Triassic Workshop 2008, Hungary

Geological excursions in the Alpine and Germanic Triassic facies areas of Hungary

Field guide

Compiled by Tamás Budai

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2008

Program

First part: Bakony Mts., Balaton Highland

September 8

Stop 1
Balatonalmádi, Köcs Lake quarry: key section of terrestrial Upper Permian sequence (Balatonfelvidék Sandstone)

Stop 2
Balatonfüred, railway cut: Permian/Triassic boundary section

Stop 3
Sóly, Lower Triassic section: Olenekian outer ramp facies (Csopak Marl)

Stop 4
Felsőörs, Szt. Kereszt (Holy Cross) Hill: Lower Anisian limestone (Iszkahegy Limestone)

Stop 5
Felsőörs Malom Valley: Middle Triassic key section of the Balaton Highland from Lower Anisain up to the Ladinian, Anisian/Ladinian boundary section

September 9

Stop 6
Szentkirályszabadja, airport quarry: Middle Anisian carbonate platform and Upper Illyrian basin succession (SB)

Stop 7
Hajmáskér, Berek Hill: Upper Ladinian – Lower Carnian basin toe-of-slope and platform carbonates

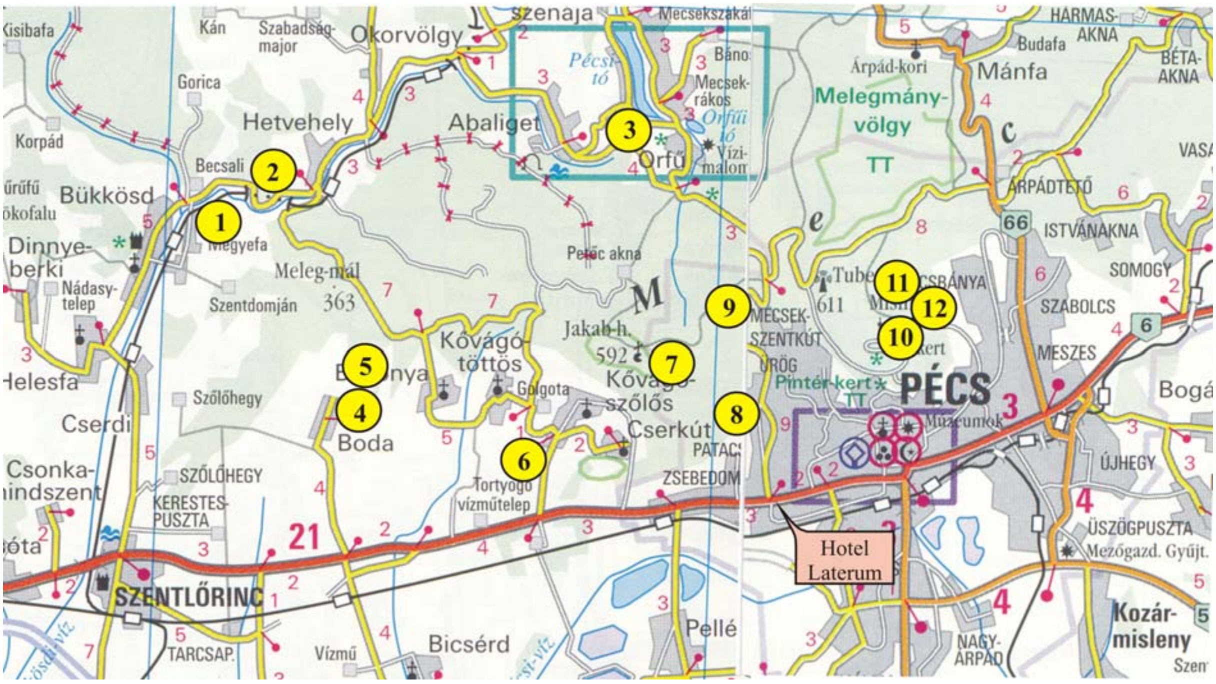
Stop 8
Pécsely, Meggy Hill: Lower Carnian limestones of basin facies (Füred Limestone)

Stop 9
Balatoncsicsó, Csukrét ravine: intraplatform Carnian marl succession (Veszprém Marl)

Stop 10
Csopak, Nosztor Valley: shallowing-upward Carnian basin sequence (Sándorhegy Limestone)

Stop 11
Veszprém, Aranyos Valley: Upper Carnian platform carbonate (Hauptdolomit)

Second part: Mecsek Mts.



September 10

Moving to Southern Transdanubia, Mecsek Mts. (3-4 hours)

Stop 1

Bükkösd, old quarry: Middle Anisian carbonate ramp (Lapis Limestone)

Stop 2

Kán Valley, road cut: Middle Anisian outer ramp (Zuhánya Limestone) and platform carbonate (Kán Dolomite)

Stop 3

Orfű: Middle Anisian outer ramp (Zuhánya Limestone)

September 11

Stop 4

Boda: Upper Permian playa lake (key section of Boda Claystone Formation)

Stop 5

Boda: Upper Permian fluvial facies (Kővágószőlős Sandstone, Bakonya Member)

Stop 6

Kővágószőlős: visit in the core depository of Mecsekérc to study drilled cores representing the basement of the western Mecsek Mts.

Stop 7

Kővágószőlős, Jakab Hill: Lower Triassic conglomerates and sandstones (Jakabhegy Fm, 2 km walk uphills to the cliffs)

Stop 8

Pécs, Patacs: Lower Anisian siltstones and marls (Patacs Fm)

September 12

Stop 9

Pécs, Remete-rét: Middle Anisian reef (Rókahegy Dolomite)

Stop 10

Pécs, Dömörkapu, Kis-rét: key sections of the Middle Anisian to Ladinian limestones („Terebratula beds", „Trigonodus beds")

Stop 11

Pécs, Kantavár quarry: key section of Ladinian lacustrine limestones and marls (Kantavár Fm)

Stop 12

Pécs, Lámpás Valley: Upper Triassic lacustrine and fluvial sandstones (Karolinavölgy Fm)

Geological setting of Hungary

Hungary lies in the central part of the Carpathian Basin, surrounded by the Alps, the Carpathians and the Dinarides (Fig. 1).

Three major geohistorical periods are reflected in Hungary`s geology:

- the pre-Alpine evolutionary stage connected with Central Europe`s Precambrian-Palaeozoic history,
- the Alpine stage, including the Late Palaeozoic, Mesozoic and Palaeogene evolution of the Tethys, with orogenic events (Eoalpine, Palaeoalpine, Mesoalpine) manifested in napped-folded tectonics and large-scale strike-slip movements,
- the Pannonian (Neoalpine) evolutionary stage lasting from the Early Miocene up to the present; a period characterized by formation of small extensional basins and then the Pannonian Basin by high-amplitude subsidence.

According to the development patterns of pre-Tertiary formations, the territory of Hungary can be divided into the following megatectonic units (Fig. 1).

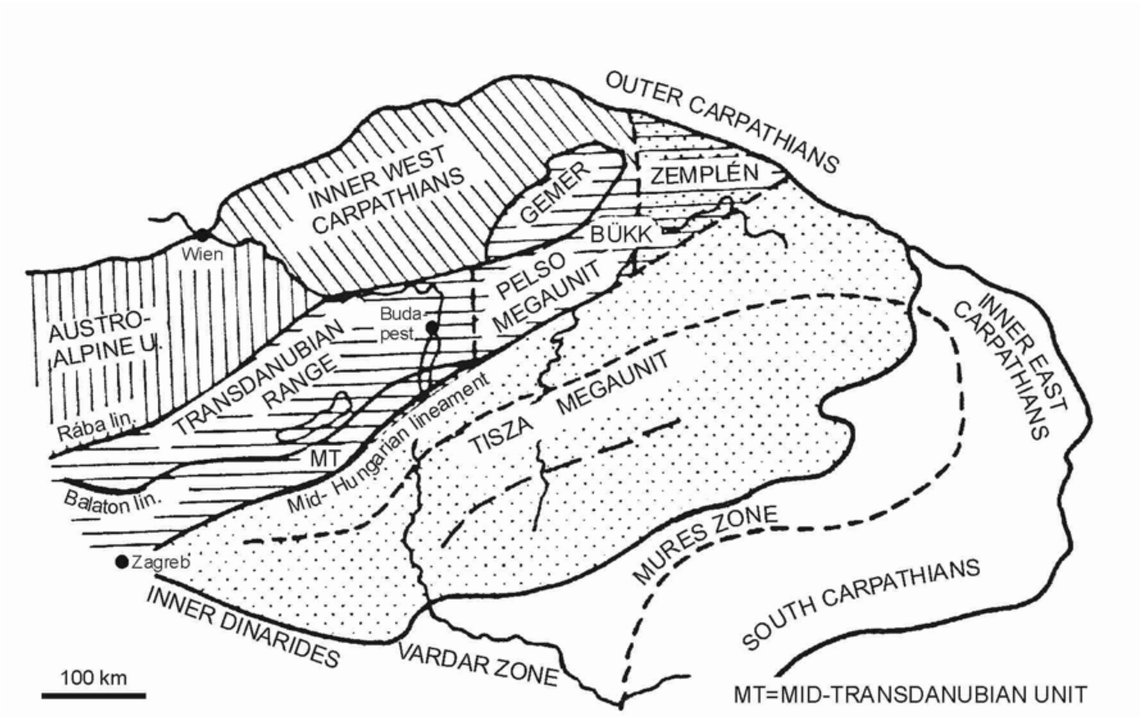


Fig. 1 Megatectonic setting of the Carpathian Basin (after HAAS et al. 1995)

The **Pelso Megaunit** is located between the Rába–Diósjenő Lineament and the Mid-Hungarian Fault Zone. It is characterized by very low-grade and low-grade metamorphic marine Early Palaeozoic formations as well as continental and marine Late Palaeozoic sequences of South Alpine affinity. In the Mesozoic, passive continental margin formations are characteristic, but in certain subunits remnants of an accretionary complex with fragments of oceanic basement are known, as well. These heterogenous basement blocks, showing Alpine and Dinaric relationships respectively, came into their present-day position via large-scale strike-slip movements in the Tertiary.

The Pelso Megaunit is made up of the following units: Transdanubian Range, Sava (Zagorje–Mid-Transdanubian), Bükk, South Gemer (Aggtelek).

The **Tisza Megaunit** can be outlined to the south of the Mid-Hungarian Fault Zone, including the Mecsek and Villány Mountains and their subsurface extension in the basement of the Great Hungarian Plain (Alföld) showing affinities with the Apuseni Mountains (W Romania). The high-grade polimetamorphic basement is covered by a Germano-type Permo-Triassic continental-shallow marine sequence. It is followed by Jurassic and Cretaceous series of different developments. Differences enable to distinguish the Mecsek, Villány and Békés Subunits.

FIRST PART

Geology of the Transdanubian Range

The mountainous, hilly Transdanubian Range (TR) traverses Transdanubia in NE–SW direction. Bakony is situated in the southwestern part of the range characterised by a syncline structure of NE–SW structural strike. Forming the southern flank of the syncline the Balaton Highland is made up by the oldest formations in the TR, Lower Ordovician to Upper Triassic formations crop out only in this area. Towards the axis of the syncline younger and younger Mesozoic formations occur, i.e. more than 2000 m thick Upper Triassic platform carbonates, Jurassic to Lower Cretaceous predominantly pelagic limestones, then Upper Cretaceous shallow to deep marine marls and limestones (Fig. 2).

Triassic stratigraphy and geohistory of the Bakony Mts

Lithostratigraphic subdivision of the Triassic of the Transdanubian Range has been established on the basis of regional geological mapping and the key-section project running parallel (Fig. 3).

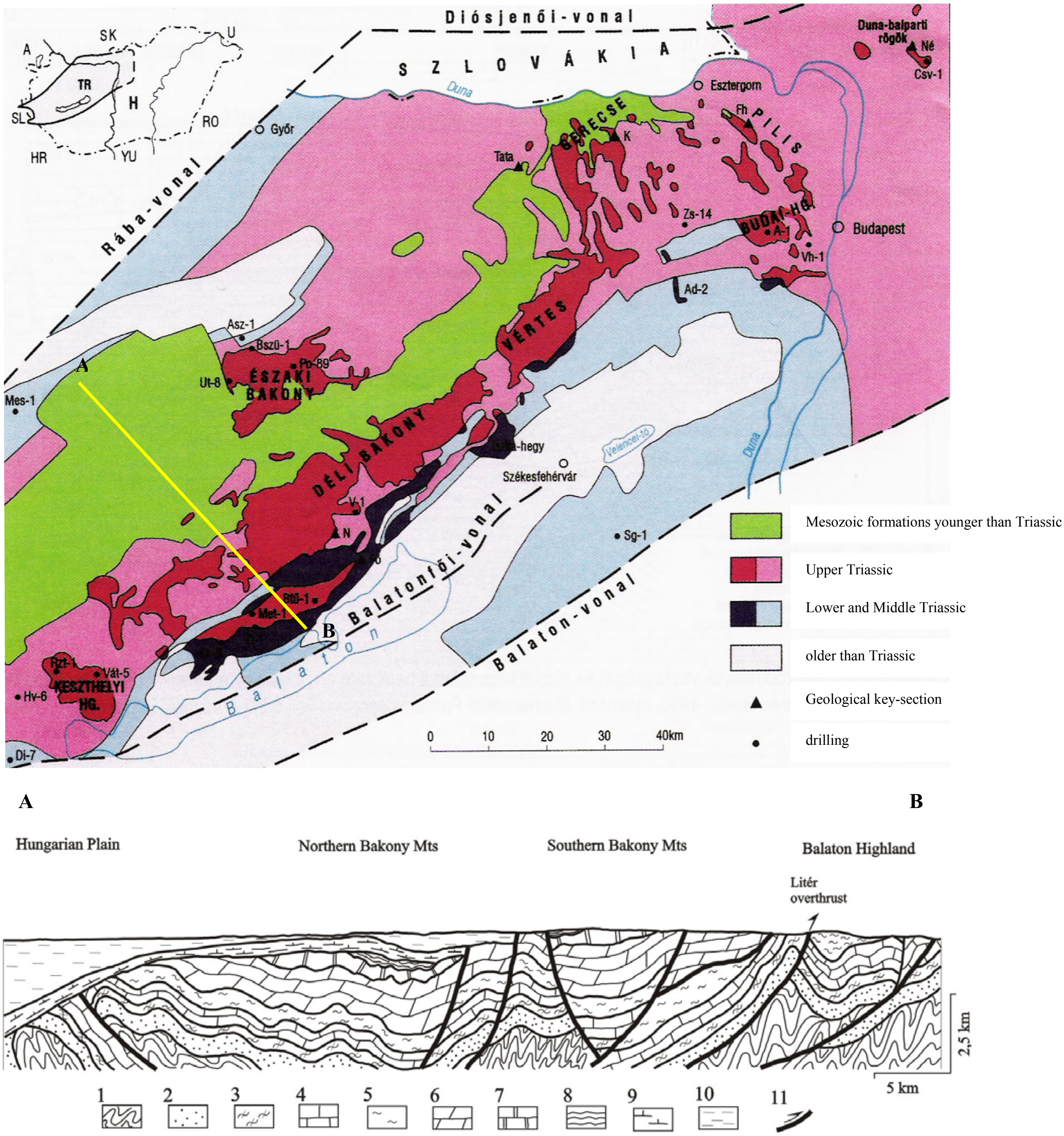


Fig. 2 Geological map (without Cenozoic formations, after HAAS, BUDAI 2004) and cross section of the Transdanubian Range (TRUNKO et al. 2000). Legend: 1. pre-alpine basement; 2. Upper Permian terrestrial siliciclastics; 3. Lower Triassic formations; 4. Middle Triassic formations; 5. Carnian marls; 6. Main Dolomite Fm; 7. Dachstein Fm; 8. Jurassic formations; 9. Cretaceous formations; 10. Tertiary sediments; 11. reverse faults.

As a consequence of significant transgression at the Permian/Triassic boundary the area of the Late Permian alluvial plain was inundated. Ramp geometry and mixed siliciclastic and carbonate sedimentation (Arács Marl, Köveskál Dolomite, Zánka Sandstone, Hidegkút

Dolomite and Csopak Marl) characterized this evolutionary stage, which lasted till the end of the Early Triassic. Due to cessation of the terrigenous input, carbonate deposition became prevailing (Aszófő Dolomite, Iszkahegy Limestone, Megyehegy Dolomite) during the Early Anisian. Extensional tectonic activity disintegrated the carbonate ramp at the beginning of the Middle Anisian (BUDAI, VÖRÖS 1992). Isolated platforms were formed (Tagyon Fm) coeval with opening of halfgraben type basins (Felsőörs Fm). Larger carbonate platforms developed during the Ladinian (Budaörs Dolomite) and the Carnian (Sédvölgy Dolomite) respectively, whereas in the deeper basins pelagic limestones and volcanic tuffs were deposited during the Late Anisian (Vászoly Fm) and in the Ladinian (Buchenstein Fm). The Carnian basins (Veszprém Fm) filled up by fine grained siliciclastics by the end of the Carnian and a levelled topography was formed. The latest Carnian to Rhaetien interval is characterized by the evolution of the huge Dachstein platform (Main Dolomite and Dachstein Fm).

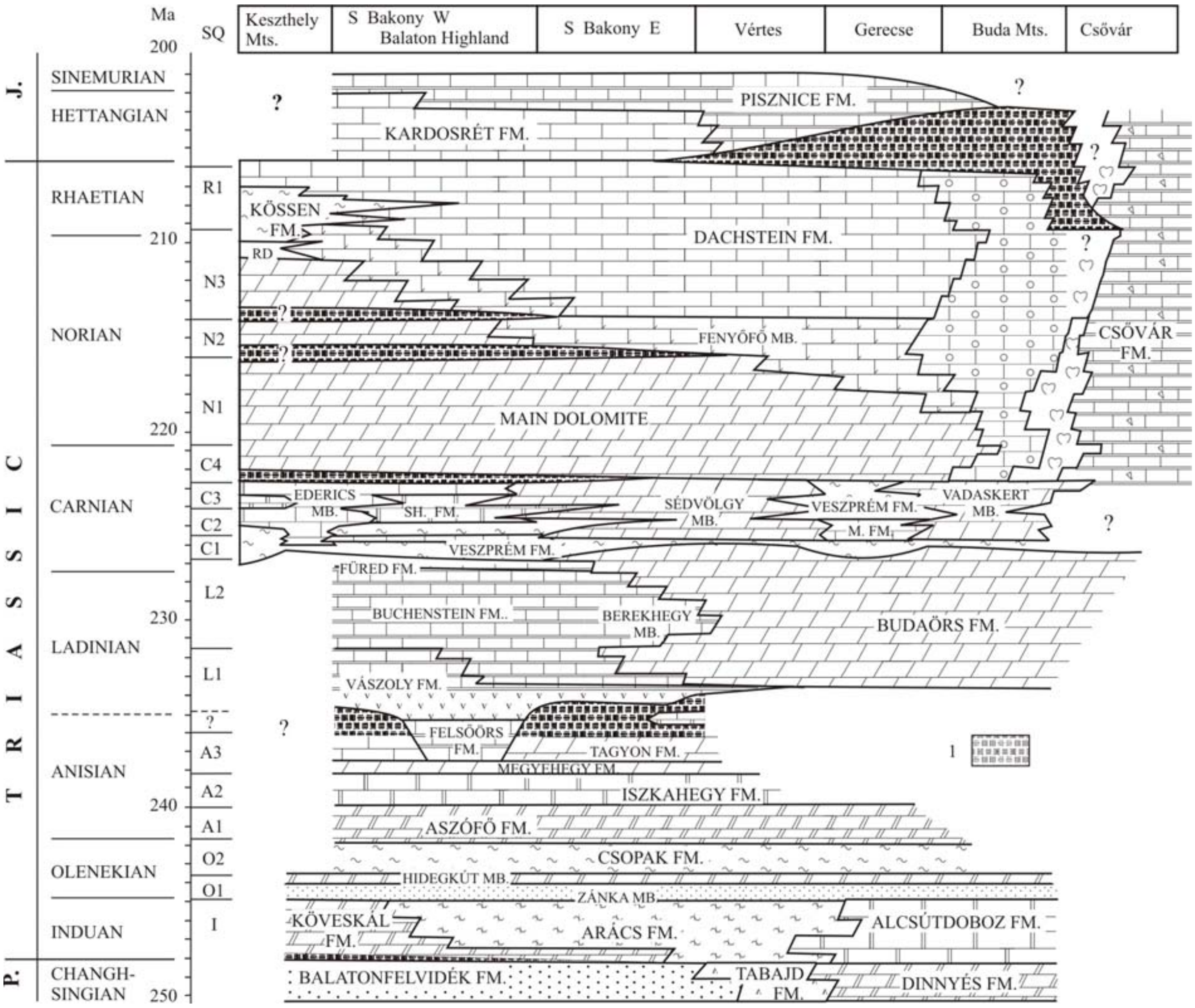


Fig. 3 Triassic lithostratigraphic units of the Transdanubian Range (after HAAS, BUDAI 1999).

