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Palynological evidence of synchronous changes within the terrestrial and marine realm at the Triassic/Jurassic boundary (Csővár section, Hungary)

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ABSTRACT

Linking marine and terrestrial events within the end-Triassic extinction is controversial, as is interpretation of carbon cycle perturbation as recorded in carbon isotope excursions. The palynofacies of the Csővár section, Hungary, was studied with the aim of inferring climatic and related vegetation changes within the Triassic/Jurassic boundary interval. The studied section represents a continuous key marine section of the NW Tethyan realm, yielding a typical Late Rhaetian to Hettangian microflora. The most striking feature within the boundary interval is the synchronous peaks of prasinophytes and trilete spores. The co-occurrence of spikes in both the marine and terrestrial signals is described for the first time from a marine boundary section. The prasinophyte and spore peaks also correspond to the previously documented prominent negative carbon isotope excursion and are proposed as a potentially powerful correlation tool. The inferred marine algal bloom and the temporary dominance of ferns in the terrestrial vegetation may signal the biotic response to the same environmental stress, which also affected the carbon cycle. A major perturbation of marine and terrestrial ecosystems is interpreted to be linked to the initial volcanic activity of the Central Atlantic Magmatic Province (CAMP) volcanism.

1. Introduction

The end-Triassic mass extinction is still the most poorly understood event among the five biggest mass extinctions in Earth history (Hallam and Wignall, 1997a) despite much recent research effort (Hesselbo et al., 2007). The extinction severely affected both the marine and terrestrial biotas. However, the causes of the ecosystem collapse still remain controversial. Climatic changes, sea-level changes, perhaps combined with oceanic anoxia (Hallam, 1997; Hallam and Wignall, 1997b), flood basalt volcanism (Marzoli et al., 1999; Hesselbo et al., 2002; Pálfy, 2003) and extraterrestrial impact (Olsen et al., 2002) are frequently cited agents that could be responsible for a sudden loss of diversity.

In this context, the diversity history of land plants, the vegetation dynamics associated with the mass extinction and the role of floral change in faunal extinctions are also a matter of debate. Changes in land plant assemblages across the Triassic/Jurassic boundary were interpreted to affect primarily the seed ferns, with the loss of the families Glossopterideae, Peltaspermaceae and Corystospermaceae. It was claimed that no other substantial plant extinction occurred at the species, genus or family level (Knoll, 1984; Ash, 1986; Traverse, 1988). On the other hand, new high-resolution regional palaeobotanical and palaeoecological studies provide evidence for extensive ecological reorganization, high species-level turnover and a recovery interval that lasted millions of years (McElwain et al., 1999; McElwain and Punyasena, 2007; McElwain et al., 2007).

Some of the microfloral evidence for changes across the Triassic/Jurassic boundary can be inferred from palynostratigraphical studies of key sections of the western Tethyan realm (Northern Calcareous Alps: von Hillebrandt et al., 2007; Kuerschner et al., 2007; Southern Alps: Galli et al., 2007; Western Carpathians and Hungary: Ruckwied, 2008) and adjoining marginal areas in Somerset, UK (Hounslow et al., 2004), Asturias, Spain (Barrón et al., 2006) and Morocco (Marzoli et al., 2004).

Palynological studies of the Triassic/Jurassic boundary with special focus on the extinction event are rare. Fowell and Olsen (1993) described a sudden floral turnover and a notable decrease in pollen and spore diversity coeval with a small iridium anomaly (Olsen et al., 2002) in terrestrial sediments of the Newark Supergroup (US). They also report a spike of fern spores that reaches a maximum of 80% within the palynomorph assemblage (Olsen et al., 1990, 2002). Whether this spike truly corresponds to the Triassic/Jurassic boundary, is subject to debate (Lucas and Tanner, 2007) and a precise correlation with marine sections of similar age in the Tethyan realm is

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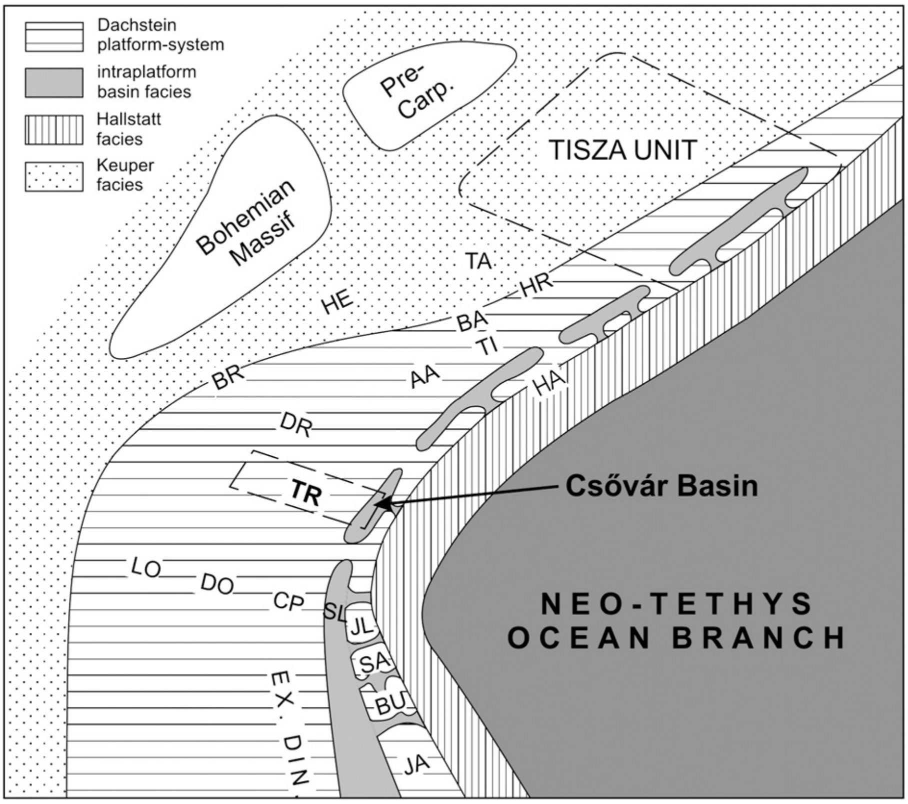


