HK-12 section, the topmost bed of the limestone is strongly condensed, and the next, 1 m thick, thin-bedded upper Valanginian marly limestone may also be somewhat condensed. Detailed sampling of these layers revealed the marked positive shift of the $\delta^{13}\text{C}$ values, proving the presence of the WE in this section (Főzy et al., 2010). The positive carbon excursion covering this condensed interval represents the upper part of the *inostranzewi* and the *verrucosum* Zones of the Mediterranean standard (Reboulet et al., 2018), corresponding to the middle part of NK3A nannofossil subzone. The same interval yielded the dwarf brachiopods (Assemblage 3), with *Lingularia sp.*, and *Fortunella praemoutoniana*. The HÉK section is much less condensed, so the WE is supposed to be more extended here than at the Hárskút HK-12 section. Although no carbon and oxygen stable isotope excursion is presented herein, we attempted to point out a late-early Valanginian to early-late Valanginian palaeoenvironmental change on the basis of nannofossil events and brachiopod assemblage turnover. This, approximately six metres thick, unit was dated as upper Valanginian by ammonoids (Főzy, this paper)

and correlated to the *verrucosum* Zone by nannofossil stratigraphy (NADP1: Szives, this paper). The lowermost part of these rather siliceous and marly layers contains a few dwarf brachiopod specimens (*Fortunella praemoutoniana*) of the Assemblage 3.

5.2. Valanginian brachiopod events in previous studies

Significant intra-Valanginian changes in brachiopod evolution have been recognized by classical and recent authors. Middlemiss (1973, p. 129) reported important changes in the late Valanginian to Hauterivian, when Tethyan brachiopod faunas spread northwards to the European epicontinental seas. Ager (1975, p. 160) went even further: “If the author was forced into... ..defining the Jurassic-Cretaceous boundary on the basis of brachiopod evidence, then he would be very tempted to do so within the Valanginian, where the perforate pygopids declined markedly, and the cyclothyri[d]s began to spell of rapid diversification.” In Provence, three brachiopod species range from the Berriasian up to the Valanginian, while three other species appear in the higher part of the Valanginian (Sandy, 1986). This may be interpreted as the occurrence of a mid-Valanginian turnover. Krobicki (1996) published detailed data on brachiopod distributions from Valanginian measured sections in the Pieniny Klippen Belt (Poland). Although the brachiopod ranges are interrupted in the Valanginian *verrucosum* Zone, no turnover was recorded after this hiatus. The apparent extinctions (Lazarus taxa) reflect the WE, but their re-appearance after the crisis may be due to the stability of the depositional environment: the pure carbonate sedimentation continues. This is a difference from the Bakony area, where the sedimentation switched to marly, during and after the WE. In the sections of the Gargano peninsula (southern Italy), platform drowning, nannoconid crisis and mass accumulation of brachiopods were recorded synchronously with the WE (Graziano and Ruggiero Taddei, 2008).

5.3. Early Cretaceous brachiopod extinctions in the Bakony Mountains

On the basis of more than 1000 identified brachiopod specimens collected from several localities in the Bakony Mountains, three steps of extinction can be pointed out in this study. The first corresponds to the

early/late Berriasian, the second to the late Berriasian to early Valanginian time interval (Fig. 7), and the third, most significant extinction and turnover coincides with the WE (Fig. 8).