Excursion

Stop 1
Upper Permian Balatonfelvidék Sandstone, Balatonalmádi

The abandoned quarry near the Köcsi Lake in the western part of Balatonalmádi (Káptalanfüred) is one of the best key sections of the Upper Permian red sandstone of the Balaton Highland. The 500-600 m-thick Balatonfelvidék Sandstone represents the Middle-Upper Permian in the SW part of the Transdanubian Range, interfingering with sabkha evaporites and shallow marine carbonates northeastward. The lower part of the formation consists predominantly of conglomerate beds alternating with sandstone layers (Budaörs Conglomerate Mb). Thickness of the conglomerate member is extremely variable in connection with the paleo-relief. In some places it may reach 200 m. However, in the area of the Köcsi Lake is not more then 10 m, indicating a paleo-high.

The lower part of the section is made up by slightly bedded coarse-grained conglomerate. It is overlain by cross-bedded pebbly sandstone which is covered by conglomerate and then sandstone beds. The pebbles derived from the Paleozoic basement, material of the grains is quartzites, phyllites, metarhyolites and metaandesites are the prevalent components.

Stop 2
The Permian/Triassic boundary, Balatonfüred

The section is located in a railway-cut, SE of Balatonarács, at a distance about 50 m of highway No. 71. The section exposes the topmost layers of the Upper Permian Balatonfelvidék Sandstone and the basal beds of the Lower Triassic succession (Fig. 4).

In the exposed section, the Balatonfelvidék Formation is represented by red siltstone and sandstone layers. The siltstone layer at the base of the succession is made up by quartz, mica and clay minerals (illite-smectite, illite-muscovite and kaolinite). The Balatonfelvidék Sandstone is a cyclic fluvial deposite, the sandy point bar and the silty overbank floodplain facies alternate, as a rule. The uneven erosion surface of the siltstone bed is overlain by cross-laminated sandstone layers. The rock is composed of fine grained quartz sand with 10-20 % feldspare and 10-15 % mica in an argillaceous matrix.

The sharp cut-off surface of the red Balatonfelvidék Sandstone is overlain by marine yellowish-grey basal layers of the Lower Triassic Nádaskút Dolomite (Köveskál Fm). The initial stage of the transgression is represented by 4 m of alternating siltstone and sandstone with sandy dolomite interlayers. The sandstone layers consists predominantly of quartz grains with dolomite cement. Ripple marks are common on the bedding plains. There is a gradual upward decrease in quartz sand and sandy dolomite occurs in the upper part of the section. The dolomites are oolitic, as a rule. The nuclei of the ooids are generally quartz sand grains.

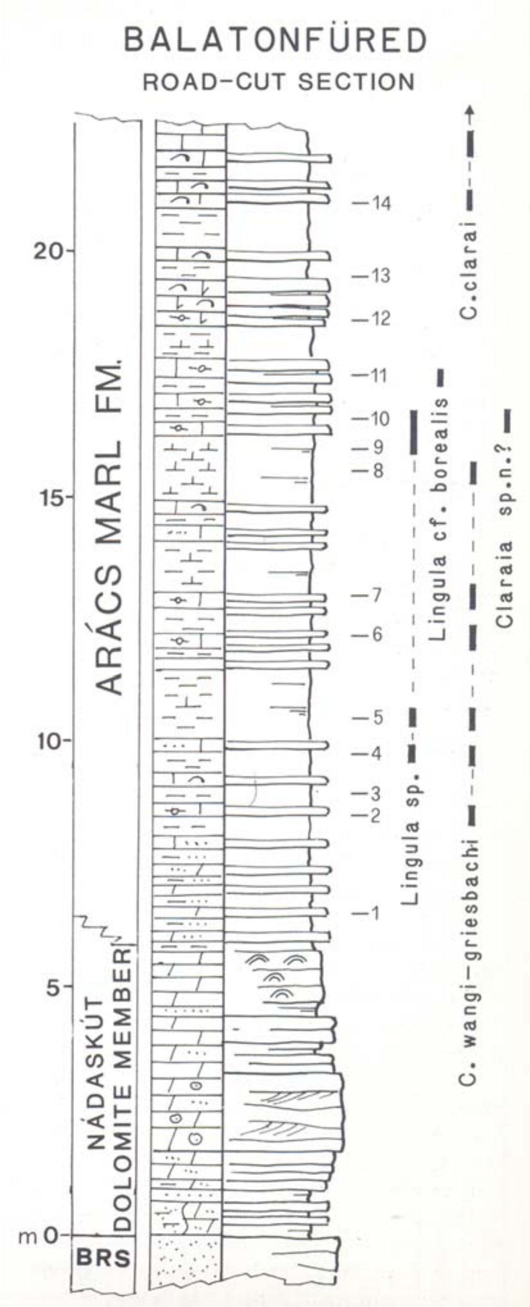


Fig. 4 Lithostratigraphic column of the Lower Triassic succession in the railway-cut and the road-cut at Arács (BROGLIO-LORIGA et al. 1990)

The Arács Marl Formation is made up predominantly by greenish-grey and brownish-red marls with siltstone and "gastropod oolite" intercalations. Bioturbation is common.

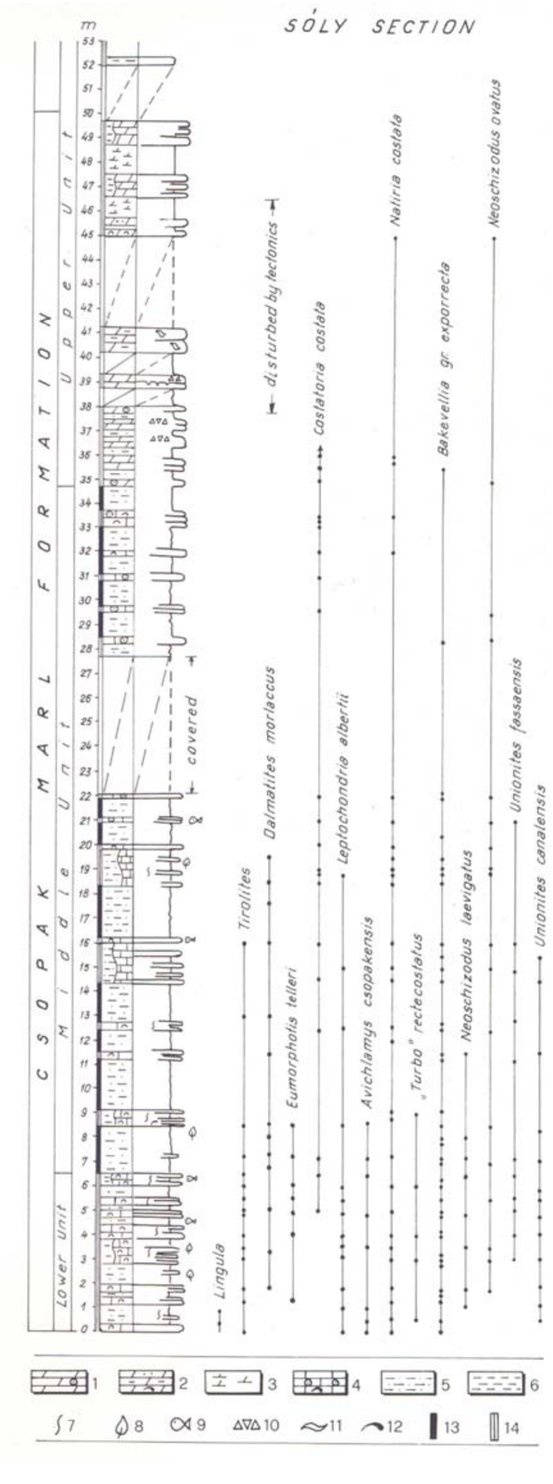
Fossils are practically missing in the exposed interval, only fragments of primitive Claraias were found in the dolomite layers. In the higher levels of the Arács Marl, the Lower Induan bivalve *Claraia clarai* was found.

Based on sporomorphs found in core-samples and the age indicator Claraia fauna, the transgression reached the Balaton Highland area in the earliest Triassic (BROGLIO LORIGA et al. 1990), whereas the topmost part of the Permian is probably missing.

Transgression near to the Permian/Triassic boundary, resulted in the flooding of the Late Permian coastal plains and alluvial plains, was triggered most probably by an eustatic sea-level rise (HAAS, BUDAI 1995).

Due to the extremely levelled topography, a significant coastal onlap took place already in the initial phase of the sea-level rise. In connection with the rapid transgression, an oolite horizon was formed at the base of the lowermost Triassic sequences. After the oolite event, three sedimentary environments were established in the area of the Transdanubian Range. In the southwestern part of the area, in a lagoon of periodically hypersaline water frequently affected by terrigenous influx, the Köveskál Formation was deposited. Northeastward, it passes into the predominantly shaly Arács Formation of intertidal to subtidal facies which further to NE is partly substituted by shallow marine carbonate facies of the Alcsútdoboz Formation.

Stop 3
Lower Triassic (Olenekian) Csopak Marl, Sóly



The Olenekian sequence of the Balaton Highland (Fig. 5) is represented by a 200 m thick, marl dominated formation. The lower member of the Csopak Marl consists of grey bioturbated marls, rich in molluscs (*Natiria costata, Turbo rectecostatus, Eumorphotis telleri, Unionites fassaensis* etc.). Open marine fossils, like ammonites (*Tirolites cassianus, Dalmatites morlaccus*) appear in the upper part of the lower member. Crinoidal and ooidic limestone interbeds (storm deposits) are common. The deepening upward open ramp succession indicates transgressive trend. The middle member of the Csopak Formation is made up of red silty marls and clayey siltstones with thin limestone interlayers. Open marine fossils (ammonites – *Dinarites*) occur mainly in the lower part of the middle member, representing most probably the maximum flooding (BUDAI, HAAS 1997).

Fig. 5 Lithostratigraphic column of the Olenekian succession at Sóly (BROGLIO-LORIGA et al. 1990). 1. dolomite (ooidic); 2. sandy, clayey dolomite; 3. dolomarl; 4. limestone (ooidic, bioclastic); 5. siltstone; 6. claystone; 7. bioturbation; 8. plant remnant; 9. fish scale; 10. collapse breccia; 11. fenestrae; 12. bivalve; 13. red; 14. grey

The upper member consists of grey, bioturbated silty marls and clayey siltsones, with limestone and dolomite interbeds. Diversity of the fauna shows a decreasing trend. Its transition towards the overlying Lower Anisian dolomites (Aszófõ Fm.) is gradual (not visible in the Sóly section).

Stop 4
Lower Anisisan Iszkahegy Limestone, Szentkereszt Hill, Felsőörs

Steeply dipping, practically vertical layers of the Lower Anisian Iszkahegy Limestone crop out on the top of the very steep, tectonically controlled northern slope of the Szentkereszt Hill. There is an excellent view from the cliff to the Malom Valley and Forrás Hill.

In the exposed interval dark grey micritic laminites alternate with thicker, bioturbated beds. These lihologies are very characteristic of the Iszkahegy Limestone.

The Iszkahegy Limestone is underlain by the lowermost Anisian Aszófő Dolomite of lagoonal and shabkha facies. It passes gradually upward into the dark grey, greyish-brown, well-stratified Iszkahegy Limestone, being generally laminated, bituminous in its lower part, and getting thick bedded and nodular upsection, locally with marl interlayers. Its microfacies is usually micritic mudstone or wackestone, with ostracodes, mollusc shells, foraminifera and subordinately echinoderm skeletons.

A subtidal, oxygene depleted lagoon may have been the depositional environment of the Iszkahegy Limestone. In the Malom Valley at Felsőörs, a monospecific ostracode assemblage indicating hypersaline environment was found in it (Monostori M. pers. com.). The trend that the predominantly anoxic laminitic facies grades upward into the bedded, bioturbated disaerobic one, may indicate a decrease in the restriction of the basin, which can be attributed to a sea-level rise.

The Iszkahegy Limestone passes upward into dolomite of lagoon facies (lower part of the Megyehegy Dolomite). This change in the lithology can be explained by increasing restriction of the basin (early highstand) probably under more arid climatic conditions.

Stop 5
Middle Anisian to Lower Ladinian basin succession of the Balaton Highland, Felsőörs, Forrás Hill

The sequence of the Forrás Hill at Felsőörs is the first and foremost Middle Triassic key section of the Balaton Highland (VÖRÖS 1993, VÖRÖS et al. 1996, MÁRTON et al. 1997, PÁLFY et al. 2003, VÖRÖS et al. 2003a). It is exposed in three, partly overlapping trenches. In the lowermost trench, the section begins with the Megyehegy Dolomite Formation (Beds 0–43) with dolomicrosparite and fine-grained dolosparite lithology. The light-grey beds of this part of the section are in contrast with the overlying yellowish-grey bituminous, banded dolomitic marls. This change in lithology suggests increasing restriction of the basin.

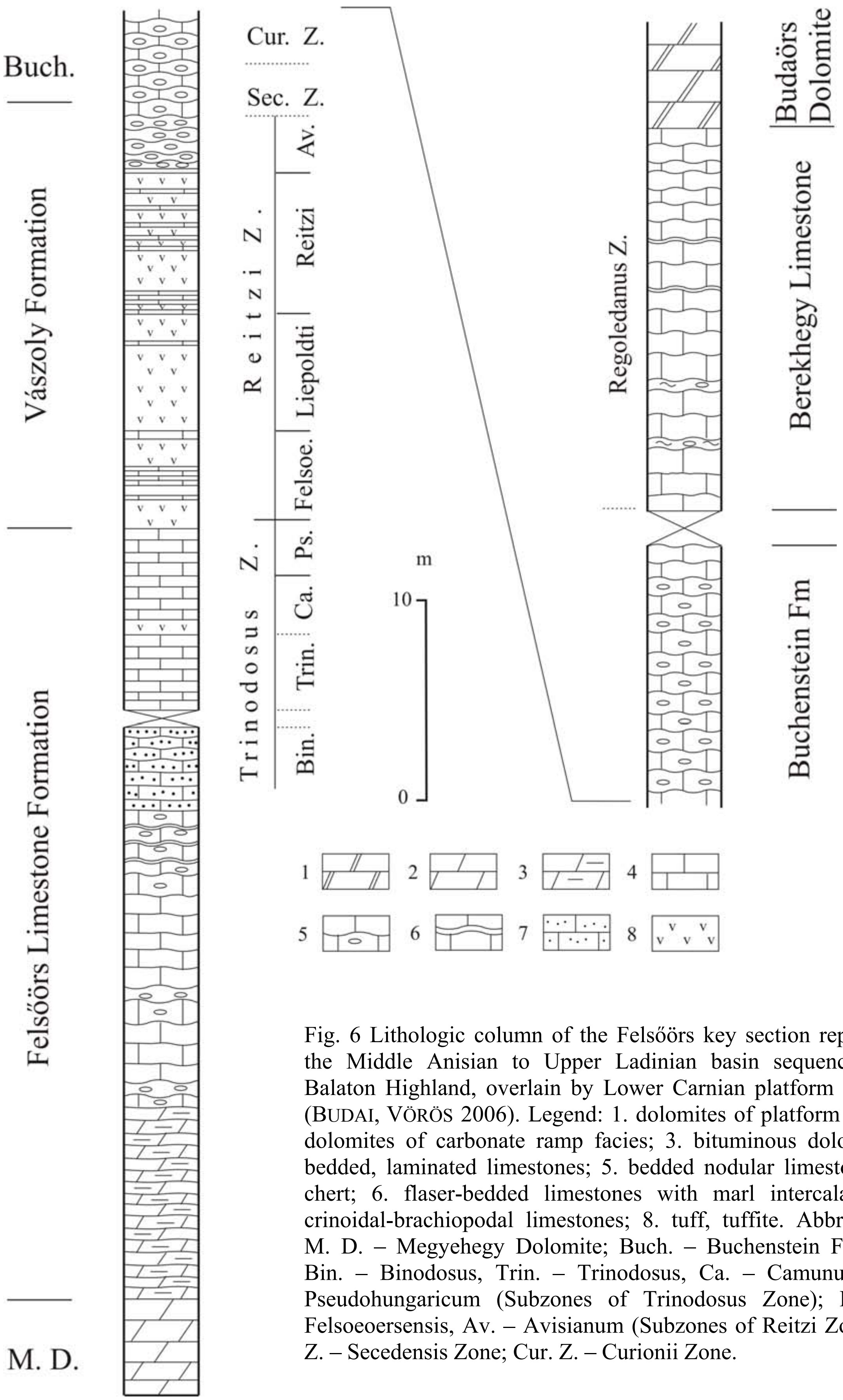


Fig. 6 Lithologic column of the Felsőörs key section representing the Middle Anisian to Upper Ladinian basin sequence of the Balaton Highland, overlain by Lower Carnian platform carbonate (BUDAI, VÖRÖS 2006). Legend: 1. dolomites of platform facies; 2. dolomites of carbonate ramp facies; 3. bituminous dolomites; 4. bedded, laminated limestones; 5. bedded nodular limestones with chert; 6. flaser-bedded limestones with marl intercalations; 7. crinoidal-brachiopodal limestones; 8. tuff, tuffite. Abbreviations: M. D. – Megyehegy Dolomite; Buch. – Buchenstein Formation; Bin. – Binodosus, Trin. – Trinodosus, Ca. – Camunum, Ps. – Pseudohungaricum (Subzones of Trinodosus Zone); Felsoe. – Felsoeoersensis, Av. – Avisianum (Subzones of Reitzi Zone); Sec. Z. – Secedensis Zone; Cur. Z. – Curionii Zone.

The next part of the section consists of grey, stratified limestone with chert nodules (Beds 44–67), representing the lower part of the Felsőörs Limestone Formation. Intercalations of slightly dolomitic, cherty, argillaceous limestones (Beds 54–55), and alternating thin-bedded marl and siliceous marl also occur. The Beds 63–71 are made up of thick-bedded to massive limestone with large chert nodules. This part of the section is represented mainly by spiculiferous biomicrites and spongolites of wackestone and packstone texture. The Middle Anisian (Upper Pelsonian) Felsőörs Limestone Formation was deposited in a low-energy environment well below the wave-base.

The Beds 68–81 represent the package of crinoidal-brachiopodal limestone. It contains a few ammonites suggesting Middle Anisian age and plenty of brachiopods (*Tetractinella trigonella, Caucasorhynchia altaplecta, Trigonirhynchella attilina, Coenothyris vulgaris* etc.).

In the trench uphill, grey, flaser-bedded limestone crops out. After a 1 m-thick tuffitic intercalation, a well-bedded sequence follows consisting of 8–20 cm thick grey limestone banks intercalated with 5–30 cm-thick yellow clay layers. Some of the limestone beds contain rich ammonite fauna (Upper Illyrian, Trinodosus Zone): *Paraceratites trinodosus, Asseretoceras camunum, Lardaroceras spp.*.

Above the Bed 99/C, tuffitic sedimentation prevails over the carbonates (Vászoly Fm.). From here up to the end of the third trench, ochre-yellow and cherty limestone appears only as thin intercalations or nodular horizons. The thick (around 18 m) tuffitic sequence consists of greenish-white, sometimes brownish-yellow potassium-trachyte tuffs, equivalent to the „pietra verde" of the Southern Alps. The limestone layers yielded characteristic ammonite association of the Reitzi Zone (*Kellnerites* spp., *Hyparpadites* sp., *Hungarites* spp. *Parakellnerites* spp., *Reitziites reitzi*). According to zircon investigations (PÁLFY et al. 2003) the radiometric age of the tuffs is between 240.5±0.5 and 241.2±0.4 Ma.

At the end of the trench, carbonate sedimentation returns in the form of pinkish-grey, nodular limestones (Buchenstein Fm.). With diminishing traces of tuffite, a thick, continuous sequence of red, cherty limestone developed (similar to the „Knollenkalke" of the Southern Alps). This typical pelagic, basinal limestone complex of Ladinian age, exposed on the hillside, provided *Chieseiceras chiesense* and *Eoprotrachyceras* cf. *curionii,* indicating the base of the Curionii Zone, i.e. the base of the Ladinian.