Fig. 1. Palaeogeography of the NW Tethyan realm during the Late Triassic (Rhaetian) and location of the Transdanubian Range (arrow marks the Csővár Basin). Abbreviations: TR — Transdanubian Range, Ex. Din. — External Dinarides, LO — Lombardy, DO — Dolomites, CP — Carnian Prealps, SL — Slovenian Trough, JL — Julian Alps, SA — Sava unit, BU — Bükk unit, JA — Jadar block, DR — Drauzug, BR — Briançonnais unit, HE — Helvetic unit, AA — Austroalpine units, BA — Bajuvaricum, TI — Tirolicum, HA — Hallstatt unit, TA — Tatricum, HR — Hronicum (after Haas and Tardy-Filácz, 2004).

difficult. An increase of marine organic-walled phytoplankton is reported from the pre-Planorbis beds of the Triassic–Jurassic transition in Somerset, UK (Van de Schootbrugge et al., 2007a). Similarly, a peak abundance of prasinophytes is observed near the Triassic/Jurassic boundary in two different sections in the Northern Calcareous Alps, at Tiefengraben (Kuerschner et al., 2007) and the GSSP candidate section of Kuhjoch (von Hillebrandt et al., 2007). In other palaeogeographical settings, no microfloral indicators of the mass extinction have been reported (Ruckwied et al., 2008; Ruckwied and Götz, 2009) and changes in palynomorph assemblages could also be interpreted to reflect palaeoenvironmental changes related to increasing humidity rather than the result of global catastrophic events.

We studied the palynofacies of the Triassic/Jurassic boundary interval in the Csővár section in Hungary, a key marine section of the NW Tethyan realm (Pálfy et al., 2007) to analyse palaeoenvironmental changes and their possible causes within this time interval. The focus of this report is a quantitative assessment of changes in the palynomorph assemblages, with particular attention to the spores and the prasinophytes.

2. Geological setting

During Late Triassic and Early Jurassic times, the study area was located within the NW Tethyan realm, bordering the Neotethys Ocean Branch (Haas et al., 1995). The outcrops near Csővár in north-central Hungary were part of the Transdanubian Range unit located at the distal margin of the Dachstein Carbonate Platform in the western part of the Neotethys shelf region (Fig. 1). This carbonate system was segmented by various intraplatform basins (Haas et al., 2000; Haas, 2002; Haas and Tardy-Filácz, 2004).

The Csővár section is situated northeast of Budapest, ca. 500 m W of the village of Csővár (Fig. 2). A predominantly limestone succession of Late Triassic and Early Jurassic age is exposed in two outcrops: The Pokol-völgy ("Devil Valley") quarry and the S slope of the Vár-hegy ("Castle Hill"). Facies analysis of the Rhaetian–Hettangian deposits reveals a long-term change in sea-level, superimposed by short-term fluctuations (Haas and Tardy-Filácz, 2004). After a period of highstand platform progradation in the Late Norian, a significant sea-level fall occurred in the Early Rhaetian, exposing large parts of the platform. A renewed transgression led to the formation of smaller build-ups fringing the higher parts of the previous foreslope that served as habitat of crinoids, representing the main source of carbonate turbidites. The higher part of the Rhaetian is characterised by proximal turbidites with intercalated lithoclastic debris flows. Distal turbidites and radiolarian basin facies become prevalent upsection, dominating in the earliest Hettangian. The next significant facies change in the Early Hettangian is marked by the appearance of redeposited oncoid-grapestone beds, indicating the end of the Rhaetian to earliest Hettangian sequence. The unique exposure of a complete slope-to-basin transition enabled detailed sequence stratigraphical analysis (Haas and Tardy-Filácz, 2004). A multidisciplinary study on sedimentology, palaeontology, stable isotopes, organic geochemistry and clay mineralogy was carried out by Pálfy et al. (2007). Up to now, only some palynological data are available from the Pokol-völgy quarry and borehole Csv-1 spanning the Carnian–Rhaetian interval (Góczán, 1997; Haas et al., 1997). Here, palynomorphs of the Triassic–Jurassic transition from the Vár-hegy section are presented for the first time.

