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ORIGIN AND EVOLUTION OF LATE TRIASSIC BACKPLATFORM AND INTRAPLATFORM BASINS IN THE TRANSDANUBIAN RANGE, HUNGARY

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Abstract: The setting and facies distribution of the Upper Triassic basin formations in the Transdanubian Range of Hungary clearly reflects the paleo-geodynamic evolution of the northwestern termination of the Neo-Tethys margin. Westward propagation of the Neo-Tethys continued during the Middle Triassic. By the Late Triassic large carbonate platforms (Dachstein-type platforms) developed on the continental margin of the newly formed oceanic branch. Progressive rifting led to downfaulting of the external (ocean-ward) margin of the platforms and formation of narrow intraplatform basins roughly parallel to the platform margin since the Carnian. Some of these basins were already filled up and reoccupied by carbonate platforms in the Triassic but some of them persisted until the Jurassic. Initiation of opening of the Ligurian-Penninic ocean-branch resulted in rifting and formation of new extensional basins in the Late Norian. In this way a large basin-system came into being (Kössen Basin) behind the platforms, so that the previous continent-encroaching platform became an isolated platform. The basins were filled up with terrigenous clay and platform-derived carbonate mud by the Late Rhaetian, giving rise to progradation of the platforms onto the former basins. Coeval rifting of the Neo-Tethys and the Ligurian-Penninic branches led to disintegration and step-by-step drowning of the Dachstein platform system in the Early Jurassic. Although the evolution of the studied basins was mainly tectonically controlled, their architecture and depositional pattern were influenced by several other factors: climate, sea-level changes and the general paleogeographic setting.

Key words: Transdanubian Range, Upper Triassic, intraplatform basin, carbonate slope, facies analysis.

Introduction

The Upper Triassic of the Transdanubian Range (TR), Hungary is made up of platform carbonates and intraplatform basin deposits. Neo-Tethys rifting in the late Anisian–Ladinian resulted in the formation of relatively large basins in the central part of the TR. Increased terrigenous influx and shedding of carbonate mud led to filling up of these basins by the latest Carnian. The leveled topography made possible the formation of an extremely extensive carbonate platform system (Dachstein-type platform). At the same time new basins were formed in the northeastern part of the TR Unit, and some of them persisted until the Jurassic. During the Norian new basins were formed both on the northeastern and southwestern sides of the TR Unit.

According to the recent paleogeographical reconstructions the TR Unit was a part of the Neo-Tethys passive margin in the Late Triassic (Dercourt et al. 1993; Haas et al. 1995a; Vörös 2000). It may have been located between the South Alpine and the Upper Austroalpine realms (Haas et al. 1995a). In the Northern Calcareous Alps (Upper Austroalpine unit), backstepping of the platform margin and formation of narrow basins near the offshore margin were explained by thinning of the continental crust due to rifting of the Tethys (Lein 1985, 1987) or Neo-Tethys according to the present-day nomenclature. In the Southern Alps, in Lombardy and also in the Carnian Fore-Alps, formation of intraplatform basins in the late Norian was attributed to incipient rifting of the Ligurian-Piedmont ocean branch (Jadoul et al. 1992; Carulli et al. 1998). On the basis of studies of the tensional features of the Late Triassic basins in the Carnian Fore-Alps, Cozzi (2000) emphasized the role of the westward propagation of the Neo-Tethys in the Southern Alps as well.

The TR Unit has got good potential for the comparative study of various intraplatform basins and analysis of their original relationships because it represents an almost complete cross-section of the Neo-Tethys paleomargin and it was affected only by relatively slight tectonic deformation during the Alpine Orogeny. In the last decade, detailed studies have been carried out to detect the stratigraphy and sedimentological characteristics of the basins. Majority of the results of these studies has been published, mainly in Hungarian (Csővár Basin — Haas et al. 1995b; Hármashatár-hegy Basin — Haas et al. 2000; Kössen Basin — Haas 1993). These results are only briefly summarized, occasionally updated and complemented here, highlighting data on the facies evolution.

The aim of the present paper is to summarize the characteristics and compare the evolutionary history of the Late Triassic intraplatform basins in the area of the TR and to consider their evolution within the structural frame of the region.

Paleogeographical and stratigraphic setting

The Transdanubian Range is located in northwestern Hungary, traversing northern Transdanubia in a NE–SW direction

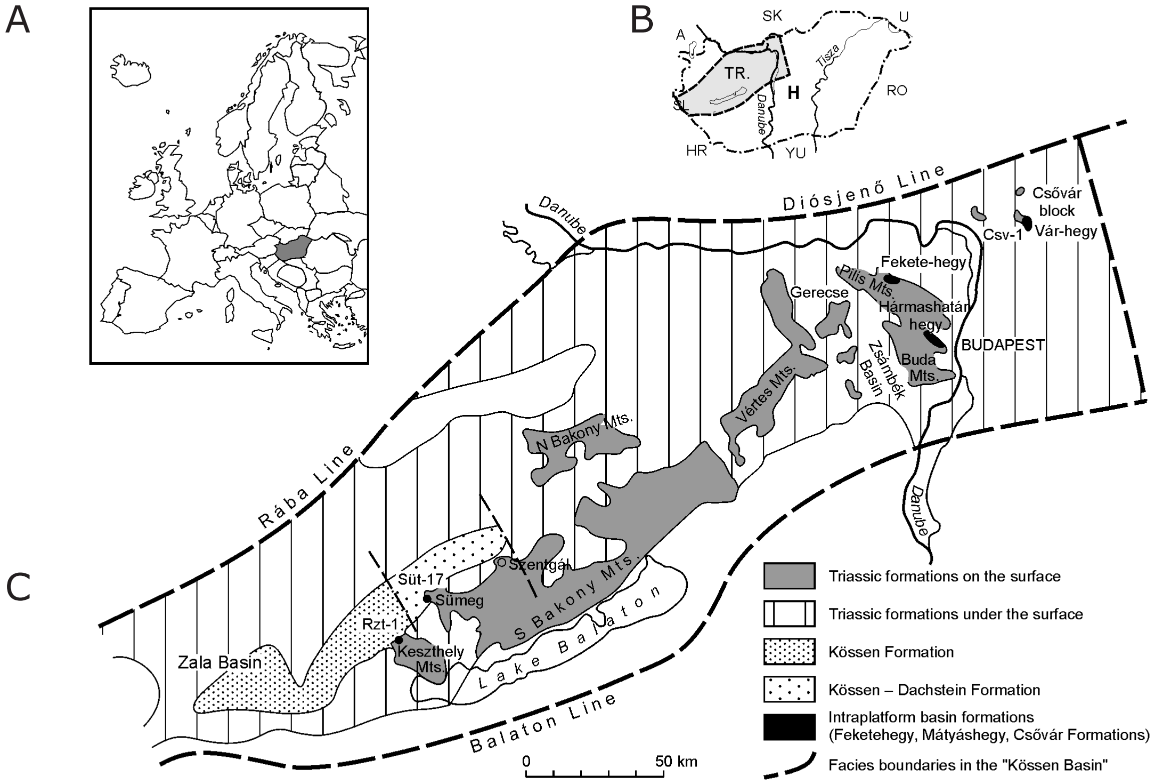

Fig. 1. A — Location of the study area in Europe and B — within Hungary. C — Upper Triassic formations in the Transdanubian Range Unit and location of the studied basins.

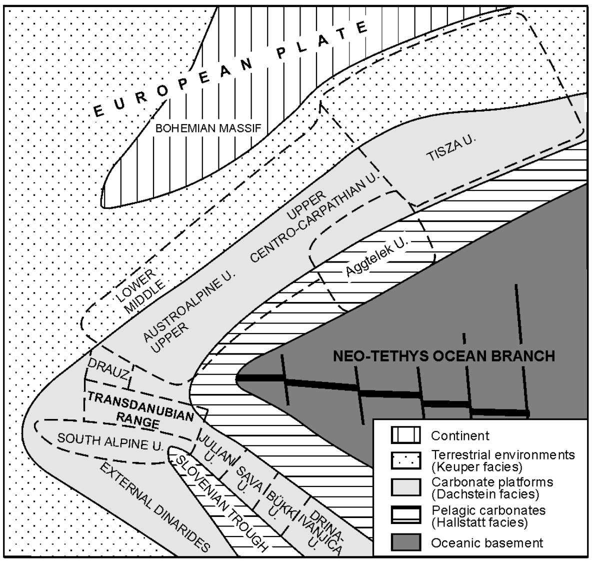

Fig. 2. Paleogeographical sketch-map of the western Neo-Tethys and reconstructed location of the Transdanubian Range Unit in the Norian.

(Fig. 1). The mountain range is made up predominantly of Triassic formations which also constitute the basement of Tertiary basins SW and NE of the mountains (Fig. 1). According to recent geodynamic concepts, the TR Unit broke away from its original location probably in the Late Cretaceous and as a result of multi-phase dislocations joined with other lithosphere fragments (terranes) reaching its present-day setting during the Tertiary (Majoros 1980; Kázmér 1984; Kázmér & Kovács 1985; Balla 1988; Csontos et al. 1992; Haas et al. 1995a). The reconstruction of the original setting of the present-day TR Unit (i.e. prior to the major orogenic movements) is based mainly on fitting of the Late Permian to Triassic facies zones (Haas et al. 1995a; Haas & Budai 1995). According to these reconstructions the TR Unit was located at the western termination of the Neo-Tethys between the South Alpine and Drauzug–Upper Austroalpine realms (Fig. 2). For the entire Late Permian–early Late Triassic interval, a segment of the Neo-Tethys margin, the present-day TR Unit, shows a definite facies polarity: its northeastern part represents the seaward side (which was located closer to the Neo-Tethys Basin), whereas its southwestern part represents the landward one. This setting was significantly modified in the latest Triassic–Jurassic due to rifting of the Ligurian-Penninic ocean branch.

In the Late Permian continental red beds (fluvial-lacustrine formations) were deposited in the southwestern part of the area of the TR Unit, whereas evaporitic dolomites of shallow lagoonal cyclic subtidal–sabkha facies formed in its northeastern part. Transgression in the earliest Triassic (subsequent to the Permian/Triassic boundary event) led to inundation of the whole area leading to a shallow ramp setting. On the ramp mixed siliciclastic–carbonate deposition took place in the Early Triassic, which was followed by prevalence of carbonate deposition in the early Middle Triassic (Early Anisian). In the Middle Anisian Neo-Tethys rifting led to the formation of extensional basins in the central part of the TR (Bakony–Balaton

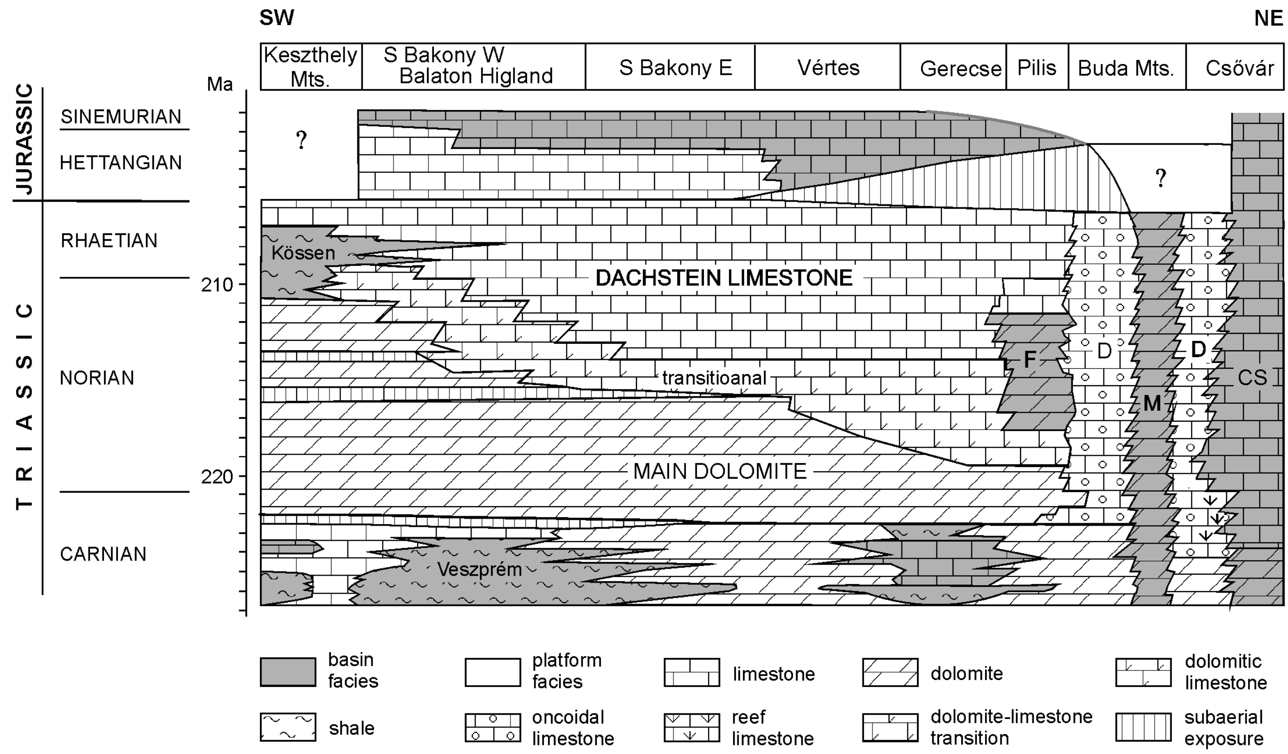

Fig. 3. Stratigraphic chart for the Upper Triassic of the Transdanubian Range. *Abbreviations:* F — Feketehegy Formation, D — Dachstein Limestone, M — Mátyáshegy Formation, Cs — Csővár Formation.