Stop 6
Middle Anisian platform overlain by Upper Anisian basin succession, Szentkirályszabadja, airport quarry

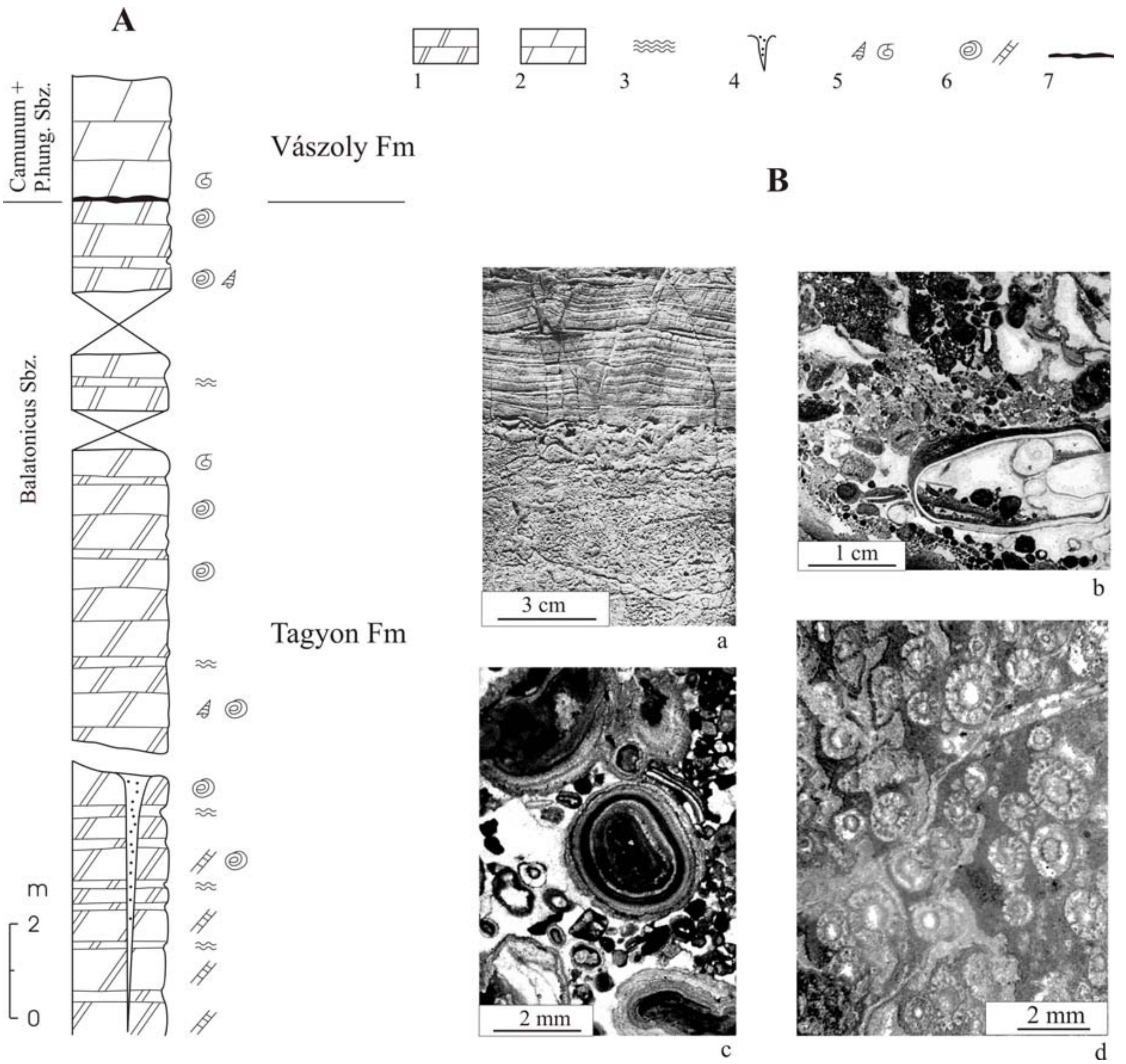


Fig. 7 – A) Lithologic column of the Tagyon Formation and the overlying Vászoly Formation in the quarry of Szentkirályszabadja (BUDAI, VÖRÖS 2006). Legend: 1. Lofer-cyclic dolomite of platform facies; 2. dolomitized limestone of basin facies; 3. stromatolite; 4. neptunian dyke; 5. gastropods, ammonites; 6. oncoids, dasyclads; 7. paleosol.
B) Characteristic facies-types of the Tagyon Formation: a. stromatolite with teepee structure (above) and oncoidal facies (below); b. ammonite shell in oncosparite; c. vadose pisoids in fine grained microoncoidal matrix; d. Dasyclads (*Physoporella pauciforata pauciforata*).

Near the local military airport, an abandoned quarry exposes the upper part of the massive or thick-bedded, dolomitised Pelsonian platform carbonate succession. The Tagyon Formation is made up by a cyclic alternation of subtidal Dasycladacean, oncoidal and laminated, locally vadose pisoidic peritidal dolomites (BUDAI et al. 1993; BUDAI, HAAS 1997). In the southern pit of the quarry a meter wide subvertical dyke penetrates the platform carbonate, which is filled by reddish micrite /microsparite containing crinoid ossicles. An ammonite (*Balatonites balatonicus*) was also found in the upper part of the dolomite proving the Pelsonian age of the platform (VÖRÖS et al. 2003b). On the northern wall of the quarry the platform series is covered by thin paleosol layer and paraconformably overlain brownish, dolomitsed ammonite bearing basinal carbonates of the Vászoly Formation representing the Trinodosus Zone (Camunum Subzone). Thus, biostratigraphic data constrain a remarkable gap between the Tagyon Formation and the overlying layers (four ammonite subzones are missing).

According to the interpretation of BUDAI, HAAS (1997) the Pelsonian platform became subaerially exposed and karstified due to the Early Illyrian relative sea-level fall. This emersion and the subsequent erosion can be correlated with the Richthofen event of the Southern Alps. Neptunian dyke was opened during the the Late Illyrian downfaulting tectonic event, probably in connection with the collapse phase of the previous updoming period (BUDAI, VÖRÖS 2006).

Stop 7
Berekhegy, road-cut and quarry

Upper Anisian to Lower Carnian platform and basin transition (Figs. 8 and 9)

Relationship of Late Ladinian platform and basin successions can be studied in the sections of Berek Hill in the neighbourhood of Hajmáskér. In the road cut of the highway No. 8 (Fig. 7) the first prograding body of the Budaörs Dolomite is overlain by red nodular limestones with tuff intercalations of the Buchenstein Fm.

This typical Ladinian basin succession is overlain by grey nodular limestones with thin marl interlayers (Berekhegy Limestone). These layers are exposed in a small abandoned quarry in a short distance N of the road cut exposures (Fig. 8).

The Berekhegy Limestone is made up by calciturbidite (allodapic limestone) layers. Grading is well visible even macroscopically. The basal part of the layers consists of coarse sand-sized carbonate lithoclasts and bioclasts of platform origin (HAAS et al. 2000). Foramiminfera: *Agglutisolenia* sp., *Austrocolomia cordevolica*, *A. marschalli, Gaudryinella* sp., *Kriptoseptida klebelsbergi*, *Meandrospirella planispira*, *Ophthalmidium plectospirus*, *O. carintum, O. exiguum, Paralingulina ploechingeri*, *Pilaminella gemerica, Reophax rudis, Schmidita inflata, Triadodiscus eomesozoicus, Turriglomina magna*, *T. carnica;* microproblematica: *Koivaella permiensis, Ladinella porata, Messopotamella angulata, Panormidella aggregata*, *Tubiphytes carinthiacus*, *T. obscurus* and *Bacinella* forms.

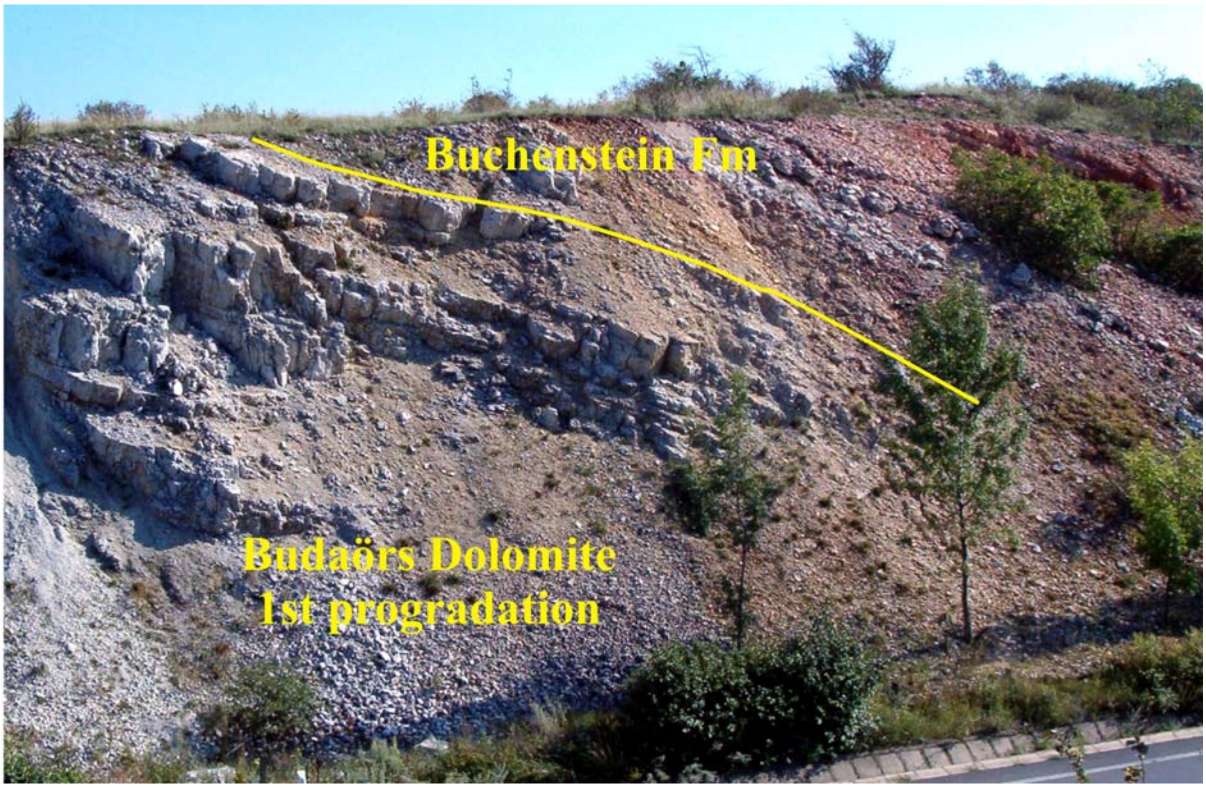


Fig. 8 Late Anisian platform overlain by Ladinian basin succession in the road-cut of Berek Hill

The topmost part of the layers is micritic, usually marly and often bioturbated. The lower part of the Berekhegy Limestone contains brachiopods and ammonites (*Celtites epolensis*) while the uppermost 3 metres of the formation was affected by late diagenetic dolomitization. It is overlain by massive dolomite of the platform facies (Budaörs Fm).

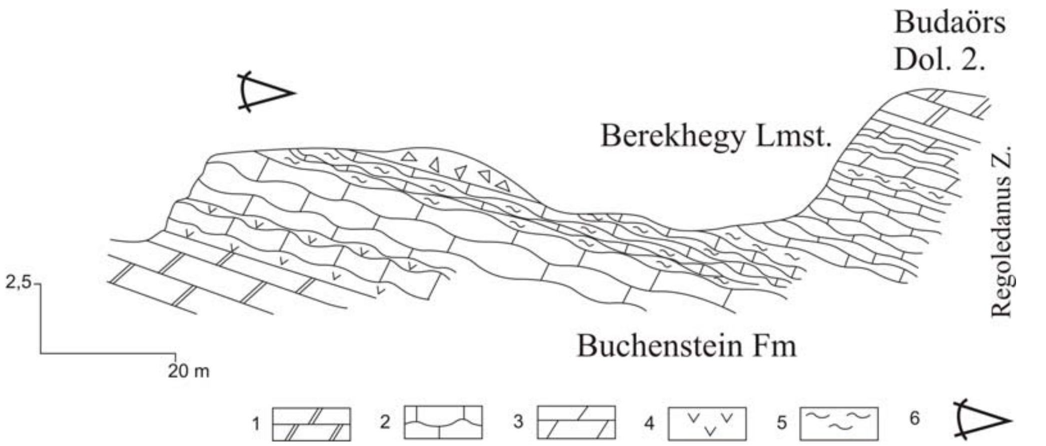


Fig. 9 Profile across the Berek-hegy quarry at Hajmáskér showing transition from the Upper Ladinian basin succession (Buchenstein Fm) through the toe-of-slope facies of Berekhegy Limestone to the Lower Carnian platform (Budaörs Dolomite) of the Veszprém plateau (BUDAI, VÖRÖS 2006). Legend: 1. dolomites of platform facies; 2. nodular limestones of basin facies; 3. dolomitized limestones; 4. tuff, tuffite; 5. marl intercalations; 6. view point to the road-cut (Fig. 8).

The turbiditic, periplatform basin succession of the Berekhegy Limestone marks the second progradation stage of the Budaörs platform in the Veszprém area. Since Upper Longobardian radiolarians were found in the lower part of the Berekhegy Limestone (HAAS et al. 2000), the progradation may have initiated in the latest Ladinian – earliest Carnian.

Stop 8
Lower Carnian basin succession of the Balaton Highland, Pécsely, Meggy Hill, quarry

On the area of the Balaton Highland the Middle Triassic basin succession is overlain by the Füred Limestone, which develops gradually from the underlying Buchenstein Formation with the decrease of the volcanites. The well bedded tabular limestone succession is built up by cyclic alternation of light grey nodular limestone beds and marl layers. Parallel with the thickening of the marl intercalations, the facies of the limestone succession shows a shallowing upward trend. The Füred Limestone is overlain by the Veszprém Marl in the basinal facies area of the Balaton Highland. Based on ammonite data (*Trachyceras aon, Dittmarites rueppeli, Sirenites* sp., *Neoprotrachyceras* etc.) and microbiostratigraphic evaluation, the age of the Füred Limestone is Early Carnian in the central part of the Balaton Highland (BUDAI et al. 1999).

At the beginning of the late Ladinian highstand period (Regoledanus Chron) the Budaörs platform intensively prograded from the Veszprém plateau to the southwest and large amount of fine carbonate particles transported to the ambient Balaton Highland basin (Füred Limestone). Platform progradation is common during this time interval in the Western Tethys, e.g. in Lombardy, in the Dolomites, in the Julian Alps, in north-western Croatia and in the Northern Calcareous Alps, as well.

Stop 9
Carnian basin succession of the Balaton Highland, Balatocsicsó, Csukrét valley

Within the Lower Carnian a significant change in the lithofacies occurs on the Balaton Highland, pelagic limestones are overlain by 800 m thick marl sequence. The lower and the upper member of the Veszprém Marl Formation is built up of dark grey, grey, thinly bedded, laminated clay marl, marl, and calcareous marl. The two thick marl sequences are separated from each other by grey, thin bedded, nodular 20 m thick pelagic limestone member (Nosztor Limestone). This cherty "filament" limestone of the basin passes towards the platforms into coarse bioclastic and lithoclastic facies, rich in brachiopods, echinoids, crinoids and sponges. The Nosztor Limestone marks the progradation of the platforms during a highstand period in the Late Julian (BUDAI, HAAS 1997, HAAS, BUDAI 1999).

The microfauna of the Mencshely and the Csicsó Marl consists of benthos Foraminifera. There are also Holothuroideas, Ophiuroideas, Echinoideas and Ostracods (GÓCZÁN et al. 1989). The Nosztor Limestone is poor in macrofauna., *Austrotrachyceras austriacum* is very rare. Conodonts are represented by *Gondolella polygnathiformis* and *Gladigondolella* sp. In the Csicsó Marl *Neoprotrachyceras baconicum, Halobia rugosa, Gonodus astartiformis, Trachyceras* sp. was found in the sequence of the Csukrét-trench.

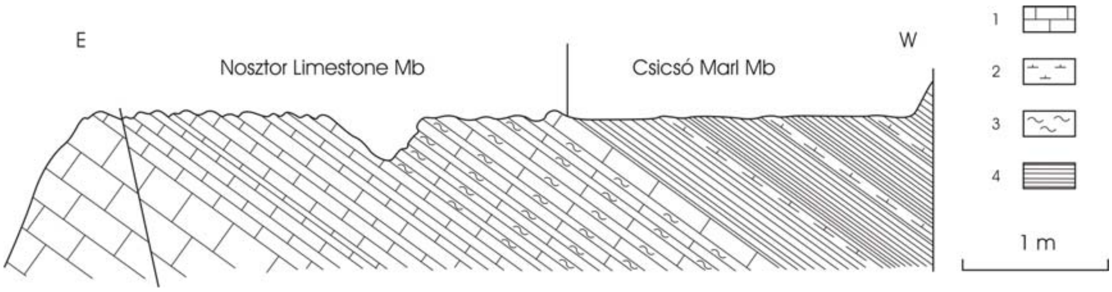


Fig. 10 Cross section of the transition from the Nosztor Limestone to the Csicsó Marl in the Csukrét valley, Balatoncsicsó (CSILLAG in BUDAI et al. 1999). 1. limestones; 2. calcareous marls; 3. marls; 4. clayey marls

Stop 10
Csopak, Nosztor valley, road-cut

Upper Carnian shallowing upward basin and platfrom succession of the Balaton Highland (Fig. 11 and 12). In the road cut of the highway no. 73. a part of the Upper Triassic sequence of the Balaton Highland can be observed. The lower part of the section shows the Upper Carnian Sándorhegy Limestone, which is the overlying formation of the 400-600 m thick Veszprém Marl of Middle Carnian age (in this section it is not represented).

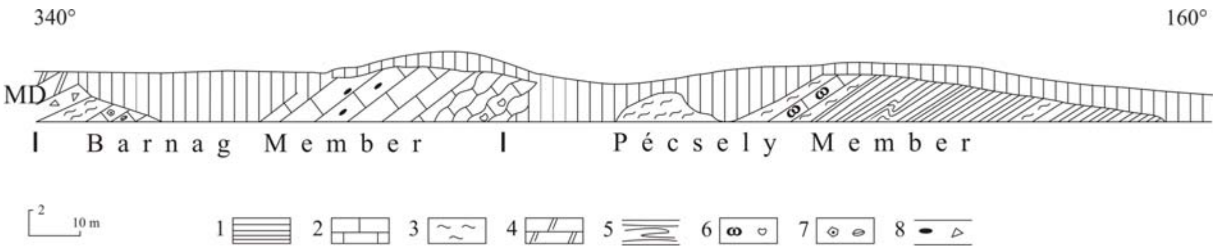


Fig. 11 Profile of the road-cut in the Nosztor valley, Csopak (TRUNKÓ et al. 2000). Legend: 1. bituminous laminite; 2. bedded limestone; 3. marl; 4. platform dolomite; 5. slump structure; 6. Cornucardia, Neomegalodon; 7. crinoid fragments, oncoids; 8. chert nodules, breccia

In the southern part of the road cut, the lower member of the Sándorhegy Formation is exposed. It is made up by laminated, bituminous limestone. Slump structures, sedimentary folds, intraclasic intercalations are common. Ganoid fish scales can be found on the bedding planes. The rich ostracode fauna is characterized by very low diversity referring to hypersalinity. Small gastropods and bivalve shell fragments are also common. Based on the facies characteristics, the lower member may have deposited on the gentle slope of a high salinity, oxygen-depleted restricted basin. A thicker megalodont-bearing (*Cornucardia hornigii*) layer is visible in the topmost part of the lower member. This may indicate the abrupt opening of the basin and it can be considered as the sign of the sea-level rise.

The bituminous limestone member is covered by a marly interval which is poorly exposed in the outcrop. It contains bivalves *Nucula* and a normal salinity Ostracode fauna.

