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From continental platform towards rifting of the Tisza Unit in the Late Triassic to Early Cretaceous

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Abstract: The Upper Triassic–Lower Cretaceous successions of the Transdanubian part of the Mecsek and Villány-Bihor Zones of the Tisza Unit have been studied from the lithological, lithostratigraphical, sedimentological, microfossil and microfacies points of view in order to correlate and interpret the significant differences between them and to draw a conclusion about their geological and paleogeographical history. After an overview of the paleogeographical reconstructions of the broader area, the succession of the Mecsek and Villány-Bihor Zones and the debated Máriakéménd-Bár Range are introduced. Until the end of the Middle Triassic the study area acted as an entity. The first fundamental difference between the two zones can be recognized in the Late Triassic when marine carbonates were replaced by thick fluvial siliciclastics in the Mecsek Zone, while it is represented only by small, local lenses with a few and thin dolostone intercalations in the Villány Zone. The Mecsek Zone is bordered southward by one of the large listric faults to the north of which very thick siliciclastics developed in the Early to Middle Jurassic, whereas it is highly lacunose in the larger western part of the Villány-Bihor Zone. The break at the base is subaerial, higher in the succession it is shallow submarine. The sediment is silty, occasionally sandy crinoidal limestone of late Early Jurassic or even Middle Jurassic in age. The Upper Jurassic in the Mecsek Zone is composed of deep-water cherty limestone while in the Villány Zone it became a thick, shallowing pelagic limestone with reworked patch reef fragments. It is clear evidence that the Mecsek Zone had a thinned continental crust thanks to the nearby rift zone while in the Villány Zone the crust remained thick. The actualized version of the Plašienka's paleogeographical model (Plašienka 2000) is introduced.

Key words: Upper Triassic, Lower Cretaceous, Tisza Unit, rifting, facies analysis, plate tectonics, paleogeography, lithostratigraphy.

Introduction

The pre-Neogene basement of Hungary is composed of two major tectonic units, namely the Pelso (part of the ALCAPA — Faupl et al. 1997) and the Tisza Units (Fig. 1). The latter name derives from the Tisza River. (This river also served as a source name for the Tisia Unit of Prinz (1926), but it included the entire basement of the Pannonian Basin therefore we are using here the name Tisza instead of Tisia for the southeastern part of the Pannonian Basin.) The Tisza Unit consists of 4 tectonic zones as follows: Mecsek, Villány-Bihor, Békés-Codru and Biharia Zones. The Pelso and Tisza Units are separated by the Mid-Hungarian Tectonic Zone. The first unit derives from the Southern and the Eastern Alps, while the latter one was part of the European continent before the Jurassic (Kovács 1982; Kovács et al. 1989).

The crystalline basement of the Tisza Unit is composed prevailingly of medium, subordinately low- and very low-grade Lower Paleozoic metamorphites. Locally, these are overlain by two types of the Variscan molasse: the lower (Carboniferous) one is composed of grey clastics and the upper (Permian) one consists of red siliciclastics with rhyolitic lava and tuff bodies. The Triassic sequence of the Tisza Unit is of German-type (Nagy 1968). The Jurassic successions in the Hungarian parts of the Mecsek and the Villány-Bihor Zones are completely different. The Lower Jurassic of the Bihor Mts resembles the Gresten and Allgäu facies but less typical and much thinner than those in the Mecsek Zone (Fig. 2).

The aim of this paper is to describe and correlate the Upper Triassic, Jurassic and Lower Cretaceous successions of the zones in the Tisza Unit using only general conclusions of the detailed microfossil and microfacies studies. The detailed results of them will be published elsewhere.

Paleogeographical outline and significance of the Tisza Unit

The affinity of the Upper Triassic and Lower Jurassic succession of the Mecsek Mountains is Germanic and Helvetic respectively. This was first recognized by Peters (1862) who used for their significant units the names Keuper and Gresten for the first time. The relationship between the occurrences of similar facies was still unknown before him. More than one hundred years later Sandulescu (1975) directly correlated the Tatrides with the Bihor and the Krížna with the Codru units. According to Bleahu (1976) the Villány and the Northern Apuseni Mts were direct continuations of the Western Carpathians. Channel & Horváth (1976) located the Tatrides, the Tisia and the Moesia as independent plates north of the Adriatic plate. Wein (1978) without using the term "Tisza Unit" was the first to indicate it with many subunits (including the

