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EVIDENCE FOR LADINIAN (MIDDLE TRIASSIC) PLATFORM PROGRADATION IN THE GYULAKESZI AREA, TAPOLCA BASIN, WESTERN HUNGARY: MICROFACIES ANALYSIS AND BIOSTRATIGRAPHY

ZSOLT RÓBERT NAGY [1], NEVENKA DJERIC [2], † SÁNDOR KOVÁCS [3], ANNA ORAVECZ-SCHEFFER [4], FELICITÁSZ VELLEDITS [5], OLGA PIROS [6] & GÁBOR CSILLAG [6]

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Abstract. A shallowing-upward carbonate sequence was studied from the outcrop at Gyulakeszi, Tapolca Basin (western Hungary), and it is interpreted as a Middle Triassic (*Curionii* or younger) platform progradation. Two lithostratigraphic units are distinguished. Microfacies analysis and micropaleontological investigation conducted on the red nodular, cherty limestone (Vászoly and Buchenstein formations) suggest that the lower unit was deposited during the *Reitzi* and the *Secedensis* ammonoid zones. The overlying white platform limestone (upper unit) is typical of a prograding platform and includes gravity-driven deposits at the base followed by periplatform facies deposited in shallow marine warm waters around the fair-weather wave base. The section at Gyulakeszi was unaffected by fabric-destructive dolomitization, which is uncharacteristic of similar platform facies in the Balaton Highland. Isopachous and radiaxial fibrous calcite cement found in the grainstone and boundstone facies are indicative of early lithification and diagenesis in the marine phreatic zone. "Evinospongiae"-type cement is described for the first time from the Balaton Highland and it is similar to the outer platform cements published previously from the Alps (Italy and Austria). The progradation could have advanced over the pelagic limestones as early as the *Curionii* zone, which is an undocumented event in the Veszprém Plateau. Similar event, however, is well known from the Western Dolomites, where aggradation was followed by intense progradation during the *Gredleri* and *Archelaus* ammonoid zones. The length of this progradation event at Gyulakeszi, however, is ambiguous since proven Ladinian (Longobardian) rocks are not exposed in the study area and were not penetrated by boreholes in the Tapolca Basin.

Introduction

The system of the progradation of the Middle Triassic platform carbonates in the Alpine-Carpathian region was developed in the Dolomites, where the spectacular exposures (e.g. Latemar and Marmolada) provided the opportunity to investigate the lateral transition of facies patterns from basin (Livinallongo/Buchenstein) to platform (Sciliar/Schlern) along a continuous isochron surface (Maurer 2000). In the Dolomites, Ladinian reefs have started-up on the former Anisian structural highs, which were surrounded by the Buchenstein basin (Maurer 2000; Emmerich et al. 2005). There was a strong biological control on reef evolution since microbial carbonates were dominant while framebuilders were less important following the Permian-Triassic biological crisis (Flügel 1982, 2002; Senowbari-Daryan et al. 1993). This factor with the Late Anisian block tectonics coupled with sea-level rise in the area, has resulted in widespread platform progradation (Farabegoli & Levanti 1982; Bosellini 1984, 1989; Pfeiffer 1988; Krainer & Lutz 1995; Mandl 2000; Maurer 2000; Berra et al. 2011; Velledits et al. 2011).

There has been a considerable amount of scientific literature published on the geology of the Middle Trias-

1 Shell Exploration and Production Company, 150 N. Dairy Ashford Rd, Houston, Texas 77041, U.S.A. E-mail: zsolt.nagy@shell.com.
2 Department of Paleontology, Faculty of Mining and Geology, University of Belgrade, Djusina 7, 11000 Belgrade, Serbia. E-Mail: nevenka.djeric@rgf.bg.ac.rs
3 Geological, Geophysical and Space Science Research Group of the Hungarian Academy of Sciences, Eötvös University, Pázmány s. 1/c, Budapest 1117, Hungary.
4 Hűvösvölgyi út 74, Budapest 1021, Hungary.
5 Limestone Bt., Andrássy Gy. u. 6, Dunakeszi 2120, Hungary. E-mail: felicitasz2012@gmail.hu
6 Geological and Geophysical Institute of Hungary, Stefania u 14, Budapest 1143, Hungary. E-mail: piros.olga@mfgi.hu; gabor.csillag.53@gmail.com

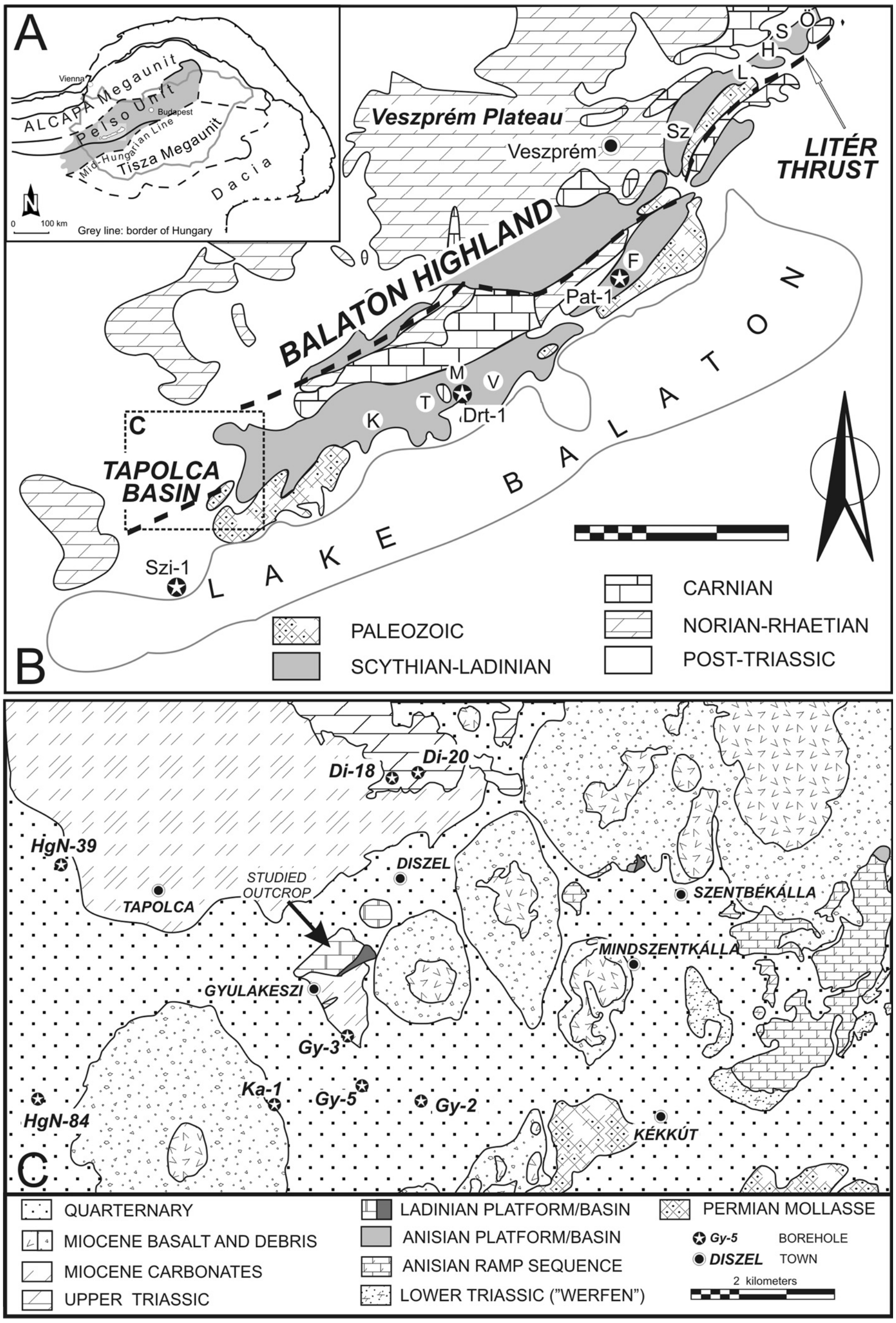

Fig. 1 - A) Main tectonic units in the wider surrounding of the Pannonian Basin. The rectangle outlines the Balaton Highland (after Kovács et al. 2011). B) Geological map of the region (simplified after Budai et al. 1999) with geologic localities and boreholes of importance mentioned in the text. K: Köveskál, T: Tagyon; M: Mencshely; V: Vászoly; Drt-1: Dörgicse-1 borehole, Pat-1: Paloznak-1 borehole; Szi-1: Szigliget borehole; Ö: quarry at Öskü; S: Sóly, Őr-hill; L: composite section from the quarry at Litér; H: composite section from the quarry at Hajmáskér and the Hmt-3 (Hajmáskér) borehole; Sz: quarry at Szentkirályszabadja; F: key section at Felsőörs. C) Insert from Figure 1b, showing the detailed geological map of the study area (modified after Budai et al. 1999) with the studied outcrop (arrow).

sic carbonates from the Balaton Highland since the late 1800s. The westernmost part of this Triassic sequence is exposed in the Tapolca Basin (Fig. 1b), and was first studied by Lóczy (1916) who described reef limestones from the area nearby the towns of Gyulakeszi and Diszel (Fig. 1c). Occurrence of nodular limestone and shallow marine carbonates were reported from the area on the 1:50,000 geological map (Budai et al. 1999) but their stratigraphic position has not been thoroughly investigated and provisionally assigned to the Middle to Upper Triassic. Similar age rocks were studied in the outcrops of the Balaton Highland (Haas & Budai 1995; Vörös 1998; Budai et al. 2001a; Vörös et al. 2003). The sediments represent deposition on attached platforms ("Szentkirályszabadja"), sea mounts ("Tagyon" and "Vöröstó"), and in the surrounding basin ("Felsőörs"), which had developed after the breakup of the Anisian carbonate ramp (Budai & Vörös 1992; Budai et al. 1993; Vörös et al. 1997; Budai & Vörös 2006). The carbonates at Gyulakeszi were deposited in a sedimentary system west of the Tagyon sea mount, and received little attention.