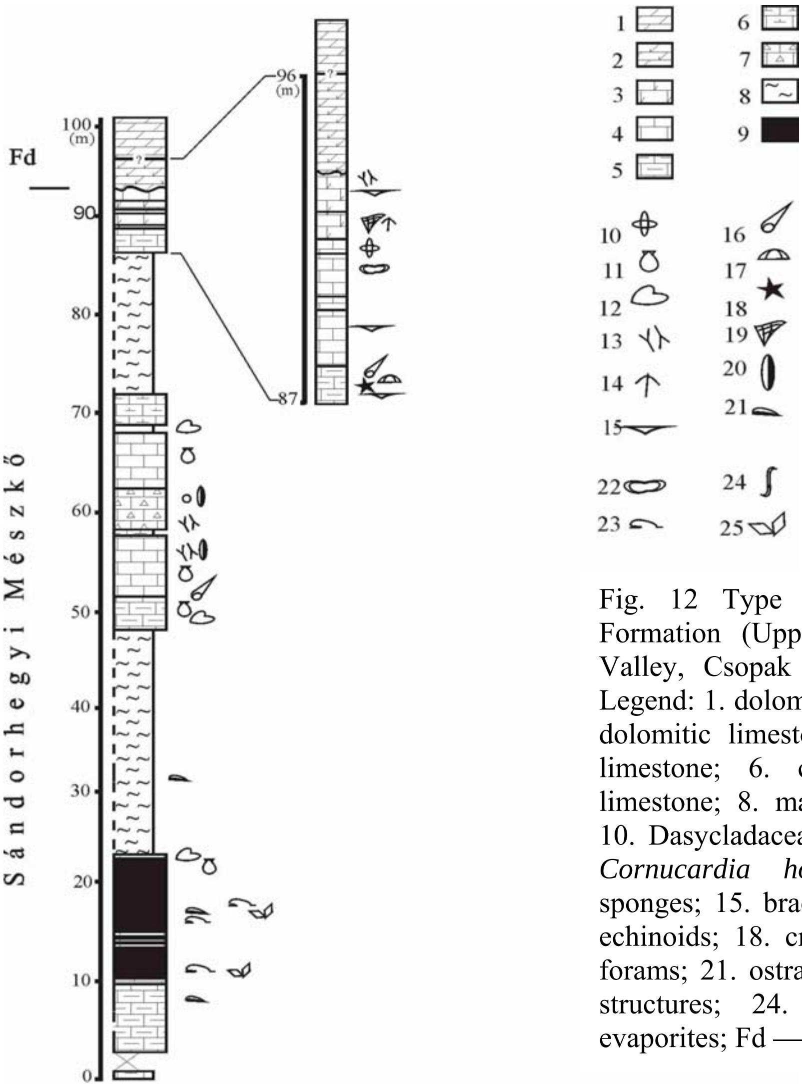


Fig. 12 Type section of the Sándorhegy Formation (Upper Carnian) in the Nosztor Valley, Csopak (after NAGY ZS. R. 1999). Legend: 1. dolomite; 2. calcareous dolomite; 3. dolomitic limestone; 4. limestone; 5. clayey limestone; 6. calcareous marl; 7. cherty limestone; 8. marl; 9. bituminous limestone; 10. Dasycladacea; 11. mollusc fragments; 12. *Cornucardia hornigii*; 13. spicules; 14. sponges; 15. brachiopods; 16. gastropods; 17. echinoids; 18. crinoids; 19. Corallinacea; 20. forams; 21. ostracods; 22. oncoids; 23. slump structures; 24. burrows; 25. vugs after evaporites; Fd — Main Dolomite Fm.

The upper member of the formation begins with nodular argillaceous limestone progressing upward into limestones of upward thickening beds. They contain gastropods and megalodonts (*Megalodus carinthiacus, Cornucardia hornigii*). Upsection, chert nodules appear in the thick limestone beds. Peloidal texture is the most characteristic, with oolitic and oncoidal interbeds becoming more frequent upwards. Benthic forams (*Aulotortus*) are abundant, sponge spicules and remnants of planktonic crinoids also occur. This litho- and biofacies refer to shallow marine, well-oxygenated environment, with upward shallowing trend. It represents the last stage of the filling up of the Balaton Highland intraplatform basin, giving rise of the progradation of the platforms during the highstand interval (BUDAI, HAAS 1997).

Upsection, following a short poorly exposed marly interval, limestone beds rich in brachipods, remnants of echinoderms and oncoids occur. In addition to benthic foraminifera, dasycladacean algae were also observed in these beds. Based on the megalodonts and the foraminifer assemblage, the upper member can be emplaced in the lower part of the Tuvalian.

Between the Sándorhegy Formation and the overlying Main Dolomite, a reddish-lilac argillaceous layer is visible. This probably indicates subaerial weathering. Just under this horizon, small filled in cavities, probably of paleokarstic origin can be found, whereas breccias are visible at the base of the reddish layer. These phenomena refer to a gap and subaerial erosion between the two formations.

At the northern end of the road cut, light grey dolomite beds crop out, representing the lowermost part of the about 1000 m-thick Main Dolomite.

Stop 11

Upper Carnian to Norian platform of the Transdanubian Range, Veszprém, Aranyos valley

The abandoned quarry is located in the outskirts of Veszprém, beside the highway No. 8. It exposes the lower portion of the about 1000 m-thick Main Dolomite, which is actually the lower part of the 2 km-thick Late Triassic platform carbonate succession. According to the data of Veszprém-1 core, drilled in a distance of 50 m from the quarry, the dolomite is underlain by the Sándorhegy Formation.

In the southern wall of the quarry the cyclicity of the dolomite succession is clearly visible. The succession is made up by alternation of thicker subtidal beds with megalodonts (*Megalodus carinthiacus* Hauer) and gastropods as well as thinner, peritidal microbial mat (stomatolite) layers (Lofer cyclicity). At the base of the wall, the details of the facies characteristics and their succession can also be studied. The bed No. 53 is oncoidal dolomite. It grades upward into the peritidal bed No. 52. In the topmost part of this bed a storm horizon with reworked fossils and rip-ups are visible. It is covered by a slightly uneven erosional surface and a few cm-thick brecciated layer of pinkish colour. It can be considered as a sign of the subaerial exposure. Then, a thin stromatolite layer follows (bed No. 51), which is covered by subtidal facies again. The dolomitization of these beds may have taken place just after the deposition of a new cycle during the lowstand intervals in the widely extended supratidal zone under semiarid climatic conditions. Based on the megalodonts, the age of the exposed section is Late Tuvalian.

SECOND PART

Geology of Southern Transdanubia

In the Mecsek region (Fig. 13) the crystalline basement is composed of Early Paleozoic – Lower Carboniferous granites, migmatite, clay slate, phyllite and serpentinite. South of the mountains these rocks are unconformably overlain by Upper Carboniferous terrigenous sandstones, in the Mecsek by Permian continental deposits. The continuous Permian – Early Triassic terrigenous clastic sedimentation was followed by marine clastics in the late Early Triassic then by carbonate accumulation in the Middle Triassic. During the Late Triassic – partly terrigenous – clastic sedimentation returned.

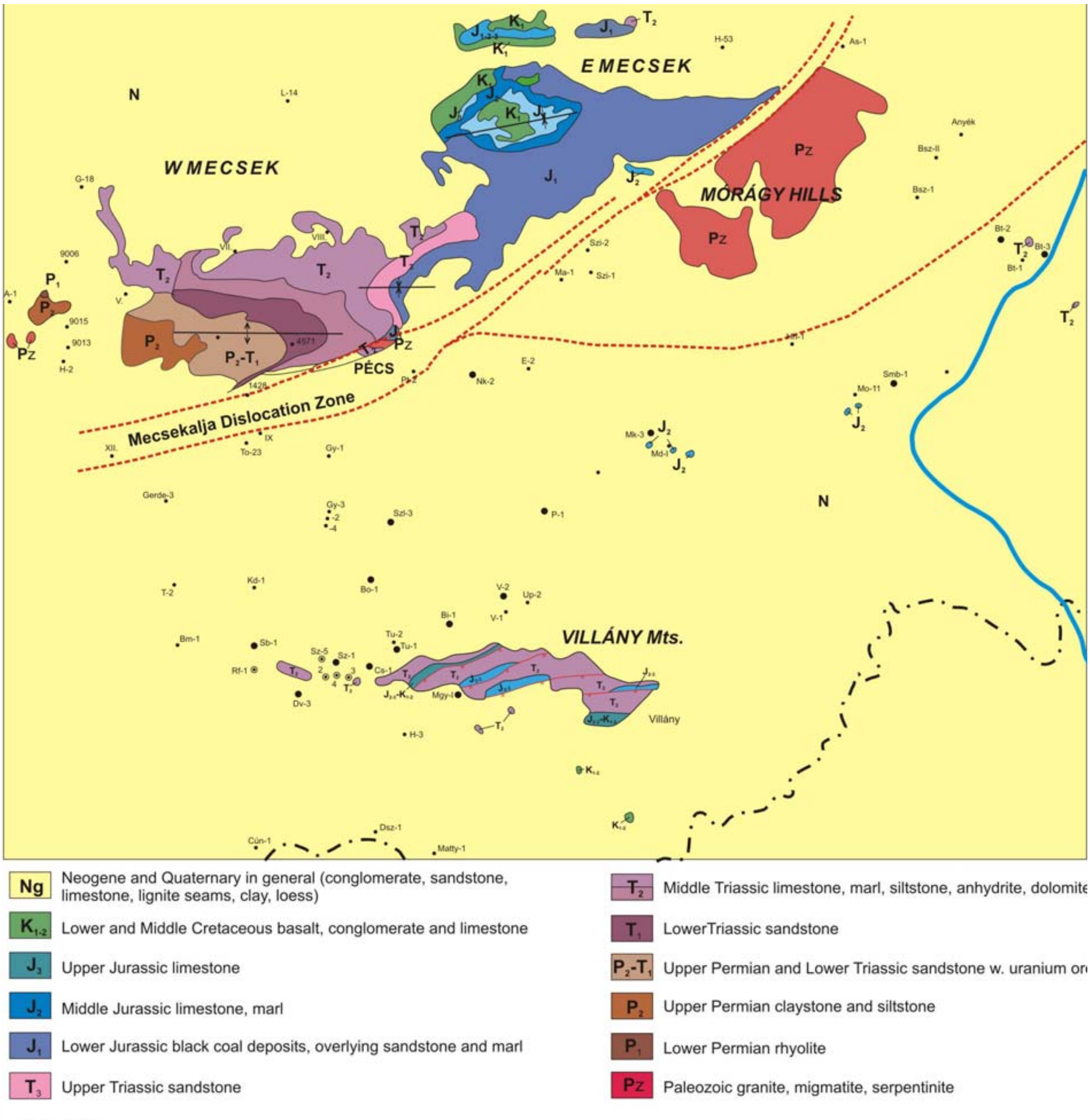


Fig. 13. Geology of SE Transdanubia

Around the end of the Triassic and in the Early Jurassic, a Gresten-type paralic coal sequence accumulated, while in the Middle and Upper Jurassic and in the Early Cretaceous pelagic sediments dominated. The Early Cretaceous was a time of basaltic volcanism, while the Middle Cretaceous of orogeny. The folded Permian–Mesozoic sequence is overlain by Miocene sediments after a remarkable unconformity.

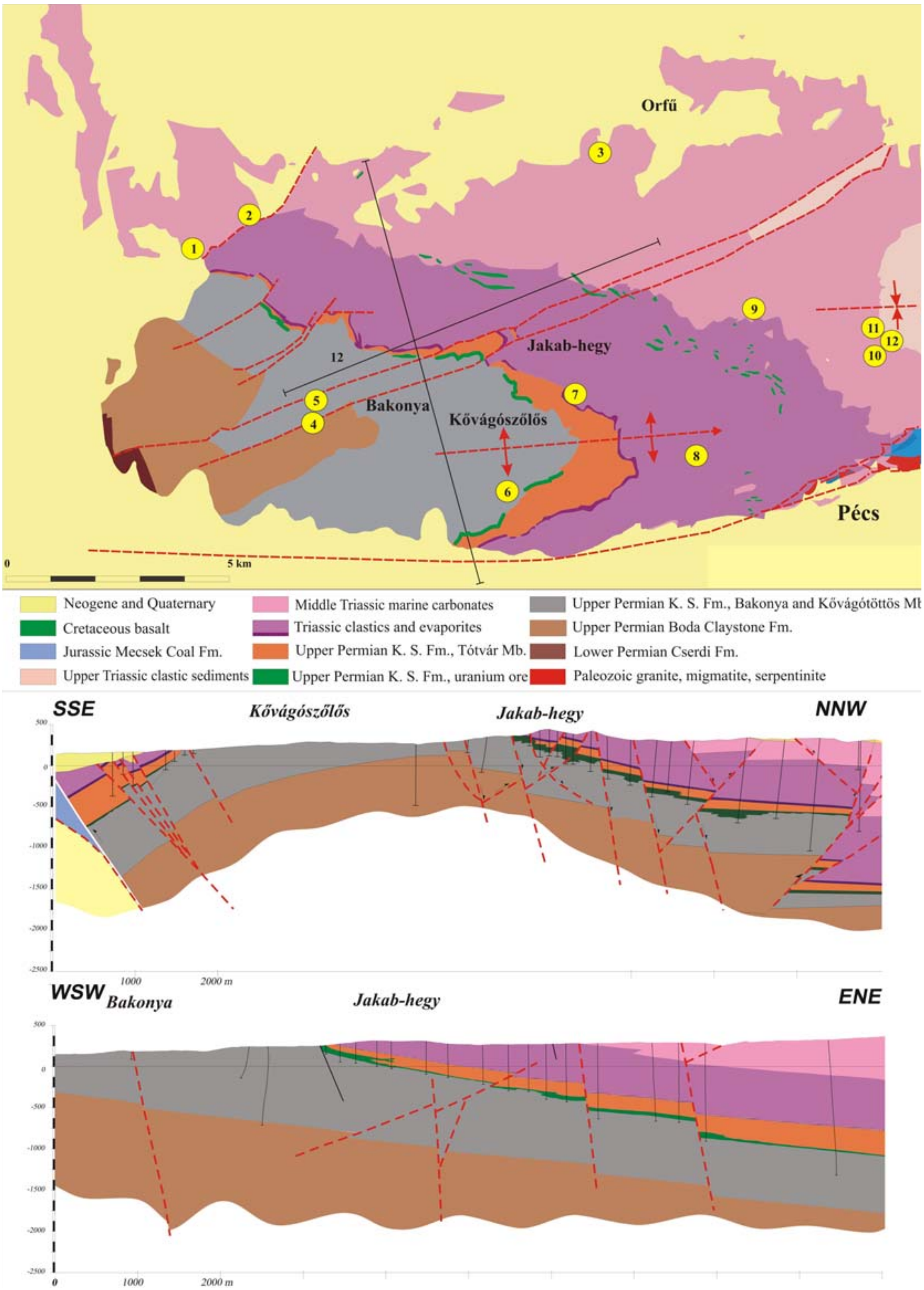


Fig. 14.: Geology of the Western Mecsek Mts. with the location of the field trip stops

The main structural characteristics of the area formed during the Cretaceous. The Eastern Mecsek is basically composed of a synclinal, the Western by an eastward dipping perianticlinal structure (Fig. 13). The imbricate structure of the Villány Mts. is also a product of the Cretaceous orogeny. The best exposures of the Permo-Triassic sequence are located within the W Mecsek anticline (Fig. 14).

Permo-Triassic stratigraphy and evolution of the Mecsek Mts.

The Early Permian molasse sedimentation (the fluvial Korpád Sandstone Fm.) was interrupted by continental rifting related rhyolite volcanism (Gyűrűfű Rhyolite), then the returning fluvial accumulation (Cserdi Fm.) changed into lacustrine (Boda Claystone) (Fig. 15.). After that, a fluvial sequence (Kővágószőlős Sandstone Fm.) was deposited in the Late Permian; its uppermost unit (Tótvár Sandstone) extends into the Early Triassic.

The Kővágószőlős Sandstone is overlain by the faunaless, Buntsandstein-type Jakabhegy Sandstone Fm. after a gap and erosional unconformity (Fig. 16). Its basal conglomerate and lower, cross-bedded, gravelly sandstone turned out to be fluvial, while the II. conglomerate level and the overlying sandstones are marine. It is covered by the intertidal Patacs Fm. Probably because of a climate change the amount of terrigenous clastics arriving into the basin decreased and a sabkha facies formed (Hetvehely Fm.). The latter two units correspond to the Röt. The sea level rise then resulted in a Wellenkalk-type carbonate sequence, Viganvár and Lapis Limestones. Between the two formations a regression event created the Rókahegy Dolomite. The Pelsonian-Illyrian Zuhánya Limestone marks the deepest water within the Triassic; the area also became tectonically differentiated at the time. This was followed by a similar dolomitic facies in the Western Mecsek (Csukma Dolomite with lofer cycles) and in the Villány Mts. In the latter area, it was overlain by dolomitic marls (Templomhegy Dolomite Member) then by Carpathian Keuper-type sandstones (Mészhegy Sandstone Fm.). In the central part of the Mecsek, a littoral ooidal, cross-bedded limestone (Kozár Limestone) was deposited instead of the dolomite. During the Ladinian the Mecsek area was uplifted and an erosional unconformity was formed, only small patches of terrigenous siderite and clay accumulated with a thickness of a few metres. The next sedimentary cycle started with an oncoidal – Trigonodus-bearing limestone (Kisrét Lmst.) and continued with lacustrine calcareous marls (Kantavár Calcareous Marl). The amount of terrigenous clastics was gradually increasing to convert into a fluvial, lacustrine, shallow marine sandstone sequence (Karolinavölgy Sandstone). A coal-bearing paralic sandstone (Mecsek Coal Fm.) is known from the Upper Triassic, the deposition of which continued in the Early Jurassic as well.

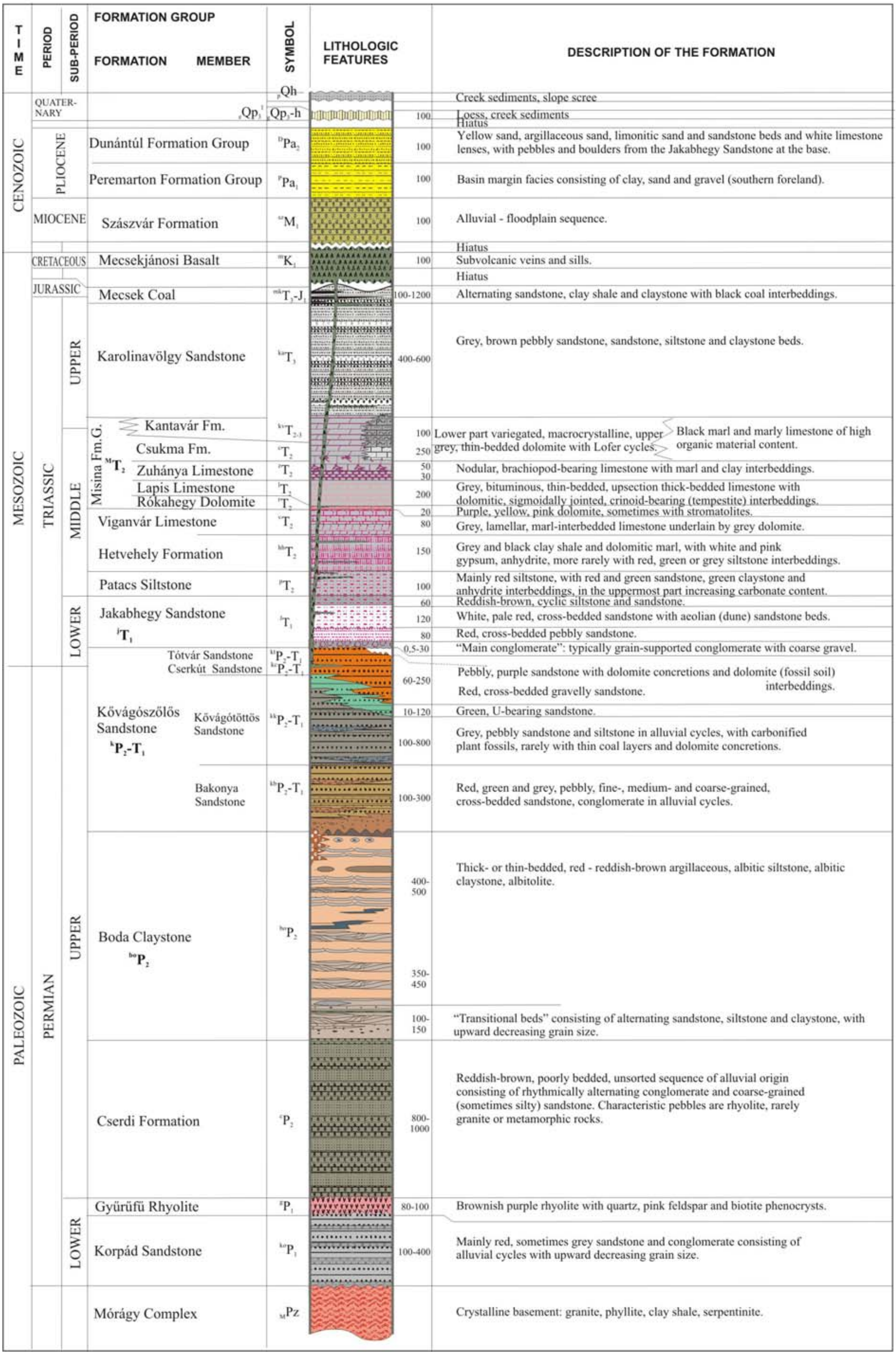


Fig. 15. Stratigraphy of the W Mecsek Mts.