Highland area) whereas on the relatively elevated blocks, small isolated carbonate platforms developed coevally. Deposition of volcanic tuffs from a distal source initiated in the latest Anisian and repeated at several times till the beginning of the Carnian. In the Ladinian, coeval deposition of condensed pelagic limestone in the basins and shallow marine carbonates on the platforms continued, with progradation of the platforms during the sea-level highstands. The segment of the Neo-Tethys margin, represented by the southwestern part of the TR (Bakony–Balaton Highland area), was affected by intense terrigenous influx in the early Carnian, resulting in gradual filling of the basins by the late Carnian (see the stratigraphic chart for the Upper Triassic — Fig. 3). On the other hand, in the northeastern part of the area of the TR (Gerecse Mts, Buda Mts, and Danube E-side blocks) continuation of the Neo-Tethys rifting led to disintegration of the Ladinian platforms and establishment of new extensional intraplatform basins in the Carnian. One of them, the Zsámbék Basin (Gerecse Mts) was also affected by an intense terrigenous influx and filled up by the Late Carnian (Haas 1994). In contrast, the basins in the northeastern part of the TR were not reached by terrigenous material and thus persisted for a long time: the Hármashatár-hegy Basin (Buda Mts) at least until the Rhaetian, and the Csővár Basin (Danube E-side blocks) also into the early Jurassic. As a consequence of the filling up of the larger basins in the inner part of the TR segment of the Neo-Tethys margin, an extremely leveled topography came into existence by the Late Carnian. A short-term subaerial exposure in some parts of the area may also have contributed to the levelling of the surface (Haas & Budai 1999). Due to the levelled topography, transgression at the beginning of the Late Tuvalian led to the formation of a huge platform system (Dachstein-type platforms). In the inner platform, cyclic peritidal successions were deposited and pervasively dolomitized under semiarid climatic conditions. In the segmented outer platform, shallow subtidal oncoidal limestone was formed. At the beginning of the Late Norian, initiation of the rifting of the Ligurian-Penninic ocean basin led to formation of large extensional basins (Kössen-type basins) in the southwestern part of the TR. Filling of these basins by fine terrigenous siliciclastics and platform derived carbonates was completed by the late Rhaetian. It was followed by fast progradation of the platform. Penecontemporaneously a small intraplatform basin was established in the area of the Pilis Mts (Fekete-hegy Basin) in the northeastern part of the TR, and filled up by carbonates prior to the Rhaetian.

Facies characteristics and evolution of the basins

The Csővár Basin

In North Hungary, east of the Danube, small outcrops of the Mesozoic basement occur in fault-bounded, uplifted blocks, which also belong to the TR Unit. They are made up of Upper Triassic platform carbonates as a rule. However, one of them, the Csővár Block, along with platform facies, also contains coeval slope and basin facies (Figs. 1, 2).

The cherty carbonate sequence was first reported by Szabó (1860) who tentatively classified it as Liassic. Vadász (1910) correlated the succession with the “Raibl Beds” and assigned it to the Carnian. A revision of this chronostratigraphic assignment was suggested by Kozur & Mostler (1973) who found Upper Norian microfossils in the Pokol-völgy quarry. Detre et al. (1988) determined Upper Norian ammonoids, Kozur & Mock (1991) and Haas et al. (1997) reported Rhaetian macro- and microfossils from the same quarry. Kozur (1993) found Hettangian and Sinemurian radiolarian fauna in samples taken from the Vár-hegy (Castle Hill). A preliminary report on the biostratigraphy of the Triassic/Jurassic boundary section on the Vár-hegy was published by Pálfy & Dosztály (1999).

In the northwestern part of the Csővár Block, thick-bedded Upper Carnian-Norian oncoidal limestone, that is the oncoidal facies of the Dachstein Limestone with bioconstructed patch-reefs (Nézsa Member) crops out. In a few outcrops, rudstones and floatstones representing the foreslope facies of the reef also occur.

In the southeastern part of the block, thin-bedded, cherty dolomite and limestone (Csővár Limestone Formation) are exposed in a quarry and outcrops. The field observations were complemented by core data. Core Csv-1 exposed an approximately 600 m-thick part of the Csővár Formation, representing the Upper Carnian–Lower Rhaetian interval (Haas et al. 1995). In the borehole, above a major low-angle fault, cherty dolomite (Pokolvölgy Dolomite Member — Carnian) was encountered in a thickness of 100 m. It was followed by thin-bedded, laminated, locally cherty limestone of basin and toe-of-slope facies. The upper part of the Csővár Formation (Rhaetian) is exposed in the Pokol-völgy quarry (Haas et al. 1995) and outcrops on the steep southwestern slope of the Vár-hegy. The Triassic/Jurassic boundary can be drawn within the Csővár Formation (Pálfy & Dosztály 1999). As to their sedimentological features, there is no significant difference between the Upper Triassic and the Hettangian part of the formation. The probably Sinemurian (Kozur 1993) cherty limestone layers, cropping out at the top of the Vár-hegy, are of deeper basin facies.

The characteristics of the distinguished lithofacies types of the Csővár Formation are summarized in Table 1 and Fig. 4. The results of facies analysis of core Csv-1 were presented by Haas et al. (1995). In this paper only the uppermost (Upper Norian–Lower Rhaetian) segment of the core section is presented (Fig. 5) for the sake of comparison with the time-equivalent basinal sections in the TR. Sections of the Pokol-völgy quarry and the Vár-hegy trench are shown in Figs. 6 and 7, respectively.

The sedimentological features and fossil assemblage of the Csővár Formation point to a toe-of-slope depositional environment, as well as slope to basin transitional zone. This paleoenvironmental setting is indicated by gravity-flow deposits (debris-flow deposits, graded, allodapic limestone etc.) and frequent occurrence of remnants of platform biota, together with typical pelagic fossil elements (Haas et al. 1995). The major facies units can be characterized as follows:

Carbonate platform — Platform carbonates, coeval with the Csővár Formation (Upper Carnian–Norian) are known in the

Table 1: Lithofacies types of the Csővár Formation. *Abbreviations:* gr — grainstone, p — packstone, w — wackestone.

Lithofacies type	***Description***	***Interpreted depositional setting***
Lithoclastic–bioclastic (Lb)	Fine calcirudite–coarse calcarenite gr, p Crinoid and mollusc fragments	proximal toe-of-slope
Oncoidal–grapestone (On)	Coarse calcarenite gr, p, w Brachiopods, molluscs, ostracodes	proximal toe-of-slope
Redeposited bioclastic wackestone (Rb)	Coarse calcarenite w Crinoids, benthic foraminifers, microproblematicums, ostracodes	proximal toe-of-slope
Proximal turbidite (Pt)	Coarse calcarenite p Crinoids, molluscs, bethic foraminifers, microbial crust fagments	toe-of-slope
Distal turbidite (Dt)	Fine calcarenite, peloidal p, and sponge spicule w alternate crinoids, molluscs, ostracodes, sponge spicules, radiolarians	distal toe-of-slope–basin
Very distal turbidite (Vt)	Laminitic: calcisilt and calcilutite alternate, w Filaments, radiolarians	basin
Sponge spicule facies (S)	Calcisilt, calcilutite w Sponge spicules, crinoids, filaments, radiolarians	basin
Filament facies (F)	Calcisilt, calcilutite w Filaments, radiolarians, echinoderm fragments	basin
Radiolarian facies (R)	Calcisilt, calcilutite w Radiolarians, sponge spicules Filaments, echinoderm fragments	basin
Condensed radiolarian facies (Ra)	Calcisilt, p Radiolarians (very abundant), sponge spicules echinoderm fragments	deep basin

