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TRIASSIC SEQUENCE STRATIGRAPHY OF THE TRANSDANUBIAN RANGE (HUNGARY)

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Abstract: On the basis of surface exposures and core sections, a comprehensive sequence analysis of the Triassic series was carried out in the Transdanubian Range. For recognition of the sequences as well as their boundaries, the regional subaerial exposure horizons, the maximum flooding intervals, the transgressive-regressive trends, the platform progradations and backsteppings, as well as signals of the higher order accommodation changes were primarily considered. Detailed analyses were accomplished in six selected sub-regions. On the basis of the results of these analyses, a composite sequence chart was compiled. The Triassic history of the Transdanubian Range can be subdivided into four stages. Within the first stage (Induan to Middle Anisian) which can be characterized by a ramp setting, five sequences have been recognized. The second stage (Middle Anisian–Ladinian) is mainly controlled by the Neotethys rifting and can be subdivided into three sequences. Infilling of the previously formed basins took place during the third stage (Carnian), consisting of three sequences. The fourth stage (latest Carnian to Rhaetian) reflects the passive margin evolution of the Neotethys. However, a new rifting (Ligurian–Penninic) began in the Late Norian and also influenced the evolution of the Transdanubian Range. Four sequences were recognized in this final evolutionary stage. About 50 % of the recognized sequence boundaries could be correlated with those reported from the Southern and Northern Alps, from the German Basin, and from Western Canada.

Key words: Transdanubian Range, Triassic, sequence stratigraphy, stratigraphic correlation.

Introduction

In the Triassic, the Transdanubian Range Unit (TR) was located on the broad shelf of the Tethys margin, between the depositional area of the Drauzug and the Northern Calcareous Alps (NCA) and the South Alpine realm (Kovács 1982; Haas et al. 1995). This large unit (230 km long and 30–50 km wide) suffered only moderate younger tectonic deformations. Thus, the original relationships of the Triassic facies zones are well preserved, providing an almost complete cross-section of the Tethys shelf, close to its western termination.

Stratigraphic studies of the Triassic series of the Transdanubian Range have been undertaken since the middle of the last century, reaching a high level at least in some parts of the region. The present-day lithostratigraphic subdivision of the Triassic in the Transdanubian Range has been worked out principally in the last two decades. Regional geological mapping projects (first of all on the Balaton Highland) and the key-section project provided a large amount of data on the stratigraphy, paleontology and sedimentology of the Triassic sequences. Biostratigraphic investigations (Szabó et al. 1980; Végh-Neubrandt 1982; Góczán et al. 1983; Haas et al. 1984; Budai & Kovács 1986; Pálfy 1986; Oravecz-Scheffer 1987; Vörös 1987; Broglio Loriga et al. 1990; Budai & Dosztály 1990; Budai & Vörös 1992, 1993; Budai et al. 1993; Góczán & Oravecz-Scheffer 1993; Vörös 1993; Kovács et al. 1994; Góczán & Oravecz-Scheffer 1996; Vörös et al. 1996; Haas et al. 1997; Vörös 1998) provided a suitable frame for detailed geohistoric and sequence analyses. In addition to the various biostratigraphic methods, magnetostratigraphy (Márton et al. 1997) and cyclostratigraphy (Haas 1988; Balog et al. 1997) were also applied to stratigraphic correlation in the last decade. Although the outcrops provide only limited possibilities for exact investigation of the successions, abundant cores promoted the stratigraphic work.

These data allow a comprehensive sequence stratigraphic analysis of the Triassic of the Transdanubian Range and a comparison with sequence stratigraphy elaborated for other regions. These comparative analyses may contribute to the solution of the open and highly debated problems of Triassic sequence stratigraphy.

Geological and paleogeographical setting

The Transdanubian Range Unit is located between the Rába-Diósjenő and the Balaton Lineaments (Fig. 1). It can be regarded as a crust-fragment which got into its present-day position as a result of a series of tectonic displacements prior to the Early Miocene. The Transdanubian Range Unit is made up of low-grade metamorphic marine Early Paleozoic formations, which are overlain by unmetamorphosed post-Hercynian and Alpine series. Geophysical data suggest the existence of a deeper structural unit which probably belongs to the Middle–Lower Austro-Alpine Unit (Horváth et al. 1987; Tari 1996).

The Alpine series of the Transdanubian Range begins with terrestrial to shallow marine Upper Permian formations. Step by step transgression took place in the Early Triassic, intrashelf rifting in the Middle Triassic, and thick peritidal car-

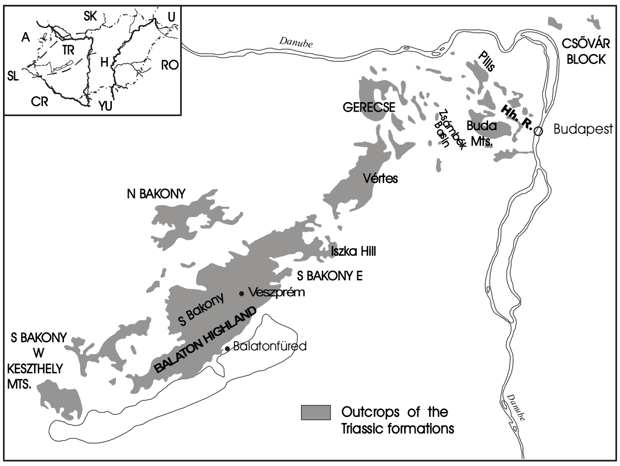


Fig. 1. Simplified map of the Transdanubian Range showing the surface extent of the Triassic formations and the sub-regions analysed from the sequence stratigraphic point of view. *Abbreviation:* Hh.R. — Hármashatárhegy Range.

bonate sequences were formed in the Late Triassic. The intrashelf rifting resumed in the Jurassic, showing a general trend of deepening. A convergent evolution started in the Early Cretaceous. The Middle and the Late Cretaceous and the Paleogene–Early Eocene tectonic events resulted in subaerial erosion and were followed by the evolution of collapse basins and transgressive-regressive cycles.

The characteristic syncline structure of the Transdanubian Range came into existence as a result of the Middle Cretaceous tectogenesis. Lower Triassic rocks crop out only in a narrow belt on the southern flank of the NE–SW trending synclinorium, that is on the classical area of the Balaton Highland, on the southern side of the Veszprém plateau and in the eastern Bakony. They were explored only by drillings in the foreland of the Vértes-Gerecse and the Buda Mountains, as well as in Northern Bakony. Anisian formations are known on the surface only from the Balaton Highland and from the eastern part of the Southern Bakony, but were also encountered in a few wells in the Northern Bakony. However, no data are available for the Anisian formations from the Vértes Mts. to the Csővár blocks. Ladinian basin sediments are limited to the southern part of the Transdanubian Range. To the NE they are substituted by coeval platform carbonates. Carnian intraplatform basin sequences are widespread on the Balaton Highland and, according to borehole data, also in the Northern Bakony. They were also explored by drillings in the southern foreland of the Gerecse (Zsámbék Basin), and a few data are available for the Buda Mountains. Upper Triassic (Carnian to Rhaetian) platform carbonates are widespread in the whole Transdanubian Range, while Upper Norian and Rhaetian basin sediments in greater thickness are limited to the south-western (Keszthely Mountains) and to the north-eastern part of the unit (Buda Mts., Csővár blocks).

Methods

Surface extension of the Triassic formations in the Transdanubian Range is fairly large (Fig. 1), but due to physiographic conditions successions of significant stratigraphic range are rarely exposed in outcrops. Consequently, exposure conditions in the Transdanubian Range can hardly be measured against those in the Alps. Fortunately, a relatively great number of cored wells were drilled in the last decades which substantially complement our knowledge on the features of the Triassic formations by providing very detailed although two-dimensional data sets for the facies successions.

Taking into account the above-mentioned circumstances, the following methods were applied for recognition and analysis of the depositional sequences (3rd order cycles).

On the basis of experiences from regional geological mapping and stratigraphic key-section project, six sub-regions were selected which appeared to be suitable for the sequence analysis. On the basis of outcrops, quarry-sections and cores, a nearly continuous composite succession could be compiled for the whole, or at least a significant part of the Triassic. For the six sub-regions composite lithostratigraphic sections were constructed.

The detailed ammonite biostratigraphy of the Balaton Highland (Fig. 2) was supplemented by parastratigraphic zonations based on various fossil groups, which made chronostratigraphic correlation possible. The regional subdivision was tied to the geochronological chart of Gradstein et al. (1994).

In the Balaton Highland classical sections play a decisive role in the definition of the Anisian/Ladinian boundary. Since a final decision on the exact position of the boundary has not yet been made, we adopted the standpoint of Vörös et al. (1996), and in the present paper we follow this concept. However, in Fig. 2, the boundary according to Gradstein et al. (1994) was also indicated and their concept was applied for the long distance comparison.

Recognition and evaluation of the sequences were based mainly on the following aspects:

1. recognition of the subaerial exposure horizons,
2. recognition of the maximum flooding horizons or intervals,
3. evaluation of the transgressive and regressive trends in the successions and determination of the inflection points (3rd order cyclicity),
4. recognition of platform progradations and backsteppings in the platform to basin transitional zones,
5. evaluation of higher order accommodation trends (high-frequency cyclic pattern).