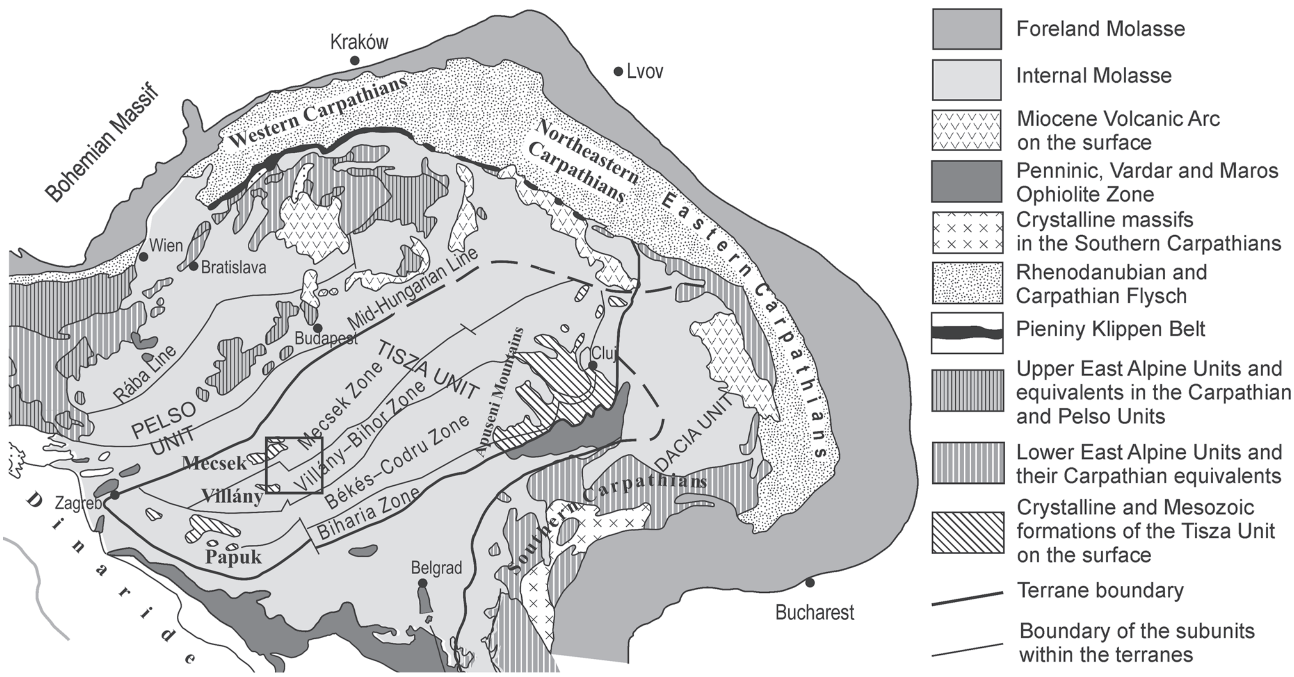


Fig. 1. The position of the Pelso and Tisza Units, subunits of the latter one on the geological map of the Alpine-Carpathian-Dinaric Arc system with indication of the study area (Császár 2005).

Mecsek, Villány, Codru and Bihor) and their broad environs in the Triassic and Early Cretaceous time parallel to the Tornquist Line, in the south-eastern continuation of the Helvetic (with the Gresten facies), the Pieniny Klippen Belt, the Tatric and the Batiza Units. This broad zone was closed south-eastward by the Danubicum, Geticum and Suprageticum. According to Kovács (1982) the Tisza Unit was situated between the Tatricum and the Maramures–Subbucovinian Units.

On the basis of ammonite assemblages Géczy (1973) set the separation time of the Tisza Unit from the European continent in the Middle Jurassic. The separation process according to Balla (1984) took place in the late Early Cretaceous. According to Kovács et al. (1989) the Tisza Unit split off the European Platform by the Penninic rifting.