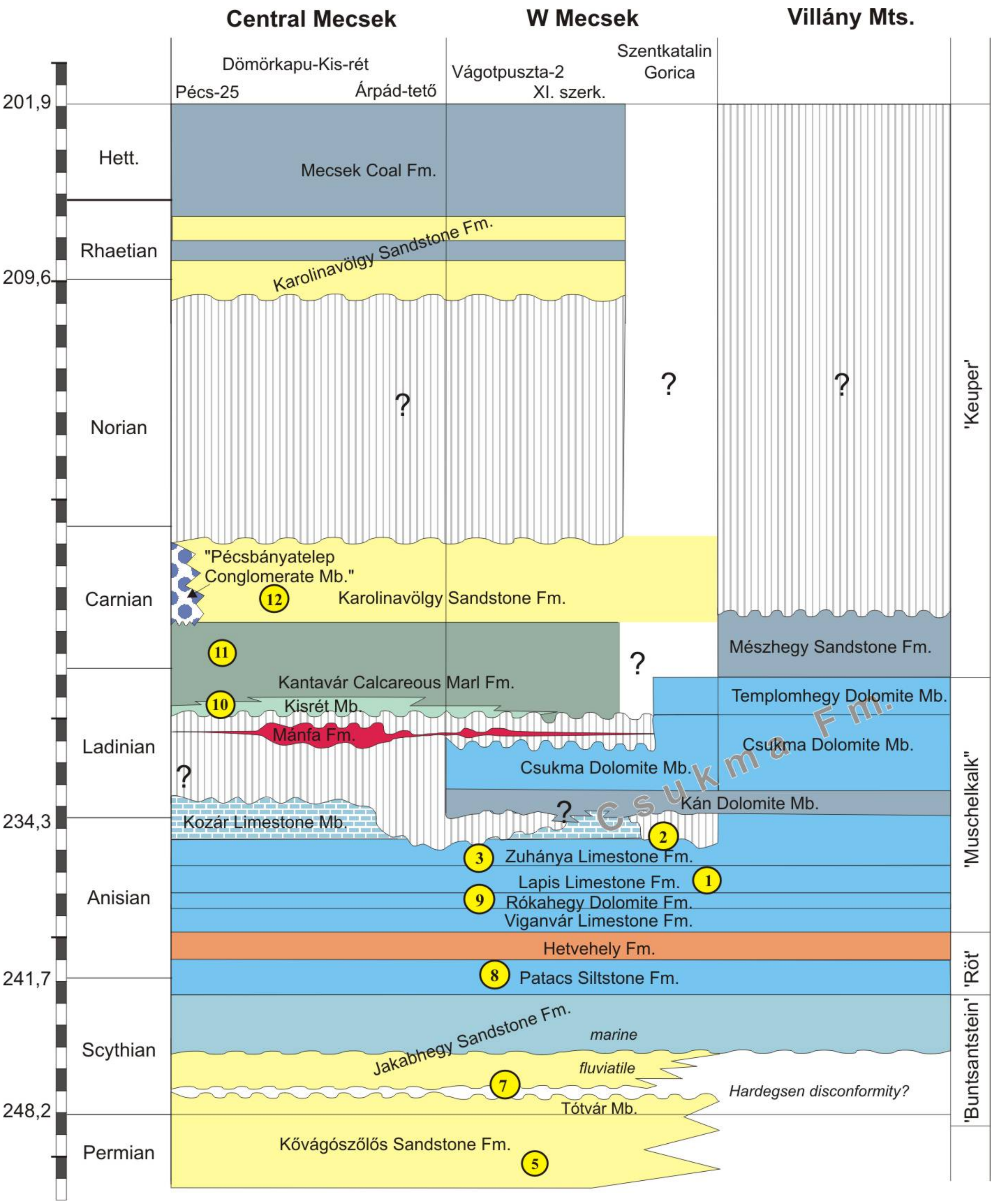


Fig. 16. Permo-Triassic lithostratigraphy of Southern Transdanubia (with the number of the field trip stops)

Excursion

Stop 1
Bükkösd, old quarry: Middle Anisian carbonate ramp (Lapis Limestone)

The abandoned old quarry of Bükkösd is located on the NE margin of the village, E of the railway. It exposes nearly the complete sequence of the Middle Anisian Lapis Limestone.

The formation accumulated in the shallow subtidal zone of a homoclinal carbonate ramp and represents the Wellenkalk in the area. Its varied lithofacies show primarily inner and mid-ramp deposition mostly above the storm wave base (Fig. 17.).

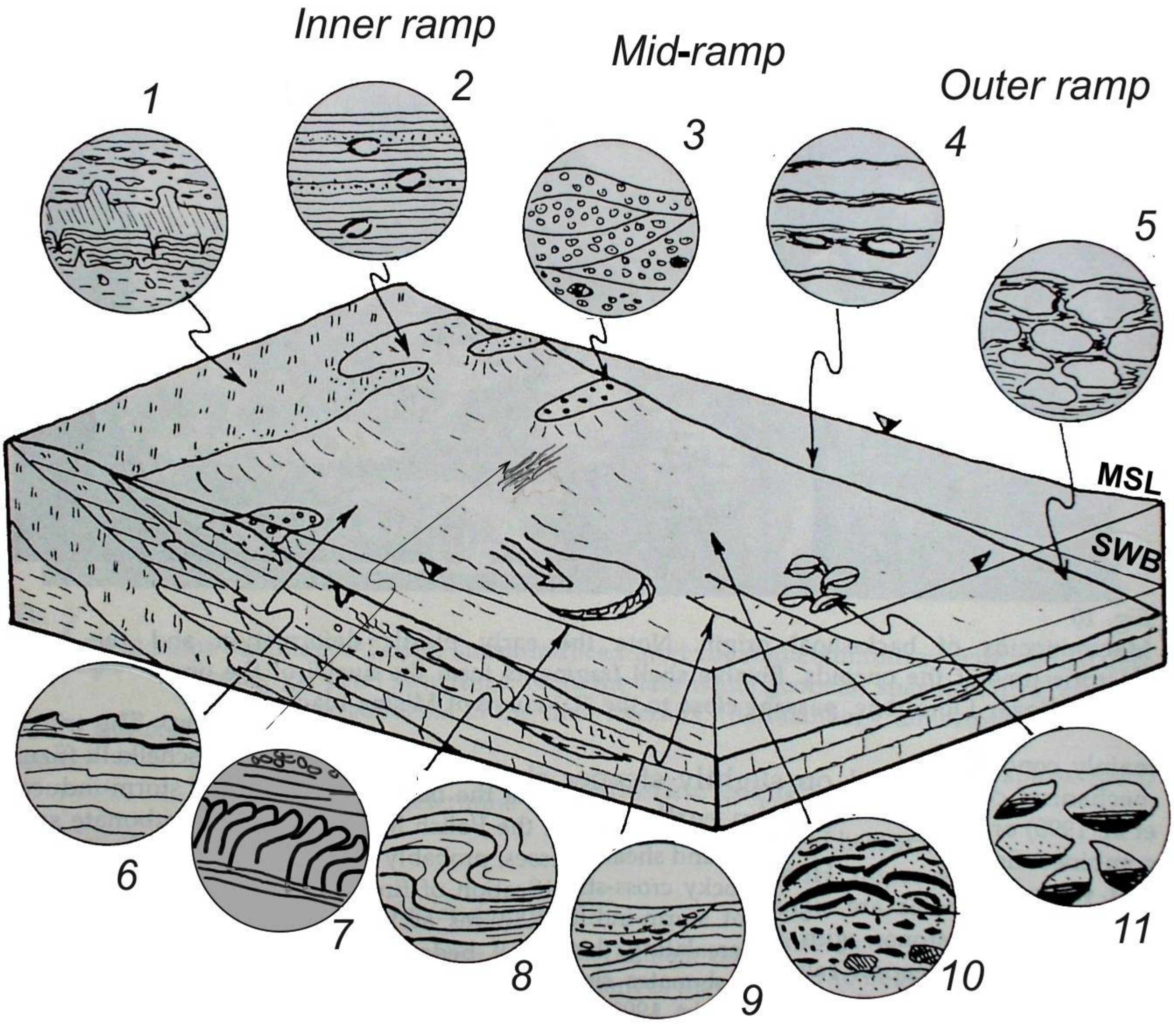


Fig. 17. Sedimentary facies of the storm-dominated carbonate ramp (after TÖRÖK 1997, modified)
1: Sabkha evaporites with enterolithic-nodular anhydrite (Hetvehely Fm.); 2: Lagoonal/lacustrine laminated, bituminous marl with ostracods (Kantavár Fm.); 3: Cross-bedded crinoidal-ooidal shoal (Kozár Lmst.); 4: Alternating limestone and claymarl beds with trace fossils (Lapis Lmst.); 5. Brachiopod-bearing nodular limestone (Zuhánya Lmst.); 6: Ripple-marked layers with hummocky cross-stratification (Kozár and Lapis Limestones); 7. Limestone with sigmoidal jointing (Lapis Fm.); 8: Slump (Lapis and Zuhánya Fms.); 9: Channel structure (Lapis and Zuhánya Fms.); 10: Tempestite with graded crinoid remnants and imbricated bivalve and brachiopod shells (Viganvár, Lapis, Zuhánya and Kozár Fms.); 11: Parautochtonous brachiopods with geopetal structure (Zuhánya Lmst.). MSL: mean sea level; SWB: storm wave base.

Proximal areas are characterised by bioclastic tempestite lenses of usually uniform composition, where crinoid ossicles and gastropod and bivalve shells rarely mix. Gutter casts, hummocky cross lamination and sporadic ripple marks also refer to storm-generated flow. More distal tempestites can appear as turbidite floatstones with bivalve shells or as micrograded beds with hardly any bioclasts (TÖRÖK 1998). The thin, wavy limestone layers separated by clayey films are distal mid-ramp deposits of quiet (stormless) periods. Similarly to other German Triassic areas, beds with sigmoidal jointing are also common (Fig. 18B), though their seismic (SCHWARZ 1975) or biogenic (*Platella* stromatolite?) origin is still debated (KONRÁD 1997). Beds with preserved ichnofossils show a relatively well-oxygenated seafloor but not very diverse benthic fauna, while the typical nodular limestones (authigenic breccias?) were formed by the rip-up and redeposition of bioturbated beds. At several spots, slumps caused syndepositional deformation.

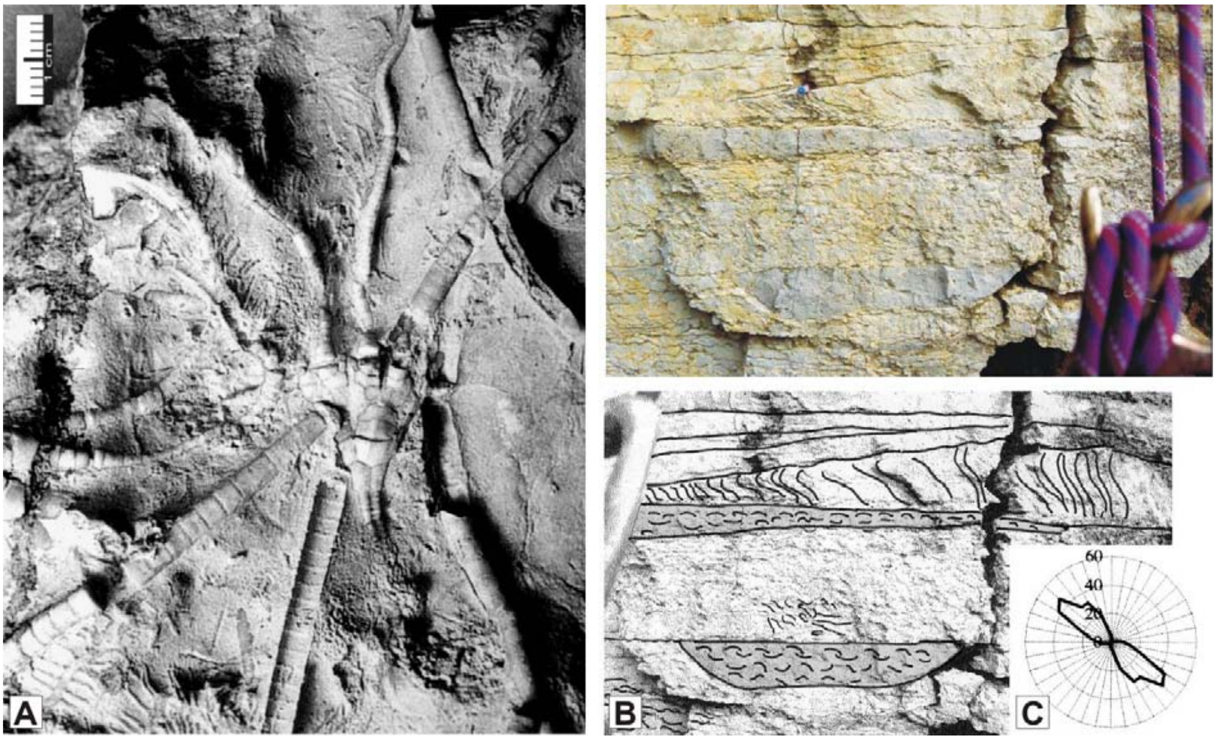


Fig.18. A. *Dadocrinus* sp.; B. supposed *Platella* bioherm in the Lapis Limestone; C. strike orientation of the sigmoidal jointing (n=240)

The upper part of the formation (Tubes Limestone Member) is thick-bedded, its crinoidal and ooidal banks and hummocky cross-stratification refer to inner ramp sediments redeposited from sublittoral sand shoals and show a relative sea level fall (HAAS et al. 2002).

The dominant elements of the usually poorly preserved macrofauna are Bivalvia (*Entolium discites, Homomya albertii, Modiola triquetra, Myophoria* spp., *Entolium discites*), Gastropoda (*Naticella* sp.), Brachiopoda (*Coenothyris vulgaris*) and Echinodermata

(*Dadocrinus* sp.) remnants, but a well-preserved Dadocrinus sp. (calyx with arms; Fig. 18A) was also found. The most common ichnofossil is *Rhyzocorallium* cf. *commune* but *Thalassinoides* and *Balanoglossites* also occur. Based on crinoids, HAGDORN et al. (1997) determined the age of the Lapis Limestone as Bithynian and Early Pelsonian (dadocrinus and acutangulus biozones).

Stop 2
Kán Valley, road cut: Middle Anisian outer ramp (Zuhánya Limestone) and platform carbonate (Kán Dolomite)

The road cut exposes the boundary between the Zuhánya Limestone and Csukma Formations (Fig. 19). The intraclast limestone of the Zuhánya Fm. is overlain by crinoidal limestone banks dolomitised in the upper part. This is covered by a dolomite sequence of 200-280 m.

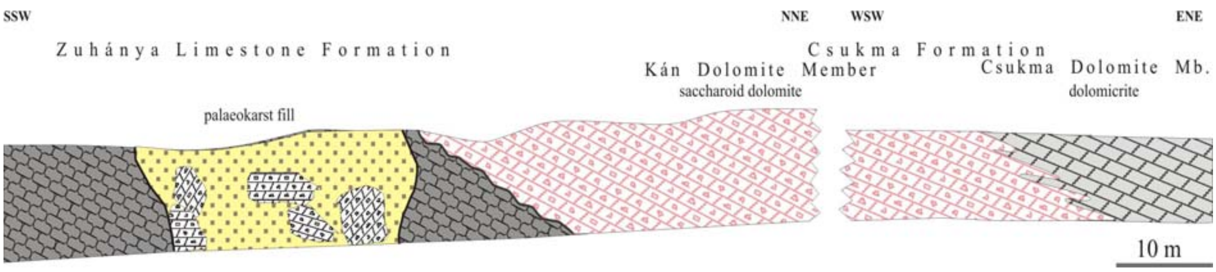


Fig. 19. Geological profile of the Kán Valley road cut

The dolomite is classified as Csukma Fm. and is widespread in the Villány and W Mecsek Mts. Its 80 m thick lower part (Kán Dolomite Member) has variegated colours, white, yellow, purple, it is coarsely crystalline, porous, with a disturbed structure. This is followed by a microcrystalline, light grey, thin- to thick-bedded dolomite (Csukma Dolomite Member) showing relict structures from Lofer cycles in polished sections (unit 'A' paleosol, unit 'B' stromatolite) (Fig. 20).

The upper part of the sequence contains green, clayey interbeddings of a still unclear origin; WÉBER (1965) described it as volcanic material. The member is 200 m thick in the Kán Valley.

In the lower unit of the Kán Dolomite, the relict texture and structure of the underlying formations can be recognised. RÁLISCHNÉ FELGENHAUER and TÖRÖK (1993) consider the entire formation a dolomitised variety of the Kozár Limestone.

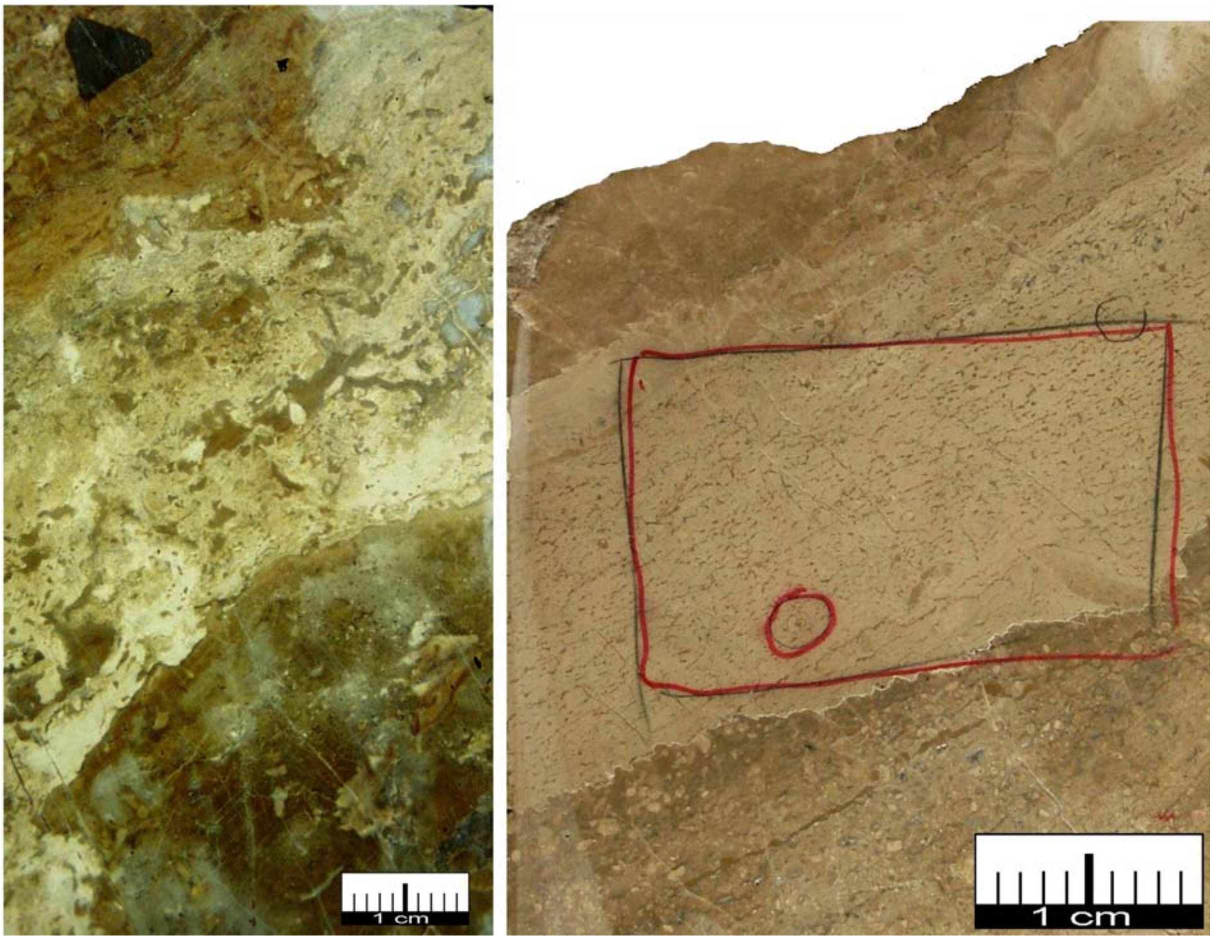


Fig. 20. Unit A and B from a Lofer cycle in the Csukma Dolomite in borehole Máriagyűd-1, 352 and 353 m.

However, Kozár Limestone is only known in the central part of the Mecsek Mts., and the Csukma Dolomite contains Lofer cycles and green clays, i.e. lithofacies unknown in the former. The borehole Gálosfa-1 drilled a few km to the NW from the present exposure traversed the Csukma Fm. in a thickness of 272 m. The borehole sequence contained several occurrences of sediment structures indicative of sabkha facies (Fig. 21).