The aim of this paper is to describe the results of observations made on the sedimentary succession after revisiting the outcrop at Gyulakeszi. Since the sedimentary rocks in the studied section were unaffected by fabric-destructive dolomitization, microfacies and biostratigraphic analyses were conducted on both units exposed in the area in order to characterize the depositional environment and the age of the carbonates. The study also provides an opportunity to improve our understanding on the sedimentary system in the area west of the Tagyon sea mount.

Geological Setting

The Balaton Highland (including the Tapolca Basin) is located in the western part of the Pelso Unit (part of the ALCAPA Megaunit, Kovács et al. 2011; Fig. 1a), which was situated between the South Alpine and the Upper Austroalpine realms during the Middle Triassic (Haas et al. 1995; Mandl 2000).

The small outcrop at Gyulakeszi in the Tapolca Basin is located about 2 km southeast from the city of Tapolca (Fig. 1c) and represents one of the very few Triassic surface exposures in the basin. The Tapolca Basin is a fault bounded Miocene basin with complex structural features (Dudko et al. 1992), which include multiple thrust faults (Litér and Veszprém) generated by regional compression during the Eoalpine Orogeny (Late Cenomanian to Early Senonian). During the Neoalpine Orogeny (Miocene), the area was subsided along dip faults due to local extension and the Triassic rocks were penetrated only by boreholes. The Triassic and older rocks generally dip to northwest and are overlain by 100-250 m Cenozoic rocks with an angular unconformity, which was interpreted from both reflection and refraction seismic profiles (Tóth & Szabadváry 1975; Szilvási & Szabadváry 1984). The area is tectonically complex and consists of mosaics of fault-blocks made up by Paleozoic crystalline rocks, Permian alluvial molasse and intrusives, and Lower Triassic transgressive mixed siliciclastics-carbonates (Haas et al. 1988; Majoros 1998). These rocks are only exposed in boreholes drilled in the area, e.g. Silurian – Devonian metamorphic phyllite in the Gy – 2 (Gyulakeszi), Permian sandstone in the Gy – 3, Permian sandstone and dacites in the Gy – 5, and Lower Triassic mixed carbonate-siliciclastics in the Ka – 1 (Kisapáti) and in the Szi – 1 (Szigliget) (Fig. 1/b-c). The Lower Triassic sedimentary sequence ("Werfen group") reaches 500 m in thickness in the Szi – 1 borehole and includes sabkha and lagoonal dolomites, sandstones, limestones and marls. The sequence was formed on a broad homoclinal ramp located close to the terrigeneous source (Haas et al. 1988). The sequence includes the reddish grey, bituminous, well stratified or laminated, poorly fossiliferous limestone and dolomite (Iszkahegy Limestone), which is poorly exposed in the town of Gyulakeszi (Budai et al. 1999). Microfauna found in the same unit from the key section at Felsőörs include *Renngartenella* sp. ostracod, which indicates hypesaline depositional environment (Monostori 1995). The unit is overlain by poorly fossiliferous dolomite (Megyehegy Dolomite equivalent to the Upper Serla in the Southern Alps), which is exposed to the east of the study area (northwest of Mindszentkálla, Fig 1c) (Budai et al. 1999). During the Pelsonian (*Balatonicus* ammonoid zone), synsedimentary block faulting has caused the breakup of the uniform ramp and abrupt change in facies development (Fig. 2). Based on Budai & Vörös (1992), platform carbonates (Tagyon Formation) were developed on the topographic highs while in the hanging-wall side, hemipelagic carbonates (Felsőörs Limestone or "Recoaro") were deposited. Small outcrops of this basin sequence were found near Szentbékálla (Fig. 1c) but are possibly missing or condensed in the study area. The tectonic event (rifting) was associated with volcanic activity during the Illyrian (Vászoly Formation, *Reitzi* ammonoid zone), which was followed by late Illyrian to early Ladinian (*Secedensis* to *Curionii* ammonoid zone) nodular limestones interbedded with tuffs, siliceous limestones, and marls (Buchenstein Formation, Fig. 2). Nodular limestones were documented from the area near Szentbékálla (Fig. 1c, Budai et al. 1999) as well as, from the studied section at Gyulakeszi (lower unit). This formation was found to be correlative with platform carbonates (Budaörs Dolomite) in the Veszprém Plateau (Budai et al. 2001a), especially on the areas of the former Anisian platforms, and represents new platform development during the Ladinian (similar to the Sciliar/Schlern platforms).

Upper Ladinian to Lower Carnian grey, well-stratified, nodular limestone (Füred Limestone Formation), a typical pelagic basinal facies in the Balaton Highland, is known on the surface from Köveskál (Fig. 1b). Upper Triassic (Carnian to Rhaetian) carbonates are poorly exposed in the area, and mostly found in boreholes drilled in the Tapolca Basin. Dolomitized limestones and dolomites (Sédvölgy Dolomite Formation) and overlying marl and limestone (Veszprém Marl Formation, Fig. 2) of Carnian age were penetrated between 167-546 m in the Hgn-39 wellbore (Fig. 1c, Budai et al. 1999). Limestone and cherty dolomites (Sédvölgy Dolomite) were described from the Di-18, Di-20 shallow wellbores and from the surface near Diszel (Fig. 1c). Carnian (Julian) platform carbonates (possibly Ederics Limestone Formation) including limestones and dolomites were described between 400-785.7m in the Hgn-84 wellbore (Knauer Gellai 1983).

The Badenian-Sarmatian (Miocene) shallow marine carbonates were deposited after a significant hiatus (Kókay 1986), which was also observed in the study area (Nagy et al. 1999).

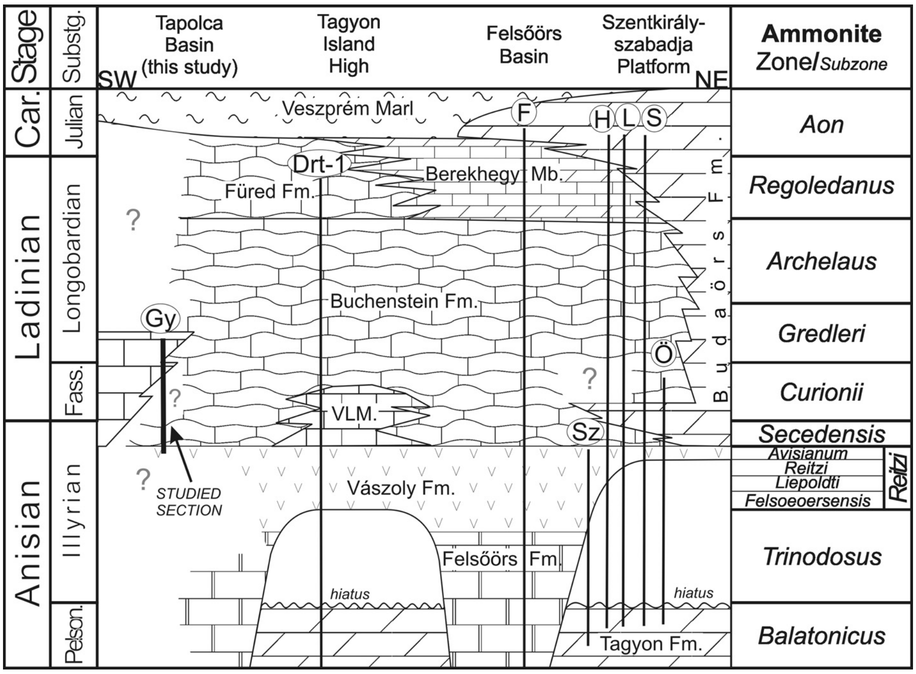

Fig. 2 - Distribution of the Middle Triassic lithostratigraphic units in the Balaton Highland (modified after Budai & Vörös 2006) along a southwest to northeast transect. Anisian/Ladinian boundary is after Brack et al. 1995. Geologic sections of significance with approximate ranges of exposures (after Budai et al. 2001a; Budai 2006; Budai & Vörös 2006) are shown with the vertical lines. Abbreviations of locations are listed in caption of Fig. 1b. VLM: Vászoly Limestone Member; Gy: studied section at Gyulakeszi. Note the progradation episodes of the "Szentkirályszabadja" Platform (after Budai 2006; Budai & Vörös 2006): *Secedensis-Curionii?* and *Regoledanus-Aon* (Carnian). The Pelsonian and Julian Substages are partially illustrated only. The horizontal dimension on the figure is not for scale.