As to the sequence boundaries, type 1 unconformities were recognized in carbonate platform successions where evidence of subaerial exposure (erosional surfaces, paleokarst, paleosoil, weathering products usually with breccias) was encountered. Type 2 unconformities were found in ramp successions at the maximum regression. They were generally indicated by peritidal facies (sabkha) although without unambiguous marks of the permanent subaerial exposure. Due to the paleogeographical setting of the study area, the lowstand or shelf-margin systems tracts could hardly be recognized. Restriction of the intraplatform basins was interpreted as an indicator of the low relative sea level. In these cases, opening of the basin was regarded as a sign of the rising sea level. The transgressive systems tracts were reflected in upward deepening facies trends and increasing diversity of the fossils

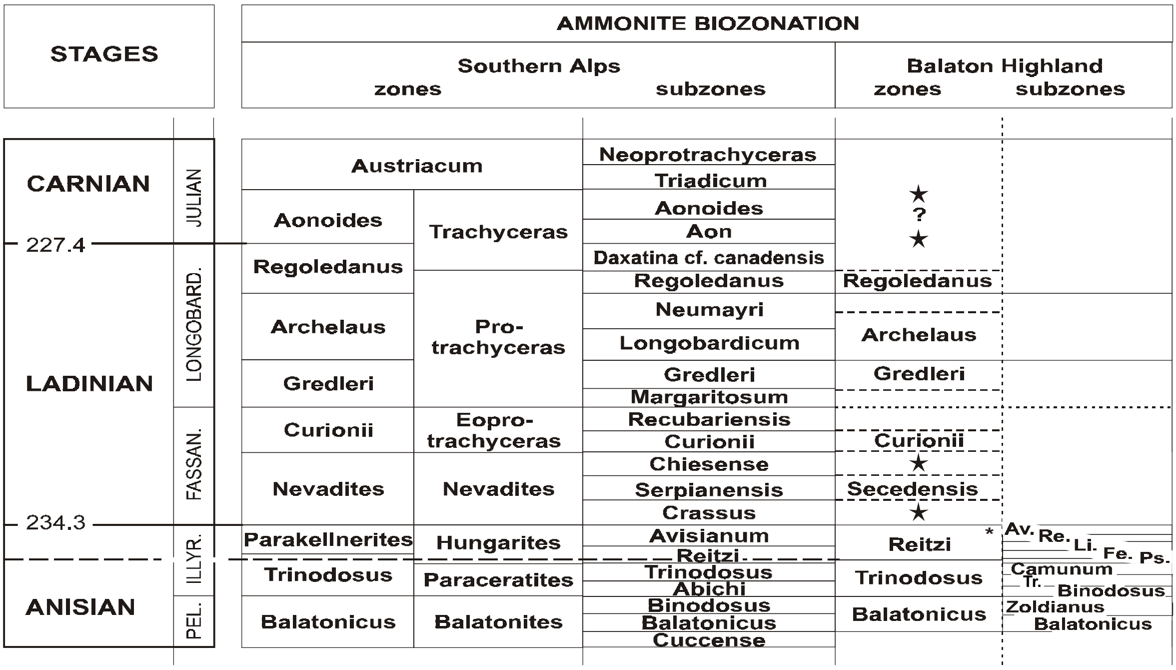


Fig. 2. Correlation of the Middle-Triassic ammonite zonation of the TR (after Vörös 1993, 1998 and Vörös et al. 1996) with the Tethyan biochronozones (after Gradstein et al. 1994). Dashed line shows the Anisian/Ladinian boundary sensu Vörös et al. (1996). *Abbreviations:* Av — Avisianum; Re — Reitzi; Li — Liepoldti; Fe — Felsoeoersensis; Ps — Pseudohungaricum; Tr — Trinodosus; * occurrence of characteristic ammonites.

in the ramp and basin settings as well as back-stepping and drowning of the platforms. The maximum flooding was frequently marked by condensed sediments in the basins. The highstand systems tract was indicated by an upward shallowing trend on the ramps and the shallow intraplatform basins, platform (foreslope) progradation and an increase in the amount of redeposited fine carbonate sediments in the basins.

Basic features of the distinguished 3rd order transgression-regression facies cycles are depicted on the chart beside the lithofacies column (Figs. 3, 4, 5). In addition to the boundaries of the cycles the chart also provides a qualitative information on the magnitude of the regressions and transgressions and the time of the climax of the transgression.

The relationship of the above listed characteristics to relative sea-level changes is indisputable. However, the position of the shoreline and facies of deposited sediments were also strongly influenced by the amount of terrigenous influx, which was controlled mainly by tectonics and climatic conditions. Structural evolution, related volcanic activity and climatic changes influenced the facies succession in many ways, so that these factors must also be considered when interpreting the evolutionary history.

Analysis of the sub-regional successions was followed by their correlation using litho- and biostratigraphic methods. This way a synoptic chart was made, providing the basis for a sequence diagram summarizing the whole Transdanubian Range. This diagram was compiled from those parts of the sub-regional charts which were supported by the most exact data both for the transgression–regression trends and the timing. This chart than served as the basis for the long-distance correlation and comparison with sequence charts from other regions (De Zanche et al. 1993; Gianolla et al. 1998; Gianolla & Jacquin 1998; Embry 1997; Moerk 1994, 1997; Rüffer & Zühlke 1995).

Sequence analysis

The Triassic evolution of the Transdanubian Range can be regarded as a long-term megacycle which was primarily controlled by the Neotethyan rifting. In the pre-rift stage, during the Early and early Middle Triassic, a wide ramp was the site of deposition for mixed siliciclastic–carbonate sediments in the Early Triassic, followed by carbonates. Initiation of rifting in the Middle Anisian led to disintegration of the simple, homoclinal ramp and to formation of isolated platforms and intraplatform basins. This was roughly coeval with the appearance of volcanic material from distal sources, indicating a relationship between the segmentation of the basement and the volcanic activity. In the syn-rift stage from the Middle Anisian to the earliest Carnian condensed carbonate sequences were formed in the basins and thick shallow marine carbonates on the platforms. The climax of deepening in the basins (maximum transgression of the long-term cycle) happened in the Late Ladinian. Cessation of active rifting and a penecontemporaneous increase in terrigenous influx led to filling in of the basins by the latest Carnian, giving rise to the formation of huge carbonate platforms in an interval from the latest Carnian to the earliest Jurassic (Haas 1994). A new rifting stage initiated in the Late Norian and intensified in the Early Jurassic as a result of the opening of the Ligurian-Penninic ocean branch.

Within these structurally controlled main evolutionary stages, sequences (3rd order transgression-regression cycles) could be defined (Figs. 3, 4, 5).

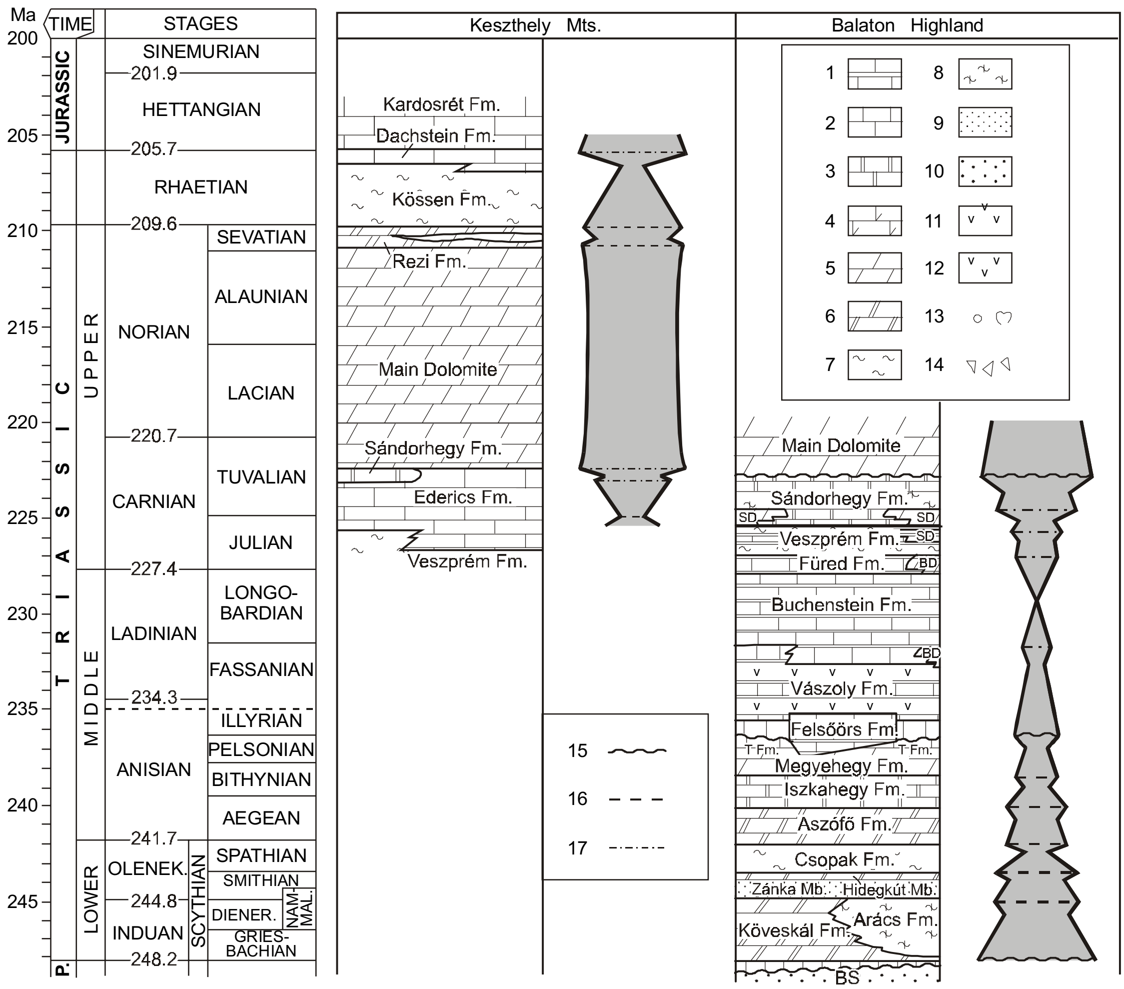


Fig. 3. Lithostratigraphic column of the Balaton Highland and Keszthely Mts. showing 3rd order transgression-regression cycles. *Abbreviations:* BD — Budaörs Dolomite; BS — Balatonfelvidék Sandstone; SD — Sédvölgy Dolomite; TFm — Tagyon Fm. *Legend:* 1. pelagic limestones (basin); 2. shallow marine limestones (platform); 3. shallow marine limestones (ramp, lagoon, restricted basin); 4. limestone-dolomite alternation (platform); 5. shallow marine dolomites (platform); 6. shallow marine dolomites (lagoon, tidal flat); 7. pelagic marls (basin); 8. shallow marine shales and carbonates (ramp, lagoon); 9. shallow marine siliciclastics (ramp); 10. terrestrial siliciclastics; 11. evaporites (sabhka); 12. volcanites; 13. oncoids, reef fossils; 14. lithoclasts. Type of sequence boundaries: 15. subaerial exposure horizon; 16. maximum regression; 17. end of progradation period.

Early Triassic–early Middle Triassic

Sequence I

Sea level rise at the Permian/Triassic boundary led to a significant coastal onlap. The former sabkha and alluvial plain were inundated in a more than 100 km wide belt. A shallow ramp came into existence, where carbonates, fine siliciclastics and argillites were deposited.

In the north-eastern part of the area (Gerecse S — core Alcsútdoboz-2), the Alcsútdoboz Limestone Formation has been defined. Overlying Permian dolomites, it consists mainly of shallow marine limestones although argillaceous intercalations are common.

In the NE part of the Balaton Highland area and in the Northern Bakony (Figs. 3 and 4), the marine Triassic succession is underlain by continental Permian. The lower Induan is represented by the Arács Marl Formation which is made up of an alternation of greenish-grey and brownish-red limestone, calcareous marl, silty marl, dolomitic marl and dolomite layers. In the southern foreland of the Vértes, interfingering of the Alcsútdoboz and Arács Formations was also detected.

In the south-western part of the Balaton Highland (Fig. 3), the share of the dolomites in the lower Induan successions shows an increasing trend. This formation consisting predominantly of silty dolomites was defined as the Köveskál Dolomite. In the westernmost part of the area the formation contains evaporites in a significant thickness.