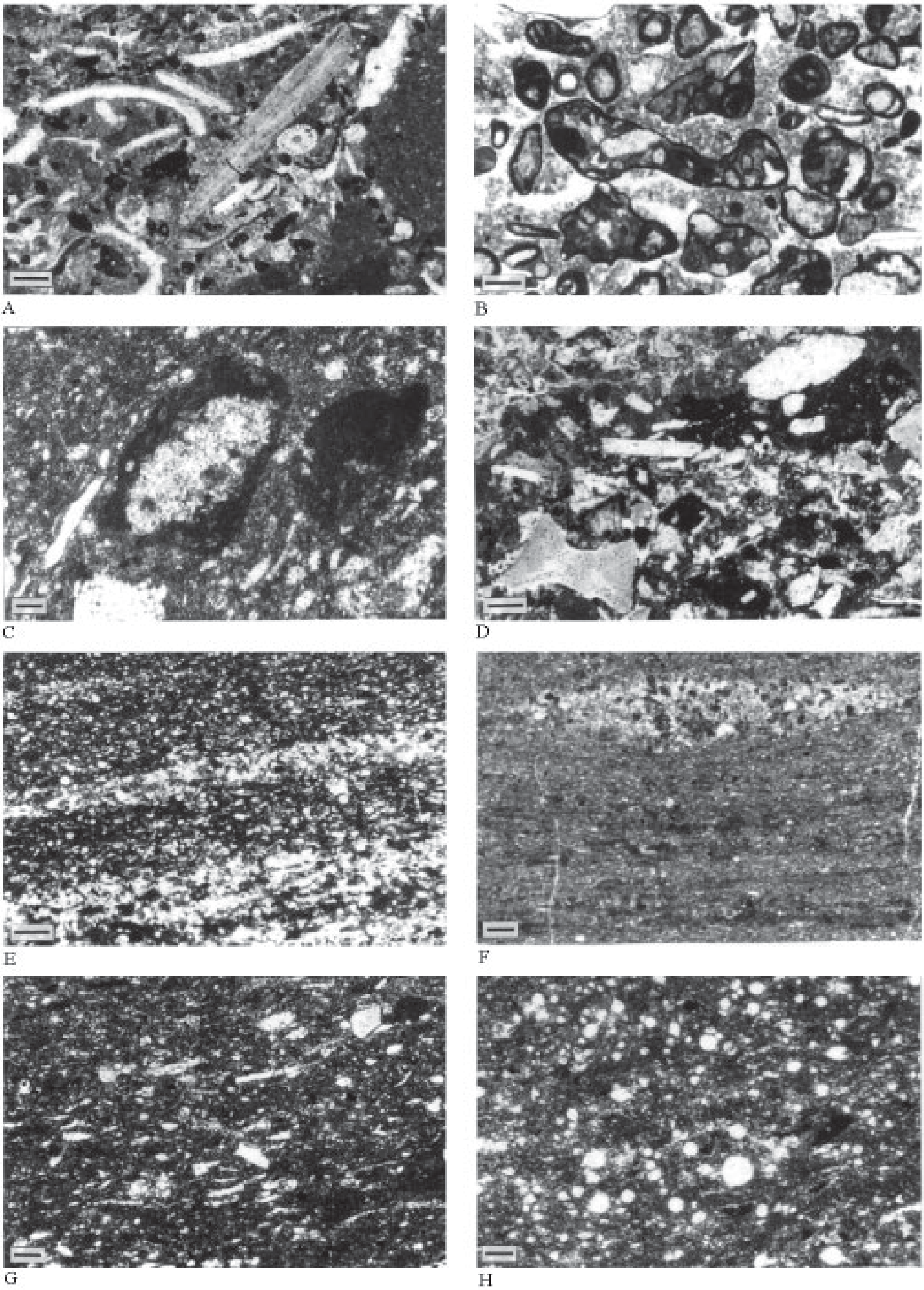

Fig. 4. Characteristic microfacies of the Csővár Formation. **A** — Lithoclastic-bioclastic facies (Lb). Mollusc shell fragments, echinoderm fragments and intraclasts. Scale bar: 0.5 mm. A part of a larger lithoclast is visible at the left margin of the microphotograph. **B** — Oncoidal-grapestone facies (On). Scale bar: 0.5 mm. **C** — Redeposited bioclastic wackestone facies (Rb). Microbially encrusted particle is visible in the central part of the microphotograph. Scale bar: 0.1 mm. **D** — Proximal turbidite (Pt). Basal part of a turbidite layer with crinoid ossicles and mollusk shell fragments. Scale bar: 0.5 mm. **E** — Distal turbidite (Dt). Scale bar: 0.5 mm. **F** — Very distal turbidite (Vt). Scale bar: 0.2 mm. **G** — Filament facies (F). Scale bar: 0.2 mm. **H** — Radiolarian facies. Scale bar: 0.2 mm.

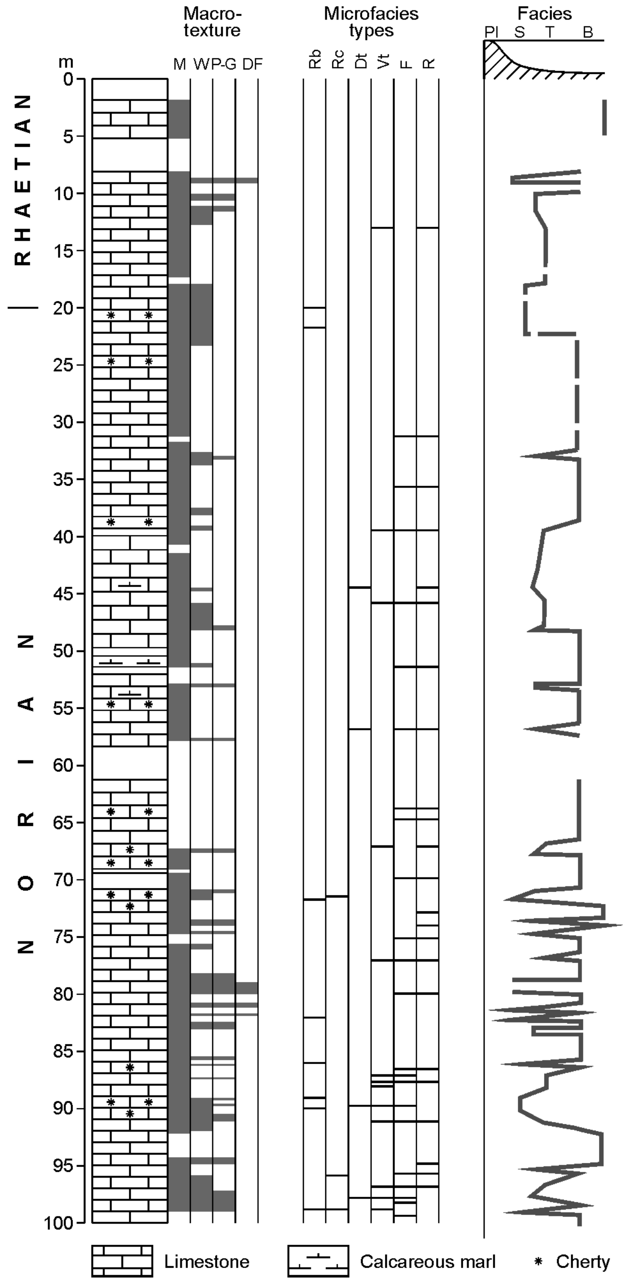

Fig. 5. Lithology, microfacies types and facies interpretation of the uppermost part of Csv-1 core. *Abbreviations:* M — mudstone, W — wackestone, P — packstone, G — grainstone, DF — debris flow deposit (debrite); Rb — Redeposited bioclastic facies, Rc — crinoidal grainstone, Dt — distal turbidite, Vt — very distal turbidite, F — filament facies, R — radiolorian facies; Pl — carbonate platform, S — slope, T — toe-of-slope, B — basin.

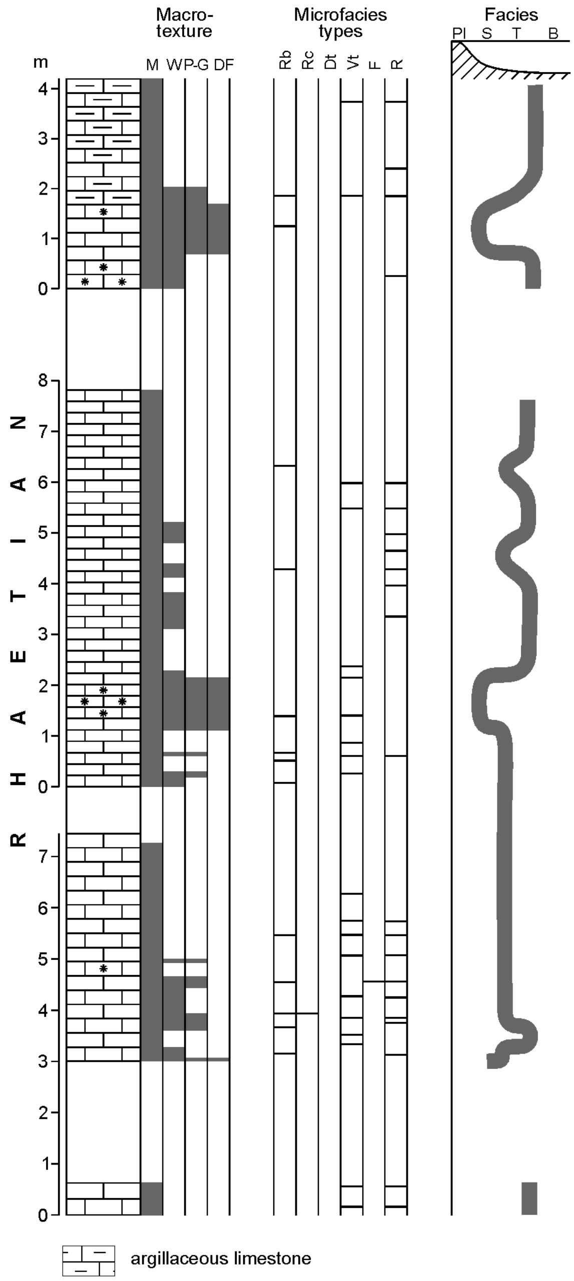

Fig. 6. Lithology, microfacies types and facies interpretation of a composite section in the Pokolvölgy quarry. For legend and explanation of abbreviations see Fig. 5.

vicinity of the study area (see Fig. 2). The nearest occurrence of coeval platform carbonates, which can be classified as Dachstein Limestone Formation, is located northwest of the Pokol-völgy quarry, at a distance of 2 km. Patch-reef and oncoidal facies occur, indicating the marginal zone of a carbonate platform.

Slope — Rudstone and floatstone consisting of coarse detritus of reefal limestone.

Proximal toe-of-slope — Debris-flow deposits, that is lithoclasts of various size and rudite–calcarenite-sized bioclast in mudstone–wackestone matrix characterize this depositional zone (Fig. 8).

Distal toe-of-slope — Predominance of turbiditic deposition characterizes this depositional environment. Above erosional surfaces (locally erosional channels), allodapic limestone, showing features of the classic Bouma sequence, are visible, alternating with laminitic limestone, that is fine-grained turbidites, deposited from low-density turbidity currents.

Pelagic basin — In the inner basin, relatively far from the slope, pelagic oozes (filament or radiolarian oozes) were de-

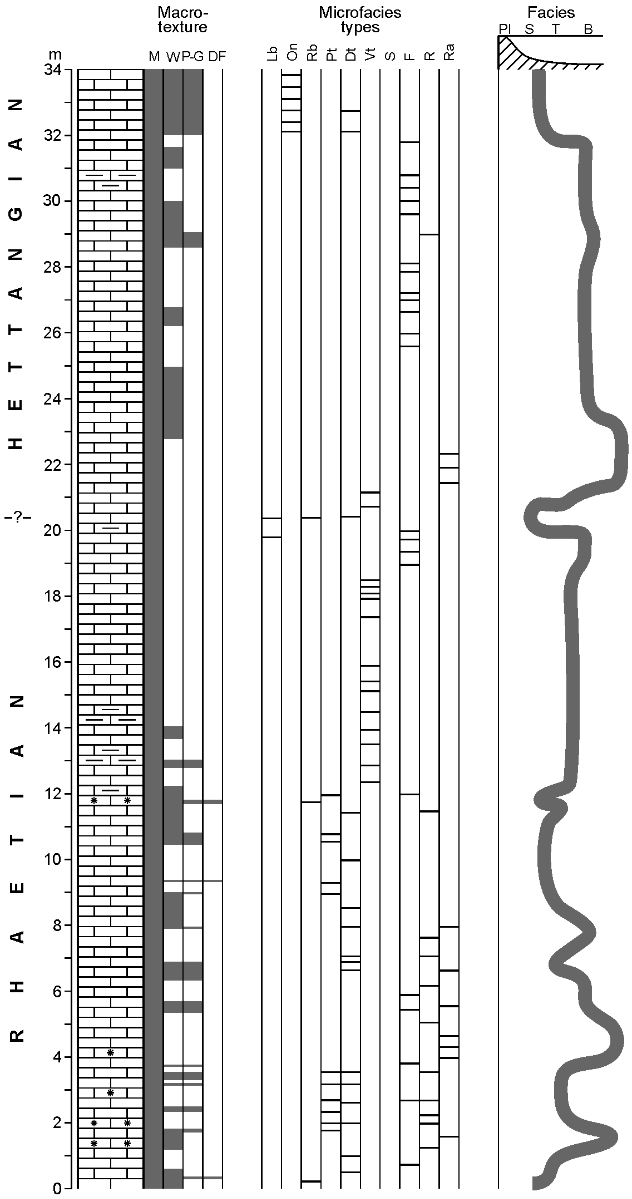

Fig. 7. Lithology, microfacies types and facies interpretation of the Vár-hegy trench. For legend see Fig. 5, for explanation of abbreviation see Table 1.