Results

Outcrop Description

The studied sedimentary succession is located in the northern outskirts of Gyulakeszi (Fig. 1c). Nodular limestone boulders and pebbles ("lower unit") were collected on the east side of a dirt road (continuation of Jókai Street) where no in-situ rock was exposed. On the west side of the dirt road white limestone ("upper unit") samples were collected from boulders and small in-situ rock exposures near the water tower, where the rock is thick-bedded or massive with 20 to 40 degree dip to northwest. The maximum thickness of the succession in the study area can be estimated to approximately 100 m, but the actual thickness may be quite different (since almost vertical dip has been observed of the Iszkahegy Limestone in the town). Due to the condition of the exposure, a preliminary lithological column has been generated to illustrate the range of important fossil groups and sampling points (Fig. 3). The contact between the lower and the upper units is not exposed on the surface. Nor the underlying and overlying rock successions are known: the former is buried under Badenian-Sarmatian age (Miocene) carbonates and Holocene sediments, while the latter is buried under Pannonian age (Upper Miocene) talus of volcanic debris.

Microfacies Analysis

Thin-section analysis has been conducted in order to characterize the microfacies of the lower (MF1) and upper unit (MF2 to MF6) on samples taken along a dip line and the description follows this sequence. The following facies types were distinguished as follows.

MF1: Fine bioclastic cherty mudstone to wackestone with radiolarians and filaments

Filaments are abundant components of the reddish-brown cherty limestone of the five samples (Fzs1 to Fzs-5 on Fig. 3) collected on the east side of the dirt road. The filaments are often enriched in layers oriented parallel with stratification. In addition fine debris of fossil fragments of unknown origin, pyrite crystals, and opaque clots were found. Radiolarians and conodonts, occasionally abundant, were recovered from the residue in some of the samples (discussed in the Biostratigraphy section).

MF2: Bioclastic graded packstone, grainstone, rudstone

The well-stratified white limestone samples with occasional reddish stain at bedding surfaces were collected in the proximity of the cherty limestone (samples Gy1 and Gy2 on Fig. 3). The beds consist of graded layers of:

i) Very-coarse (> 1 cm), poorly-sorted, slightly cross-laminated, carbonate rudstone with resedimented sub-rounded intraclasts, bioclasts of platform origin (Figs 4/1-3). The bioclasts include shell fragments of various sizes, *Tubiphyites*, recrystallized dasycladaleans, micritic lumps or micritized fossils, foraminifers and brachiopods. The clasts are mostly tightly packed in peloidal matrix or there is an insignificant calcite cement fringe at the contact. The base of the layer may be micro-erosional while the upper is gradational to the coarse intraclastic, peloidal, bioclastic grainstone (Figs 4/1-2). Occasionally, reddish-brown stain along an irregular, erosional (or dissolution?) surface was observed at the contact (Fig. 4/2). This stain was observed on the bedding surface. Reddish stain with fine crystalline dolomite was also found dispersed in the coarse grainstone. At the top of this graded layer, the amount of calcite spar increases and the contact with the overlying layer appears to be gradual with decreasing particle size. The layer was observed to vary in thickness between 3 to 8 centimeters.

ii) Cross-laminated, well-sorted peloidal grainstone with some internal normal and inverse gradation (Figs 4/1, 3). The cross-lamination is much more pronounced than in the very-coarse layer due to the uniform size of carbonate particles. The angle between the lamination and the bedding is estimated to be < 5 degrees. Bioclasts mostly include abundant foraminifers, occasional fossil fragments without any large reworked oncoids. The thickness of the layer is about 1 to 3 centimeters.

MF3: Limestone debris

The facies (samples Gy3 and Gy51 on Fig. 3) is characterized by very-coarse, monomict, poorly-sorted, intraclastic grainstone in recrystallized blocky calcite cement (Fig. 4/4). The intraclasts are severely

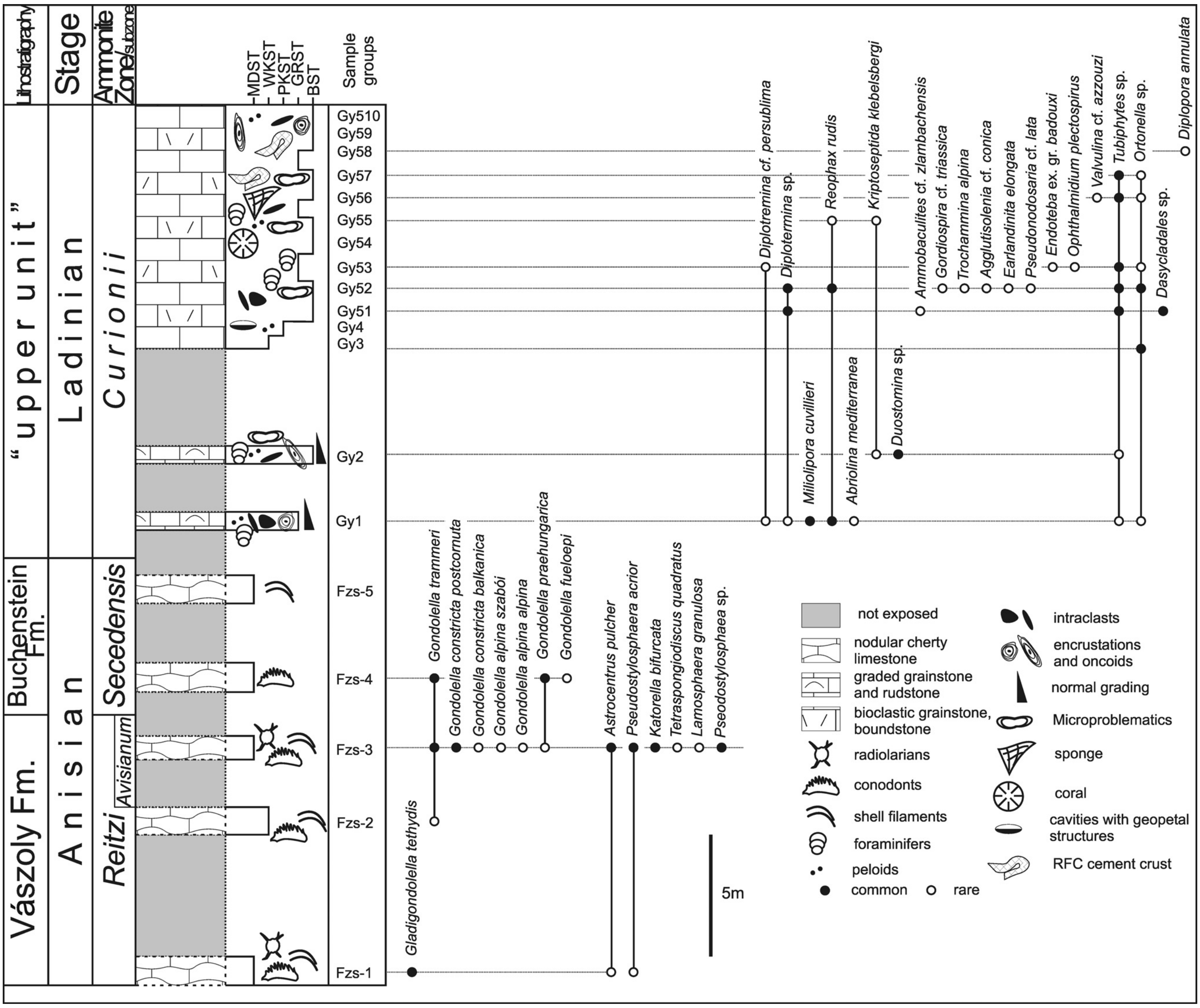

Fig. 3 - Lithological column with characteristic fossil groups and sedimentary features, location of samples, vertical range of important fossil groups (conodonts, radiolarians, foraminifers, and miscellaneous) mentioned in the text for the studied section at Gyulakeszi. Mdst: mudstone, wkst: wackestone, pkst: packstone, grst: grainstone, and bst: boundstone. Anisian and Ladinian stages are partially shown. Note that large part of the succession is not exposed (grey) and the samples from the nodular limestone were taken from not in-situ rock exposures.

recrystallized so that the original texture cannot be identified. Many of the clasts are broken and angular/sub-angular. Some of the large brachiopod and bivalve shells remained unaffected by diagenesis; the facies is otherwise unfossiliferous.

MF4: Peloidal mudstone and wackestone with cavities

White, thick-bedded or massive limestone (samples Gy4 on Fig. 3) is characterized by mudstone and wackestone with peloids with minor amount of intraclasts (Figs 4/5-6). *Tubiphytes*, recrystallized fossil fragments, calcitized sponge spicules, some (<5%) encrusted forms may also occur in the matrix. Cavities, 1 centimeter or larger, with peculiar shapes are also present (Fig. 4/5). The cavities are characterized by geopetal sediment fill at the base, blocky calcite cement at the center and irregular tops often lined with cluster of peloids. The flat base of the cavities is aligned approximately parallel with the stratification. The small, fracture-filling calcite veins often made the proper identification of the cavities challenging (Fig. 4/6).

MF5: Peloidal bioclastic grainstone and boundstone

The upper unit (samples Gy51, Gy52, Gy54, Gy56, and Gy58 on Fig. 3) was dominated by massive limestone without visible stratification. The limestone is characterized by peloidal micrites organized in thrombolytic clots and cemented by marine cement (Figs 5/1-2). The main components include encrustation (especially on sponges and corals) and subordinate calcified cyanobacteria (porostomata) and dasycladalean algae. The few sponges found have been severely recrystallized (Fig. 5/1), while the relatively rare corals are well preserved (Figs 5/2-3). Other fossils include microproblematics such as *Tubiphytes*, foraminifers including agglutinated forms (*Earlandinita* sp.) duostominids and miliolids, echinoderms, bryozoans, and shell fragments (Fig. 5/4). Pelmicrite and pelsparite areas may intermingle randomly indicating ineffective winnowing of small carbonate particles (Figs 5/3-4). Primary cavities are common and lined by isopachous marine cement followed by late cavity-filling blocky calcite, and occasionally, late saddle dolomite. Abundant radiaxial fibrous calcite cement (RFC) was also found in the grainstone facies (Fig. 5/2). In some samples, intraclasts were tightly packed displaying some faint orientation and cemented by calcite fringe.