The age of the section and the placement of the Triassic/Jurassic boundary are constrained by ammonoid, conodont, foraminiferan and

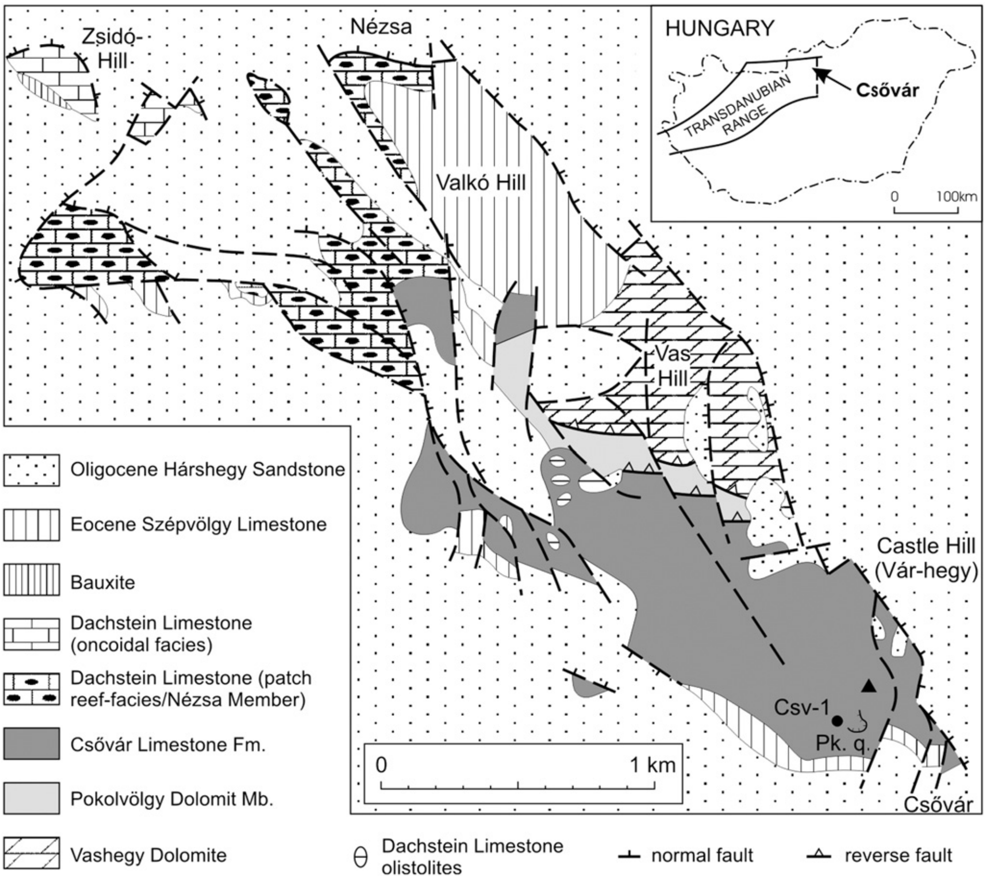


Fig. 2. Geology of the study area and location of the Csővár sections Vár-hegy (Castle Hill), marked by a triangle, Pokol-völgy quarry (Pk. q.) and the borehole Csv-1 (from Haas and Tardy-Filácz, 2004).

radiolarian biostratigraphy (Fig. 3). The latest Triassic Marshi Zone is indicated by ammonoids of the genus *Choristoceras*, including *Choristoceras* ex gr. *marshi*, occurring up to Bed 27. Correlative conodont assemblages with abundant conodonts occur up to Bed 29. They are characterized by species of *Misikella*, assigned to the *Misikella posthernsteini* and *M. ultima* zones. The last occurrence of Triassic foraminifera is in Bed 36. The Csővár section is unique for the rare and scattered occurrence of one of the youngest surviving conodont genus, *Neohindeodella*, found in Beds 54 and 74. However, Bed 62 yielded a radiolarian assemblage indicative of the earliest Hettangian *Canoptum merum* or *Relanus hettangicus* zone. The first occurrence of a Jurassic psiloceratid ammonoid is recorded from Bed 66. In summary, we regard Beds 36–62 (less than 12 m in thickness) as the Triassic/Jurassic boundary interval.

The Csővár section was one of the first Triassic/Jurassic boundary sections where a carbon isotope anomaly was documented (Pálfy et al., 2001). A pronounced negative δ^{13}C excursion is manifest in correlated peaks in both bulk carbonate and bulk organic matter (Pálfy et al., 2001, 2007). The most negative values are centered around Beds 47–49 (Fig. 4). High resolution sampling suggests that the peak may consist of high-frequency oscillations of the carbon isotope composition at or near the Triassic/Jurassic boundary, likely representing a major perturbation in the global carbon cycle, similar to that observed at other mass extinction boundaries (Pálfy et al., 2007).

3. Materials and methods

Palynofacies analysis was carried out on a total of 21 samples from the Upper Rhaetian and Lower Hettangian series exposed on the S slope of the Vár-hegy (Fig. 4). The sampled interval spans Beds 21 to 86. All samples were prepared using standard palynological processing techniques, including HCl (33%) and HF (73%) treatment for dissolution of carbonates and silicates, and saturated $ZnCl_2$ solution ($D \approx 2.2$ g/ml) for density separation. Residues were sieved at 15 µm mesh size. Slides have been mounted in Eukitt, a commercial, resin-based mounting medium. The relative percentages of sedimentary organic constituents are based on counting at least 500 particles per slide. The classification of terrestrial and marine particles follows Steffen and Gorin (1993).