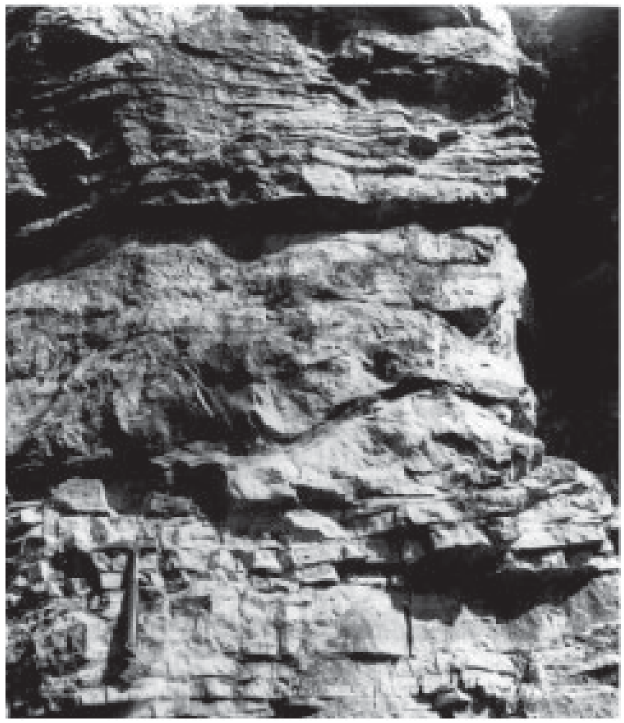

Fig. 8. Debrite intercalation in a distal turbidite succession. Large plasticlasts and lithoclasts occur in the debrite bed. Pokolvölgy quarry, Csővár.

posited as a rule. Fine lamination, that is, alternation of calcisilt and mudstone laminae, is common. It can be interpreted as a very distal, low-density turbidite. Calcarenitic turbidites are rare and very thin (mm-thick).

Basin evolution is summarized in Fig. 9. The Upper Carnian–Norian succession encountered in the Csv-1 core shows a fairly clear trend. In the lower part of the succession, the predominance of the basin facies is characteristic, whereas distal toe-of-slope facies prevails upward, thus suggesting platform progradation. Within this long-term trend, short-term facies changes can also be seen. These may reflect sea-level changes. An increasing amount of microfossils of platform-interior origin probably indicates highstand intervals (high-stand shedding — Reijmer & Everaars 1991; Reijmer et al. 1992; Schlager et al. 1994).

In the early part of the Rhaetian, represented by the basal layers of the Pokol-völgy quarry a remarkable facies change could be recognized. Appearance of a large amount of larger plant fragments (among them an imprint of a pine-cone — J. Oravecz pers. comm.) and sporomorphs of continental plants (Haas et al. 1995), suggests a significant sea-level drop, when large parts of the former platforms may have been subaerially exposed and restriction of the intraplatform basin increased (Fig. 9).

The appearance of proximal toe-of-slope facies in the higher part of the quarry can be bound to sea-level rise, when reefs (bioherms) were formed on the upper slope, whereas a large part of the neighbouring platform remained probably emerged, thus providing a relatively large amount of sporomorphs of continental plants for the basin. This model can also explain why the inner-platform foraminifers are missing in the Rhaetian part of the Csővár Formation.

According to the study of the Vár-hegy section, an upward-deepening trend characterizes the latest Rhaetian. The distal turbidites are followed by laminitic layers, that is very distal turbidites and then filament wackestones of basin facies. A thin debris-flow layer was found at the T/J boundary interval, which was determined by ammonites (Pálfy & Dosztály 2000) and conodonts (Pálfy et al. 2001). This was followed by distal turbidites and pelagic basin facies, which probably already belong to the Jurassic.

The Hármashatár-hegy Basin

In the Buda Mountains, Upper Triassic cherty dolomite and limestone of basin facies have been known since the 19th century (Hofmann 1871). On the basis of a few fossils, they were classified into the Middle–Upper Carnian (Schafarzik 1902; Lőrenthey 1907). In the same area, thick-bedded dolomites with Upper Carnian molluscs and without chert were also encountered. Accordingly, the concept of coeval shallow and deep marine Late Triassic facies already emerged in the 1920s. The juxtaposition of the significantly different facies was explained by Horusitzky (1943, 1959) by a nappe structure. On the other hand, Wein (1977) attributed the facies differences to the paleogeographical setting, assuming subparallel basins separated by submarine highs. In 1993, Kozur & Mock reported Carnian–Rhaetian age data from the cherty basin facies in the Hármashatár-hegy Range. In 1992, a core boring (Vh-1) penetrated a 200 m-thick succession of the Upper Triassic basin and slope facies, which provided data of outstanding importance from both stratigraphic and sedimentological points of view. Detailed analyses of the core samples and new concepts on carbonate platform and foreslope evolution inspired a comprehensive re-evaluation of the existing data and the results of the new studies (Haas et al. 2000).

The geological setting of the Upper Triassic basin and platform facies is shown in Fig. 10. Cherty basin facies occur in two ranges, in the southwestern and northeastern side of the Buda Mts, respectively. They are separated by coeval platform facies. The time/space relationship of the basin and platform formations are presented in Fig. 3.

The lithology, chronostratigraphic subdivision and results of petrographic and microfacies studies, as well as facies interpretation of core Vh-1, which exposed the Upper Norian–Rhaetian part of the Mátyáshegy Formation are shown in Fig. 11. The characteristic facies types recognized in the core section are presented in Table 2 and Figs. 12, 13.

A general depositional model for the Late Norian–Rhaetian part of the Mátyáshegy Formation based mainly on the studies of the microfacies and organic matter in core Vh-1, is shown in Fig. 14. A high-productivity intraplatform basin, partially separated from the open sea by isolated platforms and islands, was the site of deposition. From the ambient platform, bioclasts and lithoclasts were transported into the basin and deposited at the toe of the slope. The semi-consolidated sediments were commonly affected by synsedimentary deformation.

The main facies units can be characterized as follows:

Carbonate platform — Platform carbonates (Fődolomit = Hauptdolomit and oncoidal Dachstein Limestone), of the same age of the Mátyáshegy Formation (Upper Carnian–Rhaetian) are known in the neighborhood of the outcrops of basinal deposits. Near to the paleomargin of the platform, peculiar fossil assemblages (e.g. ammonites in platform facies) occur.

Proximal toe-of-slope — Polymict and monomict breccia represent the talus of the steep slope, whereas debrites characterize the more gentle outer part of the toe-of-slope fan.

Table 2: Lithofacies types of the Mátyáshegy Formation in the Vh-1 core.

Lithofacies type	***Description***	***Interpreted depositional setting***
Sedimentary breccia (Br)	Monomict or polymict intraformational breccia	lower slope
Redeposited bioclastic (Rb)	Calcisilt–coarse calcarenite, w Crinoids, Tubiphytes, benthic foraminifers + lithoclasts	proximal toe-of-slope
Distal turbidite (Dt)	Graded fine calcarenite, peloidal, bioclastic gr and peloidal p–w alternate	distal toe-of-slope–basin
Peloidal wackestone (Pw)	Calcisilt w, peloids, bioclasts Filaments, ostracodes, echinoiderm fragments, radiolarians, algal cysts, sponge spicules	basin (hemipelagic deposit)
Sponge spicule facies (S)	Calcisilt, calcilutite w Radiolarians, algal cysts, ostracodes, filaments, phytoclasts	basin
Radiolarian facies (R)	Calcisilt, calcilutite w, p Radiolarians (molds — very abundant), sponge spicules, filaments, ostracodes	basin
Algal cyst facies (Ac)	Calcisilt, calcilutite w, p Cysts of *Tasmanites*-type algae (very abundant), ostracodes, phytoclasts	basin
Homogenous mudtstone–wackestone (Ho)	Calcilutite m, w Phytoclasts, filaments, ostracodes, algal cysts	basin
Laminitic (La)	Alternation of microsparite and fine phytoclastic, organic rich laminae Algal cysts, ostracodes, echinoderm fragments (rare)	oxygen-depleted basin
Silty marl (Sm)	Argillaceous mudstone with significant amount of siliciclastic silt, laminitic Globular molds, sponge spicules, ostracodes	oxygen-depleted basin with terrigenous input

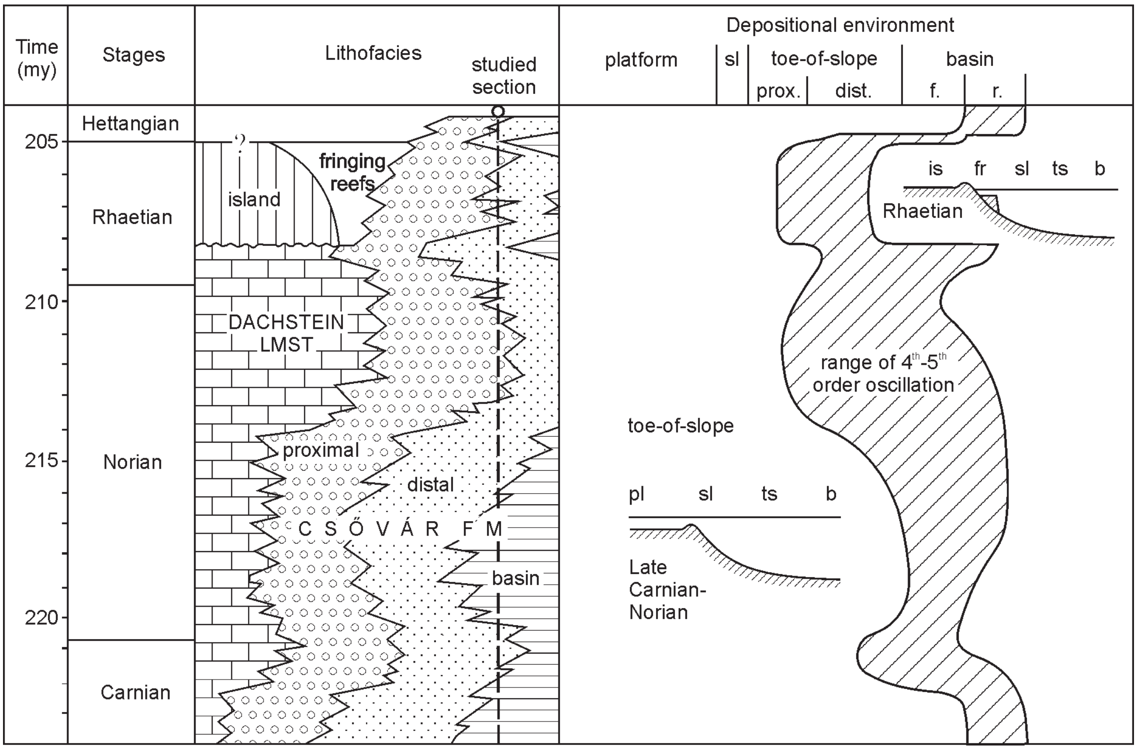

Fig. 9. Late Triassic facies models and facies changes in the Csővár Basin. *Abbreviations:* is — island, pl — platform, sl — slope, ts — toe-of-slope, fr — fringing reef, b — basin, f — filament facies, r — radiolarian facies.

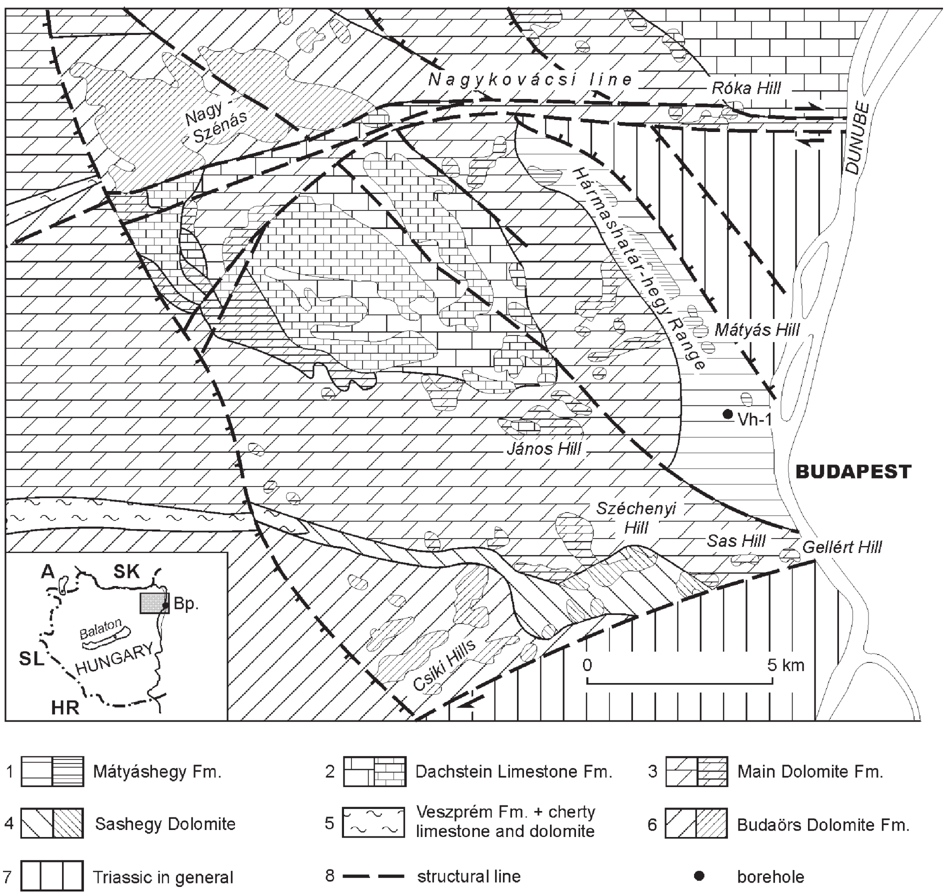

Fig. 10. Triassic formations of the Buda Mts, showing extension of the Upper Triassic platform and basin facies (after Haas et al. 2000).