The way and time of separation and collision are still the major questions in the paleogeographical history of the Tisza Unit. In the last two decades several palinspastic maps and even more papers have been dedicated either to the Tethyan Realm or just to the Alpine–Carpathian Region. In the first modern paleogeographical maps edited by Ziegler (1988) the Tisza Unit was not indicated. On the map set of Dercourt et al. (1990a,b) along the northern margin of the Tethys the Tisza Unit was indicated as an independent terrane, and the Mecsek as part of it. In the explanatory volume of the IGCP Project 198, Mesozoic and Cenozoic facies relations (Császár et al. 1990) and the paleogeographical position of the Tisza Unit (Kovács et al. 1989) were shown. Triassic facies types and their paleogeographical relations within the Tisza Unit were introduced by Bleahu et al. (1996). In the Alpine-Carpathian-Dinaric Realm several microplates were well positioned and named by Plašienka (2000) in four steps within the Sinemurian–Maastrichtian time interval. Dercourt et al. (2000), Stampfli & Borel (2002), Gaetani et al. (2003) showed a small scale, global plate-tectonic model for the Paleozoic and Mesozoic where terranes larger than the Tisza units were only indicated or united with other unit(s). On similar scale maps Bonev & Stampfli (2003, 2011) indicated microplates and even nappe sets on their paleotectonic models for the Middle and Late Jurassic and Cretaceous intervals, where the Tisza (named incorrectly Tisia) microplate was situated west of the Austro-Alpine units. The Western Carpathians are indicated on the eastern side of the Austro-Alpine units. Using detailed facies analyses another approach was introduced by Csontos & Vörös (2004) in the Alpine-Carpathian and Dinaridic framework. According to their model, frequent collision strong deformed the shape of the Tisza Unit with significant bending of the entire microplate. On the contrary on the map, the Tisza Unit (here called Bihor) and the Getic and Bucovinian Units have not been separated by any (Mures or Transylvanian) oceanic branches of the Vardar Ocean in the Late Jurassic and Early Cretaceous time. According to Haas & Péró (2004) the Tisza Unit was a direct continuation of the Lower and Upper Austro-Alpine units including the Western Carpathian Tatric, Fatric and Hronic subunits. The separation process started in the Late Triassic, but they do not indicate rifting on the map at all. Significant progress was achieved in the Bathonian when the Boreal fauna was replaced by the Tethyan fauna. The first (north-westward) dipping subduction of the Neo-Tethys is shown on the Oxfordian map and an eastward one in the Barremian and in the Albian (Haas & Péró 2004). Meanwhile the orientation and position of the Tisza Unit did not change significantly. Although the Mesozoic facies zones of the Tisza Unit are accepted to be oriented parallel to the Euro-