The roughly equal, 100 to 200 m thickness of the formations indicates a moderate and uniform subsidence of the basement. The facies differentiation reflects mainly the antecedent topography. A remarkable shift of the shoreline unambiguously proves the transgression at the base of the Triassic. Ooidic carbonates in the basal part of the successions might be related to this phenomenon. The low diversity of the fauna in the basal beds is the consequence of the end-of-Permian crisis. Increasing clay and fine siliciclastic content and faunal diversity in the middle part of the formations indicate further progress of the transgression which was probably accompanied by more humid climatic conditions. Desiccation

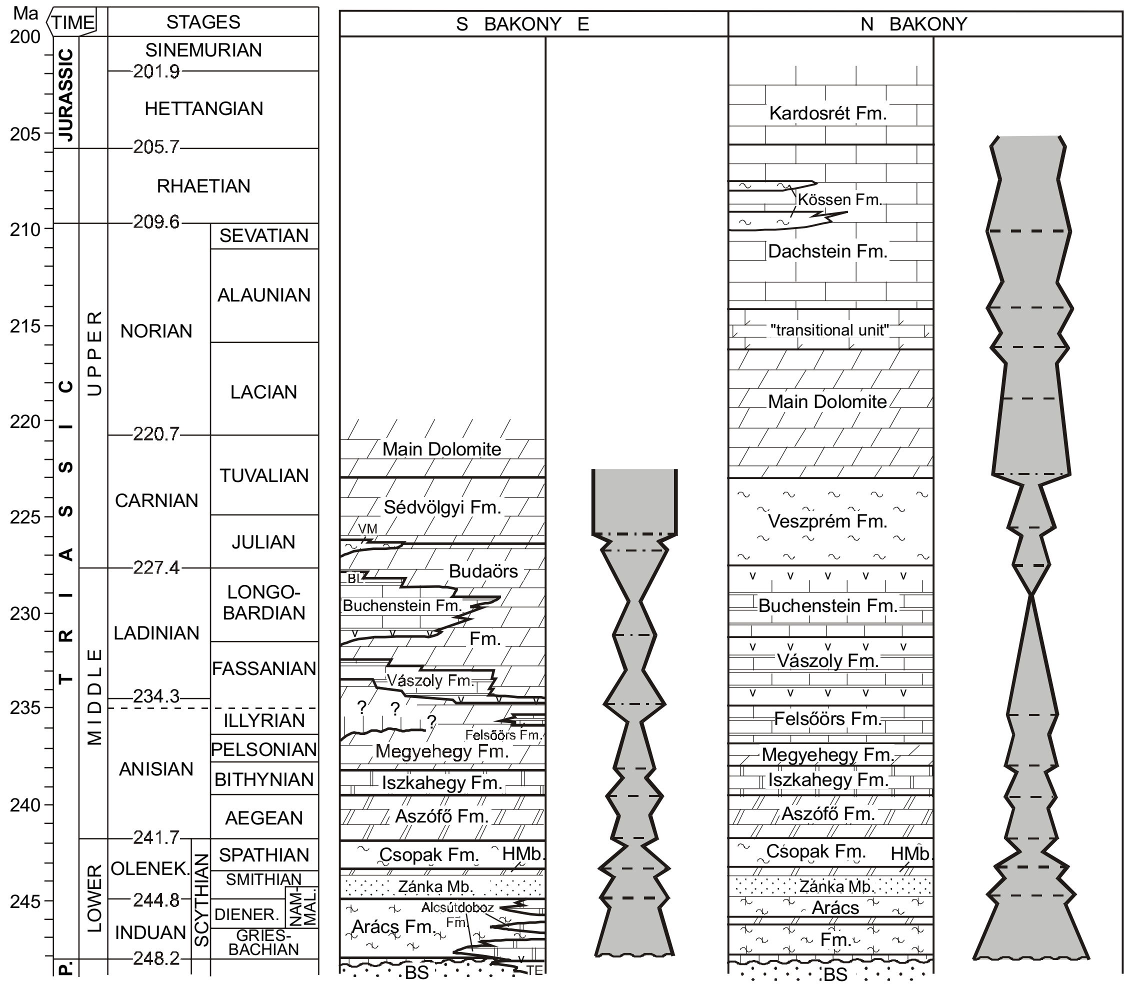


Fig. 4. Lithostratigraphic column of the Northern and Eastern Bakony Mts. showing 3rd order transgression-regression cycles. *Abbreviations:* BL — Berekhegy Limestone; BS — Balatonfelvidék Sandstone Fm.; H Mb. — Hidegkút Mb.; TE — Tabajd Evaporite; VM — Veszprém Marl. For legend see Fig. 3.

phenomena, observed in the topmost part of the Köveskál Dolomite, suggest regression which led to progradation of the tidal flat onto a large part of the former inner ramp. It was probably accompanied by a dryer climate.

Sequence O1

All of the formations of the first Triassic cycle are covered uniformly by shallow marine, predominantly red siltstone and sandstone (Zánka Sandstone Member). Thin limestone, dolomite and gastropod-oolite interlayers may also occur. Among the megafossils the Pectinids prevail. The diversity of molluscs shows an upward increasing trend (Broglio Loriga et al. 1990).

Changes in the lithofacies and increasing diversity of the biota indicate transgression from the beginning of deposition of the Zánka Member, reaching its maximum in the upper part of the unit. The overall appearance of siliciclastic material at the base of the Zánka Sandstone was probably the consequence of a significant climatic change ("Campil event"), that is the beginning of a relatively humid interval.

The siliciclastic member is overlain by silty dolomites (Hidegkút Dolomite Member). In the area of the Balaton Highland and the Northern Bakony it frequently contains anhydrite nodules. Thin siltstone interlayers are also common. Fossils are scarce even in the ooid limestones, only ostracodes were found in a remarkable quantity.

The Hidegkút Dolomite was formed on a restricted ramp. In the largest part of the Transdanubian Range a hypersaline lagoon, which received only a limited amount of terrigenous siliciclastics, might be the site of deposition. In the short-term lowstand intervals the arid tidal flat prograded onto the lagoon deposits leading to extension of the sabkhas. Restriction of the inner ramp was probably caused by offshore ooid shoals which were formed in the north-eastern part of the Transdanubian Range. Appearance of evaporitic dolomites above the oolite layers in this belt, implies a regressive trend in the course of deposition of the Hidegkút Dolomite. Regression was probably accompanied by drying of the climate as reflected in a significant decrease in the terrigenous influx and occurrence of evaporites.

Sequence O2

A new transgression-regression cycle began in the Late Olenekian (Spathian). As a result of deepening and enhanced

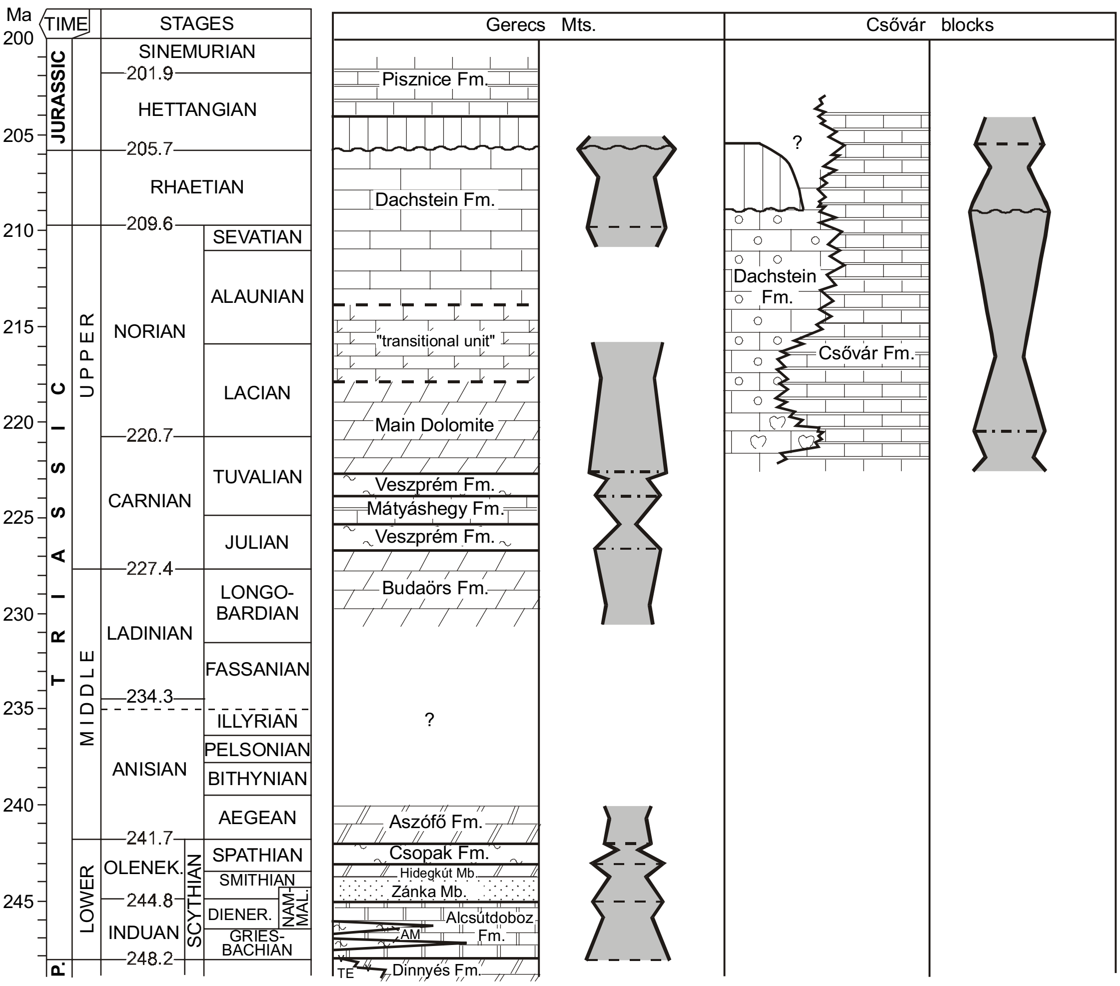


Fig. 5. Lithostratigraphic column of the Gerecse Mts. and Csővár blocks showing 3rd order transgression-regression cycles. *Abbreviations:* AM — Arács Marl Fm.; TE — Tabajd Evaporite Fm. For legend see Fig. 3.

terrigenous influx, a 150–200 m thick marl succession (Csopak Marl Formation) was formed, showing fairly uniform features all over the Transdanubian Range (Figs. 3, 4 and 5).