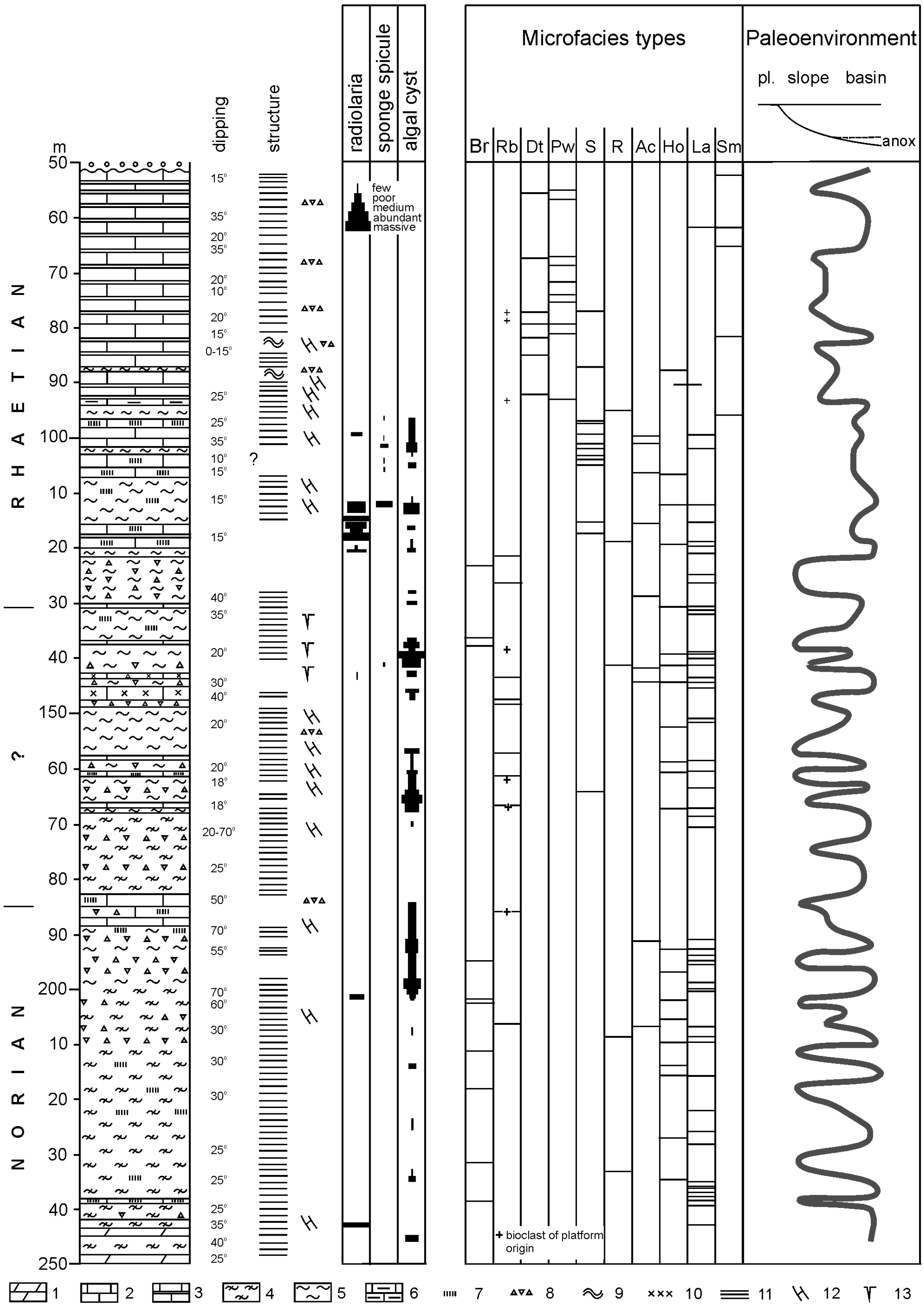

Fig. 11. Lithology, microfacies types and facies interpretation of Vh-1 core. For explanation of abbreviations see Table 2.

Synsedimentary microfaults and slump structures are also common.

Distal toe-of-slope — Deposition of fine-grained lithoclastic and bioclastic wackestone characterize this facies zone. Among the bioclasts fragments of crinoids, molluscs and detritus of microbial encrustations are predominant, along with foraminifers and ostracods of platform origin (Haas et al. 2000). Graded peloidal fine bioclastic turbidites also occur, but rarely.

Oxygenated basin facies — Peloidal wackestone, sponge spicule wackestone-packstone, algal cyst-bearing and radiolarian wackestone-packstone and homogenous, bioturbated mudstone-wackestone deposits were formed in the more oxygenated, probably shallower parts of the basin.

Oxygen-depleted basin facies — The very finely laminated, organic-rich carbonate or shale (mudstone-wackestone) was deposited in the stagnant, probably deepest, parts of the basin.

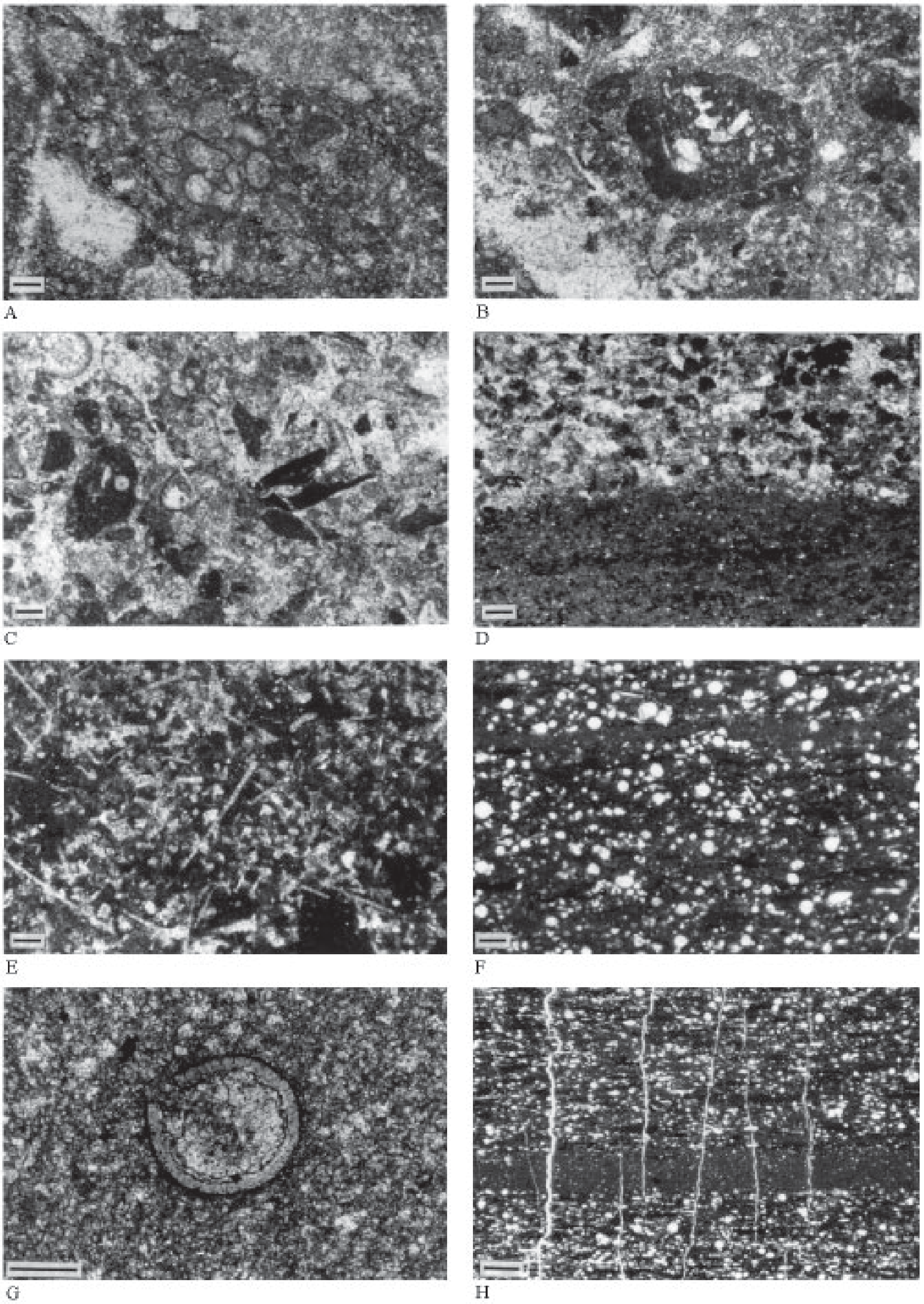

Fig. 12. Characteristic microfacies of the Mátyáshegy Formation in the Vh-1 core. **A** — Redeposited bioclastic facies (Rb) with calcareous sponge fragments. Scale bar: 0.1 mm. **B** — Redeposited bioclastic facies (Rb). Scale bar: 0.2 mm. **C** — Redeposited bioclastic facies (Rb). Scale bar: 0.2 mm. **D** — Distal turbidite (Dt). Scale bar: 0.2 mm. **E** — Sponge spicule facies (S). Scale bar: 0.2 mm. **F** — Radiolarian facies (R) with discontinuous organic rich seams. Scale bar 0.2 mm. **G** — Algal cyst (Ac). Scale bar: 0.1 mm. **H** — Laminitic facies (La). Scale bar: 0.5 mm.

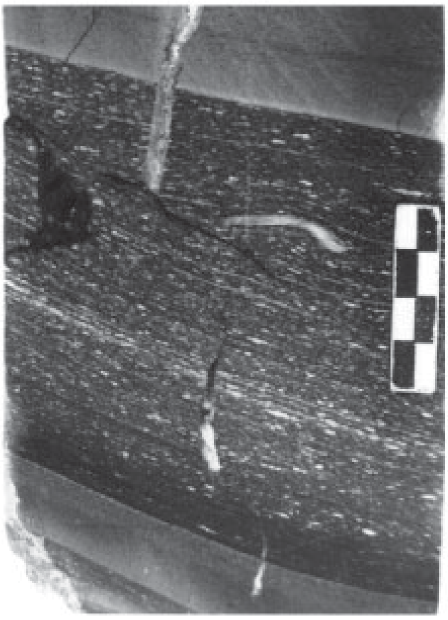

Fig. 13. Organic-rich laminitic calcareous marl (laminitic facies). Core Vh-1, 128.9. Scale bar: 2 cm.

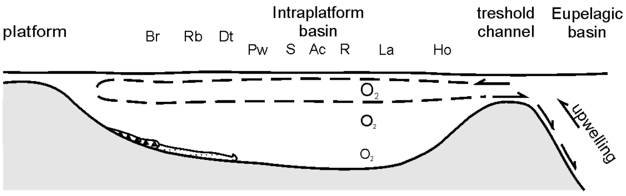

Fig. 14. Sedimentological model for the Hármashatár-hegy Basin. Size of O_2 symbols refers to the oxygen content of the water. For explanation of the abbreviations see Table 2.