MF6: "Evinospongiae"-like facies

This type of facies was found as part of the massive limestone at the uppermost levels of the outcrop (samples Gy57 and Gy59 on Fig. 3). The facies include mainly *Tubiphytes* oncoids (Fig. 5/5) and, sub-

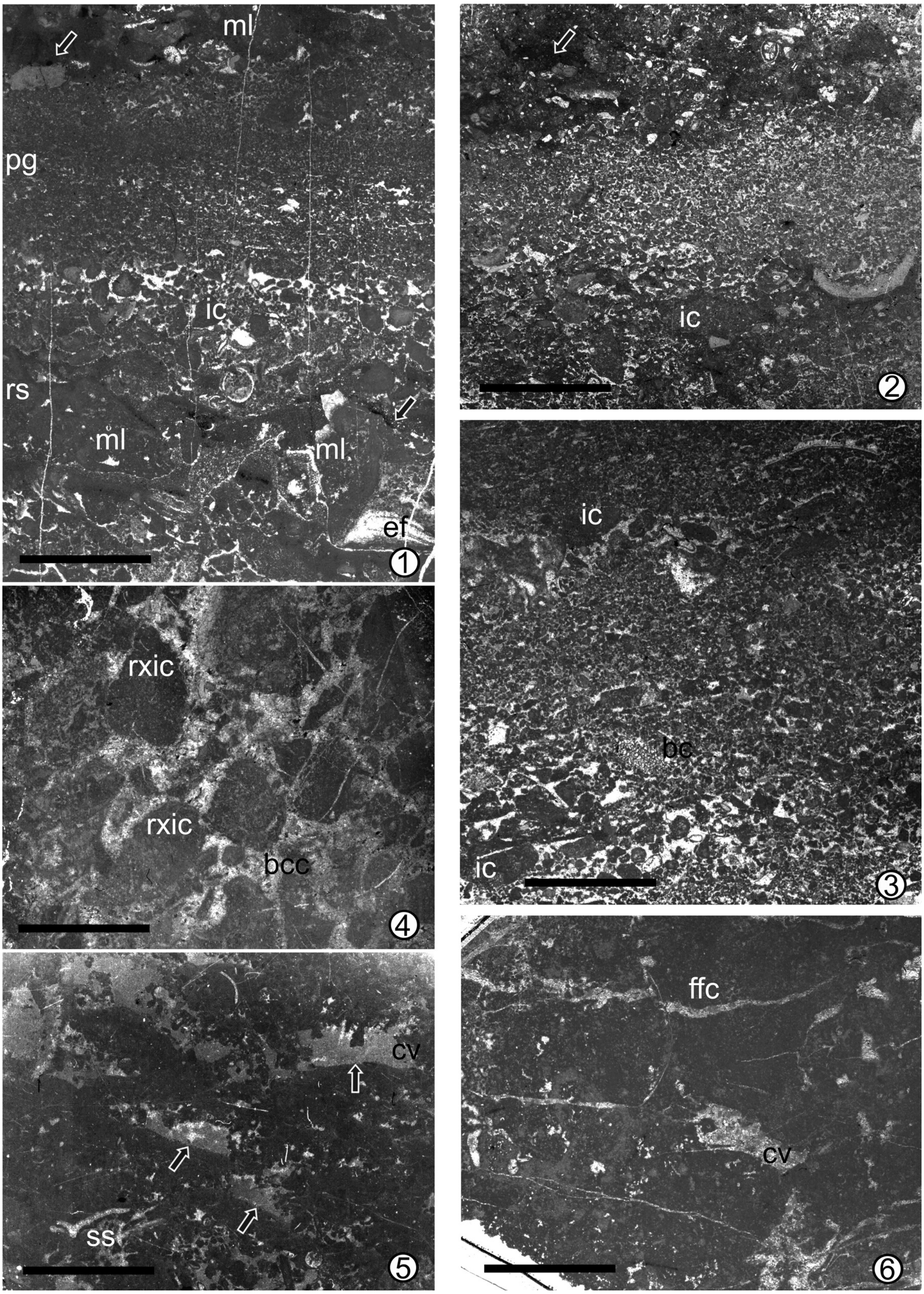

Fig. 4 - Positive thin-section scans of the various facies found in the upper unit. 1-3) graded packstone-grainstone-rudstone facies (MF2), rs: rudstone layer, pg: peloidal grainstone layer, ic: intraclasts, ml: micritic lumps, ef: echinoderm fragment, and bc: bioclast. Arrows point to microerosional surface with dolosilt. Note the normal grading in the rudstone layer in 4/1 and in the intraclastic grainstone layer in 4/2-3. In addition, note the increasing amount of spar in the mid-section of 4/1. Sample and scale bar: 1 – Gy1_1, 10 mm; 2 – Gy2_3, 5 mm; 3 – Gy2_2, 5 mm. 4) limestone debris facies (MF3), rxic: recrystallized intraclasts, bcc: blocky calcite cement. Sample and scale bar: Gy51_2, 20 mm. 5-6) peloidal mudstone and wackestone with cavities, cv: cavity, ss: sponge spicule, ffc: fracture-filling calcite. Arrows point to the cavity-filling internal sediments, note the nearly flat base of the cavities. Sample and scale bars 5 – Gy42_1, 10 mm; 6 – Gy41_1, 10 mm.

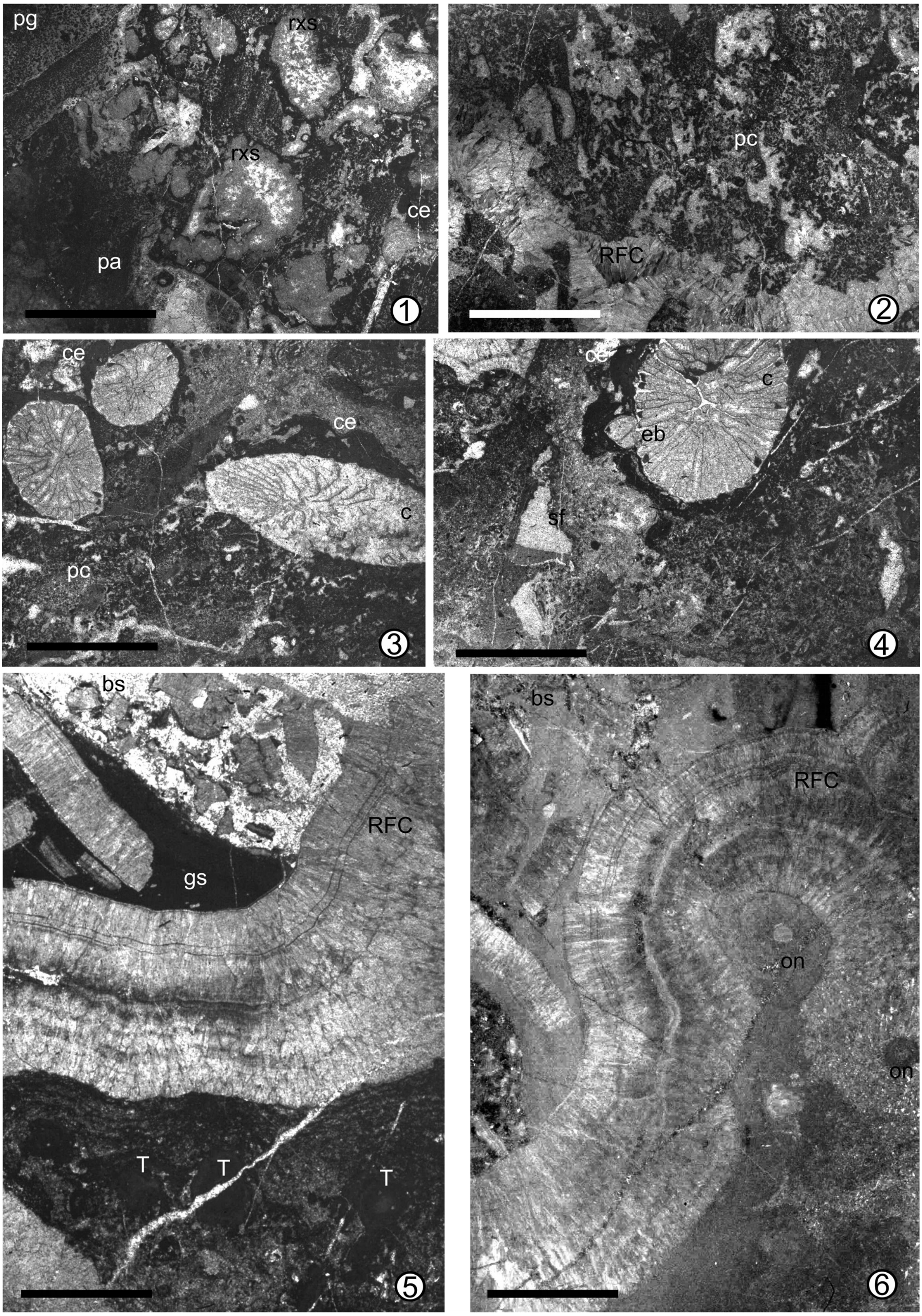

Fig. 5 - Positive thin-section scans of the various facies found in the upper unit. 1-4) peloidal bioclastic boundstone and grainstone (MF5), pg: peloidal grainstone, rxs: recrystallized sponge, pa: porostomata algae, ce: cyanobacterial encrustation, RFC: radiaxial fibrous cement, pc: peloidal clots, sf: shell fragments, c: coral, eb: encrusting bivalve? Sample: 1 – Gy54; 2 – Gy61; 3 – Gy62; 4 – Gy58, scale bars in all samples are 10 mm. 5-6) "evinospongiae"-like facies (MF6), T: *Tubiphytes*, on: oncoid nucleus, RFC: radiaxial fibrous cement, bs: broken-up cements, gs: geopetal sediments. Samples: 5 – Gy57_4; 6 – Gy57_3; scale bars are 10 mm.