Above the almost unfossiliferous Hidegkút Dolomite, the normal salinity marine assemblage of the Csopak Marl appears abruptly. The faunal diversity shows an upward increasing trend, and in the upper part of the lower member even ammonites appear (*Tirolites cassianus, T. seminodus, Dalmatites morlaccus*). Pectinid bivalves and gastropods are also common.

The upper part of the formation is made up of grey silty marl with thicker limestone interbeds. In the topmost part of the succession the siliciclastic component becomes coarser (sand-size) and dolomite intercalations with desiccation cracks also appear. The fossil assemblage shows restricted marine features.

The Csopak Marl was formed on a ramp, generally below the fair-weather wave base but above the storm wave base. Changes in the biofacies within the formation may reflect relative sea-level changes. The abrupt appearance of marine fauna at the base of the formation indicates the initiation of the transgression. The maximum flooding is marked by appearance of ammonites in the higher part of the lower member. Massive occurrence of *Costatoria costata* in the middle and upper members suggests regression and restriction of the ramp. Desiccation features in the topmost part of the formation imply periodical subaerial exposure in some parts of the ramp indicating maximum regression.

Middle Triassic

Sequence A1

At the beginning of the Anisian, due to drastic decrease of siliciclastic input, the former mixed ramp turned to a carbonate ramp, and a new transgression began (Figs. 3, 4 and 5). The lowermost Anisian sequence is made up of thin bedded dolomites and marly dolomites in its lower part, passing upward into vuggy dolomites with bird's eye and teepee structures, and desiccation cracks (Aszófő Dolomite Formation).

The Aszófő Dolomite was formed in a shallow lagoon, surrounded by a broad tidal flat belt under arid climatic conditions. The lower part of the succession was formed in the subtidal zone (TST). During the highstand period the sabkha prograded into the lagoon leading to dolomitization and precipitation of evaporites (Budai et al. 1993). "Rauhwacke type" breccias at the topmost level of the Aszófő Dolomite may have formed as a product of dissolution collapse probably under subaerial conditions. They may mark the upper sequence boundary.

Sequence A2

The next transgression commenced in the later part of the Early Anisian and led to the formation of a more or less restricted inner shelf lagoon, site of deposition of the Iszkahegy Limestone Formation (Figs. 3, 4 and 5). The lower part of the Iszkahegy Limestone is made up mainly of bituminous laminites (LST), characterized by a special, monospecific ostracode assemblage (*Renngartenella* sp.) indicating hypersaline bottom water (Monostori pers. comm.). Lack of bioturbation refers to dysaerobic to anaerobic conditions at the bottom. Laminites pass upward into bedded, strongly bioturbated limestones with forams, bivalves and gastropods (*Meandrospira dinarica, Costatoria costata, Natiria* sp.) suggesting a trend towards opening of the restricted lagoon (TST).

Sedimentary breccias in marly matrix, stromatolites, and subordinately evaporite pseudomorphs also occur in the uppermost part of the formation referring to peritidal sedimentary environment which might be established periodically. The shallowing upward trend in the upper part of the formation indicates highstand conditions.

Sequence A3

The overlying Megyehegy Dolomite represents the early part of the Middle Anisian depositional sequence (Figs. 3, 4 and 5). It was formed on a more or less restricted inner ramp.

Subsequently, due to initiation of rifting (blockfaulting) a significant lateral facies differentiation took place, leading to dissection of the former carbonate ramps in the Pelsonian. On the downfaulted blocks, basins came into existence whereas on the uplifted ones, isolated carbonate platforms evolved (Budai & Vörös 1992, 1993). The basin successions (Felsőörs Fm.) are characterized by bituminous laminites in the depocenter of the "Füred basin" with a rich ammonite (Balatonites) and bivalve (Posidonia, Daonella) assemblage. Flaser bedded cherty limestones may represent the maximum flooding interval. The overlying brachiopod-crinoid bearing limestones at Felsőörs (Binodosus Subzone, Márton et al. 1997) mark definite shallowing (HST), which is also supported by the ostracode assemblage (Monostori 1995).

The coeval platform formation (Tagyon Fm.) is made up by a cyclic alternation of subtidal Dasycladacean, oncoidal and laminated, locally vadose pisoidic peritidal limestones or dolomites (Budai et al. 1993; Vörös et al. 1997; Haas & Budai 1995).

In the Balaton Highland area, development of carbonate platforms surely continued up to the Balatonicus Zone (Budai & Haas 1997; Vörös et al. 1997). The truncated surface of the platform series is directly overlain by ammonite bearing pelagic carbonates representing the Trinodosus Zone (Camunum Subzone). Thus, biostratigraphic data constrain a remarkable gap between the Tagyon Formation and the overlying layers. However, the topmost part of the platform succession may have been eroded during subaerial exposure. Surviving platforms are presumed to exist in some parts of the eastern Bakony (Fig. 4), where above platform dolomites, the lowermost layers of the overlying basin succession belong to the higher part of the Reitzi Zone (Vörös 1998).

Sequence L1

In the north-eastern part of the Balaton Highland the Anisian basin successions are continuous (Fig. 3). In the Felsőörs section the brachiopod bearing crinoidal limestones (A3 HST) are followed by dark grey limestones with marl intercalations representing the initial stage of the next transgression period (Trinodosus Sbz.). Greenish tuffs with siliceous limestone lenses characterize the lowermost Ladinian (Vászoly Fm. sensu Vörös et al. 1997). Detailed investigation of the Ostracode assemblage (Monostori 1995) and paleoecological analysis of ammonoids (Vörös 1996) revealed a deepening trend (400 m water depth can be assumed as a minimum) up to the top Reitzi Zone (Avisianum Sbz.). No significant change is visible in the assumed highstand period.

Between the Ladinian basin (Balaton Highland area) and the coeval platform (Várpalota area) a transitional belt, that is a paleo-slope could be recognized in the Veszprém area (Fig. 6), a site of platform progradations and retrogradations. Dolomite intercalation in the basin succession marks the first progradation which can be attributed to the Secedensis–lower-Curionii Zone corresponding to the "Vászoly limestone" on the highs of the "Füred basin". The "Budaörs platform" extended over the area of the easternmost part of the Bakony (Iszka Hill), the Vértes, Gerecse and the Buda Mts. (Fig. 4).

Sequence L2

In the aforementioned transitional belt, in the Veszprém area (Fig. 6) the intercalating dolomites representing the first progradation of the "Budaörs platform", are overlain by a series of alternating tuffaceous marls and grey, nodular limestones. This series corresponds to siliceous marls above the "Vászoly limestone" on the inundated highs of the "Füred basin" (Balaton Highland area). In the deeper basins nodular, often cherty limestones were formed (Buchenstein Fm. — Nemesvámos Mb.) without any significant change in the facies. According to the latest investigations on the Upper Ladinian basin successions, the climax of deepening was probably in the Archelaus Zone.

The second progradation of the "Budaörs platform" commenced in the latest Ladinian in the slope area (Fig. 6). In the environs of Veszprém toe-of-slope facies with graded allodapic limestones containing lithoclasts of platform origin (Berekhegy Mb.) were formed in the Regoledanus Zone. In the inner part of the "Füred basin" the earliest Carnian is represented by typical basin facies of the Füred Limestone showing a shallowing upward trend in its uppermost part (Aon Zone).

In the Northern Bakony the whole Ladinian is characterized by a pelagic deep basin facies (even the Upper Anisian ammonoid assemblage shows "Schreyeralm affinity" — Vörös 1992), without any sign of prograding platforms (Fig. 4).

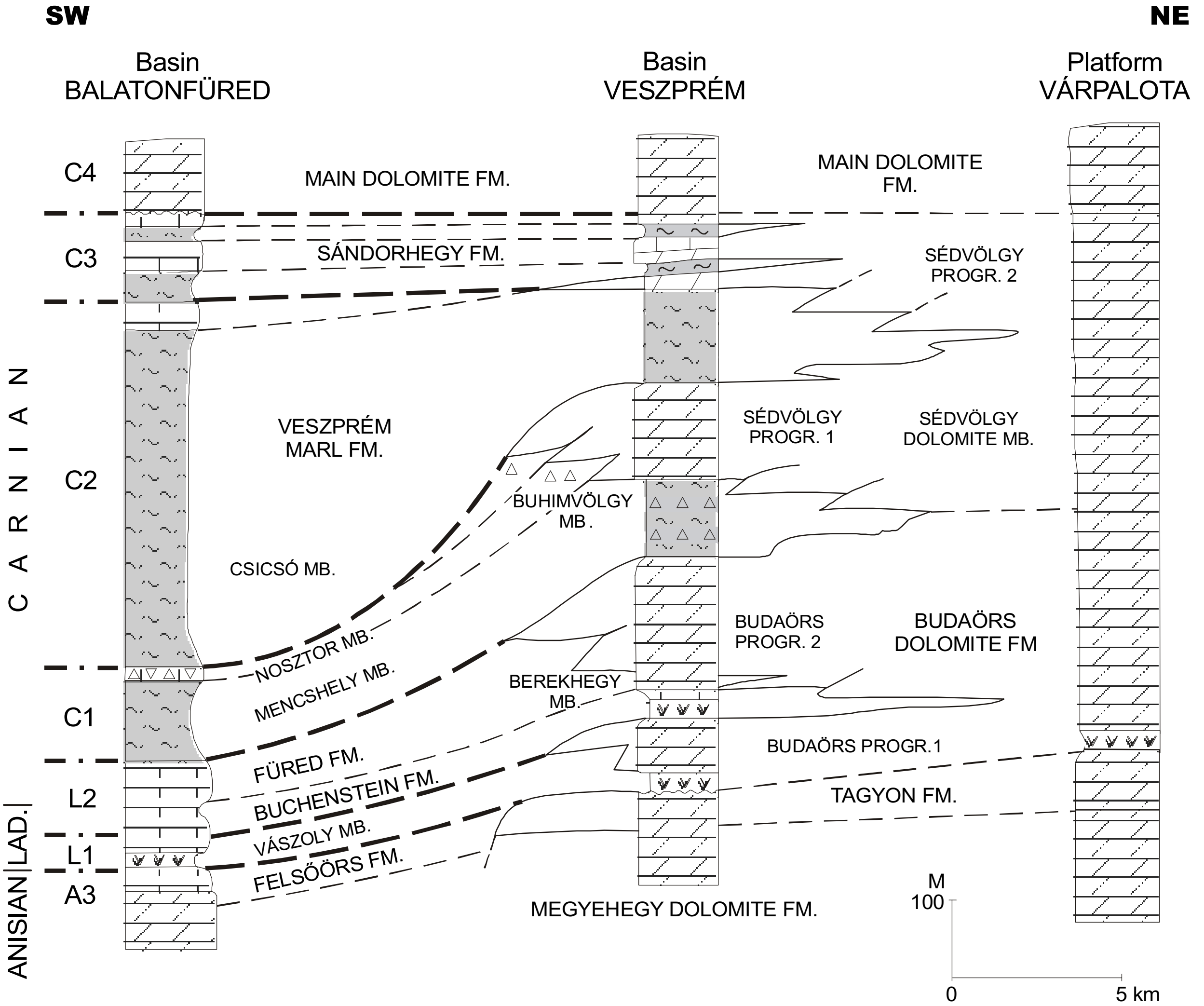


Fig. 6. Sequence stratigraphic interpretation of Middle to Upper Triassic coeval platform and basin facies in the strike of the Southern Bakony. For Legend see Fig 3, A3–C4: sequences.