The early evolution of the Hármashatár-hegy Basin is poorly known. During the Julian (Kozur & Mock 1993) above the former platform (Budaörs Dolomite) a relatively shallow basin came into being where platy dolomite was formed. There are no biostratigraphic data for the Late Carnian–Early Norian interval, but survival of the basin can be assumed. Cherty dolomite and limestone of pelagic basin facies make up the predominant part of the Hármashatár-hegy Range. On the basis of the study of core Vh-1 a more detailed evolutionary history could be presented for the Late Norian–Rhaetian interval (for details see: Haas et al. 2000).

Laminitic dolomite, rich in organic material, locally with microlayers rich in radiolarians or cysts of *Tasmanites*-type algae, is the most characteristic rock type in the Upper Norian part of the succession. It may have been formed in a restricted basin of layered water mass. The high-productivity upper water layer must have been rich in nutrients, whereas decay of organic material led to oxygen depletion in the lower water layer. Establishment of nutrient-rich surface water conditions can be explained by upwelling. The nutrient-rich water may have reached the restricted basin via intraplatform channels. At the water/sediment interface, anoxic conditions came into existence providing ideal condition for anaerobic bacteria activity. The microbial sulphate reduction, removing the inhibitor sulphate from the system, allowed the dolomite to precipitate (microbial dolomite model — Vasconcelos & McKenzie 1998). Synsedimentary microfaults, fractures, slump structures and sedimentary breccia are common in the lower and middle parts of the core section. They indicate sliding of the more or less consolidated sediments on a gentle slope.

The upper part of the core section is practically free of dolomite. It may reflect more humid climatic conditions, that is less effective water layering in the basin. Increasing kaolinite content and interlayers rich in silt-sized siliciclastics also suggest increasing humidity. The predominance of the laminitic microfacies does not change, but graded distal turbidite layers appear and basin facies with sponge spicules, radiolarians and *Tasmanites*-type algal cysts are also common.

The Fekete-hegy Basin

In a small area in the Pilis Mts, in the northeastern part of the TR, a dark grey, thin-bedded dolomite and limestone sequence crops out (Fig. 2). It probably overlies the Fődolomit (Hauptdolomit)–Dachstein Limestone transitional unit, although their boundary is not exposed, and it is conformably overlain by the Dachstein Limestone (Fig. 3).

Stache (1866) first reported the occurrence of dark, thin-bedded limestone, rich in bivalves. Schafarzik (1884) described it as a fossil-rich segment of the Dachstein Limestone. Lóczy sen. (1913) considered it to belong to the "Kössen Beds". Oravecz (1961) proposed the name "Feketehegy Beds" (which was later modified to Feketehegy Formation) and clarified the stratigraphic setting of the formation.

The lower part of the 400 to 500 m-thick formation is made up of dark grey, thin-bedded dolomite. Upsection it grades to brownish grey or dark grey, thin-bedded limestone (peloidal mudstone and skeletal wackestone). Intercalations of thicker, graded lithoclastic–bioclastic and ooidic–oncoidal calcarenite beds and cross-bedded mollusc coquinas are common. In the mudstone–wackestone layers, along with ostracods and sponge spicules, a monospecific conodont fauna *Metapolygnatus slovakensis* (Kozur) indicating the boundary of the Middle and Upper Norian was found (Budai & Kovács 1986; Kovács & Nagy 1989). The coquina beds are characterized by the massive occurrence of bivalves (*Avicula, Halobia, Myoconcha, Gervilleia, Myophoria*, etc. — Fig. 15) and gastropods (*Euomphalus, Worthemia, Noritopsis, Coelostylina*, etc.). Ammonoids (*Rhabdoceras suessi* Mojs., *Arcestes, Paraplacites, Megaphyllites*) also occur (Oravecz 1961, 1987). The occurrence of *Rhabdoceras suessi* Mojs. proves the Sevatian age of the upper part of the formation.

The Feketehegy Formation was deposited in a small, restricted intraplatform basin (Fekete-hegy Basin) which probably began forming in the Middle Norian. Restricted conditions of the basin are also evidenced by the monospecific conodont fauna. The sedimentological features of the succession point to a gentle slope (ramp) between the basin and the ambient platform. The ooid and oncoid grains and some of the bioclasts are of platform margin–inner ramp origin. The coquinas and the graded calcarenite beds are probably storm layers, which were formed on the mid-ramp, that is above the storm wave-base.

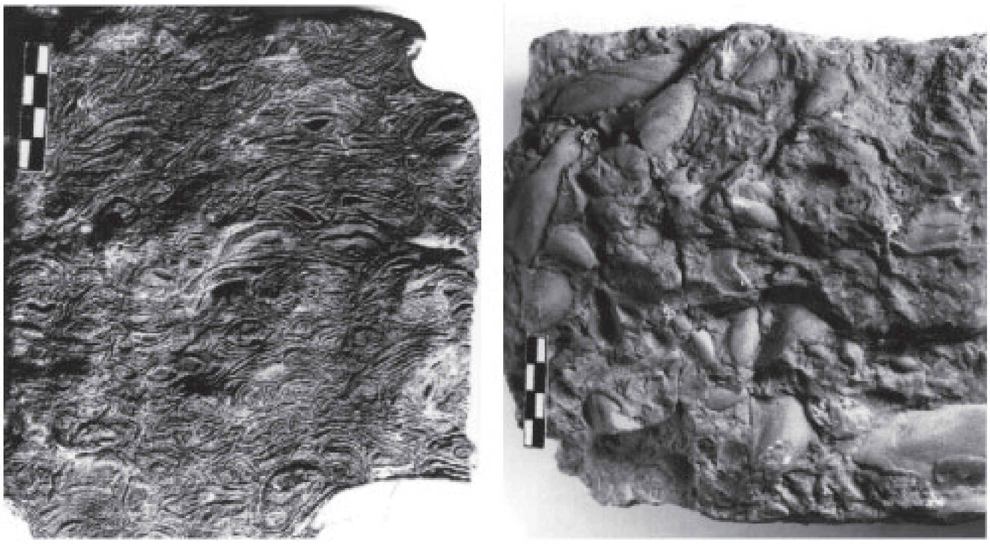

Fig. 15. Bivalve (Avicula) coquina in the Feketehegy Formation. Fekete-hegy key section. Scale bar: 2 cm.

The relatively shallow basin was filled up by the latest Norian giving rise to extension of the platform system (Dachstein Limestone) onto the area of the former basin.

The Kössen Basin

In the southwestern part of the TR Unit (South Bakony, Keszthely Mts, North Zala Basin) platy dolomite (Rezi Dolomite) and dark shale (Kössen Formation) of restricted basin facies represent the Late Norian to Early–Middle Rhaetian interval.

In the southwestern part of the Southern Bakony and also in the Keszthely Mts, already in 1913 Lóczy sen. distinguished the platy dolomite from the bedded Fődolomit (= Hauptdolomit). Noszky (1958) referred to it as "Kössen Dolomite" because it contained a "Kössen-type" fossil assemblage. Bohn (1979) defined it as Rezi Dolomite Formation.

The 150 to 300 m-thick Rezi Dolomite conformably overlays the Fődolomit. It is made up of platy, laminated dolomite with lithoclastic–bioclastic interlayers and slump structures. Mollusc coquinas are common mainly in the upper part of the formation. In the Keszthely Mts a thick-bedded dasycladacean dolomite intercalation (150–170 m in thickness) occurs in the middle part of the formation, which can be interpreted as a tongue of the Fődolomit.

In the lower part of the succession conodonts indicating the boundary between the Middle and Upper Norian were found (Budai & Kovács 1986).

The Kössen Formation overlays the Rezi Dolomite and extends over it northeastward, interfingering with the Dachstein Limestone.

The term "Kössen Beds" was introduced by Oppel (1854) in the Northern Calcareous Alps. Böckh (1872) applied the term in the TR. Later on, the term of Kössen Beds was used with many different meanings, both in the TR and the Northern Calcareous Alps. At present it is applied to dark, shaly–calcareous sequences deposited in restricted, oxygen-depleted basins (Kuss 1983; Haas 1993). In the Southern Alps (Lombardy) the Riva di Solto Shale and the cyclic Zu Limestone shows close facies relationships with the Kössen Formation (Stefani & Goldfiery 1989).

In the Zala Basin, in the southwestern part of the TR Unit, the approximately 500 m-thick Kössen Formation is made up predominantly of shale. It is overlain by Upper Rhaetian-Hettangian platform limestone.

In the Keszthely Mts the thickness of the formation may have reached 300 m, but its topmost part has been eroded. This succession is exposed in the core Rezi-1 (Fig. 16). Above a thin transitional interval (consisting of dolomite, limestone and shale), the Kössen Formation begins with alternating lithoclastic–bioclastic slope deposits and laminitic restricted basin facies. On the basis of sporomorphs, the Norian/Rhaetian boundary could be recognized in this interval (Góczán 1987). Upsection it is overlain by monotonous shale of inner basin facies.

Northeast of this area, in the westernmost part of the South Bakony, the Kössen Formation is made up of cyclic alternation of carbonate and shale intervals (Fig. 17). According to the facies studies, the carbonate beds were formed in shallow subtidal, the shale layers in deeper subtidal environments (Haas 1993). Further northeastward, the shale layers pinch out within the Dachstein Limestone (Fig. 18).

A general depositional model for the Kössen Basin in the TR Unit is shown in Fig. 19. The main stages and controlling factors of the basin evolution can be summarized as follows.

The Kössen Basin, that is the site of deposition of the Rezi and Kössen Formations, began forming at the end of the Middle Norian as a result of extensional tectonics that led to disintegration of the previously existing large carbonate platform. In the early stage of the evolution of the basin, platy dolomites (Rezi Dolomite) were formed. Intercalation of platform dolomite into the platy basin succession indicates progradation of the platform facies during highstanding sea-level, which was followed by a new transgression. An intense, climate-induced terrigenous influx led to shale deposition in the latest Norian. As a consequence, in the inner part of the 100 to 150 m-deep

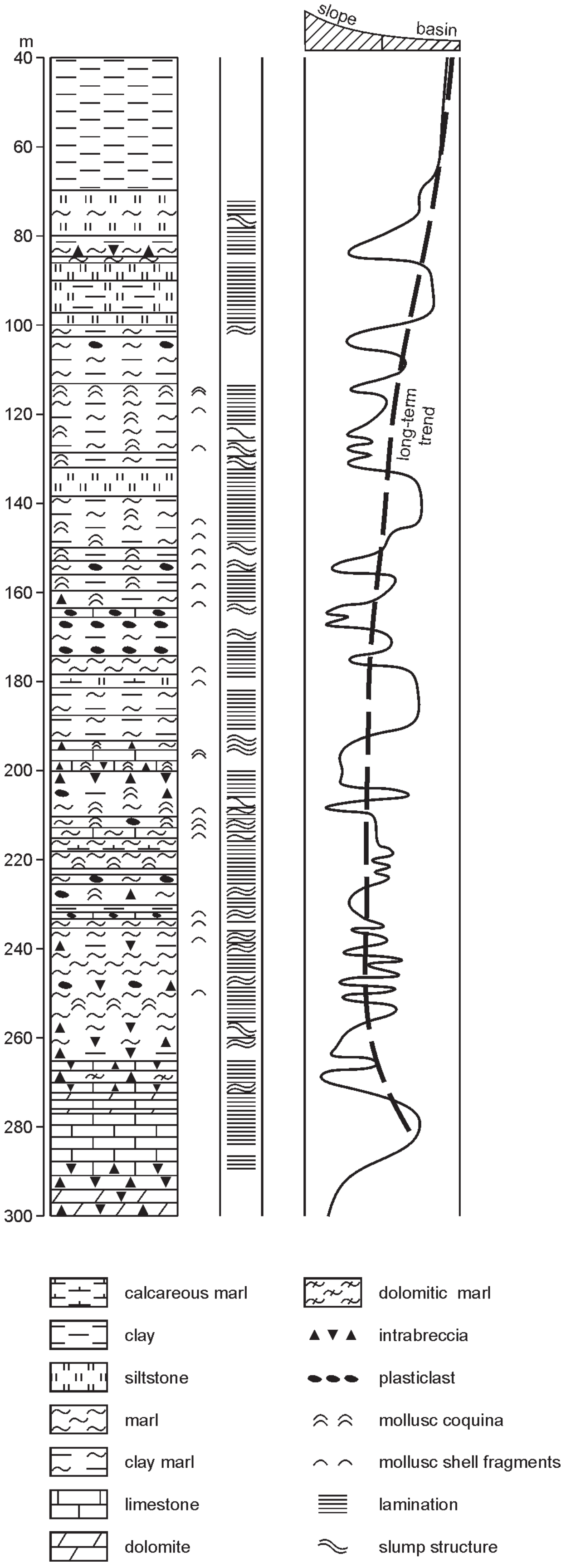

Fig. 16. Lithology, sedimentary structures and facies interpretation of core Rezi-1.