All these led KONRÁD (1998) to the opinion that a carbonate platform formed in the background of the Middle Triassic reef facies know S of the Mecsek-Villány area (BLEAHU et al. 1994). Periods of low sea level produced a sabkha environment that facilitated the dolomitisation of the platform limestone.

The upper boundary of the formation is only known in the Villány Mts. There – with the increase of clay content – the Csukma Dolomite Member evolves into dolomarls (Templomhegy Dolomite Mb.), which is then followed by the Mészhegy Fm. The relationship of the formation to the Kantavár Fm. known only in the Mecsek Mts. is still unclear; probably Kantavár Fm. and Templomhegy Dolomite are heteropic facies.

Fig. 21. Enterolithic dolomite (after anhydrite?) from the borehole Gálosfa-1, 1207 m.

The gap between Zuhánya Lmst./Csukma Fm. and Kozár Limestone/Kantavár Fm. refers to a sea level fall that corresponds to the Middle Muschelkalk evaporitic level.

No stratigraphically useful fossils have been found in the formation. From the dolomite Saurus vertebrae and *Semionotus* scales, from the Kozár Limestone Mb. radiolarians, foraminifers (*Trocholina* sp., *Frondicularia* sp.) and ammonites (*Ceratites* cf. *thüilleri* Opp.; *Ceratites* sp.) are known.

Stop 3

Orfű, Sárkány-kút: Middle Anisian outer ramp (Zuhánya Limestone)

The small valley west of the ephemeral karst spring 'Sárkány-kút' exposes Zuhánya Limestone, which represents the highest sea level of the Muschelkalk within the Tisza Unit.

Based on its key section on the slope of Misina hill, the formation was divided into two members (NAGY 1968): the brachiopod-bearing, nodular Bertalanhegy Limestone and the yellow mottled Dömörkapu Limestone. Other sites in the Mecsek (e.g. this exposure) and Villány Mts. do not support this division, as the characteristics of the two members frequently mix within the sequences, and the identical fauna does not indicate age differences either. The formation corresponds to the German (lower) Terebratula beds.

The formation was deposited on the central and outer sections of the same homoclinal carbonate ramp as Lapis Limestone (Fig. 17.). The relative sea level rise can be explained by the subsidence of the passive European margin due to Tethyan rifting, which process also seems to be responsible for the tectonic disintegration of the ramp (KONRÁD 1998; Fig. 22). Gravitational slope deposits (like several m thick slumps or the pre-diagenetic redeposition of the lime mud nodules) as well as the co-occurrence of shallow- and deep-water sediments (e.g. calcite pseudomorphs after gypsum and celestine and nodular marly limestones) or of features from oxidising and hypoxic/anoxic environments (e.g. brachiopod shells with limonitic calcite infillings, Coenothyris-banks and bitumen lenses) can refer to considerable submarine relief and to occasionally restricted circulation.

The typical lithofacies are: brachiopod- and bivalve-dominated coquinas; calcareous marls with limestone nodules; and the alternation of wavy limestone and marl layers. The coquinas can be proximal mid-ramp tempestites composed of disarticulated shells or 'parautochtonous' distal tempestites where the brachiopod community was buried by storm-generated mud flows (TÖRÖK 1993), though the latter may have also been redeposited (SEBE 2000). Nodular limestones were formed by redeposition, while wavy, bedded marly limestones with calcite-filled fissures and load casts show the effect of lithostatic pressure.

Within the Tisza Unit, only the Zuhánya Limestone contains pelagic faunal elements: ammonites (*Ceratites binodosus*, *Paraceratites*, *Acrocordiceras* and *Orthoceras* spp.; NAGY 1968, VÖRÖS 2000 ex. verb.), a nautilus (*Germanonautilus salinarius*), conodonts, radiolarians and some ostracod and sponge remnants. Brachiopods are dominated by *Coenothyris vulgaris*, other common species are *Tetractinella trigonella* and *Punctospirella fragilis*; in the present exposure also a *Glottidia tenuissima* was found in life position. Bivalves (e.g. *Hoernesia socialis*, *Plagiostoma lineatum*, *P. striatum*, *Enantiostreon difforme, Pseudocorbula gregaria*) are primarily epibenthic or semi-inbenthic (SZENTE 1997). *Placunopsis ostracina* encrustations are common; however, the *Placunopsis* bioherms typical of the German Basin do not occur here. Crinoids are represented by the stratigraphically important taxa *Eckicrinus radiatus*, *Holocrinus acutangulus, H. dubius* and *Dadocrinus* sp. (HAGDORN et al. 1997).

Based on the conodont association *Gondolella bifurcata, G. bifurcata hanbulogi* and *G. bulgarica*, the formation is dated as Upper Pelsonian (not entering the *Paraceratites trinodosus* zone; KOVÁCS–PAPSOVÂ 1986). The foraminifer *Glomospira densa* and the crinoids (HAGDORN et al. 1997) shows that the fossil-bearing beds belong to the Pelsonian and (Lower) Illyrian.

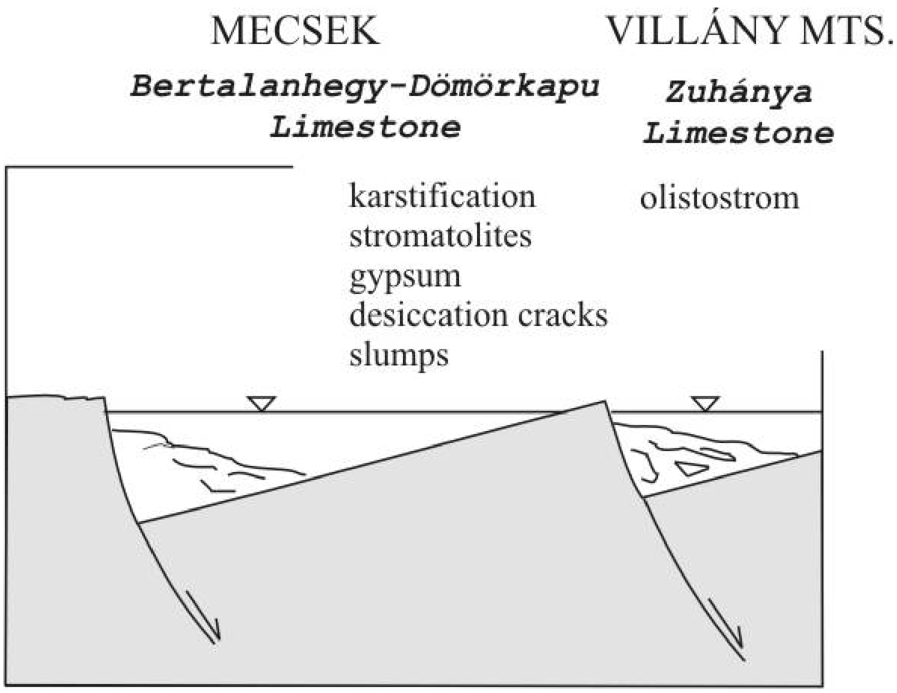


Fig. 22. A model for the tectonic differentiation of the ramp (KONRÁD 1998)

Stop 4

Boda: Upper Permian playa lake (key section of Boda Claystone Formation)

The exposure on the southern margin of the village gives insight into the upper third of the Boda Claystone (Fig. 23); the outcrop in the centre of the settlement (Fig. 24) also represents the upper part of the formation with a typical lithofacies of desiccated, laminated dolomite.

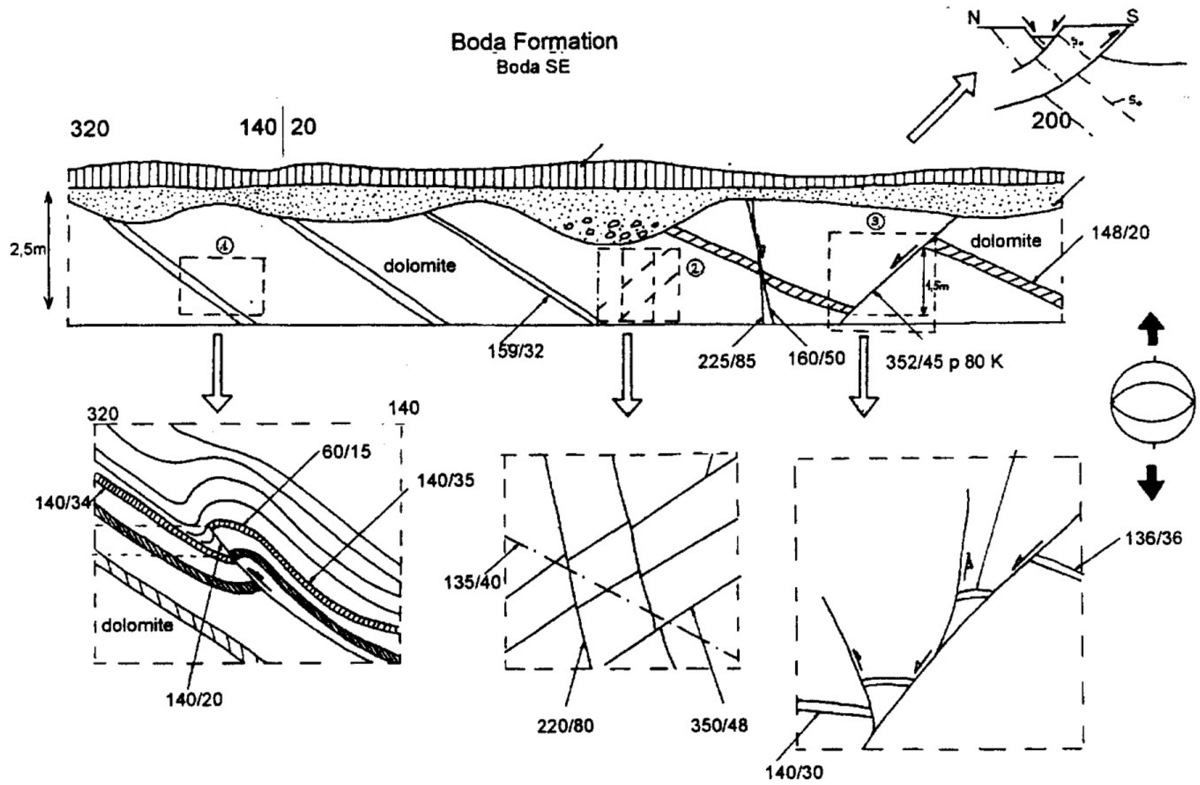


Fig. 23. The exposure of Boda Claystone on the southern margin of Boda village.

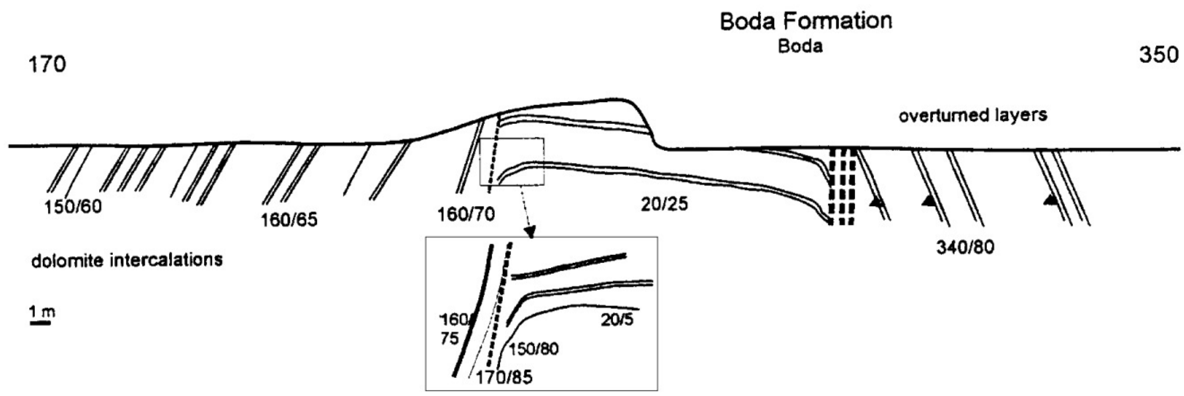


Fig. 24. The outcrop of Boda Claystone in the centre of the village.

Geological mapping allowed the distinguishing of three main units within the formation (Fig. 25):

- Lower, 'transitional' sandstone (100 to 150 m), characterised by fine-grained sandstone beds.
- Middle albitic claystone-siltstone with sandstone beds (350 to 450 m). It is characterised by cm or dm thick micaceous siltstone and fine-grained sandstone beds.
- Upper claystone, albitic clayey siltstone and silty claystone with dolomite and siltstone beds, with desiccation cracks and in the upper part of the sequence with septarian dolomite concretions (400 to 500 m).

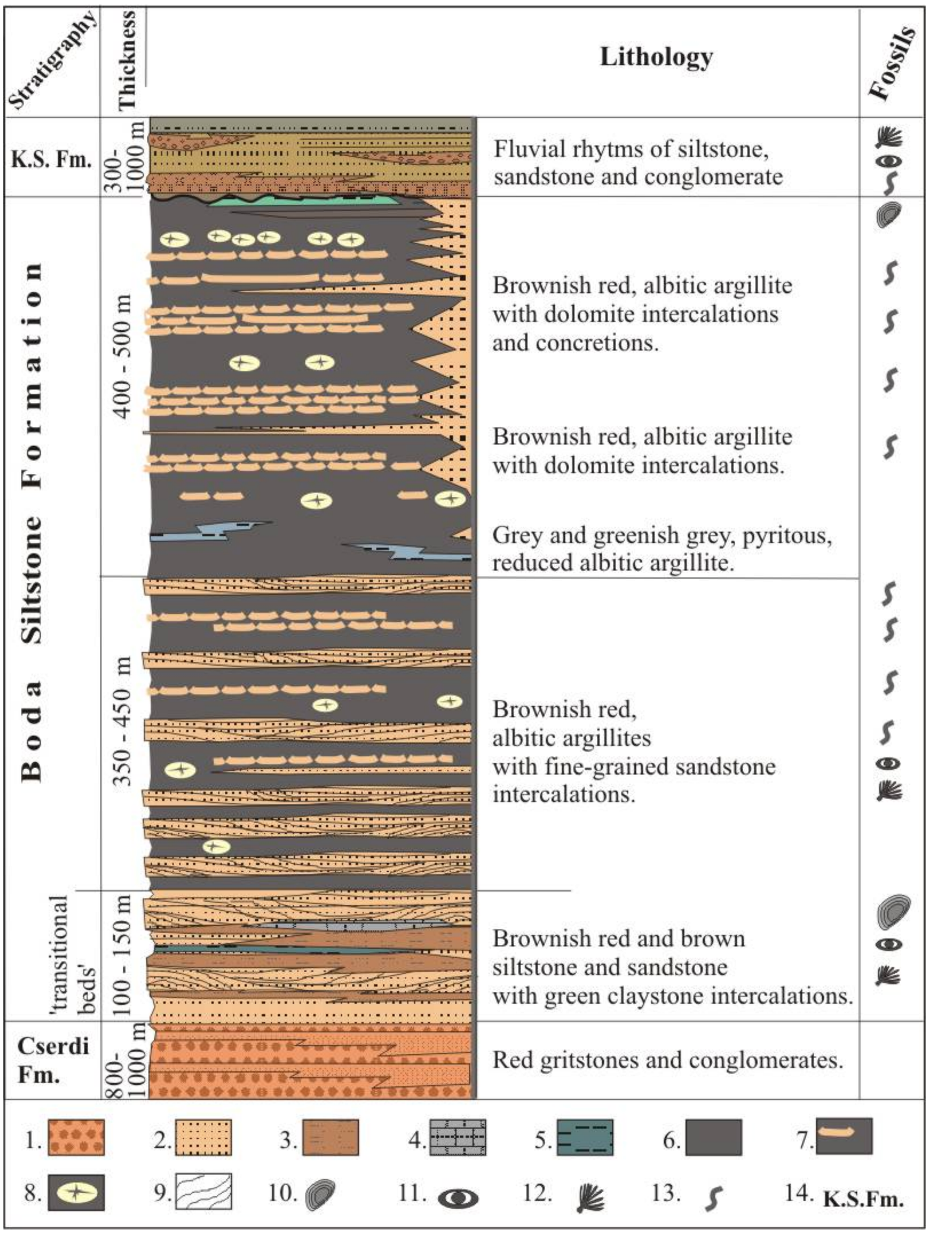


Fig. 25. Lithology of the Boda Claystone Formation.
Legend:
1. conglomerate,
2. sandstone,
3. clayey sandstone,
4. limestone,
5. claystone,
6. albitic claystone,
7. dolomite,
8. concretion,
9. cross-bedding,
10. phyllopod,
11. sporomorph,
12. macroflora,
13. trace fossil,
14. Kővágószőlős Sandstone Fm.

The dominant minerals of the formation are quartz, clay minerals, albite, carbonates and haematite. The detrital quartz grains lie within the siltstone interval. The dominant phyllosilicate is illite-muscovite, chlorite is less frequent, more common in reduced beds. The other main constituent of the BCF besides the clay minerals is albite, with an average frequency of 33 %. Calcite and dolomite are around 10 %, the latter occurs as separate beds as well. Haematite occurs in 5-10 %. The frequency of haematite shows a positive correlation with the clay minerals, while the latter have a negative correlation with albite. Based on mineral constituents, the main rock types are albitic claystone, siltstone, albitolite, dolomite and sandstone.

In the exposures the rock types thick-bedded, unstratified silty claystone and desiccated claystone and siltstone can be observed.

The green claystones in the lower, transitional beds of the formation provided a few phyllopods (Fig. 26). The material collected during mapping in the 1960s was identified as Lower Permian *Lioestheria lallyensis* (FÜLÖP 1994).

From the reduced beds, BARABÁSNÉ STUHL (1981) identified the following spores and pollen indicating an early Late Permian age:

- Disaccites pollen:
  - *Lueckisporites virkkiae* Potonie et Klaus (norma Aa, Ab Visscher)
  - *Jugasporites omai* Helby
  - *J. delassaucei* (Pot. et Klaus) Leschik
  - *Gigantosporites hallstattensis* Klaus
  - *Striatites* sp.
  - *Limitisporites leschiki* Klaus
  - *Platysaccus papilionis* Pot. et Klaus
  - *Gardenasporites heisseli* Klaus
  - *Falcisporites zapfei* (Pot. et Klaus) Leschik
  - *Paravesicaspora splendens* (Leschik) Klaus
  - *Klausipollenites schaubergeri* (Pot. et Klaus) Jansonius
  - *Sulcatisporites* sp.
- Monosaccites pollen:
  - *Striatimonosaccites sp.*
  - *Nuskoisporites klausi* Grebe
- Polyplicat pollen:
  - *Vittatina costabilis* Wilson
- Spore:
  - *Converrucoisporites* sp.

Trace fossils are more common in the well-bedded rock types and usually indicate low- and mid-energy environments. Mineralogical, petrographical, geochemical and sedimentological characteristics of the formation refer to deposition in a shallow, alkaline lake under an arid – semi-arid climate.

Fig. 26. Two phyllopods (length 3 mm) from the lower beds of the Boda Claystone

Stop 5
Boda: Upper Permian fluvial facies (Kővágószőlős Sandstone, Bakonya Member)

Having left the previous exposure, we cross an important structural zone to reach the outcrop that already belongs to the northern flank of the anticline.

The formation usually overlies the Boda Claystone concordantly but with an erosional surface. This outcrop shows a varied fluvial sequence (Fig. 27).

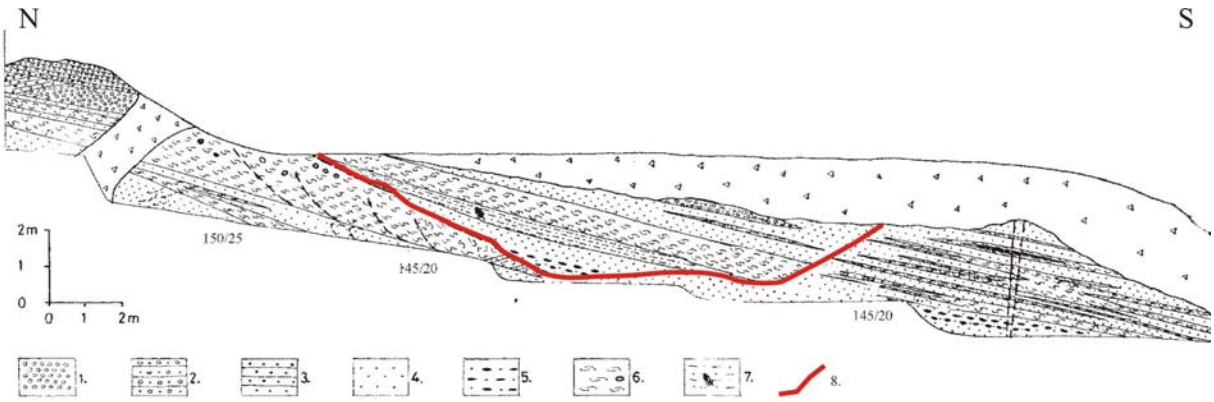


Fig. 27. The outcrop of Bakonya Sandstone N of Boda. 1. conglomerate; 2. gravelly sandstone; 3. coarse-grained sandstone; 4. fine-grained sandstone; 5. sandstone with claystone pebbles; 6. siltstone with nodular weathering; 7. silty claystone with plant fossils; 8. channel.