Early Late Triassic

Sequence C1

In the Early Julian, a significant change took place in the character of the sedimentation in the area of the basins (Figs. 3, 4 and 6). Predominance of pelagic carbonate deposition was replaced by formation of marls (Veszprém Marl Formation). This can be explained by a climatic change from arid to more humid climatic conditions.

Roughly parallel with the climatic change a new transgression was initiated. Sea level rise combining with the effect of enhanced influx of fine terrigenous material resulted in drowning of large parts of the carbonate platforms in the course of the Julian. This cycle was completed by progradation of the platforms in the higher part of the Julian (Austriacum Zone). It means that the first Carnian sequence includes the lower member of the Veszprém Marl (Mencshely Marl) and ends with the middle member (Nosztor Limestone) in the basins and the lower part of the Sédvölgy Dolomite or the Ederics Limestone on the platforms.

In the core Veszprém-1, representing the slope between the platform and the basin, above the lower member of the Veszprém Marl, progradational succession of the toe-of-slope and platform facies of the Sédvölgy Dolomite was clearly visible. The maximum flooding horizon can be marked out between the basinal shales and the lithoclastic slope facies, while the upper sequence boundary can be put onto the top of the progadational successions (Fig. 6).

In the southern foreland of the Gerecse Mts. (Zsámbék Basin), transgression in the Julian led to drowning of the “Budaörs platform” (Fig. 5). In the Late Julian, the carbonate content of the restricted basin succession significantly increased and cherty limestones and dolomites were formed (Mátyáshegy Formation). This trend may reflect flourishing of ambient carbonate platforms and shedding of carbonate mud during the highstand interval.

In the area of the core of the platforms (eastern part of the Southern Bakony, Vértes, Buda Mts.) the transgression is marked only by thin clayey interlayers and cherty limestones and dolomites in the platform carbonates. Cherty dolomites of Julian age (Kozur & Mock 1991) in the Buda Mts. indicate establishment of basin conditions also in this area. Basin evolution in the area of the Csővár block was probably also initiated at this time, although biostratigraphic evidence is available only from the Late Tuvalian (Haas et al. 1997).

Sequence C2

The platform progradation episode is followed by a new transgression and recurrence of intense terrigenous input in the Late Julian. It manifests itself by the deposition of marls in the basins (upper member of the Veszprém Formation — Csicsó Marl Member) and retrogradation of carbonate platforms (higher part of the Sédvölgy Dolomite and the Ederics Limestone). The highstand of this cycle is indicated by progradation of platforms. In the Keszthely Mts., the Csicsó Marl is overlain by slope deposits (Csillag et al. 1995) and it is followed by platform facies of the Ederics Limestone (Fig. 3). In the "Füred basin" (Balaton Highland area), cessation of sea level rise led to restriction and deposition of bituminous limestones (Pécsely Member of the Sándorhegy Formation). It was followed by the next transgression prior to the end of the Julian (Góczán & Oravecz-Scheffer 1996).

Sequence C3

In the well exposed and carefully studied sections of the Balaton Highland the upper part of the Sándorhegy Formation represents an individual depositional sequence (Figs. 3 and 6).

The bituminous limestone succession is overlain by a bed containing rich shallow marine fauna (*Cornucardia hornigii*) indicating a trend towards opening of the restricted, oxygen depleted basin. Marls above the Cornucardia Bed containing normal marine fossils represent the transgressive systems tract. Thin to medium bedded shallow marine limestones also containing particles of carbonate platform origin were formed during the highstand when the ambient platforms began to prograde into the shallow basin. The succession shows an upward shallowing trend, although intercalation of a thin marl interval in its upper part refers to higher frequency oscillation of the relative sea level which modified this trend.

In several sections, the Sándorhegy Formation appears to be truncated, and the erosion surface is covered by a reddish clayey, brecciated layer which may be regarded as a product of subaerial weathering marking the upper sequence boundary (Budai & Haas 1997).

In the Keszthely Mts., reappearance of marls above the Ederics Limestone indicates the transgression (TST), whereas shallow subtidal carbonate beds mark the final stage of the basin upfilling during the highstand (Góczán et al. 1983).

In the Gerecse Mts. (Zsámbék Basin) upfilling of the basin continued in this period but depositional sequences cannot be recognized (Fig. 5). In the Buda Mts., platforms and basins evolved coevally. In the highstand period prograding platforms occupied the south-western basin which may have been actually the marginal belt of the Zsámbék Basin, whereas in the north-eastern intraplatform basin deposition of cherty limestones and dolomites continued.

Sequence C4

The large basins of the Balaton Highland and the Northern Bakony and also the "Zsámbék Basin" were completely filled up by the Late Tuvalian. Thus, in a predominant part of the Transdanubian Range Unit an extremely levelled topography came into being. By contrast, the intraplatform basins of the Buda Mts. and the Csővár block survived, due to lack of significant terrigenous input and steep marginal slopes which hampered the platform progradation.

After a brief subaerial exposure episode which extended over the western side of the unit, a rise in sea level led to inundation of the levelled shelf. Behind a narrow outer platform zone characterized by high energy, a very wide shallow subtidal inner platform and tidal flat environments emerged site of deposition and early diagenetic dolomitization of the Main Dolomite (Haupt-dolomit).

Exact timing of the lower sequence boundary is difficult. However, on the basis of sporomorphs, forams and Megalodontids it may be placed at the boundary between the Middle and Upper Tuvalian (Végh-Neubrandt 1982; Góczán & Oravecz-Scheffer 1996).

In the platform series of the Buda Mts. the Main Dolomite represents this interval whereas in the "Hármashatárhegy basin", deposition of the basin succession probably continued. In the northern part of the Csővár block (Fig. 8) bioherms–biostromes (patch reefs) with calcisponges, hermatypic corals and brachiopods crop out. They probably belong to the C4 sequence (HST). They show an interfingering relationship with the oncoidal facies of the Dachstein Limestone, which also makes up the overlying succession. The coeval Upper Carnian basin succession was documented by the Csővár-1 core in which, a gradual shift of facies from the eupelagic basin to the distal toe-of-slope could be pointed out below the Carnian/Norian boundary (Haas et al. 1997). This can be regarded as a sign of platform progradation, and the upper boundary of the sequence C4 was put at the end of this trend.

Late Late Triassic

Sequence N1

In the Early Norian, cyclic deposition and early dolomitization continued in a predominant part of the platform of the Transdanubian Range. In the Buda Mts., the pervasively dolomitized series progressed into a partially dolomitized one (transitional member between the Main Dolomite and Dachstein Limestone — Fenyőfő Member) in the Middle–Late Norian and the zone of the transitional unit probably shifted south-westward over time. Since early tidal flat dolomitization may have been controlled both by climatic and paleo-environmental factors (frequency of storm inundation of the tidal flat, Haas 1988), this shifting may reflect a gradual change of these factors. Fischer-plot analysis of the Ugod Ut-8 core in the Northern Bakony indicated markedly decreasing accommodation in the topmost segment of the Main Dolomite and a remarkable gap between the Main Dolomite and the Fenyőfő Member (Balog et al. 1997) which was interpreted as the upper boundary of the N1 sequence. In contrast, in the Csővár-1 core, significant facies change was not observed in this interval (Fig. 5), a gradual shift from the pelagic basin to the toe-of-slope facies was visible from the Upper Carnian to the Upper Norian (Haas et al. 1997).

Sequence N2

Recognition of this sequence was also based on Fischer-plot analysis of core sections in the Northern Bakony (Balog et al. 1997). The stacking pattern of Lofer cycles suggests that the Fenyőfő Member might represent a 3rd order depositional cycle at least in the territory of the Northern Bakony (Fig. 4). This may have been the stage of platform evolution when pervasive dolomitization in the short-term subaerial exposure periods came to an end in large parts of the platform. However, exact timing of this event is ambiguous due to the poor biostratigraphic evidence. According to megalodontids (Végh-Neubrandt 1982) and foraminifers (Oravecz-Sheffer 1987) the Fenyőfő Member and also a significant part of the Dachstein Limestone is Norian in the Bakony Mts.

Sequence N3

Fischer-plot analysis of core Porva Po-89 in the Northern Bakony, revealed a 3rd order cycle (about 3 Ma duration) in the lower part of the Dachstein Limestone (Balog et al. 1997). According to these studies, based on evaluation of the Lofer cycles, the upper sequence boundary can be drawn at about the Norian/Rhaetian boundary (Fig. 4). This interpretation is also constrained by facies trends in the "Csővár basin": an increasing amount of redeposited bioclasts of platform origin until the end of the Norian and the appearance of a large amount of terrestrial plant remnants in the earliest Rhaetian (Fig. 5).

In the south-western part of the Transdanubian Range (western end of the Bakony and Keszthely Mts.), the Main Dolomite is overlain by restricted basin facies of the Rezi Dolomite (Fig. 3). This facies change can be attributed to a relative sea level rise due to the initiation of extensional tectonic movements leading to basin generation in the external zone of the carbonate platform, at the boundary between the Middle and Late Norian (Budai & Kovács 1986). Subsequently, but still in the Late Norian (Sevatian), another marked change happened in the newly formed basins. The carbonate sedimentation was followed by deposition of shales (Kössen Formation). This lithological change probably reflects a climatic change to more humid conditions leading to a significant increase in the terrigenous influx.

Sequence R1

In the Rhaetian a single sequence can be recognized. This sequence is clearly demonstrated on the Fischer-plots of the Dachstein Limestone successions in the Gerecse and Bakony Mts. (Balog et al. 1997). Facies trends in the Kössen Formation also support this conclusion (Haas 1993). The Kössen Formation begins with Upper Norian lithoclastic layers of slope and toe-of-slope facies. It progresses into a restricted deeper basin facies representing the Lower Rhaetian (LST to TST). The maximum flooding is marked by onlap of the clayey basin facies onto the inner part of the "Dachstein platform" in the Middle Rhaetian. In the Late Rhaetian the platform limestones prograded onto the previously filled "Kössen basin" (HST). The upper sequence boundary can be drawn at the Triassic/Jurassic boundary where the peritidal-subtidal cycles are replaced by a permanently subtidal series (Kardosrét Limestone Fm. of Lower Hettangian age).