4. Palynofacies patterns

The studied samples of the lower part of the Vár-hegy section yield a typical Late Rhaetian palynomorph assemblage, characterised by a high amount of Circumpolles (*Corollina*), *Rhaetipollis germanicus*, *Ovalipollis pseudoalatus* and numerous trilete spores such as *Acanthotriletes* spp., *Concavisporites* spp., and *Deltoidospora* spp. The marine fraction is marked by foraminiferal test linings and prasinophytes of the genera *Tasmanites*, *Cymatiosphaera* and *Pterospermella* (Plate I, Appendix A). A sudden increase in the abundance of prasinophytes (22%) is recognized in Bed 47 (Fig. 4), corresponding to a peak abundance of trilete spores (35%). Prasinophytes of the genus *Tasmanites* constitute the peak in Bed 47. The spore spike is documented by peak abundance of *Concavisporites* spp. and *Deltoidospora* spp. Acritarchs (*Micrhystridium* spp.) are very rare throughout the section and dinoflagellate cysts are absent.

Palynofacies of the sedimentary series exposed in the Vár-hegy section are dominated by terrestrial components. Numerous needle-shaped opaque particles, as well as a high amount of large translucent

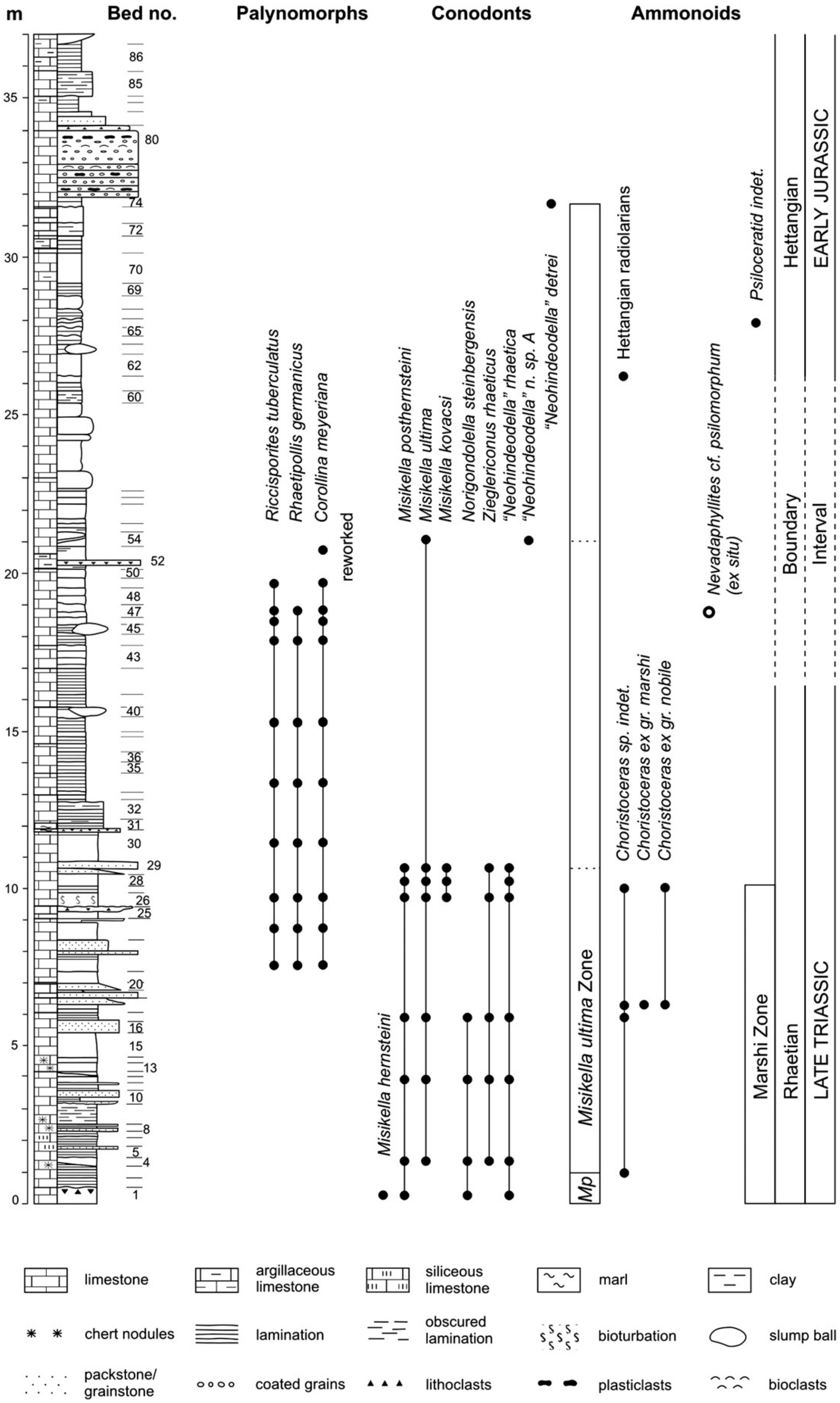


Fig. 3. Biostratigraphy of the Csővár section. Ammonoid, conodont and radiolarian data from Pálfy et al. (2007), and palynomorph data (this study).

plant fragments (Plate I) within the phytoclast group are a characteristic feature of the Rhaetian part of the section (Beds 21 to 49).