The first topic, emerging from our results, is the recognition and interpretation of the stepwise brachiopod extinctions within the Berriasian and at the Berriasian/Valanginian boundary. A part of the most abundant Berriasian brachiopod species (Assemblage 1), belonging to the genera *Monticlarella*, *Svaljavithyris*, *Pygope* and *Sphenope* disappeared at the early/late Berriasian boundary (Fig. 6). This is interpreted as a first phase of a stepwise extinction, followed by a partial rejuvenation of the brachiopod fauna (E₁ in Fig. 7). A next, similar phenomenon is recorded within the Assemblage 2, at the Berriasian/Valanginian boundary, where further three species of the genera *Triangope*, *Pygope* and *Oppeliella* disappeared, and one species of *Antinomia* appeared (E₂ in Fig. 7). This process is interpreted as a stepwise extinction and partial rejuvenation of the brachiopod fauna during the Early Cretaceous, heralding the major extinction at the WE. These earlier phases of extinction of brachiopods might be related to widespread palaeoenvironmental and palaeoclimate changes, which occurred during the late Berriasian and early Valanginian in the Tethyan region, e.g. enhanced fertilization (Föllmi, 1995; Duchamp-Alphonse et al., 2007; Morales et al., 2013, 2015, 2016) and presumed cooling after the late early Valanginian (McArthur et al., 2007). It should be noted that *T. triangulus angulata*, which markedly differs from *T. triangulus* by its short hinge margin and concave lateral sides, was recorded also in the Gerecse Mountains (Vörös, 2015). These, partly distorted specimens were collected from the upper Valanginian Bersek Marl, and were misidentified by Vörös (2015) as *T. triangulus*. The manifestations of the WE were demonstrated in the Gerecse Mountains as well (Bajnai et al., 2017; Főzy, 2017), and the *T. triangulus angulata* specimens came definitely from above the Weissert horizon. This further endorses that this taxon belongs to the “post-Weissert” assemblage of brachiopods.

The second major topic is the demonstration of the most significant extinction of the Early Cretaceous brachiopod fauna in the Bakony Mountains, connected to the early late Valanginian WE. The eight species, belonging to *Pygope*, *Antinomia*, *Nucleata* and *Vjalovithyris*, persisting up to the early Valanginian, ultimately disappeared at the lower boundary of the upper Valanginian (Fig. 8). The extinction

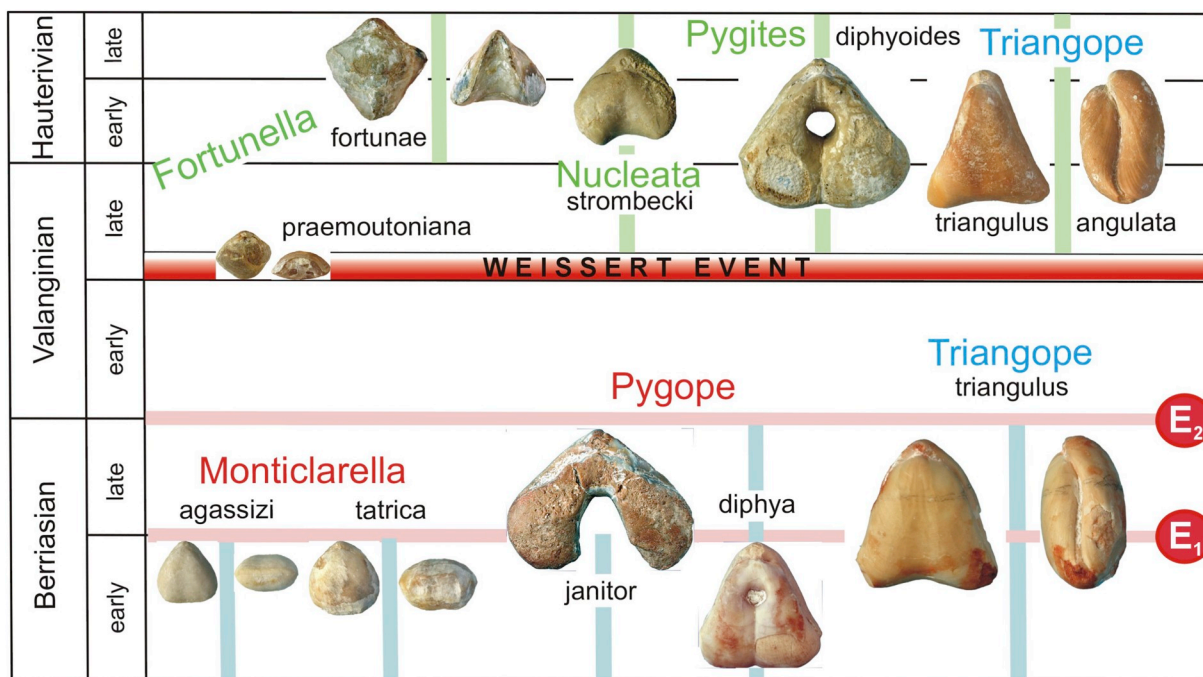


Fig. 7. Stepwise extinction of the Berriasian brachiopod taxa, prior to the Weissert Event. E₁: first phase at the early/late Berriasian, E₂: second phase at the Berriasian/Valanginian boundary.