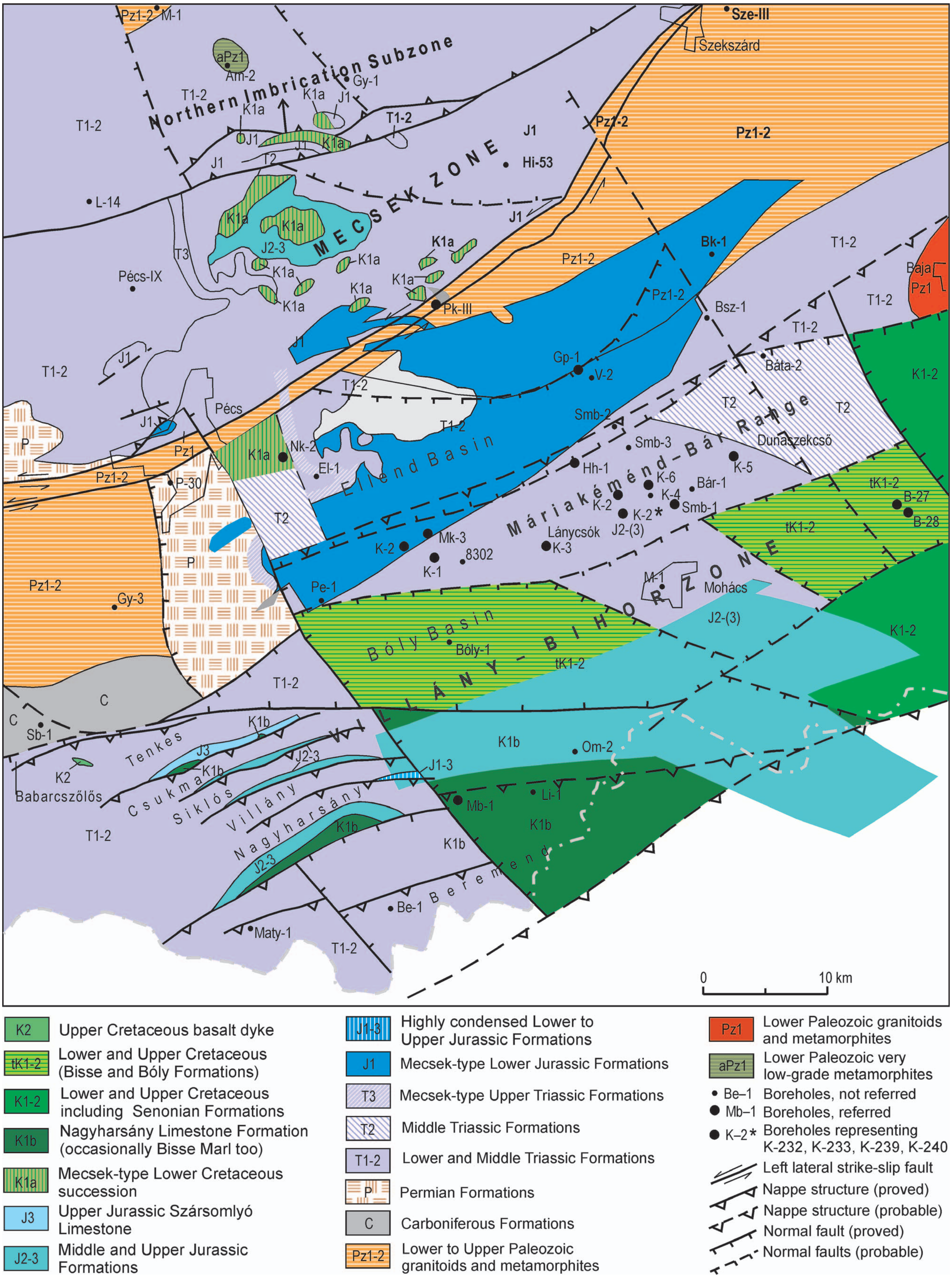


Fig. 2. Geological map of South Transdanubia without Cenozoic formations (a detail from the basement map of Fülöp et al. 1987, modified).

pean margin, this situation cannot be recognized on the sketch map of Schmid et al. (2008). Similarly to the facies zones of the ALCAPA, the same facies zones before the Late Jurassic ought to be found in the Tisza and Dacia microplates on their fig. 2b, but in reality they are different. At the same time the subdivision of the "Tisza Mega-Unit" (see their Plate 1) is controvertible. Based mainly on geophysical and geochemical measurements Ionescu et al. (2009) envisage the South Apuseni ophiolites as remnants of a back-arc basin of the Transylvanian, called the "Eastern Vardar" Ocean. The result of the Late Jurassic W–SW dipping subduction of the oceanic crust beneath the island arc is the obducted oceanic basement on the Bucovinian continental crust. The consequence of it is the eastward subduction of the oceanic crust, collision and thrusting of ophiolites and island arc on the Tisza Unit in the early Late Cretaceous.

The situation of the microplates at Vörös (2012 — see his fig. 1 therein) is similar to the maps of Schmid et al. (2008 — their fig. 2b and plate 1) but more realistic in both the recent tectonic map (his fig. 1a) and the early Late Jurassic paleogeographical sketch map (his fig. 1b).

Radical changes in the sedimentary environment of the Mecsek–Villány area from the Late Triassic till the Late Jurassic

Tectonic fragmentation of the continental crust at the end of the Middle Triassic

The Lower and Middle Triassic sequences of both the Mecsek and Villány-Bihor Zones developed in the same (ramp to platform) facies starting with the fluvial, continued with coastal and shallow-marine carbonate sedimentation. There are only minor differences in lithology, but contrarily more in thickness between the Lower and Middle Triassic formations of the Mecsek and Villány Zones (Török 1988; Konrád 1997; Galácz et al. 2008).

In addition to the local occurrence of the highly clayey Kantavár Formation of lagoon facies the Upper Triassic of the Mecsek Zone is represented by the Karolinavölgy Sandstone Formation of 400–500 m thickness (Figs. 3 and 4). At several places, it may repeatedly contain sub-angular quartz pebbles, but limestone and dolostone breccia and conglomerate beds also occur. Based on its poor fossil content (a few ostracods, phyllopods, bivalves, gastropods, fish remains, palynomorphs and plant remains), the formation was deposited in fluvial, deltaic and lacustrine environments (Nagy 1968; Konrád 1997). The sources of the crystalline rocks are metamorphic and granitic rocks.

On the contrary, the thickness of the Upper Triassic of the Villány Hills ranges between 0 and 40 m (Figs. 3 and 4). The succession (Mészhegy Formation) is composed of alternating, highly variegated calcareous marl, marl, siltstone, thin-bedded dolostone and sandstone of shallow-water origin on a flat lying coastal area (Vörös 2010). Its fossil content is very poor, just a few bone fragments of dinosaurids and plant remains are found. The sedimentation must have been ephemeral, mainly ***lacustrine*** with some ***marine*** intercalation in the lower part (Rálischné Felgenhauer 1987). The proper date of sedimentation within a very long time interval (close to 30 Ma) cannot be specified.