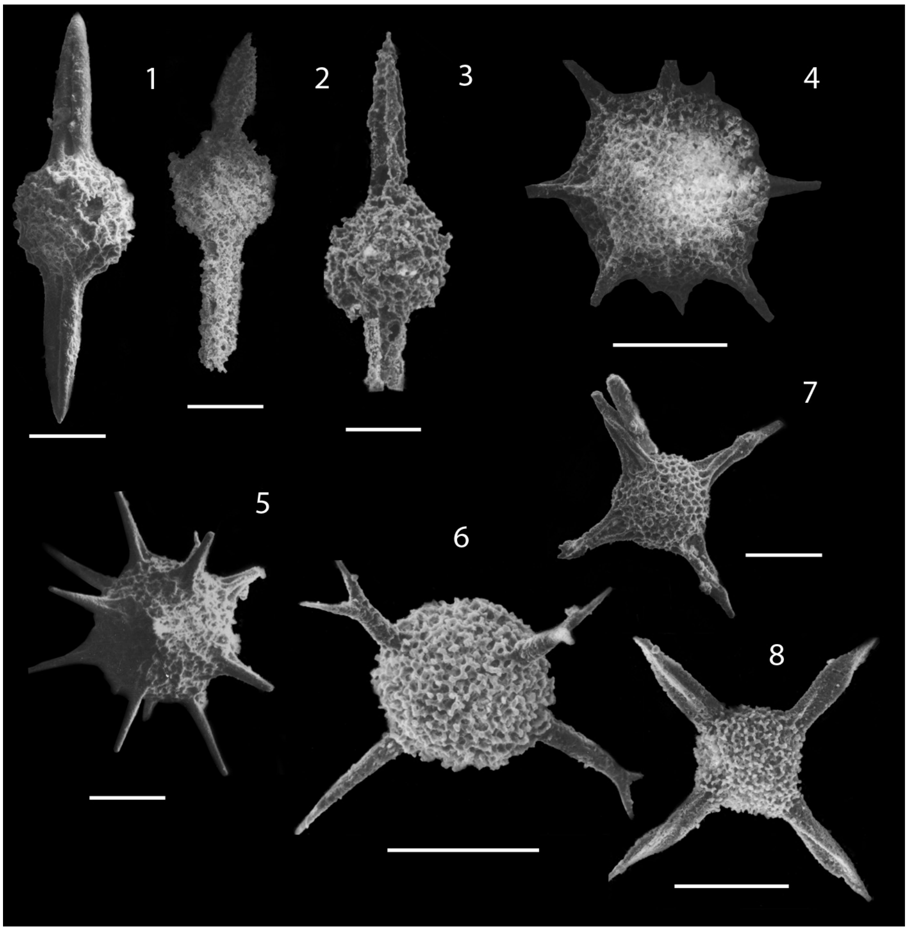

Fig. 6 - Radiolarians from Gyulakeszi (lower unit). Sample numbers are indicated. For each figure the scale bar is 100 µm. 1-2) *Pseudostylosphaera acrior* (Bragin), Fzs-3 and Fzs-1. 3) *Pseudostylosphaera* sp., Fzs-3. 4-5) *Astrocentrus pulcher* Kozur & Mostler, Fzs-1 and Fzs-3. 6) *Katorella bifurcata* Kozur & Mostler, Fzs-3. 7) *Lahmosphaera granulosa* (Dumitrica, Kozur & Mostler), Fzs-3. 8) *Tetraspongodiscus quadratus* Lahm, Fzs-3.

ordinately, other platform-derived encrusted shell fragments; otherwise it is unfossiliferous. It is characterized by large amount of isopachous, radiaxial, fibrous calcite cement arranged in concentric bands (Figs 5/5-6). The cement is characterized by several generations of growth bands and contains small trapped organic matter inclusions. Parts of large cement were broken-up and were found floating in the matrix (Fig. 5/5). The gravitational sediments consist of micrite followed by broken cement fragments displaying geopetal structures. Similar macroscopic texture with abundant cement encrustations were described from the Austroalpine Triassic as "Großoolith" (German 1971), as "evinospongiae" from the Southern Alps (Gaetani et al. 1981; Frisia Bruni et al. 1989; Russo et al. 2000), and from the Ladinian-Carnian of Monte Caramolo (Calabria, Southern Italy) by Boni et al. (1994).

Biostratigraphy

Large boulders were collected at five locations (samples Fzs1 to Fzs-5) on the east side of the dirt road from the reddish-brown nodular cherty limestone. The same samples were processed for micropaleontological analysis in order to identify the conodonts and radiolarians from the insoluble residue. Foraminifers, algaes, sponges and corals were identified from thin sections.

Conodonts

Four out of five samples collected at Gyulakeszi provided satisfactory number of conodonts (Fig. 3).

Sample collected at the lowermost part of the outcrop (Fzs-1) yielded *Gladigondolella tethydis* and many unidentifiable *Gladigondolella* elements, while the Fzs-2 sample contained *Gondolella* cf. *trammeri*. Higher up in the section, the Fzs-3 sample yielded the richest and most diverse conodont fauna (Fig. 3), which includes *G. trammeri* at adult stage, *Gondolella constricta postcornuta*, *Gondolella constricta balkanica*, *Gondolella alpina szaboi*, *Gondolella alpina alpina*, and questionable *Gondolella praehungarica*. The first appearance of this conodont assemblage was also found in the reddish, cherty nodular limestone bed #111A to H (above the "reitzi tuff") at Felsőörs, the purplish red crinoidal limestone bed # -6 at Mencshely, and in the reddish limestone bed #16A at Vászoly (locations are on Fig. 1b). The presence of this assemblage indicates the establishment of full pelagic connections of the basin (Kovács 1994). In sample Fzs-4, *G. trammeri* at adult stage, *G. praehungarica* and *Gondolella fueloepi* were found (Fig. 3). This conodont association was also represented in beds #119 and upward in Felsőörs (Kovács 1994, Vörös et al. 2003). The *G. praehungarica* likely signals the establishment of deeper water environment (e.g. not present in the Vászoly section). Sample Fzs-5 did not yield any preserved specimens for identification (Fig. 3).

Radiolarians

Poorly to moderately preserved radiolarians were obtained from three out of five samples (Fig. 3) and most of the identified species are illustrated in Figure 6. Only one of the samples had very diverse fauna, some of which have also been described from the classic Middle Triassic sections (Buchenstein and Füred formations, Fig. 2) at Felsőörs and Köveskál (Fig. 1b) (Kozur & Mostler 1981, 1983, 1994; Kozur 1984; Dosztály 1991, 1993).

The sample collected at the lowermost part of the outcrop (Fzs-1) contained *Astrocentrus pulcher* (Fig. 6/4) and *Pseudostylosphaera acrior* (Fig. 6/2). Advanced Oertlispongidae were not found in this sample. The sample Fzs-3 contains moderately preserved radiolarian assemblage (Fig. 3) including *Astrocentrus pulcher* (Fig. 6/5), *Katorella bifurcata* (Fig. 6/6), *Pseudostylosphaera acrior* (Fig. 6/1), *Lamosphaera granulosa* (Fig. 6/7), *Tetraspongodiscus quadrates* (Fig. 6/8), and *Pseudostylosphaera* sp. (Fig. 6/3). In samples Fzs2, Fzs4 and 5, the radiolarians were in such a bad preservation that the determination was not possible.

Katorella bifurcata, *Pseudostylosphaera* sp. and *Pseudostylosphaera acrior* found at Gyulakeszi were also described from the section at Felsőörs (bed #87) and from the Pat-1 (Paloznak) borehole (at 55.8 m) (Fig. 1b) by Dosztály (1991).

Foraminifers

Foraminifers were determined from thin sections made from the white limestone (upper unit, Fig. 3). The foraminifers were found predominantly in the graded packstone, grainstone, rudstone facies (MF2) and the peloidal bioclastic boundstone and grainstone facies (MF5).