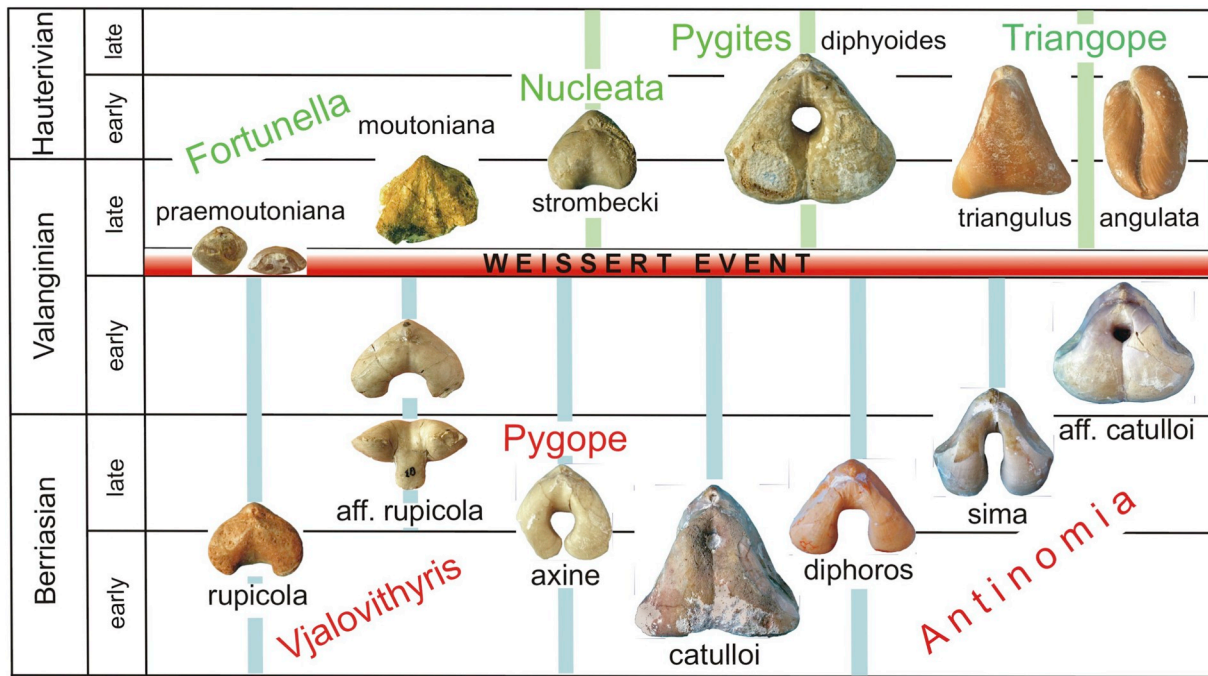


Fig. 8. Extinctions and turnover of brachiopod taxa at the Weissert Event.

horizon is marked with a poorly preserved, almost monospecific brachiopod fauna (*Fortunella praemoutoniana*, *Lingularia* sp.; Assemblage 3). Lingulides are regarded as typical “disaster taxa” (e.g. after the end-Permian mass extinction, Rodland and Bottjer, 2001); on the other hand, the minute *F. praemoutoniana* was found exclusively at this horizon, what points to its special adaptation to harsh environment. Dwarfism is a typical feature of biota living in stressful (e.g. dysoxic) conditions (e.g., Lukeneder, 2003; Baeza-Carratala et al., 2015). After this biotic crisis at the time of the *verrucosum* Zone, a different brachiopod fauna appeared in the late Valanginian (Assemblage 4) (Fig. 8). A complete turnover of brachiopod species is seen within the genera *Fortunella*, *Nucleata* and *Triangope*. The previously dominant genera *Pygope* and *Antinomia* are substituted by *Pygites diphyoides*, which was not recorded in lower stratigraphic levels in the Bakony Mountains. This assemblage prevailed through the Hauterivian and partly persisted to the Barremian (Fig. 6). The “mid”-Valanginian biotic crisis, i.e. (1) the disappearance of the well diversified early Valanginian Assemblage 2, and (2) the appearance of the earliest late Valanginian disaster taxa (*verrucosum* Zone, Assemblage 3), seem to be in clear cause-and-effect relationship with the WE, as proven by the isotopic signal recorded in the section HK-12 by Főzy et al. (2010). This phenomenon is the biotic response to the complex environmental changes that characterize the WE, including calcification crisis due to excess CO₂, and enhanced fertility (Erba and Tremolada, 2004; Gréselle et al., 2011; Erba et al., 2019). Evidence of carbonate dissolution on bedding surface just below the “Weissert horizon”, in our section HK-12 (Bed 10), recorded by Főzy et al. (2010), is can be linked either to the calcification crisis (Erba et al., 2019), or to the high magnitude sea level rise (Haq, 2014; Ray et al., 2019).