Palynofacies of the carbonates exposed in the upper part of the Vár-hegy section, dated as Early Hettangian based on radiolarians and ammonoids (Pálfy et al., 2007), are dominated by degraded organic matter, small equidimensional phytoclasts and foraminiferal test linings (Plate I), pointing to a distal basinal setting (Beds 61 to 86).

The general dominance of terrestrial components throughout the section reflects a persistent high supply from the hinterland. The various preservation stages of terrestrial phytoclasts, displayed in different sizes and shapes of plant debris as well as translucent to opaque particles, may point to the transport mechanism of sedimentary organic matter within the slope-to-basin setting, strongly related to the occurrence and frequency of turbidites along the slope. Fresh sedimentary organic material is transported into the basin by frequently occurring turbidity currents. The relatively high amount of *Corollina* spp. points to semi-arid conditions of the hinterland. The described microplankton assemblage, dominated by prasinophytes, is characteristic of a permanently stratified deeper basin (cf. Tyson, 1995).

The most striking feature of the entire succession is represented by a synchronous peak abundance of both spores and prasinophytes, corresponding to the δ^{13}C negative excursion described by Pálfy et al. (2001, 2007). The sudden increase in the abundance of prasinophytes, known as “disaster species” (Tappan, 1980; Van de Schootbrugge et al., 2007a), may point to short-term changes of the ocean chemistry. The lack of dinoflagellate cysts and the very low abundance of acritarchs in the studied interval preclude the comparison of the reaction of these plankton groups with the observed prasinophyte signal. Significantly, the detected prasinophyte bloom correlates with the peak abundance of trilete spores (Fig. 4). Both signals, the marine and terrestrial, are recorded together in the Csővár section which has not been reported from other marine Triassic/Jurassic boundary sections.

5. Discussion

Palynomorph assemblages of the Csővár section display a typical Rhaetian-Hettangian microflora, dominated by bisaccate pollen grains, trilete spores and pollen of the *Circumpolles* group. A floral mass extinction was not recognized in the Transdanubian Range. Palynomorph assemblages of the Csővár section are similar to the assemblages of the Germanic Basin (cf. Schulz, 1967; Lund, 1977; Orłowska-Zwolińska, 1983; Weiss, 1989; Lund, 2003) comprising marker species such as *Rhaetipollis germanicus* and a high amount of *Corollina* spp. in the lower part of the section of Late Rhaetian age. The palaeogeographic proximity of the Transdanubian Range to the Northern Calcaerous Alps and the Tatra Mountains explains why the palynomorph assemblages of these areas are very similar (Kuerschner et al., 2007; Ruckwied and Götz, 2009). The Triassic/Jurassic boundary interval is marked by a characteristic increase in spores within the entire NW Tethyan realm as documented in reference sections of the Tatra Mountains (Ruckwied and Götz, 2009), the Mecsek Mountains (Ruckwied et al., 2008), and the Northern Calcareous Alps (Kuerschner et al., 2007; Bonis et al., 2008). However, a major difference from the Alpine sections is the lack of the Hettangian marker species *Cerebropollenites thiergartii* which was reported by Kuerschner et al. (2007) and von Hillebrandt et al. (2007) from the Tiefengraben and Kuhjoch sections (Austria). These authors propose the lowest occurrence of this pollen grain as a potential palynological marker for the Triassic/Jurassic boundary. It occurs within the shift to more negative δ^{13}C values in the lower part of the main carbon isotope excursion, above the extinction level of Triassic biota and approximately at the lowest occurrence of the first Jurassic ammonite, *Psiloceras spelae*. Kuerschner et al. (2007) also reported a high abundance of prasinophytes from the interval of the initial carbon isotope excursion which they interpret as representing a bloom of green algae that flourished as a result of a disturbance of the marine ecosystem. A bloom of organic walled, green algae “disaster species” is also known from the Triassic/Jurassic boundary interval of the St. Audrie's Bay section in Somerset, UK (Van de Schootbrugge et al., 2007a) and these authors suggested that the proliferation of green algal phytoplankton may be triggered by elevated carbon dioxide levels in the atmosphere and oceans during mass extinction events. The occurrence of prasinophyte blooms in sections from different regions may support this hypothesis. Thus, the prasinophyte spike in the Csővár section is likely to record a geographically widespread event rather than a local palaeoecological phenomenon.