In the peloidal grainstone (sample Gy1 and Gy2) small duostominids (e.g. *Diplotremina* sp.(Figs 7/1-2), *Diplotremina* cf. *persublima* (Figs 7/3-4), *Duostomina* sp., (Fig. 7/5)), miliolids (e.g. *Turriglomina* cf. *magna* (Fig. 7/6), *Miliolipora cuvillieri* (Figs 7/8-9)) and some agglutinated forms (*Reophax rudis* (Figs 7/10-11)), and the lowermost part of the white limestone also contains the rare taxon *Abriolina mediterranea* (Fig. 7/12). The peloidal bioclastic boundstone and grainstone (samples Gy51 and up on Fig. 3) yielded miliolids (e.g. *Gordiospira* cf. *triassica* (Fig. 7/13)), agglutinated forms (e.g. *Agglutisolenia* cf. *conica* (Fig. 7/14), *Ammobaculites zlambachensis* (Fig. 7/15)), duostomids (*Diplotremina* cf. *persublima*), Trochmminidae (e.g. *Trochammina alpina* (Fig. 7/16)), Earlandinitae (e.g. *Earlandinita* sp., Fig. 7./17), *Earlandinita elongata* (Fig. 7/18)), nodosarids (e.g. *Pseudonodosaria* cf *lata* (Fig. 7/19)), and Endotebidae (e.g. *Endotebanella* ? sp.(Fig. 7/20), *Endoteba* ex. gr. *badouxi* (Fig. 7/21)).

Other microfossils from the section

The thin-section analysis revealed some additional forms but the number of these was subordinate, except for the microproblematics and encrustations. All of these forms were found in the well-stratified or massive limestone at the uppermost part of the outcrop (Fig. 3).

The most important fossil component of the limestone in terms of numbers and importance is *Tubiphytes* sp. found as reworked bioclasts in the graded grainstone and rudstone facies (MF2, samples Gy1 and 2), in the peloidal bioclastic grainstone and boundstone facies (MF5, samples Gy51 and up) (Fig. 8/1) and, most importantly, the "evinospogiae"-like facies (Figs 5/5-6). Very few dasycladaleans were found in the samples including partially recrystallized *Diplopora annulata* in the MF5 facies (sample Gy58; Fig. 8/2). In addition, reworked specimens were also found in the MF2 facies.

Several corals were found in the MF5 facies (sample Gy54) but include only the species *Volzeia badiotica*, which was commonly encrusted by blue-green algae (Figs 5/3-4). This scleractinian coral has been described from the Pantokrator Limestone (Greece) (Schäfer & Senowbari-Daryan 1982), the Northern Calcareous Alps (Rüffer & Zamparelli 1997), Oman (Bernecker 1996), Slovenia (Buser et al. 1982; Turnšek 1997), Russian Federation (Melnikova & Roniewicz 2007), Pamir (Punina 1997) and ranges from Ladinian to Carnian. Several porostromata algae represented by the *Ortonella* (Figs 8/3-4); and *Ladinella porata* (Fig. 8/5) were found in the MF5 facies.

Discussion

Depositional environment

The mudstones and wackestones with occasional filament debris (MF1) from the lower unit are characteristic of deep water sedimentation. Similarly to previous observation made in the Balaton Highland (Budai et al. 1999; Budai 2006), the notable lack of redeposited platform elements in the basinal limestone is evidence for distant deposition from the source of shallow marine platform elements. The lithology and microfauna (conodonts and radiolarians) of the lower unit is characteristic of the basinal facies and similar rocks are exposed on the surface along the entire length of the Balaton Highland (Budai et al. 1999). In general, the basin facies reaches its maximum thickness on top of former Anisian basins ("Felsőörs"), while it is about half of that on top of former platforms (e.g. in Drt-1(Dörgicse) borehole, Fig. 1b) (Budai et al. 1993). The possible thickness of the unit at Gyulakeszi is estimated to be <50 m.

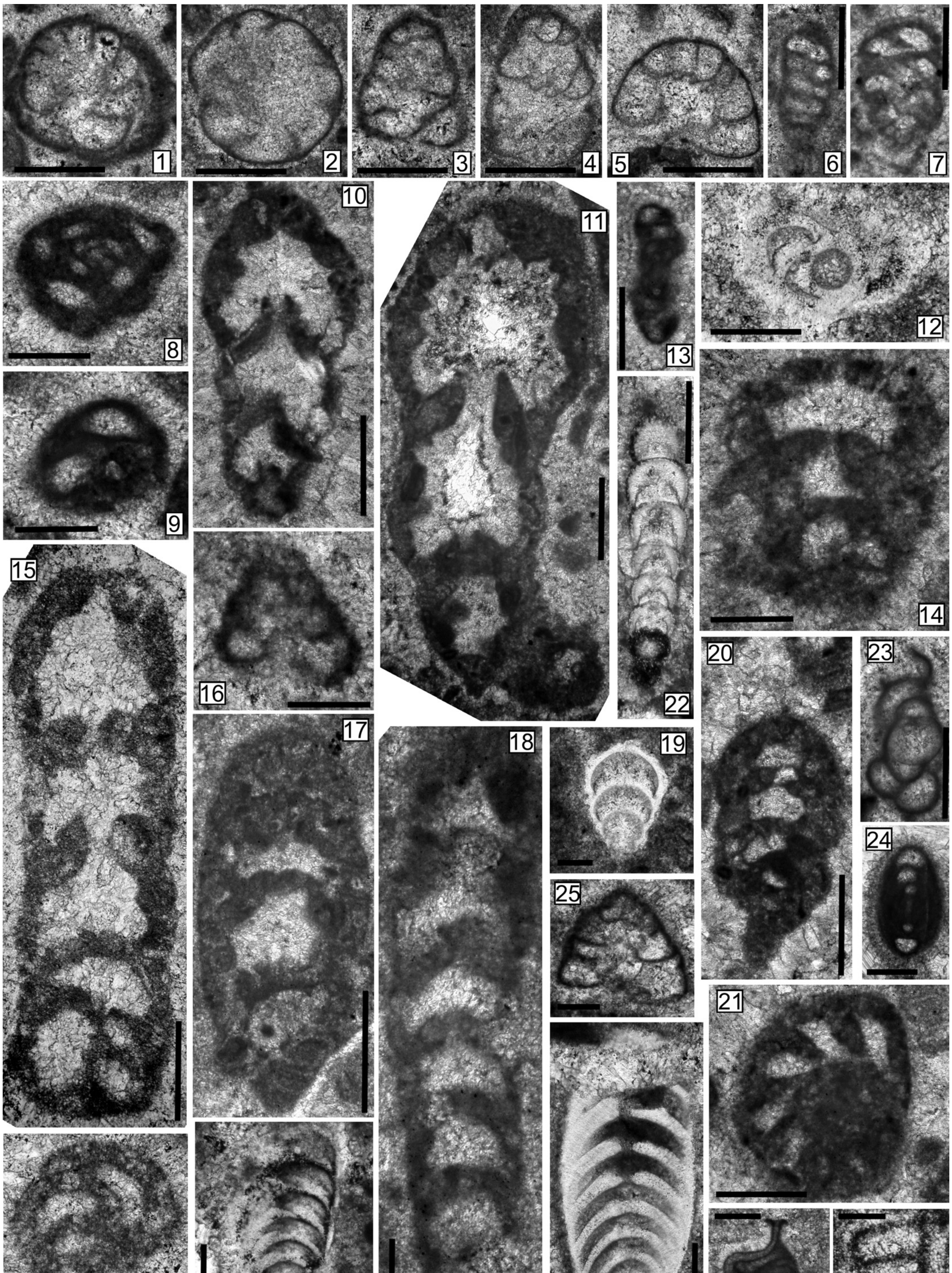

Fig. 7 - Foraminifers identified at Gyulakeszi (upper unit). Sample numbers are indicated. Scale bar is 100 μm unless stated otherwise 1-2) *Diplotermina* sp., 1 – Gy11_3; 2 – Gy52_3. 3-4) *Diplotermina persublima* Kristan-Tollman, 3 – Gy11_4; 4 – GY53_1. 5) *Duostomina* sp., Gy22_1. 6) *Turriglomina magna* Urosevic, Gy11_2. 7) *Valvulina* cf. *azzouzi* Salaj, Gy56_1. 8-9) *Miliolipora cuvillieri* Brönniman & Zaninetti, 8 – Gy12_1; 9 – Gy12_3. 10-11) *Reophax rudis* Kristan-Tollman, 10 – Gy521_1; 11 – Gy551_2. Note the intraparticle isopachous cement. 12) *Abriolina mediterranea* Luperto, Gy12_4. 13) *Gordiospira* cf. *triassica* Urosevic, Gy521_2. 14) *Agglutisolenia* cf. *conica* Senowbari-Daryan, Gy521_4. 15) *Ammonbaculites* cf. *zlambachensis* Kristan-Tollman, Gy51_1, scale bar 50 μm. 16) *Trochammina alpina* Kristan-Tollman, Gy521_3. 17) *Earlandinita* sp., Gy522_4. 18) *Earlandinita elongata* Salaj, Gy522_1, scale bar 50 μm. 19) *Pseudonodosaria* cf. *lata* Tappan, Gy522_2. 20) *Endotebanella* ? sp., Gy522_4. 21) *Endoteba* ex. gr. *badouxi* Zaninetti & Brönniman in Zaninetti et al., Gy53_3. 22) *Nodosaria* cf. *raibliana* Gümbel, Gy21_1. 23) *Hayenella*? sp., Gy11_1. 24) *Ophthalmidium plectospirus* Oravecz-Scheffer, Gy531_3, scale bar 50 μm. 25) *Tetrataxis* sp., Gy531_2. 26) *Gaudryina* ? sp., Gy12_5. 27-28) *Kriptoseptida klebelsbergi* Oberhauser, 27 – Gy21_1; 28 – Gy551_1. 29) *Paraophthalmidium* sp., Gy531_1, scale bar 50 μm; 30) *Paleolituonella*? sp., Gy531_4, scale bar 50 μm.