In the Gerecse Mts. the topmost part of the Rhaetian Dachstein Limestone is missing and the earliest overlying formation is the Middle–Upper Hettangian shallow marine Pisznice Limestone (Fig. 5). The truncated top of the Dachstein Limestone suggests a slight subaerial erosion prior to the block-forming extensional tectonics, leading to inundation of the downfaulted blocks (Fülöp 1976; Haas 1995).

In the basin succession of the Csővár block (Fig. 5), restricted basin facies indicates the base of the R1 sequence. The large amount of sporomorphs and other terrestrial plant remnants in the whole Rhaetian succession suggest the proximity of an exposed island. At the same time, redeposited shallow marine bioclasts and lithoclasts imply the establishment of a small fringing platform on the upper slope of the island (Haas et al. 1997). In the basin succession marked facies change was not visible at the Triassic/Jurassic boundary, that is the slope facies continues in the Hettangian.

Composite sequence stratigraphic chart

The composite sequence chart (Fig. 7) is the summary of the cycle analyses of the selected sub-areas. For the compilation of the composite chart those parts of the regional charts were considered which provided the best records of the succession and the best biostratigraphic constraints.

For the interval from the Permian/Triassic boundary to the Upper Carnian, the classic sections and the complementing cores of the Balaton Highland were the basis for the composite chart, but the series exposed in the eastern part of the Bakony and core data in the Northern Bakony were also taken into account. Core sections in the southern foreland of the Gerecse Mts. provided important data on the Lower Triassic facies distribution. In the Lower Triassic 3 sequences were defined. They are clearly visible in the aforementioned sub-areas and their chronostratigraphic position is fairly well constrained. Recognition of the Anisian sequences is less plausible and the stratigraphic position of the boundaries of the third sequence (A3) is rather ambiguous. Initiation of rifting in the Middle Anisian makes recognition of the sea-level cycles even more difficult. This fact is reflected in the uncertain subdivision of the Ladinian. We recognized only two sequences, although it cannot be excluded that due to intense subsidence of the basins, one or more sequences remain hidden. Four sequences were distinguished in the Carnian of which the lower three can be regarded as well constrained. The fourth Carnian and the three Norian sequences are recognizable but their timing is rather ambiguous. The Rhaetian is represented by a single well defined sequence.

On the basis of the sequence stratigraphic subdivision discussed above, a new chronostratigraphic chart was compiled (Fig. 8) showing the relationships of the lithostratigraphic and within them the lithofacies units along a SW–NE cross section of the TR. It also demonstrates the facies migrations reflecting the relative sea-level changes.

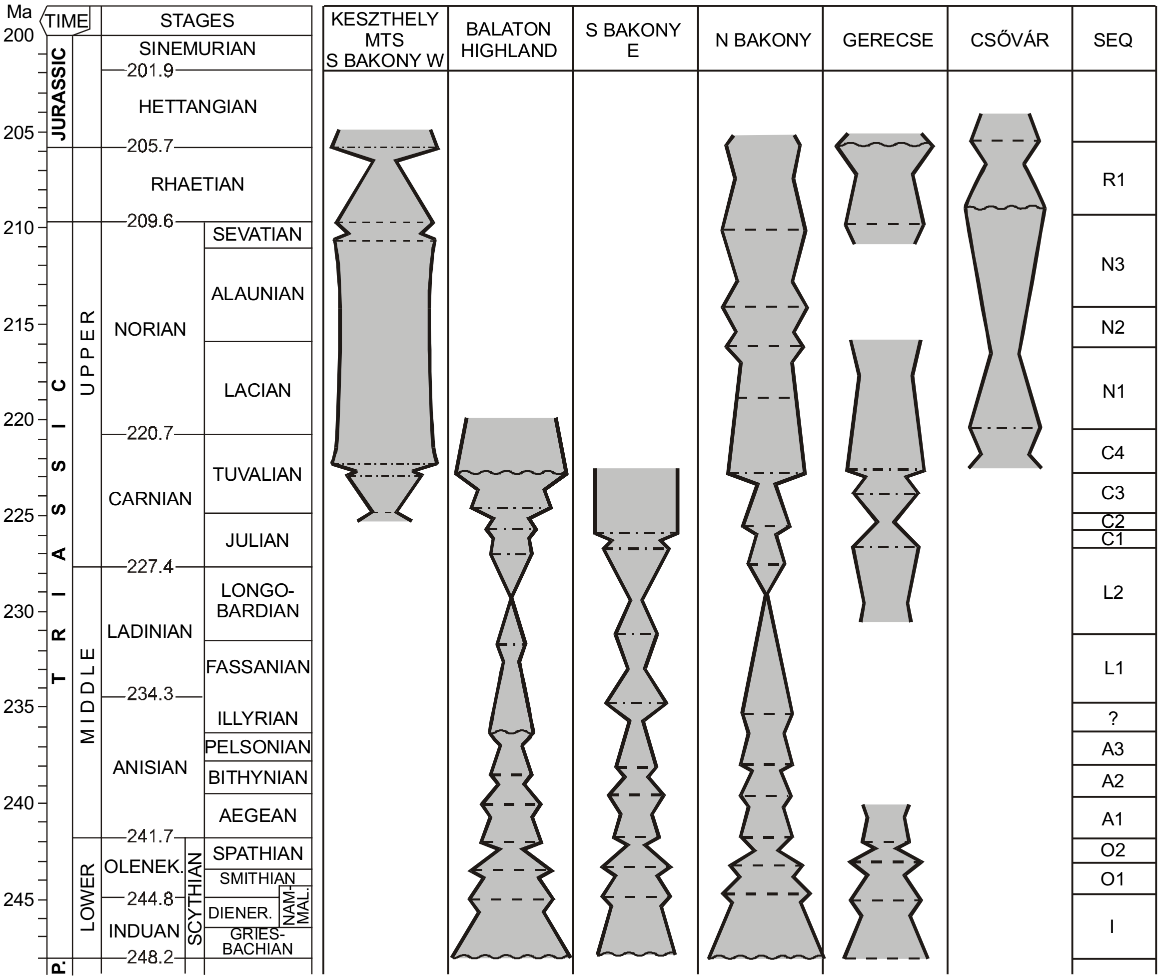


Fig. 7. Composition of sequence stratigraphic charts of the sub-regions of the Transdanubian Range.

Long distance correlation

The composite sequence chart accomplished for the Transdanubian Range made possible a comparison with the published charts for other regions (Southern Alps — De Zanche et al. 1993; Gianolla et al. 1998; Northern Calcareous Alps — Rüffer & Zühlke 1995; German Basin — Aigner & Bachmann 1992, 1997; Western Canada — Embry 1997; Davies 1997). The comparison (Fig. 9) revealed a fairly good coincidence of the recognized sequence boundaries in the Transdanubian Range and those in the relatively distant regions. In some cases the boundaries pointed out in the Transdanubian Range have not been recognized in other regions, and there are boundaries which were recognized in some of the other regions, but which we could not detect in our study area. Since the Alpine regions were in the most intimate paleogeographical relationship with the Transdanubian Range and on the other hand the German Basin was an area which was not affected by the Tethyan rifting, we make some comments on the comparison with these regions below.

Lower Triassic

In the Early Triassic, the westward progressing Tethys bay protruded between the African and European parts of the Pangea, and a broad shallow ramp came into existence. It was separated from the German Basin by the uplifted Hercynian Ranges. The sedimentary basins of the Transdanubian Range and the Southern Alps were located on the Tethyan ramp whereas the Northern Alps represent the transitional belt between the ramp and the continental basins.

Sequence stratigraphic correlation of the Lower Triassic of Lombardy and the Northern Calcareous Alps can hardly be accomplished due to lack of available analysis, but the uppermost Scythian (Spathian) sequence can still be distinguished in the latter units, as well. Comparing the cycle charts of the Transdanubian Range, the Dolomites, the German Basin and Western Canada we can conclude that a marked facies change in the middle part of the Scythian (around the Dienerian/Smithian boundary) can be recognized in all of the areas but significantly fewer sequences could be detected in the Transdanubian Range than either in the Dolomites or in the German Basin. In the Induan, two sequences of the Dolomites and the German Basin show a fairly good correlation while in the Transdanubian Range and in Western Canada only a single sequence could be recognized.

A marked facies change in the middle of the Olenekian (around the Smithian/Spathian boundary) occurred in each of the compared areas (O1/O2 in the Transdanubian Range). This sequence boundary, showing features of intense erosion