The third topic to be discussed here is the complete turnover of brachiopod species, and particularly the appearance of *Pygites diphyoides*, in the latest Valanginian to Hauterivian recovery phase. As most brachiopods investigated here were sessile and adapted to relatively stable, warm conditions, both climatic and depositional system changes could result their extinction and a turnover to more stress-tolerable forms. Two major, partly related, controlling factors can be accounted: (1) Changes in depositional environment. In the sections of the Bakony Mountains, with continuous sedimentary and brachiopod

record (HK-12, HÉK; Figs. 3 and 4), the previous calcareous sedimentation switched to deposition of marls in the late Valanginian. Charbonnier et al. (2020) pointed out increased weathering due to more humid climatic conditions in this time interval which may lead to increased continental runoff into the basin of the present Transdanubian Range. The turbid water, due to the increase of siliciclastic influx, and the soft bottom were unfavourable for brachiopod taxa adapted to pure carbonate and partly hard bottom prevailed in “pre-Weissert” period. During the delayed replenishment other brachiopods, better adapted to the new circumstances, entered the area. The sedimentary condensation may amplify the change of brachiopod assemblages. (2) Changes in palaeoclimate. The late Valanginian cooling episode (Gröcke et al., 2005; McArthur et al., 2007; Gréselle et al., 2011; Bodin et al., 2015), and climatic fluctuations (Föllmi, 2012; Charbonnier et al., 2020), following the WE were also detrimental for the Berriasian brachiopod association, accustomed to the warmer sea of the Tethys ocean. Our Berriasian brachiopod Assemblage 1 is a slightly reduced prolongation of the Tithonian assemblages recorded in the Bakony Mountains (Vörös et al., 2019b), which were adapted to the “Tithonian climatic optimum” (see the compilation by Bodin et al., 2015). On the other hand, the change of climate to the “Late Valanginian coldhouse” (Bodin et al., 2015) was favourable for new colonizers from the north, probably better adapted to the cooler waters. A further controlling factor can perhaps be accounted, namely the coeval, mostly submarine volcanic activity within the western part of the Tethys (pers. comm. by M. Krobicki). A well documented case of late Valanginian volcanism and associated brachiopod fauna was reported from the Mecsek Mountains (Hungary) by Bujtor et al. (2013), however the direct influence of this volcanic episode to the brachiopod faunas of the Bakony Mountains is only hypothetical. The most striking, WE-related extinctions and turnover, affecting most seriously the subfamily Pygopinae, are demonstrated in Fig. 8. Besides two *Vjalovithyris* species (*V. rupicola*, *V. aff. rupicola*), the only remaining species of *Pygope* (*P. axine*) and the four *Antinomia* species (*A. catulloi*, *A. diphoros*, *A. sima*, *A. aff. catulloi*) abruptly and definitively disappeared at the base of the late Valanginian. The interval of the WE was free of pygopides. Afterwards, *Pygites diphyoides* appeared in the late Valanginian and became abundant in the Hauterivian. This was not a simple taxonomical substitution as it may