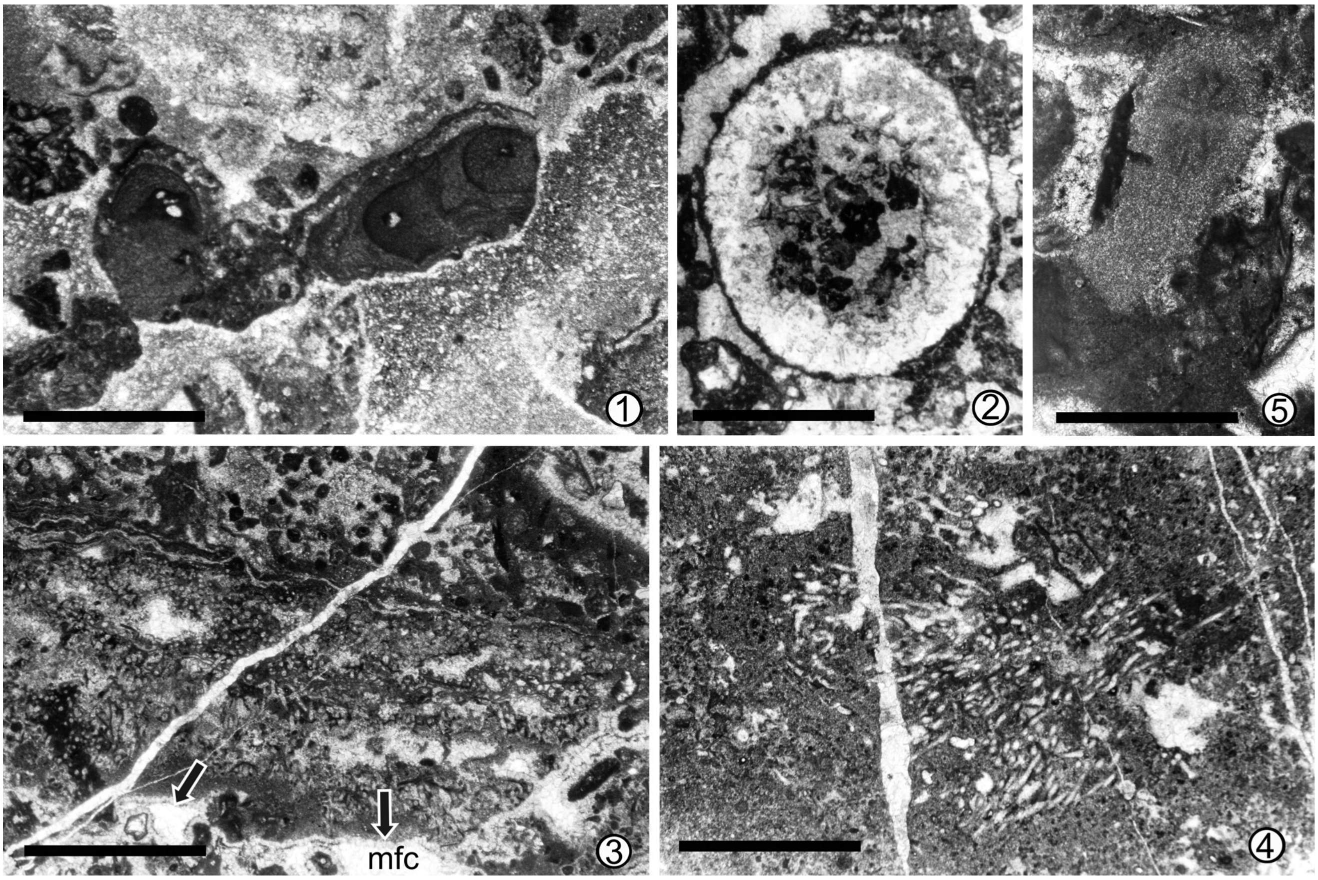

Fig. 8 - Miscellaneous microorganism found at Gyulakeszi (upper unit) in the MF5 facies. 1) *Tubiphytes* sp. In MF5 facies, scale bar is 300 µm, 2) *Diplopora annulata* Schafhäutl in MF5 facies, sample Gy59, scale bar is 3 mm. 3-4) *Ortonella* porostomata algae in MF5 facies, samples 3 – Gy52_1, scale bar is 500 µm. 5) *Ladinella porata* Ott in the MF5 facies, scale bar is 100 µm.

The facies described from the upper unit is characteristic of a shallowing-upward cycle and represents a prograding wedge of a shallow marine carbonate platform. The graded packstone, grainstone, rudstones (MF2) described at the lower part of the white limestone (samples Gy1 and Gy2) are characteristic of gravity-driven sedimentation. The micro-erosional contact at the base, the resedimented platform bioclasts, reworked dolomitic silts originating from possible subaerial exposure, poor-sorting and small amount of matrix, and graded-bedding are all evidence for deposition from proximal turbidites. It cannot be determined from the outcrop whether the graded units are intercalated with the pelagic, such as in the Ladinian of the Carnic Alps (Pfeiffer 1988; Krainer & Lutz 1995), the Julian Alps (Celarc et al. 2013) or part of a single shallowing upward unit. Note that no reworked shallow marine platform elements have been described by Budai et al. (2001a) in the pelagic deposits from the Veszprém Plateau. Reworked clasts from algae-sponge build-ups were described from the partially dolomitized Upper Ladinian (Longobardian) to Carnian (early Julian) thin-bedded Füred Limestone Formation (Berekhegy Member, Fig. 2) from Hajmáskér (Haas et al. 2000; Budai et al. 2001a). Neither the age of the underlying basinal facies nor the fossils assemblage of the Füred Limestone show similarities with the upper unit described at Gyulakeszi (discussed later).

All of the remaining facies described at Gyulakeszi are typical of a peri-platform environment deposited in shallow marine warm waters around the fair-weather wave base. The reconstruction of the lateral facies relationship cannot be completed because of the quality of the surface exposure and the lack of analogues in the Balaton Highland. Similar facies associations and plausible depositional model that can be used for the section at Gyulakeszi, however, have been described in details from the Northern Calcareous Alps (Brandner & Resch 1981; Henrich 1982), from the Dolomites (Gaetani et al. 1981; Russo et al. 2000; Marangon et al. 2011).

Diagenesis including dolomitization

The isopachous cement found in the peloidal bioclastic grainstone and boundstone facies (MF5) (Figs 7/11, 8/3) suggests that the platform top was affected by marine-phreatic diagensis. In the same facies (MF5), radiaxial fibrous calcite cement also occurs (Fig. 5/2) that bundles clusters of peloidal grainstones together. The early lithification and cementation of the platform components was most likely significant since the lack of primary platform framework formed by organisms. Despite the large amount of early cement, the significant porosity left in the limestone was filled by cavity-filling blocky calcite cement. The volumetrically important, massive precipitation of abundant concentric crust (Figs. 5/5-6) consisting of fibrous marine cements ("evinospongiae") took place in the outer margin and on the upper slope (Russo et al. 2000). These cements are major constituents of the facies, in addition to the abundant broken cements and cement debris, which contribute to the carbonate production.

It is important to note that the section at Gyulakeszi is unaffected, except for minor late void-filling dolomite, by pervasive, fabric-destructive dolomitization. Such dolomitization was described as widespread from studies of cores and outcrops in all Triassic platform carbonates in the area of the Veszprém Plateau and eastern Bakony by previous authors (Haas et al. 2000, 2014; Budai et al. 2001a, b). Similarly, the majority of the platform carbonates in the Dolomites have been diagenetically altered by dolomitization (Blendinger 1997; Schubel & Veblen 2005). Russo et al. (2000) suggested that the lack of dolomitization of the Marmolada, Latemar, Vernel and Ombrettola platforms in the Dolomites resulted from the sealing effect of the low-permeability Ladinian volcanics preventing dolomitizing fluid from circulating through these units. The absence of Ladinian volcanics ("Wengen") in the successions of the Balaton Highland is well known (Budai & Vörös 2006); therefore, the dolomitizing fluids would have no barrier to flow and would have caused pervasive dolomitization of the platform carbonates (e.g. Haas et al. 2014). Large thickness of Carnian marl section (Veszprém Marl) is known from the Tapolca Basin (Fig. 2), which could have prevented the dolomitization of carbonates from refluxing fluids. The cause for the absence of pervasive dolomitization of platform carbonates is yet to be investigated.

Stratigraphic evaluation of fossil assemblages

The exact timing of the platform progradation is uncertain due to the nature of the exposure. Evaluation of the conodont and radiolarian fauna recovered from the lower unit is equivocal since bed-by-bed sampling was not possible (Fig. 3).

The common occurrence of conodonts including *G. constricta postcornuta, G. constricta balkanica, G. trammeri, G. alpina alpina* and *G. alpina szaboi* in the Fzs-3 sample (Fig. 3) is indicative of deposition during the *Avisianum* ammonoid subzone (*Reitzi* Zone). Similar assemblage appearing in bed #111E at Felsőörs (Kovács 1994; Kovács et al. 1994) is associated with ammonoid specimens such as *Halilucites* cf. *costosus*, *Parakellerites? hungaricus*, *Hungarites lenis* (Vörös 1993). In sample Fzs-4, *G. praehungarica* and the first appearance of *G. fueloepi* suggests deposition during the *Secedensis* ammonoid zone. The fossil assemblage in these two samples from Gyulakeszi is characteristics of the uppermost part of the Vászoly and lowermost Buchenstein formations in the Balaton Highland (Kovács 1994). This distinction, however, cannot be made on the basis of lithostratigraphy or facies analysis due to the sparse exposure. It is important to point out that the *Gondolella bakalovi* group, found in bed #130 at Felsőörs by Kovács (1994) just above bed #129, which was recently defined as the base of *Curionii* ammonoid zone by Vörös et al. (2008), was not recovered at Gyulakeszi.