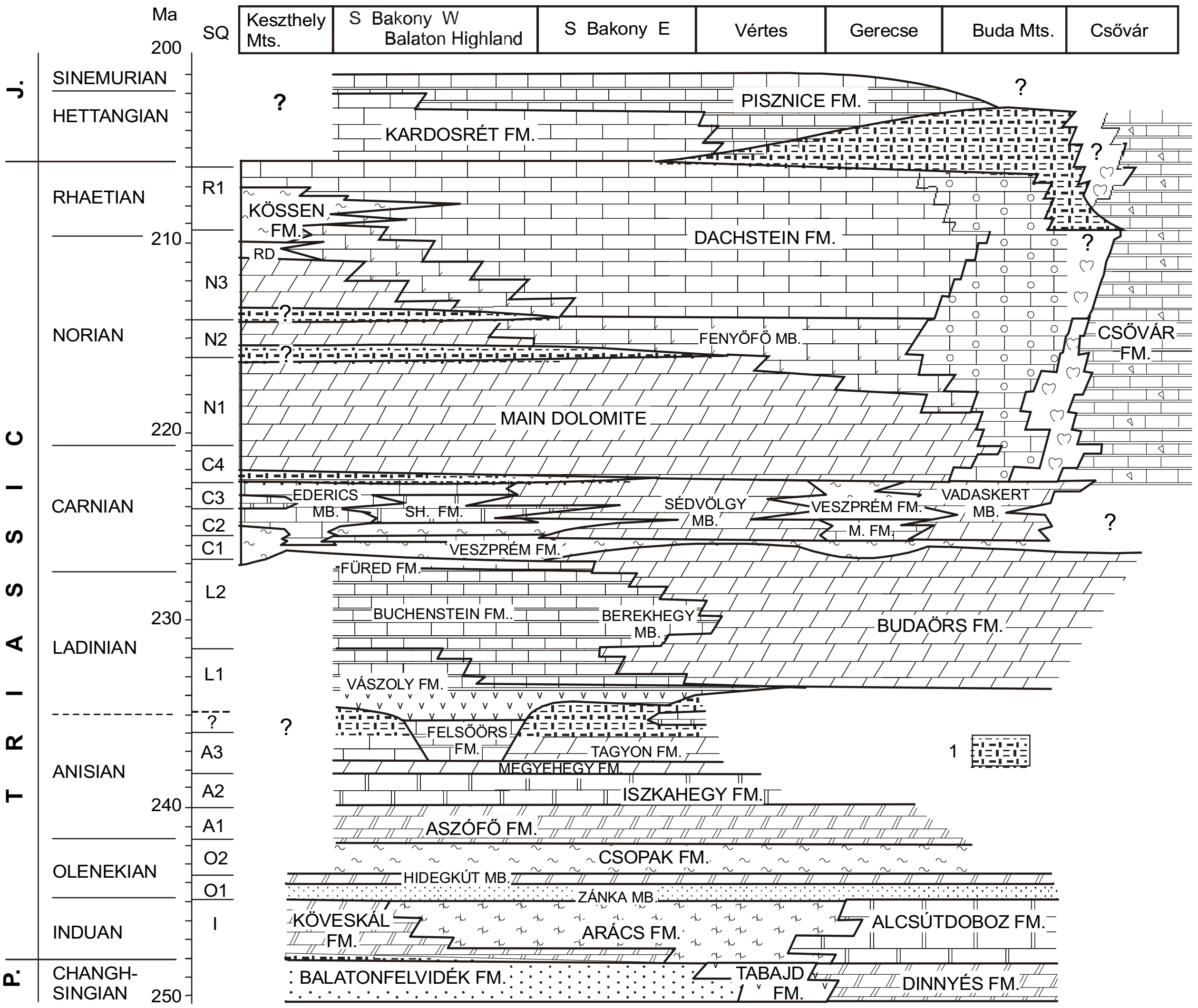


Fig. 8. Chronostratigraphic chart of the lithostratigraphic units of the Transdanubian Range. *Legend:* 1. stratigraphic gap; for other symbols see Fig. 3. *Abbreviations:* M Fm. — Mátyáshegy Fm.; RD — Rezi Dolomite; SH Fm. — Sándorhegy Fm.

("Hardegsen Diskordanz") is the most spectacular one in the German Basin (B3/B4). It is probable, however, that the relative sea-level fall was tectonically enhanced in the German Basin (Aigner pers. comm.).

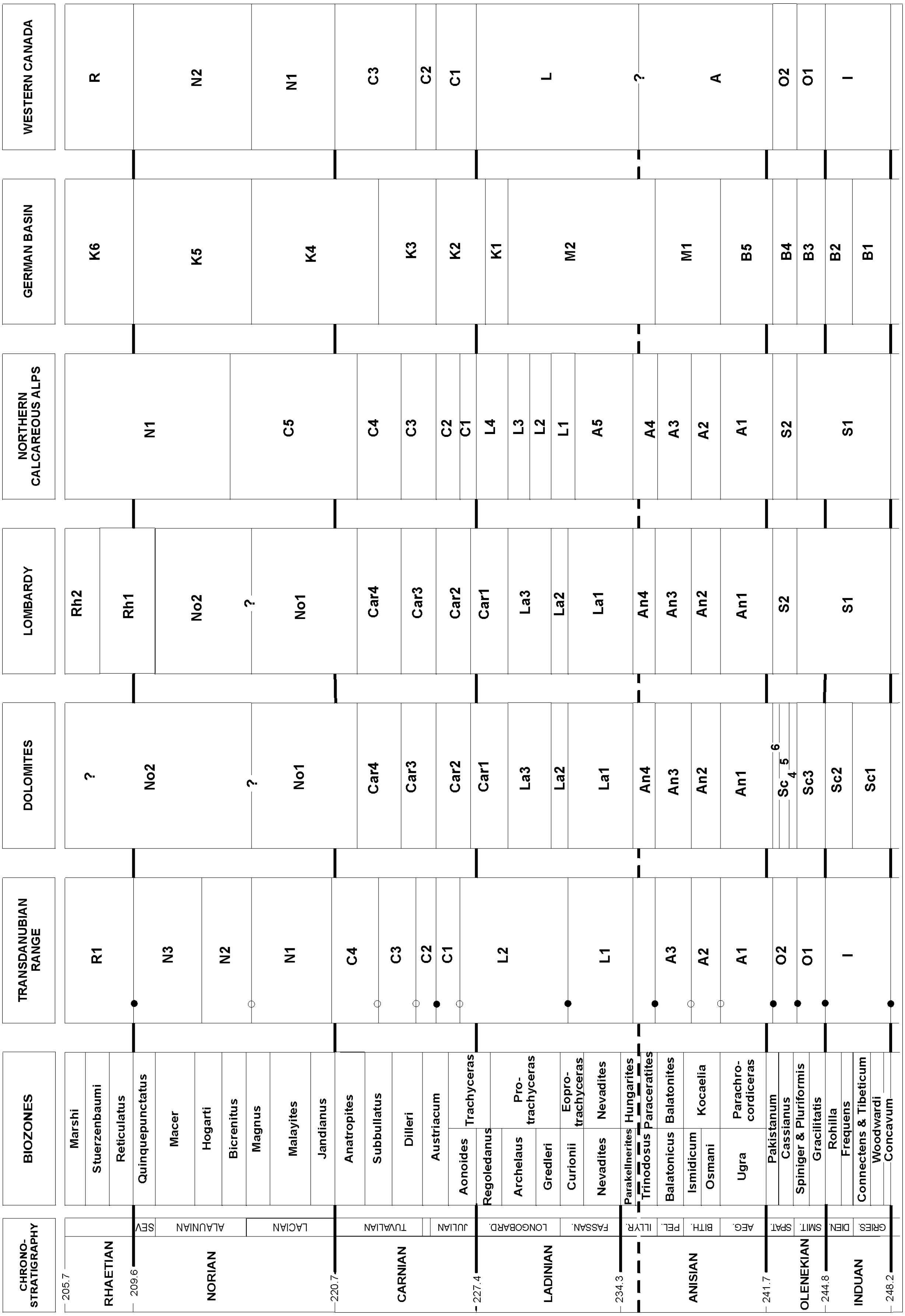
In the uppermost Scythian of the Transdanubian Range and the German Basin only a single sequence was recognized (O2=B4) showing fairly good correlation with the corresponding North Alpine S2 and with the Spathian sequence of Western Canada. In contrast, in the Dolomites three sequences were defined within the Upper Olenekian, although one cannot exclude the possibility that they actually reflect higher order eustatic sea-level changes or local tectonic activity.

Middle Triassic

For the Early Anisian a wide carbonate ramp, akin to that in the Southern Alps can be reconstructed in the TR. Facies distribution and thickness of the formations indicate southwestward deepening of the ramp at least in the area of the Bakony which is also similar to the trend recognized in the Southern Alps (Budai 1992).

In the Middle Anisian extensional synsedimentary tectonics enhanced the lateral facies differences in the Transdanubian Range and the Southern Alps. This effect was not detectable in the Northern Calcareous Alps where a homoclinal carbonate ramp came into being in the Anisian and the lateral facies migrations define the sequence boundaries (Rüffer & Zühlke 1995).

Fig. 9. Sequence stratigraphic correlation of the Triassic successions of the Transdanubian Range, the Dolomites (De Zanche et al. 1993; Gianolla et al. 1998), Lombardy (Gianolla et al. 1998), the Northern Calcareous Alps (Rüffer & Zühlke 1995; Bechstädt & Schweizer 1991), the German Basin (Aigner & Bachmann 1992, 1997) and Western Canada (Embry 1997). Dashed line shows the position of the Anisian/Ladinian boundary sensu Vörös et al. (1996). On the chart of the TR the dots mark those boundaries which show a significant coincidence. The circles mark the boundaries which might be correspond with sequence boundaries recognized in other regions but the coincidence is poor, most probably due to problems of the biostratigraphic correlation. The same abbreviations are used on the sequence stratigraphic chart of Western Canada, as on that of the Transdanubian Range.


CHRONO-STRATIGRAPHY
BIOZONES
TRANSDANUBIAN RANGE
DOLOMITES
LOMBARDY
NORTHERN CALCAREOUS ALPS
GERMAN BASIN
WESTERN CANADA
RHAETIAN
NORIAN
CARNIAN
LADINIAN
ANISIAN
OLENEKIAN
INDUAN
205.7
209.6
220.7
227.4
234.3
241.7
244.8
248.2
SEV.
ALAUNIAN
LACIAN
TUVALIAN
JULIAN
LONGOBARD.
FASSAN.
ILLYR.
PEL.
BITH.
AEG.
SPAT.
SMIT.
DIEN.
GRIES.
Marshi
Stuerzenbaumi
Reticulatus
Quinquepunctatus
Macer
Hogarti
Bicrenitus
Magnus
Malayites
Jandianus
Anatropites
Subbullatus
Dilleri
Austriacum
Aonoides
Trachyceras
Regoledanus
Archelaus
Pro-trachyceras
Gredleri
Curionii
Eopro-trachyceras
Nevadites
Parakellnerites
Hungarites
Trinodosus
Paraceratites
Balatonicus
Balatonites
Ismidicum
Osmani
Kocaelia
Ugra
Parachro-cordiceras
Pakistanum
Cassianus
Spiniger & Pluriformis
Gracilitatis
Rohilla
Frequens
Connectens & Tibeticum
Woodwardi
Concavum
R1
N3
N2
N1
C4
C3
C2
C1
L2
L1
A3
A2
A1
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?
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A5
A4
K6
K5
K4
K3
K2
K1
M2
M1
B5
B4
B3
B2
B1
R
L
A

In the realm of the Western Tethys, a lowermost Anisian sequence was generally recognized. It is represented by the Aszófő Dolomite in the TR, the San Lucano Mb. and the Lower Serla Dolomite in the Dolomites as well as the Carniola di Bovegno in Lombardy (An1). The lithostratigraphically analogous Reichenhall Fm. in the NCA is defined as the highstand segment of the topmost Scythian sequence (S2 — Rüffer & Zühlke 1995). In the German Basin the lowermost Anisian sequence (evaporitic Röt) is regarded as the topmost unit of the Buntsandstein (B5 — Aigner & Bachmann 1992).

The next Anisian sequence (A2) corresponds to the Iszkahegy Limestone in the TR. Its lower laminitic portion can be correlated with the Lombard Lower Angolo Limestone (TST) whereas the upper one may correspond to the lower member of the peritidal dolomites of the Val Brembana Fm. (HST) which is separated from the upper member by a karstic subaerial unconformity surface (Jadoul et al. 1992a). In the Dolomites, this sequence begins with the Piz da Peres Conglomerate which is overlain by upward shallowing carbonate ramp deposits (Gracilis Fm., Col Alto Fm. — De Zanche et al. 1993; Gianolla et al.1998).