Kővágószőlős Sandstone is known in the W Mecsek, in its NW foreland and in the area S of the E Mecsek. It is composed of 4 members: the variegated Bakonya Sandstone, the grey Kővágótöttös Sandstone with abundant plant fossils and coal seams, the red Cserkút Sandstone with silicified tree trunks and the purple Tótvár Sandstone. Colour variations are dominantly diagenetic, the initially reduced, fossil-bearing beds were posteriorly oxidised by solutions, while along the redox-fronts uranium ores were precipitated (Fig. 28).

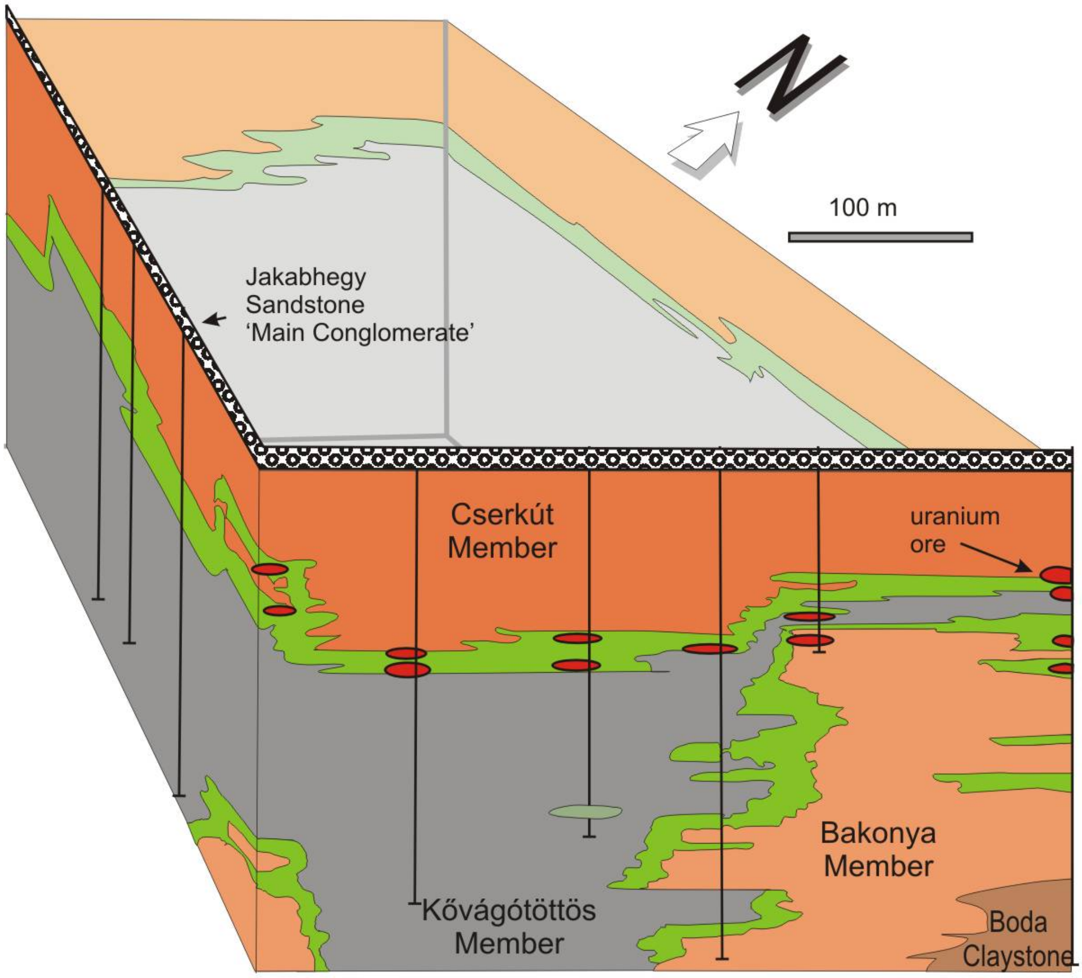


Fig. 28. Block diagram of the Pécs occurrence of the Kővágószőlős Sandstone based on boreholes, without the overlying formations.

The clastics of the 200-1200 m thick Kővágószőlős Sandstone Fm. originate mostly from granite (Mórágy Complex) and the Gyűrűfű Rhyolite, insignificant amounts from metamorphic rocks. They contain a considerable fraction of feldspars. The formation is composed of typical fluvial cycles. A large number of measurements of plant fossil, pebble and cross-bedding orientations indicate a transport from NNW to SSE (Fig. 29).

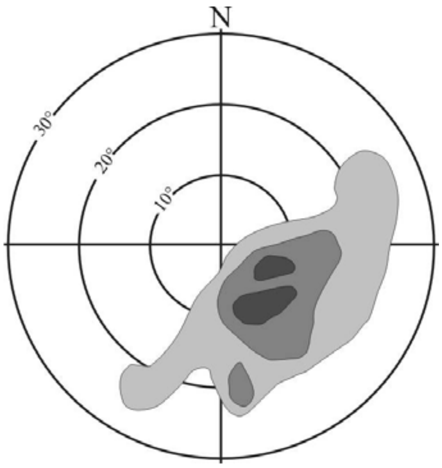


Fig. 29. Distribution of back-tilted cross-beddings in the Kővágószőlős Sandstone based on several hundred measurements (KONRÁD 1997).

The fauna of the formation is extremely poor. VÁRSZEGI (1961) described the phyllopods *Eusestheria dawsoni* Jones and *Eioleaia leaiformis* Raymond from the Kővágótöttös Mb. Trace fossils were found in the floodplain facies. The macroflora collected by J. Böckh in the 19th century was first identified by O. Heer. Plant macrofossils indicating an Upper Permian age were limited to a small group of needle-leaf trees, the *Araucarites* trees. Microflora consists of bisaccate needle-leaf pollen and some spore types. The so-called norm-forms Ab, Ac and B of the Upper Permian *Lueckiksporites virkkiae* Pot. et Klaus 1954 are typical (BARABÁSNÉ STUHL 1981). Pteridophyte spores almost completely lacking in the Permian but typical of the Lower Triassic appear with a dramatic suddenness at the lower boundary of the Tótvár Sandstone, thus this member is classified as Triassic (BARABÁSNÉ STUHL 1993).

Stop 6
Kővágószőlős: visit in the core depository of Mecsekérc Ltd. to study drilling cores representing the basement of the western Mecsek Mts.

Mecsekérc Ltd. is the legal successor of the Mecsek Ore Mining Company. The sequence of the W Mecsek (Fig. 15.) is overviewed with the help of the few core samples stored in their core depository out of the nearly 2000 cores drilled during the exploration period.

Stop 7
Kővágószőlős, Jakab Hill: Lower Triassic conglomerates and sandstones (Jakabhegy Fm.)

The Jakab Hill forms the N flank of the Kővágószőlős anticline. The boundary between the Kővágószőlős Sandstone and the Jakabhegy Sandstone Fm. is visible on its slope and on the small hills in its continuation. Jakabhegy Sandstone overlies the older rocks with erosional unconformity and probably with a minor gap. The boundary is often tectonically deformed, bedding-plane slip ’smeared’ the erosion surface.

The basal part of the section is red or greyish-red hard conglomerate or pebbly sandstone („Main Conglomerate”), which is overlain by cross-bedded, pebbly sandstone, then pale red, pale violet, cross-bedded sandstone. This in turn is followed by the ‘pale sandstone’, then by a cyclic sequence of ’reddish-brown siltstone and sandstone’ (Fig. 30). The formation has a thickness of 250 m. It is widespread in the Tisza Unit; it is known from boreholes in the basement of the Great Hungarian Plain and crops out in the Apuseni Mts. in Transylvania. In the W Mecsek it overlies the Kővágószőlős Sandstone with nearly continuous sedimentation, while at other sites it covers the crystalline basement or older Permian rocks with erosional and angular unconformity.

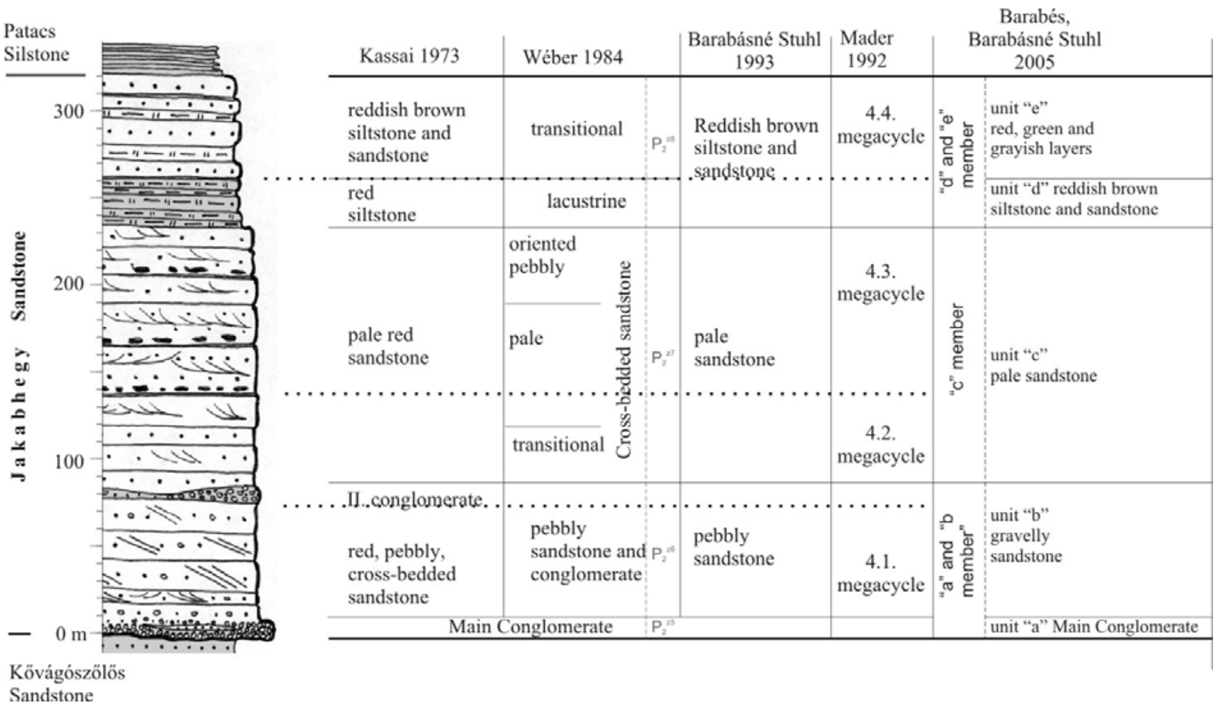


Fig. 30. Subdivision of the Jakabhegy Sandstone Fm. according to various authors.

The gravel material of the formation does not differ considerably from that of the underlying rocks but the sediment is more mature and contains hardly any plagioclase. The dominant cement changes from carbonate to silica. The orientation of cross-bedding is different from that in the underlying formation, its variation is higher and several distinguished directions are visible. The sandstone contains no fauna, in the fine-grained beds *Arenicola*-type trace fossils have been found.

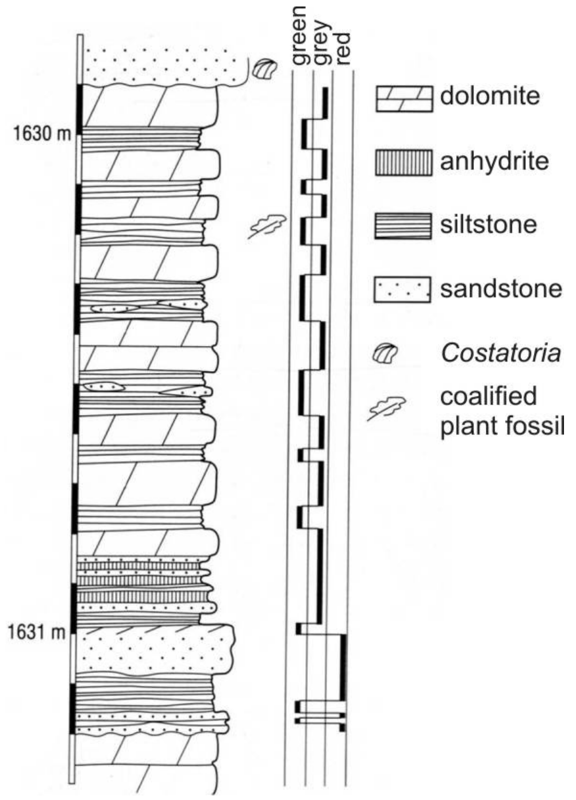
The facies of the formation is still being debated. According to the most recent views (BARABÁS, BARABÁSNÉ STUHL 2005), the main conglomerate and the overlying cross-bedded, gravelly sandstone are of fluvial delta origin, while the upper part of the formation was deposited on a tidal flat.

Stop 8
Pécs, Patacs, Boróka dűlő: Lower Anisian siltstones and marls (Patacs Fm.)

The key section of the Lower Anisian Patacs Siltstone is located on the NE margin of Pécs. Since it is in relatively bad condition, it is worth having a look at the formation in a parallel road cut, where the somewhat tectonised flanks of the dirt road expose a long section of the sequence.

The Early Anisian transgression and the decrease in the relief resulted in a facies shift and in the deposition of finer-grained sediments after the Jakabhegy Sandstone. The transition to the overlying Patacs Siltstone is continuous, the boundary is drawn at the appearance of green beds, of phyllopod-bearing green claystones, of Mn-rich beds and at the disappearance of graded sandstones (NAGY 1968).

The formation was deposited in the littoral part (tidal flat) of a shallow ramp and represents the lower part of the Röt in the region. It displays a continuous transgression and marks the beginning of the transition from a purely siliciclastic to a carbonate ramp.



The formation is built up of sandstone-siltstone(-claystone) cycles (Fig. 31.), the thickness of which gradually decreases. The lower part contains azurite and malachite-bearing siltstone beds showing a 'Mansfeld copper shale' facies. Upwards in the sequence the number of reduced beds (green siltstones, grey dolomites) grows, as well as the ratio of green claystones to the more littoral ripple-marked red sandstones and siltstones.

Fig. 31. A typical cycle from the upper part of Patacs Fm. in the borehole Gálosfa-1 (KONRÁD 1997)

The increase of carbonate content (mainly dolomite), magnesite nodules in the dolomites and enterolithic anhydrites in the upper part show a sabkha environment and refer to the drying of the climate. Subaerial conditions are recorded by desiccation cracks in the claystones and by pedogenesis-related carbonate concretions.The most common fossils are phyllopods; ichnofossils (*Arenicola*) also occur. Marine bivalves (*Costatoria costata, Myophoria* sp.) and *Lingula tenuissima* appear in the upper third of the sequence (NAGY 1968). Early Anisian age is proved by the typical sporomorph association (*Triadispora crassa, Stellapollenites thiergartii*; BARABÁSNÉ STUHL 1993).

Stop 9
Pécs, Remete-rét: Middle Anisian reef (Rókahegy Dolomite)

The Rókahegy Dolomite is known in both the Mecsek and Villány Mts. In the Mecsek it was used as a marker horizon during mapping due to its small thickness (20-30 m) and characteristic variegated colours (yellow, purple, red, grey). It was called 'boundary dolomite' and the Lower/Middle Triassic boundary was drawn at its base. In the Villány Mts. it is reddish brown with a thickness of 100 m.

Algal mat stromatolites, desiccation cracks, authigenic breccias and ooidal beds are typical of the formation. In the Mecsek area (for the distribution, see Fig. 32), the base of the formation has a characteristic reef facies previously identified as *Thecosmilia* coral (BÖCKH 1876; KOLOSVÁRY 1955; Detre in KÓKAI & RÁLISCH-FELGENHAUER 1981).

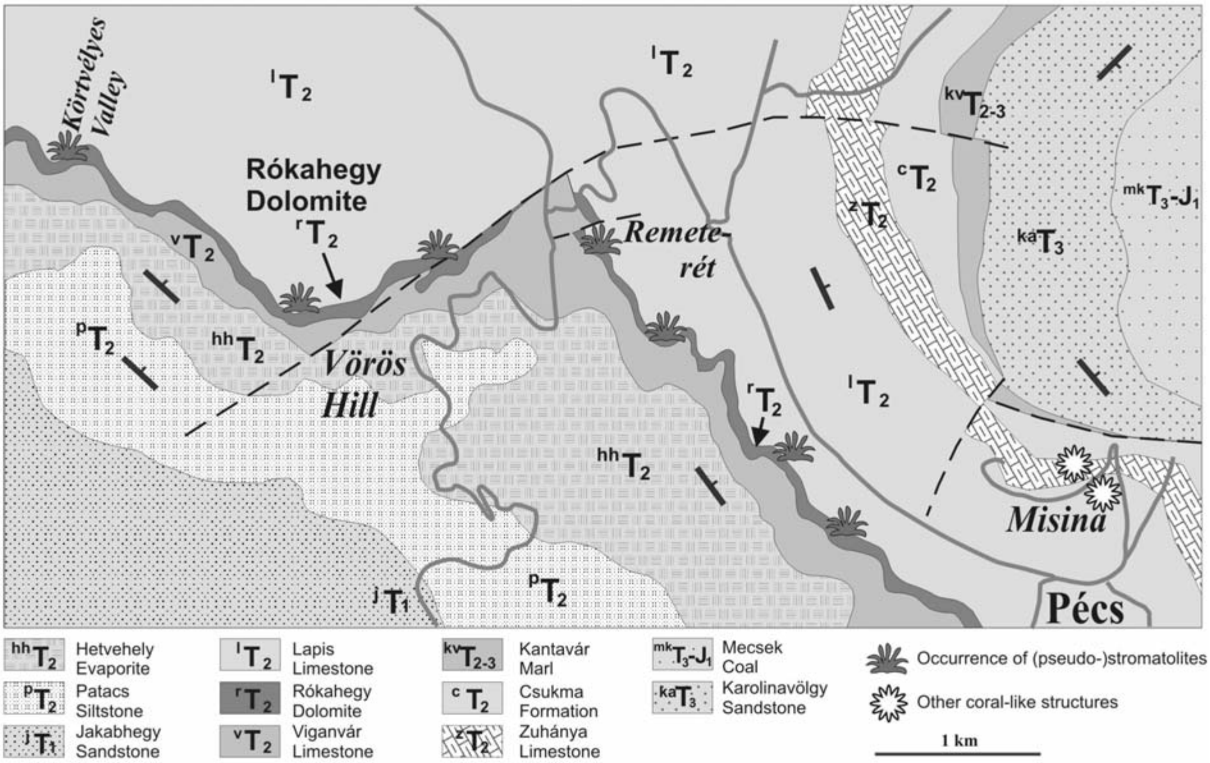


Fig. 32: Distribution of the 'coral reef' in the W Mecsek

In the thin-bedded to microlaminated marls overlying the Viganvár Limestone Formation there are dark grey, almost black, spheroidal, concentric structures of silky lustre. Upsection, these formations constitute thin beds of layered structure. Above them, there is a 2-4 m thick bed in which finger-like (reef) structures, frequently in a fan-like pattern, are found mostly perpendicular to the stratification. Their interior is usually filled by dark grey or black, coarsely crystalline calcite. Their matrix is yellowish or brownish-grey dolomite or limestone and contains calcite pseudomorphs after euhedral gypsum. According to the latest studies (KONRÁD 1997), these phenomena are stromatolites and show a strong resemblance to the stromatolitic facies of the regressive cycle published by HOFFMAN (1976) (Fig. 33). The structures do not have septae but the microstructure characteristic of stromatolites is visible at places (Fig. 34).