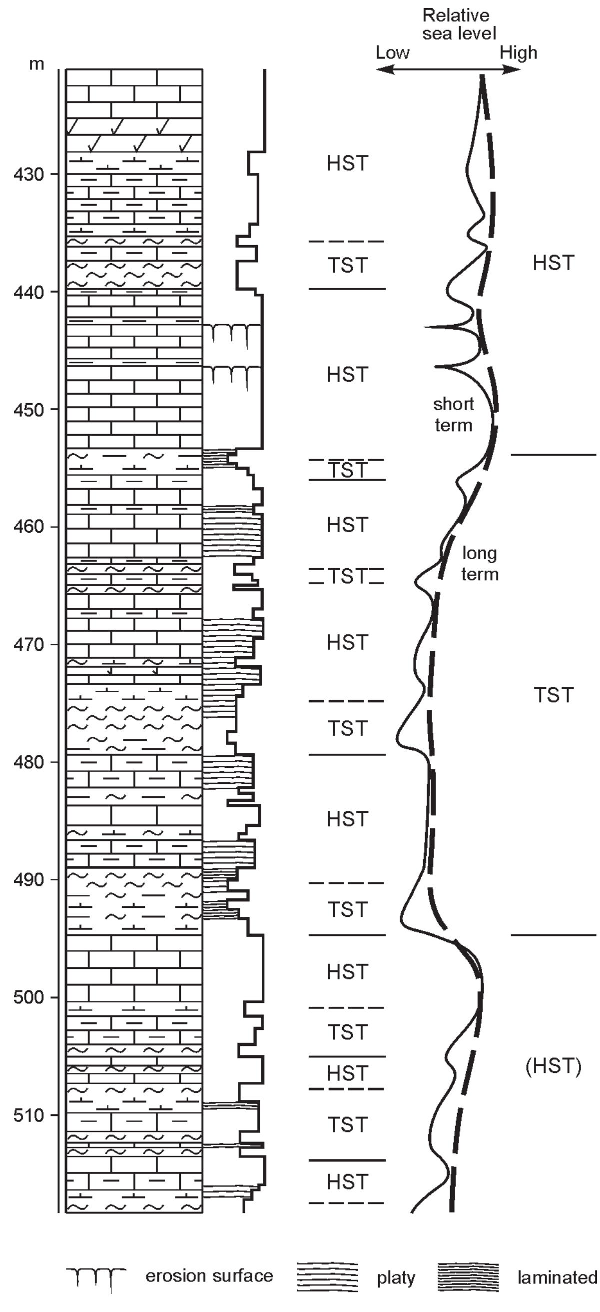

Fig. 17. Lithology and interpretation of relative sea level changes in the core Sümeg Süt-17. For legend see Fig. 16. *Abbreviations:* HTS — highstand systems tract, TST — transgressive systems tract.

basin, argillaceous marl, marl, and siltstone, rich in organic material, were deposited under stagnant, oxygen-depleted conditions. The gentle slope (distally steepened ramp — Read 1982) between the basin and the ambient platform was populated by a rich epibenthic bivalve fauna, whereas the upper slope (shallow ramp) was inhabited by shallow subtidal biota. Redeposited remnants of the aforementioned organisms were accumulated at the toe of the slope together with fragments of lithified or semilithified sediment (Fig. 20). The lithoclasts and plasticlasts originated from the shallower parts of the ramp.

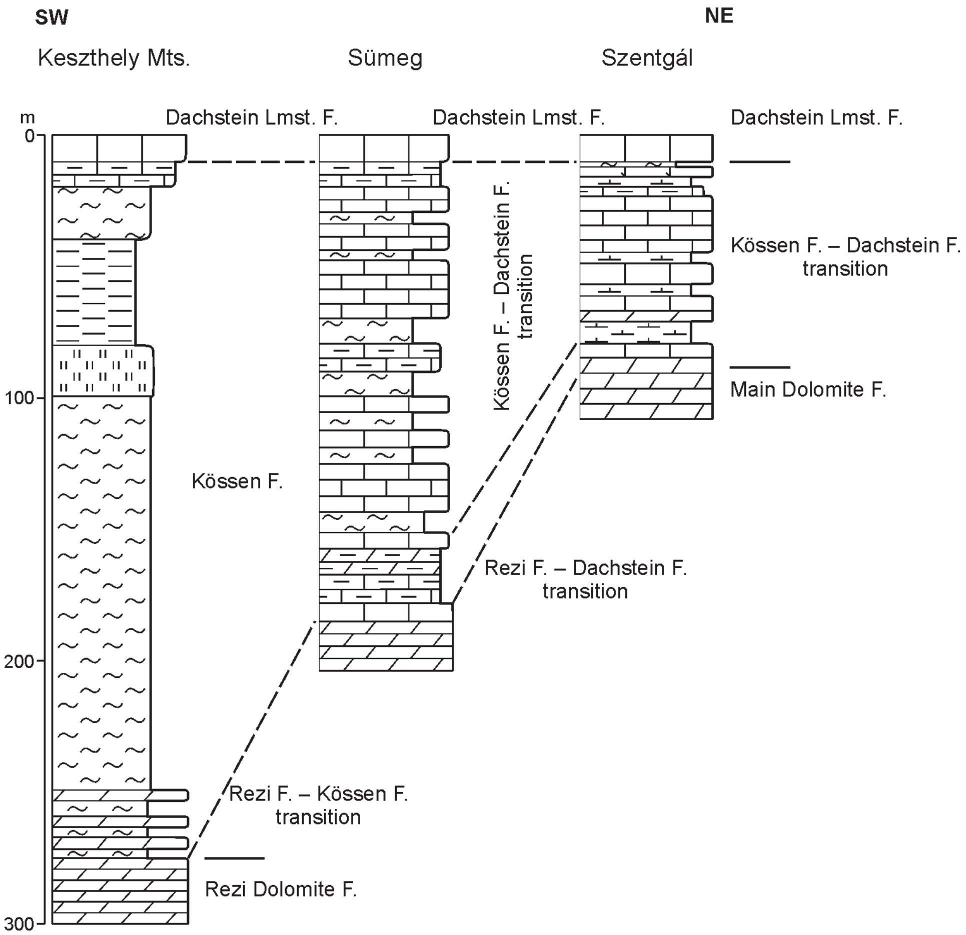

Fig. 18. Relationship of the coeval Kössen and Dachstein Formations in the SW part of the Transdanubian Range, along a SW–NE section.

Sedimentological analysis of the sections revealed that sea-level changes significantly controlled the features of the succession (Haas 1993; Haas & Budai 1995, 1999). In the area of the Keszthely Mts, the toe-of-slope facies in the lower part of the Kössen Formation is overlain by a laminitic deeper basin facies reflecting sea-level rise in the early Rhaetian. At the climax of the transgression, the clayey basin facies extended over the upper slope and even some parts of the platform. This was followed by regression in the highstand interval when the Dachstein Platform re-occupied a large part of the former basin. This third order cycle is superimposed by higher order (probably 4^{th} and 5^{th} order) transgression-regression cycles. It is clearly demonstrated in the cyclic successions of the wide gentle slope (ramp) between the Dachstein Platform and the Kössen Basin.

Facies relationships and summary of Late Triassic basin evolution

In the TR Unit, segmentation of the practically undifferentiated ramp began in the Middle Anisian. It was attributed to the Neo-Tethys rifting (Budai & Vörös 1992, 1993; Haas & Budai 1995). It is worth mentioning that this rifting affected the central part of the TR (Balaton Highland) whereas in the northeastern part of the TR a large carbonate platform came into existence in the Ladinian.

Segmentation of the Budaörs Platform was initiated in the Early Carnian (Julian). The Zsámbék Basin (basement of a Tertiary basin W of the Buda Mts and the southwestern part of the Buda Mts–Sas-hegy Range) and the Hármashatár-hegy Basin (northeastern part of the Buda Mts–Hármashatár-hegy Range) began forming at this time and most probably the evolution of the Csővár Basin also began at the same time.

The Zsámbék Basin was affected by intense influx of fine siliciclastics (“Reingraben Event” — Lein 1987) leading to the complete filling of the basin by the latest Carnian (Late Tuvalian) and establishment of carbonate platform conditions (deposition of the Fődolomit Formation) in the area of the former basin (Haas 1994; Góczán & Oravecz-Scheffer 1996).

In contrast, the Hármashatár-hegy Basin and the Csővár Basin received only poor terrigenous siliciclastic influx and fault-controlled steep slopes did not favour platform progradation. Therefore these intraplatform basins persisted for a long time.

A tectonically tranquil interval occurred during the latest Carnian to middle Norian, giving rise to the complete building up of the Dachstein platform-system. In the Csővár Basin, slow and small-scale progradation of the platform took place coevally (Haas 1997).

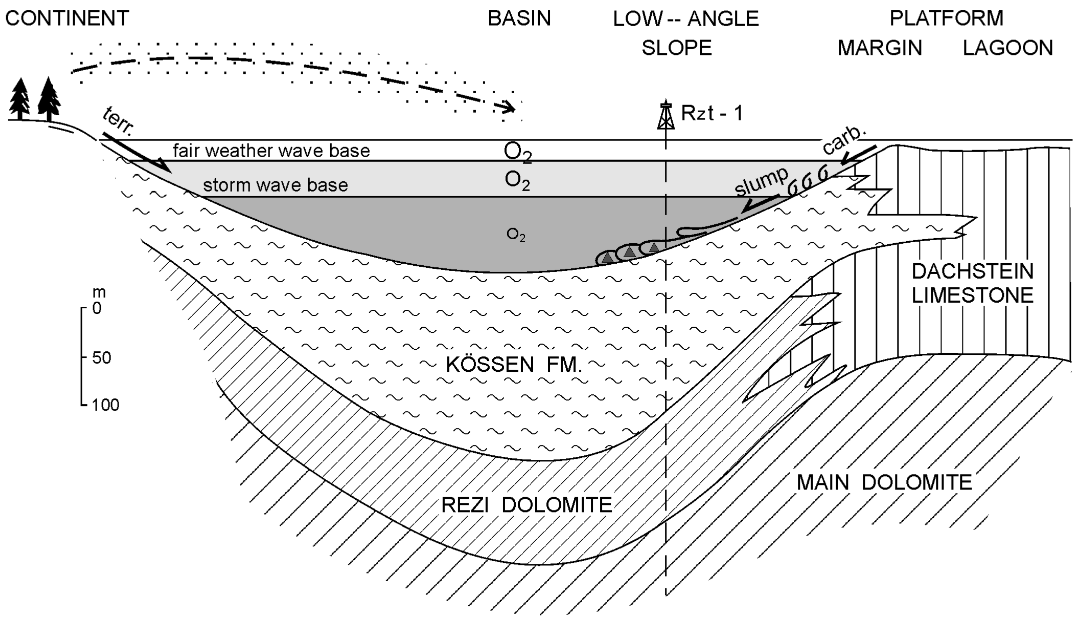

Fig. 19. Sedimentological model for the Early Rhaetian Kössen Basin. Size of O_2 symbols refers to the oxygen content of the water.