The Middle Anisian sequence (A3) of the "Füred basin" shows similarity with the corresponding Lombardian sequence. The lower part of the Megyehegy Fm. (Megyehegy Mb. sensu Vörös et al. 1997) corresponds to the upper part of the "peritidal dolomite" in the Brembana Valley (Jadoul et al. 1992a). Bituminous laminites of the Felsőörs Fm. can be correlated with the Upper Angolo Limestone and indicates the maximum flooding (Balatonicus Subzone). The nodular limestones in the Aszófő section and the crinoidal–brachiopodal limestones in the Felsőörs section (Binodosus Sbz.), representing the highstand interval, can be correlated with the Cimego Limestone in Lombardy.

In the TR as in Lombardy, a remarkable gap was recognized (Budai & Haas 1997) above the Middle Anisian platforms (Dosso dei Morti and Camorelli in Lombardy; Tagyon and Megyehegy in the TR). On the Middle Anisian platforms of the Balaton Highland, the upper part of the cyclic platform carbonate succession belongs to the Balatonicus Subzone. It is overlain by the transgressive tract of the next sequence (Camunum Subzone).

In the Dolomites, the lower boundary of the An3 is marked by the Voltago Conglomerate overlying the shallow marine Bithynian carbonates. The establishment of the "Upper Serla platform" can be related to the highstand interval.

In the German Basin, the Bithynian and Pelsonian sequences could not be distinguished within the Lower-Muschelkalk (M1) sequence. The maximum flooding is indicated by the appearance of Mediterranean faunal elements corresponding most probably to the Balatonicus Zone (Vörös 1992).

The progradation of the "Budaörs platform" towards the "Füred basin" in the middle part of the Ladinian (Curionii Zone) (Budai & Haas 1997) may correspond to the progradation of the South Alpine platforms (San Salvatore Dolomite and Esino Limestone in Lombardy, and Sciliar Dolomite 1 in the Dolomites).

In the Northern Calcareous Alps, the most spectacular transgression of the Middle Triassic was initiated at the end of the Illyrian ("Reifling event") and the highstand period might have been in the Middle Ladinian (Rüffer & Zühlke 1995). This sequence (A5) shows a fairly good correlation with the Lower Ladinian sequence in the TR and also in the Southern Alps.

The Upper Ladinian succession of the TR was interpreted as a single sequence. In contrast, in the Dolomites three sequences (La2, La3, Car1) were distinguished within the same time interval, and are reflected in three progradational events (Sciliar 2, 3 and Cassian 1). In the TR marked progradation of the "Budaörs platform" at the turn of the Ladinian–Carnian shows a good correlation with the Cassian 1 progradation in the Dolomites (Car1) and similarly intense progradations in the Northern Calcareous Alps (Brandner 1984).

Upper Triassic

The Late Triassic evolution of the TR can be subdivided into three major stages. The first stage is characterized by postrift infilling of the Middle Triassic basins. This was completed by the latest Tuvalian. At this stage predominantly siliciclastic infilling of the basins was strongly influenced by the climatic conditions. The second one is a relatively tranquil period when large carbonate platforms came into being. This was followed by a new basin formation and basin infilling period from the Sevatian to the Late Rhaetian when tectonic and climatic effects played a significant role in the facies distribution. Due to the paleogeographical setting of the TR, its evolution was akin to those of the Southern Alps and the Northern Calcareous Alps. Continental deposits characterize the Upper Triassic of the German Basin (Keuper) where, in addition to base level changes, climatic conditions controlled the sedimentation.

The four sequences recognized in the TR cannot be perfectly correlated with the four Carnian (more exactly Ladinian–Carnian) sequences of the Southern Alps (De Zanche et al. 1993). The correspondence is better with the Northern Calcareous Alps and the Drauzug where 3 shale-carbonate cycles provide the basis of the subdivision (Bechstädt & Schweizer 1991; Hagemeister 1988).

The first Carnian sequence (C1) of the TR begins in the Lower Julian. In the basinal areas of the Balaton Highland and the Northern Bakony the pelagic limestones are overlain by marls (Mencshely Mb. — TST) also indicating a significant climatic change roughly coeval with the initiation of the sea level rise. The combined effects of sea level rise and influx of fine terrigenous material led to drowning of large parts of previous platforms (e.g. in the Gerecse Mts.). Progradation of the platforms (Sédvölgy Dolomite 1) indicates the highstand of this sequence. The C1 sequence of the TR can be correlated with the Car2 sequence of the Dolomites (De Zanche et al. 1993). The second progradation of the Cassian Dolomite and the Breno Fm. is interpreted as indicator of the HST of this sequence. The first marl-carbonate cycle in the Northern Calcareous Alps and the Drauzug (C2) is roughly coeval with our C1 sequence.

Sequence C2 in the TR (Csicsó Marl — TST, progradation of the Ederics Limestone on the SW and of the Sédvölgy Dolomite 2 on the NE — HST) corresponds to the Car3 in the Southern Alps. The upper part of the Dürrenstein Fm. forms the HST. The second shale-limestone cycle of the NCA (C3) corresponds to our C2 sequence.

Sequence C3 in the TR (marl in the basal part of the Barnag Mb. — TST, upward shallowing limestone in the upper part of the Barnag Mb. — HST) may correspond to the Car4 in the Southern Alps, although we placed the lower boundary of the overlying Main Dolomite (= Dolomia Principale) somewhat deeper than De Zanche et al. (1993) did, because a significant part of the Main Dolomite is Tuvalian. In the Dolomites the lower sequence boundary is a major regional unconformity. It is overlain by sandstones, varicoloured shales, limestones and dolomites of the Raibl Fm. (TST) with vuggy dolomites and gypsum in its topmost part (HST). This sequence is coeval with the third shale–limestone cycle of the NCA. The C2/C3 sequence boundary in the Transdanubian Range corresponds well to the Mid-Carnian boundary of Western Canada.

In the German Basin, a major erosion surface occurs between the Gipskeuper and the Schilfsandstein indicating a significant base-level change (K2/K3 boundary — Aigner & Bachmann 1992, 1997) which is approximately coeval with a crucial change in the climate from arid to humid. This marked sequence boundary was placed by Aigner & Bachmann (1997) at the top of the Lower Carnian (using the former tripartite scale). However, biostratigraphic constraints are poor and it is suspected that it actually corresponds to the intensification of the terrigenous input in the Tethyan realm in the Early Carnian (L2/C1 in the TR). The K3/K4 boundary in the Upper Carnian may correspond to the top of the sequence C3 in the TR, that is the base of the Main Dolomite.

In some sections on the Balaton Highland, there is a subaerial exposure horizon between the Sándorhegy Fm. and the Main Dolomite. Subsequently a new transgression gave rise to the formation of the widely extended Main Dolomite. Trends of facies migration or marked changes could not be recognized within the thick platform carbonate series either in the TR or in the Alpine region. On the contrary, progradation of the platform could be detected in the toe-of-slope and basin succession in the easternmost part of the TR, in the topmost Carnian. This was the basis of the definition of the sequence C4.

Sequence stratigraphic subdivision of the extremely long Norian is difficult and perhaps the most crucial problem of the Triassic sequence stratigraphy. In the Tethyan realm, this interval is represented predominantly by platform carbonates, whereas continental deposits characterize the German Basin.

The conditions for the sequence analysis appear to be relatively favourable in the TR because we have a record on the platform margin and the upper part of the succession was not affected by pervasive dolomitization, providing a good chance for the precise analysis of the high-frequency cycles. The Norian marine siliciclastic succession in Western Canada has been subdivided into two sequences. The boundary between them can be correlated quite well with N1/N2 boundary in the Transdanubian Range and with the K4/K5 boundary in the German Keuper.

In the Middle–Late Norian in Lombardy and in the easternmost Southern Alps extensional tectonics led to disintegration of the former large platforms, and basins came into existence. Structural evolution was very similar in the NCA (Lein 1987) and TR (Haas et al. 1995; Haas & Budai 1995) and consequently sediment deposition was highly influenced by the tectonics in each of these regions. A marked change in the sedimentation occurred in the Sevatian when carbonate deposition was followed by deposition of shales (Riva di Solto Shale, Kössen Fm.). This change was attributed to sea-level change (the base of sequence Rh1 in Lombardy — Gianolla et al. 1998), climatic change (Jadoul et al. 1992b) or an interaction of both factors (Burchell et al. 1970; Haas 1993). According to our analysis in the TR, the establishment of the basin, the sea-level change and the remarkable climatic change were not coeval, and the R1 sequence initiated in the earliest Rhaetian. In the Late Rhaetian platforms prograded again (Zu Limestone and Conchodon Dolomite in Lombardy, Rhaeto-Liassic limestone in the NCA, upper part of the Dachstein Limestone in the TR) and the upper boundary of the R1 in the uppermost part of the Rhaetian can also be correlated in the Alpine realm. A sequence in the Rhaetian was also defined in the German Basin (K6) and in Western Canada (Embry 1997).

Conclusions

1. Sequence analysis carried out in the TR revealed that by combining the best constrained segments of sub-regional charts, a reliable sequence subdivision can be deduced for the whole region even if the exposure conditions are relatively poor. Using this method, a significant part of the local controlling factors can be filtered out, and the composite chart reflects mainly those controlling factors which affected the whole region.

2. The Triassic evolutionary history of the TR was governed predominantly by the Neotethys rifting, but it was also influenced by the incipient rifting of the Ligurian-Penninic ocean branch from the Late Norian. Four evolutionary stages could be distinguished. The first stage (Early Triassic to Middle Anisian) is subdivided into 5 sequences. These sequences were recognized in every (4) sub-region where this part of the succession was known. Within the second stage (Middle Anisian–Ladinian) 3 sequences were recognized. This classification is based on the successions of the Balaton Highland and the eastern part of the Southern Bakony. In the third stage (Carnian), 4 sequences were recognized. On the basis of the exposures and cores on the Balaton Highland the lower three of them can be regarded as well constrained, although their presence is less plausible in the inner basin successions (Northern Bakony) and in the area of the carbonate platforms (eastern side of the Southern Bakony). The lower 3 sequences of the fourth (Norian–Rhaetian) evolutionary stage were deduced on the basis of Fischer-plot analysis. The fourth (Rhaetian) sequence was recognized in several sub-regions and appears to be reliably defined.

3. Approximately 50 % of the cycle boundaries can be well correlated with those reported from the Alpine areas, the German Basin and Western Canada. There are some discrepancies in some cases (a further 30 % of the boundaries) which can be attributed most probably to the problems of the

biostratigraphic correlation. The Norian sequences which were defined using the Fischer-plot method could not be correlated with the published sequence boundaries, but it must be noted that for the Norian reliable sequence definitions are missing. Fairly good correspondence between the TR and the Alpine sequences can be attributed first of all to their intimate paleogeographical relations and similar structural evolution. In accordance with this, the most definite correspondence could be established in the Olenekian–Middle Anisian and in the Carnian intervals which were the tectonically quietest periods when effects of the global sea-level changes were not masked by local factors.

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