The radiolarian assemblage is typical for late Anisian to Carnian. The determined species are common in the Buchenstein Formation of Recoaro (e.g. Lahm 1984) and, except for *Katorella bifurcata*, are similar to the rich and well-dated radiolarian assemblage of the *Eoprotrachyceras curionii* ammonoid zone (Stockar et al. 2012).

Critical taxa in terms of biostratigraphy from the upper unit include the rare dasycladalean *Diplopora annulata* (Fig. 8/2), which was first recorded in the Illyrian and disappeared by the Carnian (Piros & Preto 2008). Budai et al. (2001b) described a mass occurrence of dasycladaleans including *D. annulata annulata, D. annulata philosophy,* and *Gyroporella* sp. from the white to beige, well-stratified dolomite of the Budaörs Dolomite in the Iszkt – 1 (Iszkaszentgyörgy) borehole, eastern Bakony. *D. annulata* was also found in the same Dolomite overlying the Vászoly Formation at Öreg-Iszka. Based on the algae, upper Illyrian to lower Fassanian age was assigned to the formation by the authors. *D. annulata* was also described from the peloidal grainstone to boundstone facies from the platform top of Marmolada (Calcare del Latemar) by Russo et al. (2000), and from the Sciliar Dolomite (*Curionii* zone) by Farabegoli & Levanti (1982).

The foraminifers are less important in terms of chronostatigraphic significance. *Abriolina mediterranea* was found to be a diagnostic foraminifera for the Fassanian to Longobardian in the Northern Calcareous Alps (Rüffer & Zamparelli 1997), in the Latemar (Emmerich et al. 2005), and in the southern Apennines (Ciarapica et al. 1990). *Agglutisolenia* cf. *conica* was described from the western Dolomites by Brandner et al. (1991), *Endoteba* ex gr. *badouxi* was described from the Northern Calcareous Alps (Rüffer & Zamparelli 1997), Western Carpathians, Silica Nappe, NE Hungary (Velledits et al. 2011) and *Trochammina alpina* was described from the Carnic Alps by Pfeiffer (1988) and all considered Ladinian.

Similar facies consisting of reworked platform elements were described from the Berekhegy Limestone

Member (Fig. 2, Haas et al. 2000) in the Balaton Highland. The age of the progradation was late Longobardian to early Julian, which was based on the presence of biostratigraphically important foraminiferal taxa (such as *Austrocolomia marschalli*, *Turriglomina carnica*, *Meandrospirella planispira*, *Schmidita inflata*, *Triadodiscus eomesozoicus*). The ammonoid *Celtites epolensi*, found in the underlying unit at Hajmáskér (Vörös 1998; Buchenstein Formation), suggested the deposition during *Regoledanus* Zone (upper Longobardian). Since these foraminifers were not found, as well as, the basinal facies (lower unit) is postulated to be of the *Curionii* zone or older, the section at Gyulakeszi is not equivalent to the Berekhegy Limestone.

Local and regional correlation of the progradation event

The progradation event was preceded by the deposit of the marine transgression (Vászoly Formation) during the *Avisianum* subzone (*Reitzi* zone). Pelagic sedimentation (Buchenstein Formation) was ongoing during the *Secedensis* zone (sample Fzs-4). There is no evidence for shallow marine sedimentation during these ammonoid zones at Gyulakeszi but, based on the sporadic samples (Fig. 3), an unexposed, and less apparent, progradation cannot be excluded. It is also important to note that, although there is no evidence for *Curionii* zone or younger pelagic rocks, these cannot be ruled out due to the incomplete exposure between the lower and upper units. Microfossil assemblages (mainly foraminifers and algae) recovered from the upper unit indicate that the platform progradation has reached the area during the *Curionii* zone or later.

Progradation events were widespread during the Middle Triassic evolution of the carbonate platforms the Alps-Carpathian-Pannonian region. The variation in the onset of these events was interpreted to represent different paleogeographic positions where the subsidence rate, local and regional tectonics, sediment production, or distance form volcanic centers were controlling the growth of these platforms (Maurer 2000). The rest of this section describes some well-known examples to illustrate this point.

In the nearby Veszprém Plateau (Fig. 1b), the minor role of progradation in the evolution of the Pelsonian and late Illyrian platforms was possibly in connection with intense tectonic subsidence (Budai & Vörös 2006). In contrast, the Anisian platforms were mainly controlled by eustatic sea-level changes the carbonate producers were able to keep pace with. As a result, aggradation of platform carbonates was insignificant compared to progradation during the pre-*Curionii* zone (Budai & Vörös 2006). The "Szentkirályszabadja" platform (Budaörs Formation on Fig. 2) started up during the *Secedensis* zone and prograded over the former Anisian basins (Vászoly Formation in Fig. 2). The Budaörs Formation was studied at several road cuts, quarries and boreholes (Fig. 1b) in the Veszprém area (Budai et al. 2001a). At Litér quarry, the Vászoly Formation is overlain by well-stratified dolomite without identifiable fossils or structure. At Hajmáskér, fenestral structures were documented from the dolomite and at Öskü, breccias beds, algal laminites and slump features were found in the dolomites. Based on ammonoids at Öskü (*Euprotrachyceras* cf. *curionii, E.* cf. *recubariense, E.* cf. *rieberi*), the progradation ended as early as *Curionii* ammonoid zone; therefore pre-dating the one at Gyulakeszi, and was followed by marine transgression. Eupelagic carbonate sedimentation (Buchenstein Formation) was continuous from the Fassanian to the late Longobardian (*Gredleri* and *Archelaus* zones).

Shallow marine, fossiliferous platform carbonates were also described from boreholes and various outcrops located in the Iszkahegy area, Eastern Bakony (Budai et al. 2001b). The carbonates include white to beige well stratified dolomite with remnants of dasycladales and bioclastic limestones with abundant encrustations and sponges. These facies represent deposition on a low-relief ramp with characteristics fossil assemblage typical of resedimentation from patch-reefs to subtidal lagoons. The onset on carbonate sedimentation was determined as early as Illyrian and comparable to the Contrin Formation of the Dolomites (Farabegoli & Levanti 1982). The core of this platform, however, was able to keep up with the subsequent sea-level rise and aggradation was ongoing until the Carnian without the interruption of pelagic sedimentation.

In other part of the Western Tethys, several episodes of progradation were documented. In the Western Dolomites, two major growth patterns were described from the Schlern/Rosengarten platforms by Maurer (2000): aggradation with only limited progradation during the *Reitzi*/*Secedensis*, a transition to progradation during the *Curionii* and rapid progradation during *Gredleri* and *Archelaus* zones. Variations in the rate of subsidence were interpreted as the driving force while marked increase in carbonate production is suggested to be another important parameter behind the change from aggradation to progradation (Maurer 2000). Other examples from the Western Tethys include the Sciliar episodes in Dolomites (De Zanche et al. 1993; Gianolla et al. 1998) and in the Julian Alps (Jadoul et al. 2002), carbonate production and debris shedding followed by complete progradation in the Kamnik-Savinja Alps (Buchenstein and Schlern in Celarc et al. 2013), and progradation of the Aggtelek reef during the *Curionii* zone in the Aggtelek Plateau (reef phase 2 in Velledits et al. 2011).

Conclusions

The small outcrop at Gyulakeszi represents the westernmost exposure of Middle Triassic rocks in the Balaton Highland. A bed-by-bed sampling was not possible due to the unexposed sections. Nevertheless, the results obtained in this study provide the first insight into the sedimentation processes, biota and evolution of the area west of the “Tagyon” sea mount. The following list summarizes the main conclusions of the study:

• Six microfacies representing basin to platform environments were identified. The sequence of these facies indicate a shallowing-upward succession, which includes depositional environments such as distal basin with occasional reworked sediments; a more proximal slope with gravity-induced graded turbidites; outer platform margins with intense cementation; biogenic crusts and thrombolites, and debris and cavities on the platform top. This is the first time that these platform environments have been documented from the Middle Triassic in the Balaton Highland.

• This study presents biostratigraphic (conodonts) evidence that the lower unit was deposited during the *Avisianum* subzone (Vászoly Formation) and *Secedensis* ammonoid zones (Buchenstein Formation) and it is similar to the rocks found in key basin sections of the Balaton Highland (Felsőörs, Mencshely and Vászoly). The characteristic conodont taxa of the *Curionii* zone were not recovered but their absence cannot be ruled out due to significant unexposed sections.

• The sporadic micropaleontological samples taken from the pelagic succession do not unequivocally prove continuous pelagic sedimentation. Our results cannot exclude the possibility of an earlier carbonate progradation at Gyulakeszi during the *Secedensis* ammonoid zone, for example, which the sparse sampling could have missed.

• This work demonstrates that the platform progradation reached the area during the *Curionii* zone or later. This observation postulates that the sedimentary system west of the Tagyon sea mount had developed markedly different from the nearby Felsőörs Basin where pelagic sedimentation was prevalent during the *Curionii* zone. The variation of these sedimentary patterns, in these two neighboring basins as well as in other basins in the Western Tethys, is controlled by the subsidence rate, local and regional tectonics, sediment production, or distance from volcanic centers.

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