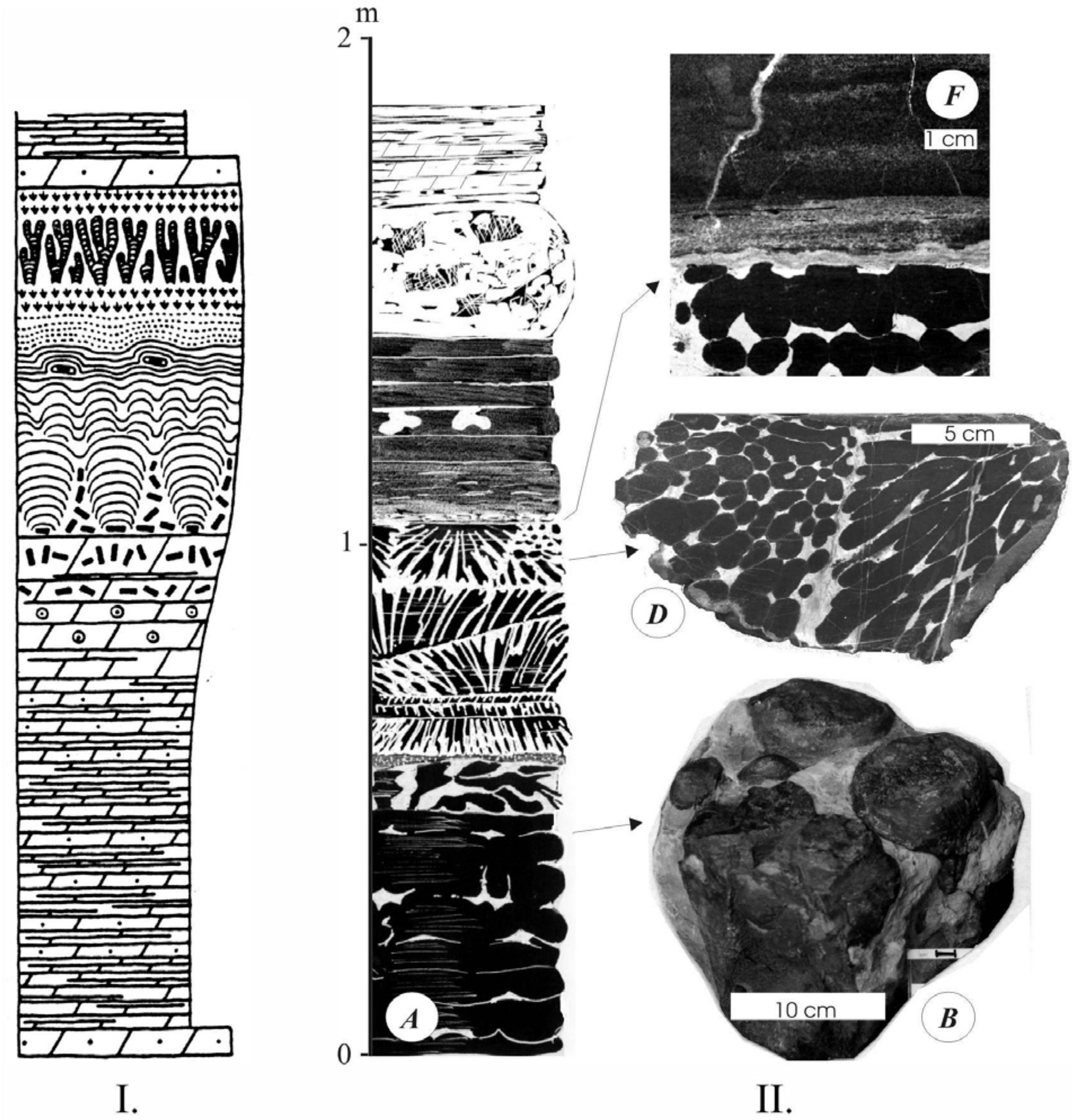


Fig. 33: Section of a regressive cycle and the profile of the reef structure at Remete-rét.

The reef is covered by brown dolomite, in some cases with a rauhwacke structure. Above it yellow or red saccharoidal and argillaceous dolomite layers occur. Higher up the final beds of the sequence are more calcareous, often grey-mottled. The first beds of the overlying Lapis Limestone are generally of intraformational breccia character with red angular dolomite clasts sitting in a dark grey or purplish grey matrix (RÁLISCHNÉ FELGENHAUER 1988b).

The shallow-water sediments seem to have been dolomitised already at the syn- or early diagenetic stage. Late epigenic dolomitisation almost completely obliterated the original textural features.

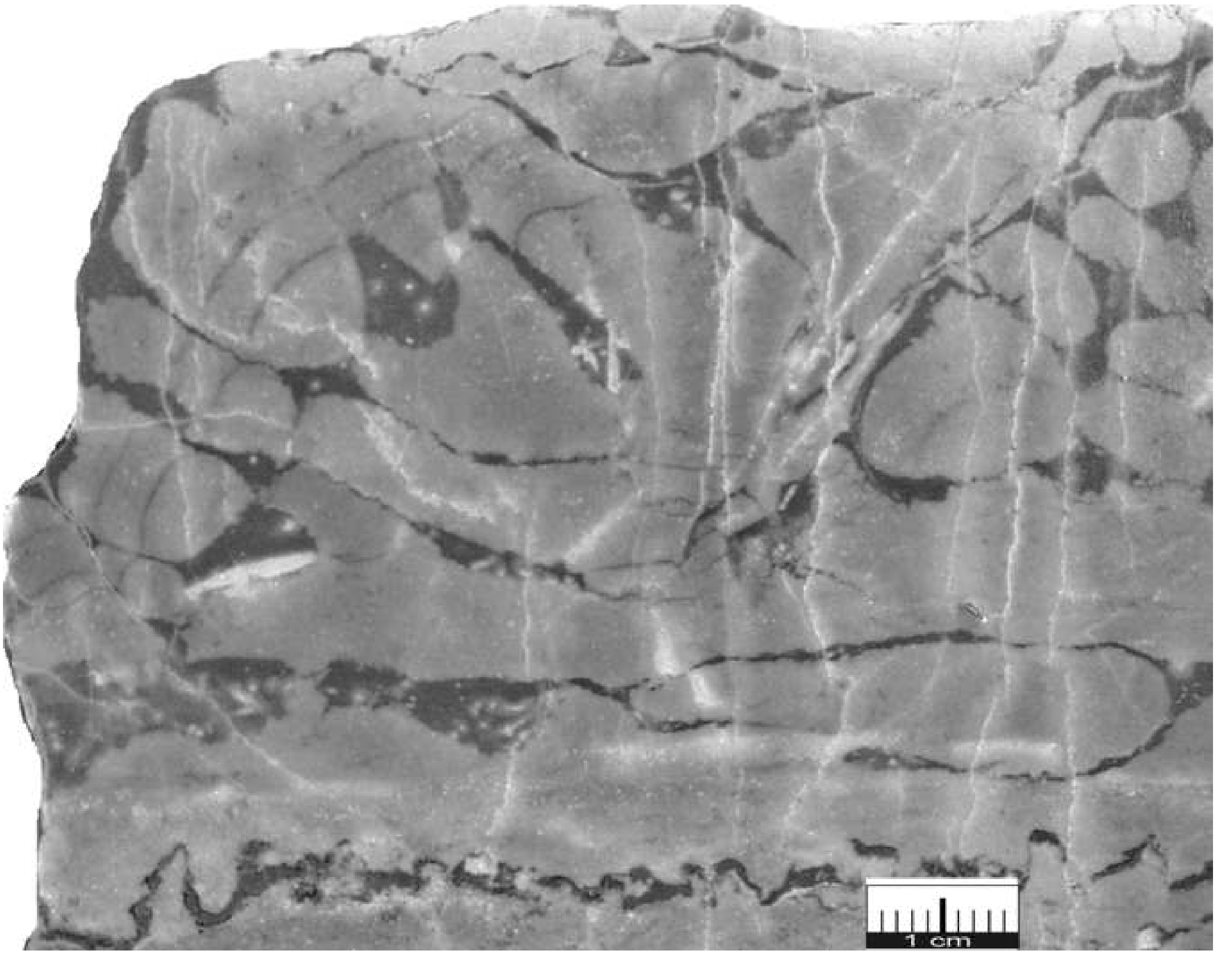


Fig. 34: Stromatolite microstructure in the outcrop of the reef facies in the Körtvélyes Valley; polished section.

Thus, the formation previously defined as showing an open shelf facies with intense water circulation, actually marks a regressive event between the Viganvár and the Lapis (Wellenkalk) Formations. The occurrence of stromatolites and gypsum crystals indicates bad circulation and a high-salinity environment. According to KONRÁD (1998), the remarkable thickness differences (in the Villány Mts. the thickness is 100 m, with several thick breccia (scarp breccia?) layers) and the various facies of the formation refer to tectonic events, to dislocation along listric faults.

Stop 10
Pécs, Dömörkapu, Kis-rét: key sections of the Middle Anisian to Ladinian limestones („Terebratula beds", „Trigonodus beds")

On the N margin of Pécs, in and near the U-curve of the road running up to the peak Misina, several key sections of Muschelkalk limestones are located.

The inner edge of the curve makes up the key section of Zuhánya Limestone (Fig. 35), where the division into two members was established by E. NAGY (1968). The section is usually in fairly bad condition without cleaning, but earlier its lower part provided the first age-diagnostic conodonts and a few Ceratites binodosus (RÁLISCHNÉ FELGENHAUER 1986). The upper part is poor in fossils and shows dolomitised patches.

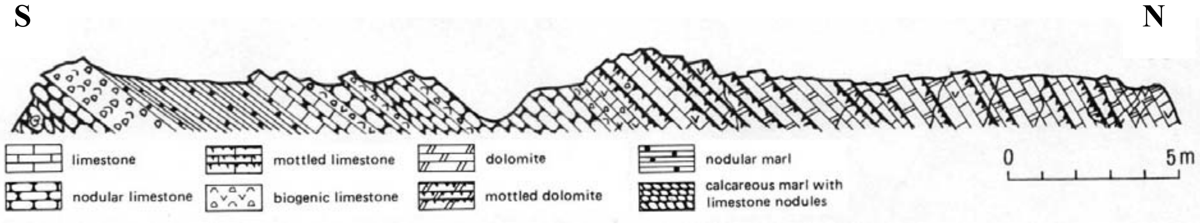


Fig. 35. The key section of Zuhánya Limestone along the Misina road (Rálischné Felgenhauer 1986)

Along the outer edge of the road lies the key section of the Kozár Limestone (Fig. 36), a member of the Csukma Fm. It follows Zuhánya Lmst. with a gradual transition: red and yellow patches disappear, while secondary dolomitisation becomes more frequent (RÁLISCHNÉ FELGENHAUER 1986).

The Kozár Limestone indicates the shallowing of the carbonate ramp. It is thick-bedded, massive, though beds become thinner upsequence. In the lower part, ooidal-crinoidal calcarenite lenses are interbedded into the laminated mudstone or the structureless, bioturbated layers. Ooidal layers are structureless or cross-laminated; their base, as well as that of the bioclastic layers, can be erosional. These sediments were transported by submarine currents from littoral or sublittoral sand shoals to the mid-ramp (TÖRÖK 1998); the ooidal-crinoidal sand shoals of the German Muschelkalk (e.g. Trochitenkalk) are not known in the area. The upper part is characterised by laminated or massive grey micrites, autoclastic breccia horizons with reverse grading and thin bioclastic layers with few bivalves and foraminifers. The lack of bioturbation indicates temporary disaerobic bottom conditions.

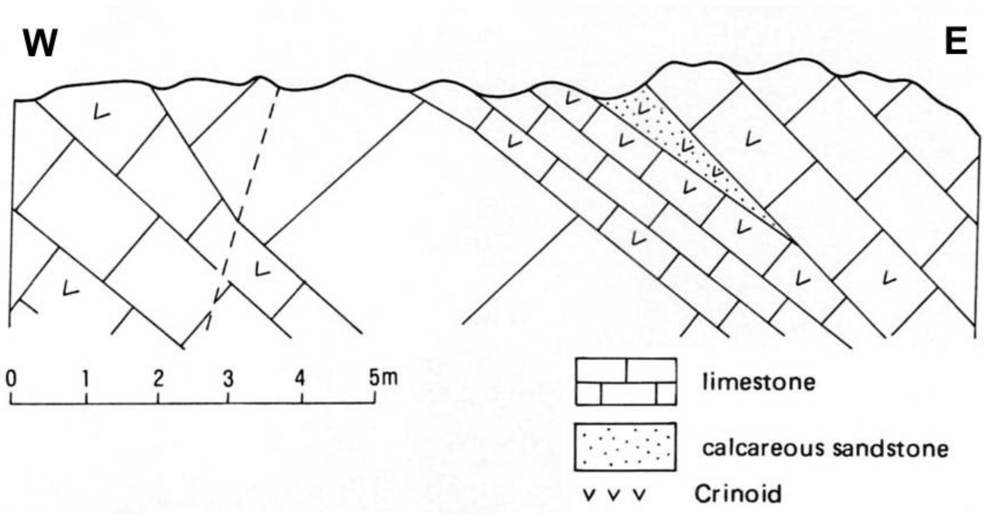


Fig. 36. The key section of Kozár Limestone along the Misina road (RÁLISCHNÉ FELGENHAUER 1986)

The crinoids (*Chelocrinus, Encrinus*) belong to the silesiacus zone (HAGDORN et al. 1997); the stratigraphic position refers to Upper Illyrian (and perhaps Lower Ladinian) age (BÉRCZINÉ MAKK et al. 2004).

About 50 m from the road to the NW, the tourist trail runs along the key section of the 'oncoidal limestone' belonging to the Kisrét Member of the Kantavár Fm. This formation overlies the Zuhánya or the Kozár Limestones or the Kán Dolomite (depending on location) after a gap of unknown length. The gap is indicated by the max. 15 m thick Mánfa Siderite, a kaolinitic-sideritic white or green clay or claystone, which can be reached here a few tens of cm-s below the oncoidal limestone. Previously this clay was considered volcanic tuff (NAGY, RAVASZNÉ BARANYAI 1968), but it may also be a subaerial paleosol or a swamp sediment (HAAS et al. 2002).

The Kisrét Limestone indicates a temporary transgression leading to the formation of a brackish-freshwater lagoon. It is a dark grey or black bituminous limestone composed of oncoidal beds and gastropod and bivalve coquinas. The three lithotypes do not follow a definite order in the various exposures.

Along the tourist trail practically pure oncoidal limestone is exposed. Oncoids can be as large as 7-8 cm in diameter and usually formed around mollusc shell fragments. At places they were plastically deformed; broken pieces were encrusted again.

The coquina beds (some of them also with oncoids) can be studied about 1 km to the NW, at a clearing called Kis-rét. The impoverished fauna indicates environmental stress and contains no age-diagnostic fossils. The thick-shelled bivalves were identified as *Trigonodus* cf. *sandbergeri*, *T.* aff. *problematicus, T. sandbergeri* var. *hungaricus* (VADÁSZ 1935, SZENTE 1997). Below the limestone the kaolinitic clay was exposed by trenching.

Stop 11

Pécs, Kantavár quarry: key section of Ladinian lacustrine limestones and marls (Kantavár Fm.)

2 km to the NNE of the Misina peak, the abandoned quarry of Kantavár used to work heavily tectonised black calcareous marls and limestones belonging to the Kantavár Formation.

The lower part of the section is built up of thick-bedded, laminated limestone, while upwards it becomes shaley as the clay content increases and it gradually evolves into the Karolinavölgy Sandstone. Lower beds contain abundant ostracod, Chara and gastropod fossils, often substituted by calcite or pyrite. On bedding planes oriented plant remnants (e.g. *Equisetites*) and coalified fragments can be found.

The monospecific ostracod fauna (*Darvinula liassica*) and the characeae (MONOSTORI 1996) indicate a freshwater lacustrine environment having evolved from a completely restricted lagoon. The formation was previously considered partly analogous with the Lettenkeuper, but the lithofacies and the high quantity of ostracods support correspondence to the Upper Muschelkalk 'Bairdienton' (TÖRÖK 2000). According to the palynological studies of BÓNA (1995), the Ladinian/Carnian boundary can be drawn within the Kantavár Formation.

Stop 12

Pécs, Lámpás Valley: Upper Triassic lacustrine and fluvial sandstones (Karolinavölgy Fm.)

The key section of the Upper Triassic Karolinavölgy Sandstone Fm. was described by RÁLISCHNÉ FELGENHAUER (1988a). The Formation gradually develops from the topmost fine-grained clastic layers of the Kantavár Formation through a decrease in carbonate content and an increase in grain-size. The transitional part ('Cassian sandstone') is more clayey than the upper levels (Fig. 37).

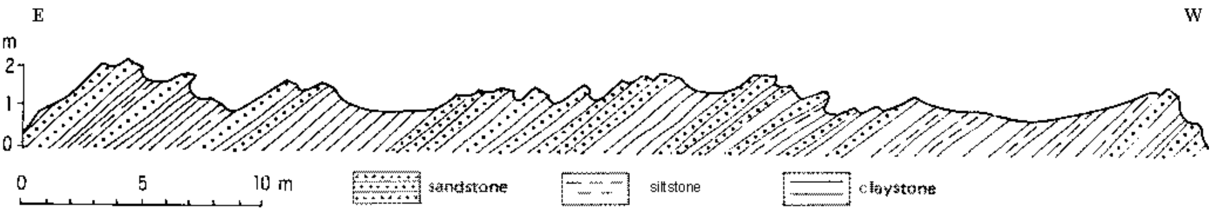


Fig. 37. Profile of the key section of Karolinavölgy Sandstone in the Lámpás Valley.

Upwards the Karolinavölgy Sandstone also shows a gradual transition towards the Mecsek Coal Formation. Its lithological boundaries can be drawn at the first sandstone layers at the base and at the first swamp deposits at the top. The 450-600 m thick formation consist of alternating thick sandstone, siltstone and claystone layers.

At the bottom the fine-grained sediments in the sandstone often contain claystone inclusions, much more rarely siltstone bands. Also characteristic of the sequence are the siderite nodules in the lowermost and topmost layers, the clayey ironstone and the coal seams. In the lower unit, lagoonal and lacustrine facies is typical with subordinately occurring delta facies. The whole formation is built up by generally regressive sedimentary cycles.

The central part starts with delta deposits; upsection it is predominantly of lacustrine, subordinately of lagoonal facies (RÁLISCHNÉ FELGENHAUER 1988a).

The upper part is built up of fluvial, then delta, and finally lacustrine sediments, with definite transgressive cycles. The colour here is usually greenish grey due to the chamositic cementation. The sequence is rather poor of fossils. In the lower part of the sequence E. NAGY (1968) found calcareous algae (*Micrhystridium*), phyllopods (*Isadora minuta* Goldf., *Isaura ovata* Lea), badly preserved molluscs (*Pleuromya* cf. *ambigua* Bittn.) and gastropods (*Acteonina* cf. *scalaris* Munst). Ostracods were also mentioned and at an upper levels fish remains are abundant (*Depedius inornatus* Henry, *Semionotus* sp. scales, *Acrodus minimus* Ag. teeth and fossil fins). In the middle part some poorly preserved gastropods, phyllopods and plant fossils (*Equisetites* sp., *Czehkanowskia* sp., *Podozamites* sp., *Clathropteris* sp.) can be found. In the upper part fossil plants (*Zamites distans* var. *longifolia* Presz), phyllopod moulds (*Isaura hungarica* Vadász) and bivalves (*Cardinia hofmanni* Böckh et Vadász) were characteristic.

The most important sporomorphs are *Leptolepidites reissingeri* (Reinh.), *Duplicisporites* sp., *Aratrisporites scabratus* Klaus., *Triadispora hyalina* (Madier, 1964) n. comb., *Striatoabirites ay tugü* Visscher, *Ovalipollis ovalis* W.Kr., *Undulatosporites lucens* Leschik, *Undulatosporites angulineus* Leschik.

The Karolinavölgy Formation can be divided both lithostratigraphically and biostratigraphically into three parts. The lower part starts at the base of the Carnian. The Carnian/Norian boundary is marked by the *Ovalipollis ovalis*-type pine pollens while the spore *Triancoraesporites ancorae* (Rhein) E. Sch. found in the upper part is characteristic of the Rhaetian. The Triassic/Jurassic boundary – where these spores are already completely missing– can be drawn within the Mecsek Coal Formation (RÁLISCHNÉ FELGENHAUER 1988a).

The Karolinavölgy Formation indicates regression at the end of the Triassic. The underlying lagoonal-lacustrine sediments were covered by delta deposits, then the area transformed into a swamp- or bog-type basin. In the upper part of the section the appearing transgressive interbeddings show a transition toward the Jurassic sedimentary cycle. The upper boundary of the formation is drawn at the first coal seam. This was deposited in the Late Triassic, therefore the accumulation of the Mecsek Coal Fm. started as early as the Rhaetian stage. The Karolinavölgy and Mecsek Coal Fms. are both similar to the European Rhaeto-Liassic facies (Gresten-type coal-bearing sequence), they differ in their greater thickness.

The outcrop exposes the lower part of the formation (Fig. 37). Siltstone, coaly clay and fine-grained clayey sandstone beds alternate here, with frequent siderite nodules and clay ironstone intercalations. In the upper part of the section coarse-grained and gravelly sandstones also appear (RÁLISCHNÉ FELGENHAUER 1988a).

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