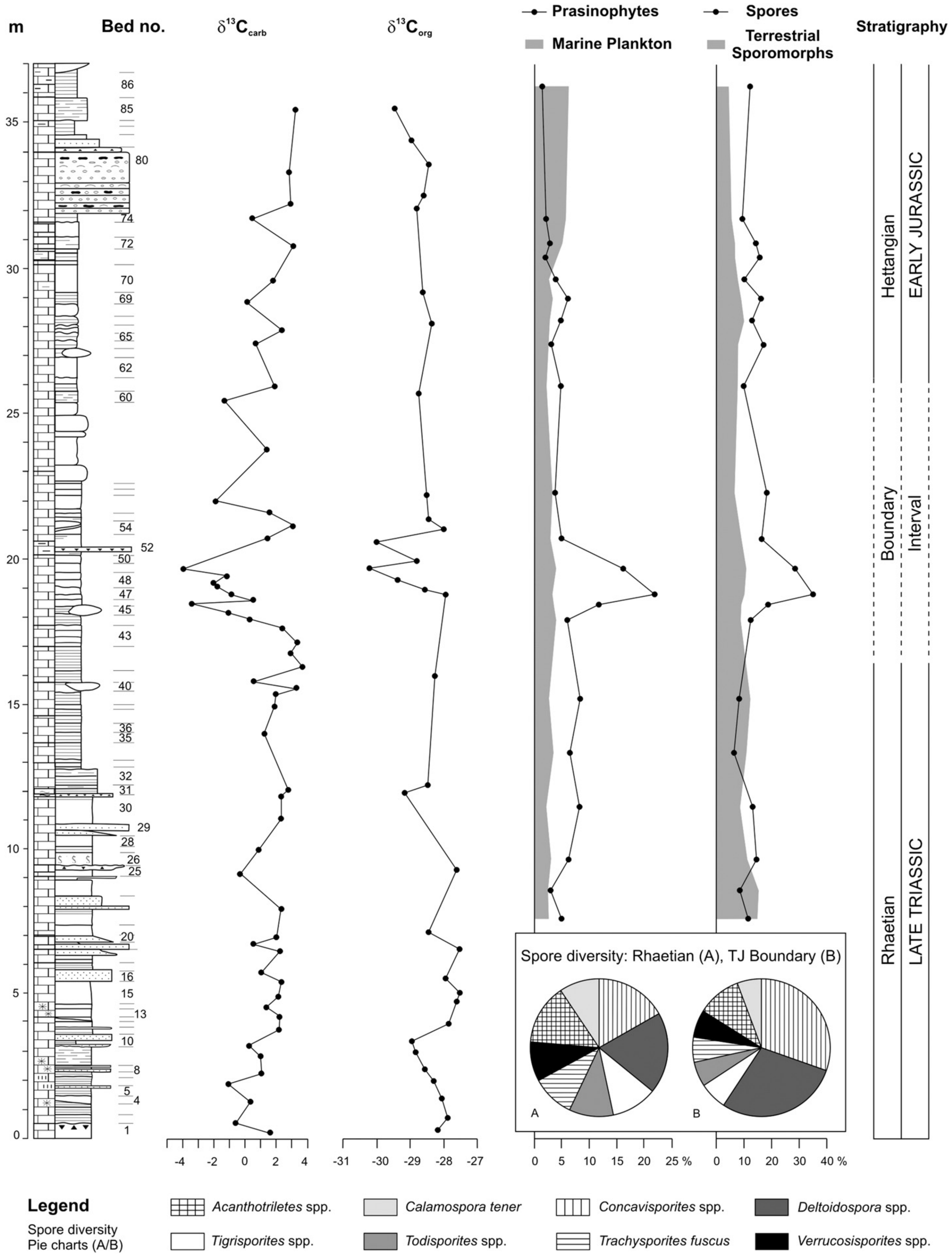
Similar to our observations at Csővár, a spore spike at the Triassic/Jurassic boundary was reported from the Newark Basin in the eastern US (Olsen et al., 1990; Fowell et al., 1994). A sudden increase in the relative abundance of spores was also recognized in other sections of the NW Tethyan realm (Ruckwied et al., 2008; Ruckwied and Götz, 2009) as well as in the Danish–German Basin (Heunisch et al., 2008) and in Sweden (Van de Schootbrugge et al., 2007b). Therefore, this change in the sporomorph assemblage is seen as a reflection of a supra-regional change in the hinterland vegetation. Due to the fact that this signal is observed in sediments deposited in different palaeoenvironmental settings, it is unlikely to be caused by sorting or preservation. Van de Schootbrugge et al. (2007b) investigated the microfloral assemblages of two cores from Germany and Sweden and recognized an abrupt change within the assemblages studied. Conifers, seed ferns and cycads-ginkgophytes were replaced by herbaceous ferns and fern allies at the Triassic/Jurassic boundary. Thus, the authors propose that this floral turnover was triggered by the Central Atlantic Magmatic Province (CAMP) volcanism since during phases of high volcanic activity, the release of sulfur (mostly SO_2 and some H_2S) may cause short-term cooling and a regional acidification of terrestrial ecosystems through the formation of sulfuric acid (H_2SO_4) rain.

Heunisch et al. (2008) observed a contemporaneous turnover of marine phytoplankton communities and interpreted this change to be not only driven by changes in humidity/aridity and/or sea-level changes but as a response of severe environmental changes that were most likely triggered by the Central Atlantic Magmatic Province (CAMP) volcanism.