reflect a change between adaptive morphotypes and/or a migration event. It was claimed, in fact, that the forms with small, posteriorly lying perforations were restricted to the Alpine-Mediterranean regions (i.e. on the intra-Tethyan microcontinents), while *Pygites*, with large, central perforations lived in the more turbid environments of the European shelves (e.g. Vocontian basin) (Sandy and Vörös, 1988; Kázmér, 1993). Our data from the Bakony Mts. are in partial agreement with this assumption. In fact, the dominant species of the Berriasian fauna, *Pygope diphya* and *Antinomia catulloi* bear narrow perforations, close to the simple umbo (Fig. 5–14, 15). However, some other species (*Pygope janitor*, *P. axine*, *Antinomia diphoros*, *A. sina*) with large central perforation, or bifid lobes, were also frequent in the Berriasian fauna and declined prior to (*P. janitor*), or definitely at the WE (Figs. 7 and 8). This proves that centrally perforated pygopines did thrive in the intra-Tethyan (Alpine-Mediterranean) areas, in contrast to the previous assumption by Sandy and Vörös (1988) and Kázmér (1993). On the other hand, we confirm the observations of these authors, concerning *Pygites diphyoides*. The perforation of this species lies also in nearly central position moreover its ventral umbo bears sulcus in the median fold (Fig. 5–2, 3). In fact, *P. diphyoides* was abundant from the late Tithonian to the Hauterivian, with an acme in the Berriasian, and was distributed along the European margin (Jarre, 1962; Dieni and Middlemiss, 1981). However, in the Valanginian, it appeared in the intra-Tethyan (Alpine-Mediterranean) areas, e.g. in the Venetian Alps (Dieni and Middlemiss, 1981), and became exclusive in the Bakony Mountains. In this area the *Pygope-Antinomia* group, irrespective of the size and position of perforation, did not survive the WE, and was substituted by *Pygites diphyoides*, a new element, immigrated from the European shelf in the late Valanginian times.

6. Conclusions

Two sections in the Bakony Mountains (Hárskút, HK-12; Hárskút, Édesvíz, Key Section) encompassing the Berriasian to Hauterivian interval were correlated by the ammonoid and nannofossil biostratigraphy and lithology. Although no carbon and oxygen stable isotope are known for the more expanded HÉK section so far, we have derived the stratigraphical extent of the WE indirectly, on the basis of the nannofossil distribution and brachiopod assemblage composition, after bed-by-bed comparison with the chemostratigraphically dated HK section.

On the basis of the rich brachiopod material, collected from the above and other, biostratigraphically dated, measured sections, and localities, it is demonstrated that some of the most abundant early Berriasian brachiopod species (members of Assemblage 1) disappeared at the early/late Berriasian boundary. A next, partial extinction and turnover occurred at the Berriasian/Valanginian boundary, within the Assemblage 2. This stepwise extinction was apparently related to coeval cooling and enhanced fertilization in the Tethyan region.

The most significant extinction of the Early Cretaceous brachiopod fauna in the Bakony Mountains is connected to the early late Valanginian WE. The rich early Valanginian fauna (eight species of *Pygope*, *Antinomia*, *Nucleata* and *Vjalovithyris*) disappeared at the lower boundary of the upper Valanginian. The extinction horizon is marked with an almost monospecific, dwarf brachiopod fauna (*Fortunella praemoutoniana*, *Lingularia* sp.; Assemblage 3).

In the late Valanginian an abundant brachiopod fauna (Assemblage 4) appeared, with a complete turnover of species. The genera *Vjalovithyris*, *Pygope* and *Antinomia* disappeared definitely and were substituted by *Pygites*. The species *Pygites diphyoides*, which was not recorded in lower stratigraphic levels in the Bakony Mountains, became abundant in the Hauterivian.

The complete turnover of brachiopod species in the late Valanginian recovery phase is assumed to have been controlled by two factors. (1) Change in the depositional environment due to sea level rise and increased weathering, from pure calcareous to marly. The turbid water, due to the increase of siliciclastic influx, and the soft bottom were

unfavourable for brachiopod taxa adapted to pure carbonate and partly hard bottom prevailed in “pre-Weissert” period. During the late Valanginian replenishment, other brachiopods, better adapted to the new circumstances, entered the area. (2) Change in palaeoclimate. The cooling and/or climatic fluctuations after the WE might be detrimental for the earlier, Berriasian brachiopod association adapted to the warmer Tethys. The late Valanginian climate change was favourable for new colonizers from the north, better adapted to the cooler waters.

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