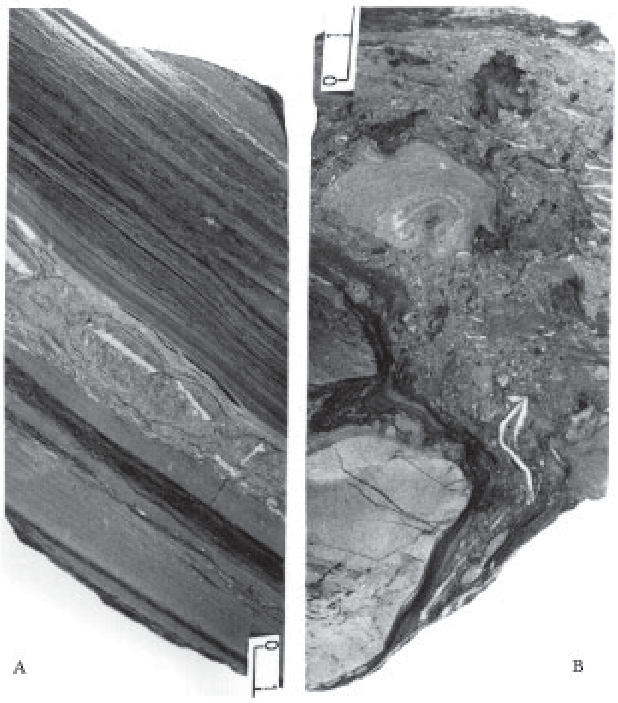

Fig. 20. Characteristic lithofacies of the Kössen Formation. A — Organic rich laminite (calcareous marl) with a bioclastic slump interlayer. Core Rezi-4, 105 m. B — Lithoclasts and plastoclasts in a slump bed. Core Rezi-4, 50 m. Scale bar: 1 cm.

At the end of the mid-Norian, extensional tectonics led to formation of new basins in the area belonging to the SW part of the present-day TR Unit. Consequently, the continent-encroaching Dachstein Platform was transformed into an isolated platform. This process, that is the initial stage of evolution of the large Kössen Basin system, was roughly coeval with onset of the development of the small Fekete-hegy Basin (northeastern part of the TR). In the Hármashatár-hegy Basin, lithoclastic intercalations in the Mátyáshegy Formation may indicate tectonic rejuvenation of the basin-bounding fault system. The back-stepping trend of the toe-of-slope facies zones in the Csővár Basin can be explained by down-faulting of the platform margin, roughly at the same time.

In the latest part of the Late Norian a significant change occurred in the sediment deposition of the Kössen Basin. Pure carbonate (dolomite) deposition was replaced by deposition of argillaceous sediments, probably reflecting a marked climatic change. More arid conditions were replaced by more humid ones, leading to an enhanced terrigenous siliciclastic influx (Haas 1994). In the Hármashatár-hegy Basin, the dolomite and dolomitic marl are substituted by limestone and silty marl, roughly in the same period (Haas et al. 2000).

The evolution of the Kössen Basin came to an end by rapid progradation of the Dachstein Platform in the late Rhaetian. In the area belonging to the southwestern part of the present-day TR Unit, development of the carbonate platform system continued until the end of the Hettangian, whereas in the northeastern part of the TR Unit, disintegration, unequal subsidence and drowning of the Dachstein Platform began at the end of the Triassic.

The relationship of the Late Triassic facies and evolutionary history of the depositional area of the TR Unit can be explained by double rifting as a consequence of coeval westward progression of the Neo-Tethys and eastward opening of the Ligurian-Penninic ocean basins. Formation of the new extensional basins in the northeastern part of the TR, that is near to the margin of the Neo-Tethys shelf, can be attributed to Neo-Tethys rifting. Segmentation of the wide continent margin was interrupted in the latest Carnian. A new extensional period began at the end of the Middle Norian, affecting mainly the area represented by the southwestern part of the TR Unit, which was originally located close to the later Ligurian ocean basin. Therefore this process can be attributed to Ligurian-Penninic rifting. Disintegration and drowning of the platforms resumed at the very end of the Rhaetian in the northeastern part of the TR, probably reflecting the rejuvenation of Neo-Tethys rifting in this time. This was followed by the disruption of the large platform in the southwestern part of the TR from the Early Sinemurian on, which can be linked to Ligurian-Penninic rifting.

Facies and paleogeographical relationships outside the TR Unit

Remnants of the huge Dachstein platform-system are well known in the Central Western Carpathians (Michalík 1980, 1993; Haas et al. 1995b), Upper Austroalpine (Zankl 1967, 1971; Tollmann 1976; Fruth & Scherreiks 1982; Haas et al. 1995a) and South Alpine units (Bosellini & Hardie 1988; Ogorelec 1999) and also in the Dinarides (Dimitrijevic & Dimitrijevic 1991), that is in various segments of the Neo-Tethys passive margins.

The relationships of the segment of the Kössen Basin in the TR with that of the classic Kössen facies area in the Upper Austroalpine realm appears to be plausible. Similarities with the Riva di Solto Basin in the Southern Alps have also been documented (Haas 1993; Haas et al. 1995; Haas & Budai 1995). In the Hauptdolomit facies zone of the Northern Calcareous Alps (Bajuvaricum and parts of the Tirolicum), the Kössen Formation conformably overlies the Upper Norian Plattenkalk (thin-bedded dolomite and limestone) which is similar to the Rezi Dolomite. Akin to the situation in the TR, by the Late Rhaetian, large parts of the basin were filled up with shale and limestone, and the carbonate platforms were re-established ("Oberrhät" Limestone). In the Dachstein Limestone facies zone the Kössen Formation pinches out. It occurs only in the most external part of the Tirolicum as a thin intercalation within the Dachstein Limestone (Golebiowsky 1990).

In Lombardy, the tectonic segmentation of the Dolomia Principale Platform led to the formation of smaller intraplatform basins, site of deposition of the Aralata Group, consisting of organic-rich carbonates (Jadoul 1985; Jadoul et al. 1992). This was followed by deposition of the Riva di Solto Shale, of a much greater lateral extension. The facies change has been attributed to a significant climatic change and sea-level rise (Burchell et al. 1990). The Riva di Solto Shale is overlain by the Zu Formation, consisting of shale-limestone cycles with a shallowing upward facies trend. In the Late Rhaetian the platform carbonates re-occupied the former basin (Conchodon Dolomite).

The relationships of the Hármashatár-hegy and the Csővár Basins beyond the TR are much less known. The Csővár Formation shows very close similarity to the Pötschen Limestone (Schlager 1967), a characteristic Norian formation of the Hallstatt facies unit of the Northern Calcareous Alps and the Inner Western Carpathians. As far as the Rhaetian is concerned, the predominantly carbonate lithology of the Csővár Formation significantly differs from that of the contemporaneous Zlambach Marl of the Hallstatt facies unit. In contrast, the Rhaetian segment of the Mátyáshegy Formation is akin to the Zlambach Formation in terms of its biofacies and lithofacies characteristics. It is worth mentioning that toe-of-slope facies containing detritus of the Dachstein Reef Limestone was also reported from the Zlambach Marl in the Northern Calcareous Alps (Janoschek & Matura 1980).

Detailed sedimentological investigations of the Pötschen Limestone section in the Gosau Valley were carried out by Reijmer (1991). His studies revealed that the succession was made up of calciturbidites containing mainly pelagic material, that is planktonic or pseudo-planktonic bioclasts in fine carbonate mud. The lithofacies and biofacies in the Csv-1 core show features very similar to those described by Reijmer (1991) but due to the lack of continuous core detailed studies of the facies changes and cyclicity could not be carried out. Calciturbidites in the Rhaetian part of the Csővár Formation show practically the same characteristics as were observed by Reijmer (1991) in the Pötschen Limestone, with the exception of debrite interbeds that were not reported in the studied section of the Pötschen Limestone.

The Pötschen Limestone is also known in the Silica and Torna Nappe (it is slightly metamorphosed in the latter unit) in North Hungary (Aggtelek–Rudabánya Mts), as well as in Slovakia. In the Silica Nappe it consists of grey, thin-bedded cherty limestone with *Halobia* coquina interbeds. In the lower part of the formation intraconglomeratic and allodapic crinoidal intercalations are common (Balogh & Kovács 1981). The most frequent radiolarian and radiolarian-filament microfacies represent basin facies, whereas crinoidal coquinas and intraconglomerates indicate toe-of-slope depositional environments. The formation has been dated to the Tuvalian to Early–Middle Norian mainly on the basis of conodonts (Kovács 1986). In the Silica Nappe the Upper Norian–Rhaetian is represented by the Zlambach Marl consisting of brownish-grey marl with grey limestone interlayers. Due to its significantly higher terrigenous content this part of the sequence differs considerably from the Rhaetian part of the Csővár Formation, but is akin to the Rhaetian of the Mátyáshegy Formation. The Zlambach Marl is overlain by the Liassic "fleckenmergel" facies in the territory of Slovakia.

In the Carnic Fore-Alps, in the eastern part of the Southern Alps, Upper Triassic facies akin to those in the Buda Mts were reported (Crauli et al. 1988; Cozzi & Podda 1998). Among the carbonate platforms that made up the Norian Dolomia Principale and Rhaetian Dachstein Limestone, small intraplatform basins occur. In the basins Norian cherty dolomite (Dolomia di Forni) and Rhaetian to Liassic limestone were formed. The platforms are bounded by N–S and NE–SW-trending synsedimentary listric faults (Cozzi 2000). At the foot of the faults, megabreccia was accumulated; further on, graded doloarenites and in the inner part of the basins distal turbidites and mudstone facies were reported (Cozzi & Podda 1998).

In the Southern Karavanks (in a section between Mittagskogel and Hahnkogel, Austria), a thick Upper Triassic intraplatform basin succession was investigated by Krystyn et al. (1994) and the authors emphasized the similarity of this series with the time-equivalent formations in the northeastern part of the Transdanubian Range. The intraplatform basin in the Southern Karavank region began to form at the Carnian/Norian boundary interval. The Lower and Middle Norian are represented by 200 m-thick cherty dolomite with slump structures, sedimentary breccia and turbidites. This is followed by a 300 m-thick pelagic platy limestone formation of Late Norian–Rhaetian age. It consists of crinoidal and radiolarian turbidites and bioturbated wackestones, but no coarse clastics occur in the upper part of the succession. Just as in the Csővár Block, a continuous succession of deeper basin facies represents the Rhaetian to Early Jurassic interval.

Conclusions

Due to Neo-Tethys rifting, extensional basins began forming in the central part of the TR during the Middle Triassic. Some of them persisted until the Late Carnian. A new rifting stage was initiated in the Early Carnian, which resulted in the formation of narrow intraplatform basins in the northeastern part of the TR Unit.

In the late Norian, incipient rifting of the Ligurian-Penninic Ocean led to formation of the Kössen Basin in the external belt of the shelf that is in the southwestern part of the TR Unit. Therefore, since that time a double rift system may have been in operation.

Although formation of the basins was tectonically controlled, their sedimentation pattern, facies characteristics, architecture and evolution were influenced by various factors. The most important of these are:

— the paleogeographical setting of the basins, that is their relation to the continental hinterland (source area of the siliciclastics) and the shallow marine (subtidal) carbonate factories.

— climate, which basically controlled the siliciclastic input and also influenced the carbonate production and mode of diagenesis (e.g. dolomitization).

— sea-level changes which controlled the geometry of platform carbonates and also determined the size and restriction of the intraplatform basins. Signals of the 3rd-order relative sea-level changes are generally recognizable in the successions. Higher order cyclicity was recognized in the successions formed on the wide ramp between the Dachstein Platform and the Kössen Basin.

Intraplatform basin successions akin to those in the TR are known also in the Central Western Carpathians, Northern Calcareous Alps and Southern Alps, indicating a similar scenario of basin evolution.

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