The spore spike, recording a sudden change of the terrestrial vegetation, and the prasinophyte bloom, reflecting a similarly abrupt event in the marine realm, indicate a significant perturbation of the biosphere at the Triassic/Jurassic boundary. A correlative signal is also documented in the δ^{13}C isotope record. Hesselbo et al. (2002) discussed a causal relation of the negative δ^{13}C excursion and the initial volcanic activity of the Pangaean Atlantic rifting. Recent ^{40}Ar/^{39}Ar dating of flood basalts in Morocco and Portugal (Nomade et al., 2007; Verati et al., 2007) confirm the isochroneity of the Central Atlantic Magmatic Province (CAMP) volcanism and major changes in marine and terrestrial ecosystems at the Triassic/Jurassic boundary. Alternatively, Olsen et al. (2002) postulate a bolide impact as the main trigger for the drastic changes at the end of the Triassic. In the lack of substantial evidence for an end-Triassic impact, our data from Csővár are fully consistent with the model where the initial volcanic activity of the CAMP is related to climatic change, the negative δ^{13}C excursion, and also leads to the perturbation in marine and terrestrial ecosystems at the Triassic/Jurassic boundary.

6. Conclusions

Results of a palynofacies study from the Triassic/Jurassic boundary section at Csővár contribute to our understanding of the end-Triassic environmental and biotic events. The synchronous changes within the terrestrial and marine realm, as documented by the prominent and correlated spikes of spore and prasinophyte abundances within the Triassic/Jurassic boundary interval, are interpreted to indicate sudden


m
Bed no.
δ13Ccarb
δ13Corg
Prasinophytes
Spores
Marine Plankton
Terrestrial Sporomorphs
Stratigraphy
0
5
10
15
20
25
30
35
86
85
80
74
72
70
69
65
62
60
54
52
50
48
47
45
43
40
36
35
32
31
30
29
28
26
25
20
16
15
13
10
8
5
4
1
-4 -2 0 2 4
-31 -30 -29 -28 -27
0 5 10 15 20 25 %
0 10 20 30 40 %
Hettangian
EARLY JURASSIC
Boundary
Interval
Rhaetian
LATE TRIASSIC
Spore diversity: Rhaetian (A), TJ Boundary (B)
A
B
Legend
Spore diversity Pie charts (A/B)
Acanthotriletes spp.
Calamospora tener
Concavisporites spp.
Deltoidospora spp.
Tigrisporites spp.
Todisporites spp.
Trachysporites fuscus
Verrucosisporites spp.

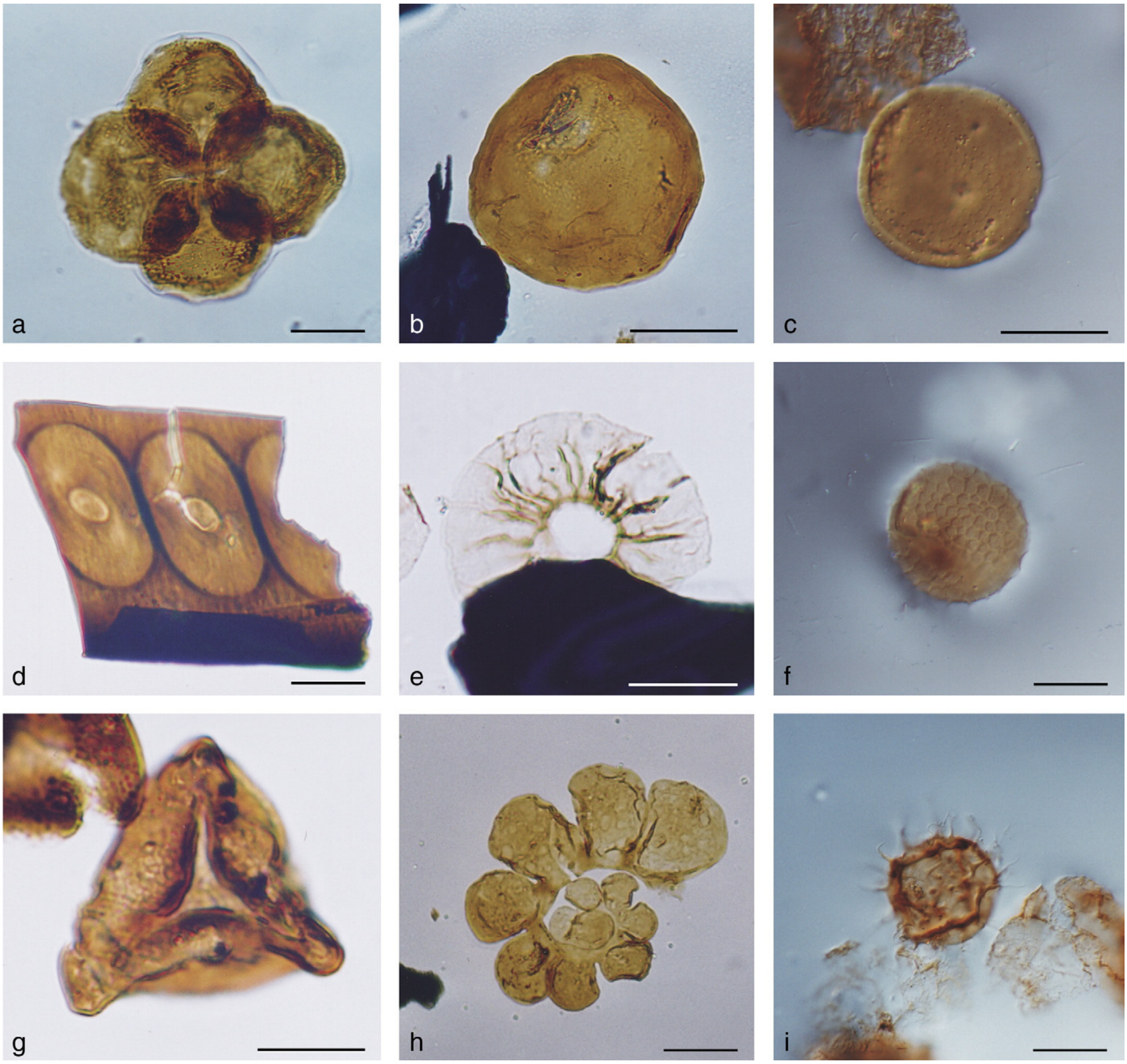


Plate I. Palynomorphs of the Csővár section (Vár-hegy): (a) *Corollina meyeriana* (Bed 47; E.F. 111,8/14,2); (b) *Tasmanites* sp. (Bed 46; E.F. 121,3/13,7); (c) *Tasmanites* sp. (Bed 47; E.F. 109,2/11,3); (d) translucent phytoclast (Bed 23; E.F. 111,4/15,6); (e) *Pterospermella* sp. (Bed 47; E.F. 111,0/19,1); (f) *Cymatiosphaera* sp. (Bed 49; E.F. 124,3/12,6); (g) *Concavisporites* sp. (Bed 23; E.F. 132,4/9,2); (h) foraminiferal test lining (Bed 71; E.F. 128,6/15,6); (i) *Micrhystridium* sp. (Bed 34; E.F. 114,3/10,2). Scale 10 µm.

palaeoenvironmental changes. Biostratigraphic data from conodonts, radialorians and ammonoids (Pálfy et al., 2007) confirm the stratigraphic position of this event at the Triassic/Jurassic boundary. Therefore, we propose this signal as a potentially powerful correlation tool for short-term changes at the Triassic/Jurassic boundary of the NW Tethyan realm and adjacent areas. However, open questions remain about the terrestrial vegetation dynamics, changes in land plant communities and the relations of floral change and mass extinction.

Our results will be useful for comparison with other terrestrial localities, e.g. in Hungary (Mecsek Mts.; Ruckwied et al., 2008), the United States (Newark Basin; Fowell and Olsen, 1993), China (Junggar Basin; Hornung et al., 2007) and Kyrgyzstan (Madygen; Voigt et al., 2006), to establish the global extent of environmental changes within this period.

Furthermore, the present palynofacies results, indicating a high terrestrial input throughout the entire section, imply the vicinity of a

Fig. 4. Relative abundance of prasinophytes and trilete spores showing synchronous peak abundances corresponding to the δ^{13}C negative shift, Csővár section (Vár-hegy). Isotope data from Pálfy et al. (2007). Prasinophytes of the genus *Tasmanites* constitute the peak in Bed 47. The spore spike is documented by peak abundance of *Concavisporites* spp. and *Deltoidospora* spp. Grey-shaded curves show relative percentages of marine plankton and terrestrial palynomorphs, respectively. The general dominance of land-derived phytoclasts causes the low amount of marine and terrestrial palynomorphs. There is no major change in the abundance of marine plankton and terrestrial palynomorphs throughout the section studied, whereas within these groups the prasinophyte and spore spikes are a striking evidence of a major perturbation of the biosphere at the Triassic/Jurassic boundary. Pie charts illustrate changes in the spore assemblage with peak abundance of *Concavisporites* spp. and *Deltoidospora* spp. at the Triassic/Jurassic boundary. Data from Bed 30 (Rhaetian, pie chart A) and Bed 47 (TJ Boundary, pie chart B). For a key to the lithologic column, see Fig. 3.

terrestrial source area near the restricted Csővár basin. This provides new constraints on the palaeogeographic interpretation of the earliest Jurassic Tethyan shelf.

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Appendix A. Alphabetical list of palynomorphs identified in the Csővár section

Spores
Acanthotriletes varius Nilsson, 1958
Acanthotriletes spp.
Calamospora tener (Leschik, 1955) Mädler, 1964
Concavisporites rhaetoliassicus Achilles, 1981
Concavisporites spp.
Deltoidospora crassexina Lund, 1977
Deltoidospora spp.
Tigrisporites spp.
Todisporites major Couper, 1958
Todisporites spp.
Trachysporites fuscus Nilsson, 1958
Verrucosisporites spp.
Pollen grains
Alisporites sp. div.
Cycadopites spp.
Corollina meyeriana (Klaus, 1960) Venkatachala and Góczán, 1964
Corollina spp.
Lunatisporites sp.
Ovalipollis minimus Scheuring, 1970
Ovalipollis ovalis (Krutzsch, 1955) Scheuring, 1970
Ovalipollis pseudoalatus (Thiergart, 1949) Schuurman, 1976
Perinopollenites elatoides Couper, 1958
Rhaetipollis germanicus Schulz, 1967
Ricciisporites tuberculatus Lundblad, 1964
Undetermined bisaccate pollen grains
Acritarchs
Micrhystridium spp.
Prasinophytes
Cymatiosphaera spp.
Pterospermella spp.
Tasmanites spp.

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