Further diversification of types and rates of sedimentation in the Early Jurassic

There is no break in sedimentation between the Triassic and the Jurassic in the Mecsek area (Fig. 3). In the Late Rhaetian

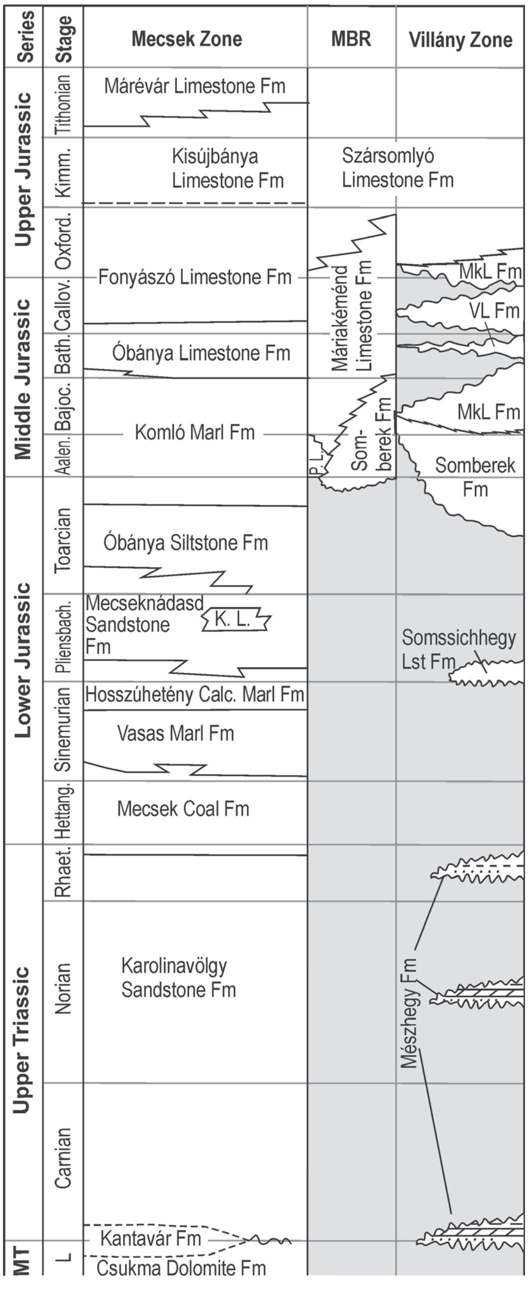


Fig. 3. Upper Triassic and Jurassic sequences of the Mecsek and Villány Zones including the Máriakéménd–Bár Range. **L** — Ladinian, **MBR** — Máriakéménd–Bár Range, **MT** — Middle Triassic, **KL** — Kecskehát Limestone Formation, **MkL** — Máriakéménd Limestone Formation, **PL** — Pusztakisfalu Limestone Formation, **VL** — Villány Limestone Formation.

(Bóna 1983)–Early Sinemurian (Földi 1967; Szente 2012) the Upper Triassic sandstone-shale-conglomerate is replaced by alternation of sandstone, foliated clay, and mudstones with many coal seams of Gresten facies (Mecsek Coal Formation) Vozár et al. (2010) indicate coal seams in the Carnian part of the Karolinavölgy Sandstone, but it occurs only in the Rhaetian, and it is the base of the Mecsek Coal. The much broader mineral spectra and larger quantity of clastic silicate minerals in the northern part of the coal field area than those in the southern part give evidence about the northwesterly source of the siliciclastics. This idea is supported by larger feldspar content of the sandstone beds in the north than that in the south. The increased clay content of the Lower and Middle Jurassic was intensively studied and evaluated by Raucsik & Varga (2008) from the climatic point of view. Breccia and conglomerate beds of Triassic dolostones and limestones, occasionally quartz and metamorphites and some tuffs and tuffites intercalate in the formation (Nagy 1968, 1971). The thickness of the Mecsek Coal varies between 100–1200 m (Fig. 4), rapidly decreasing to the north and less rapidly to the east. The lower member of the formation is barren in fauna, but starting with the middle member the succession is enriched in varied fossils. The most common elements are the molluscs, often with lumachella-like occurrences: bivalves, gastropods of epicontinental affinity (Szente 1992) and in the upper part there are also a few ammonites. Freshwater bivalve and dinosaur footprints are rare. The sedimentary environment starts with ***fluvial*** and ***lacustrine*** facies, continues with ***delta plain*** (***deltaic swamp***) and finishes with coastal plain (often swamp) facies overprinted with eustatic changes. The formation is overlain by Middle Sinemurian shallow subtidal grey Zobákpuszta Sandstone Formation (Raucsik 2012a) with some marl and breccia beds as intercalations in the 300 m thick formation. It is followed by the Vasas Marl Formation of deep sublittoral origin. The most typical fossil elements of the 300–400 m thick clay marl to calcareous marl formation are *Gryphaea* div. sp., plant remains, in addition to which varied bivalves, benthic foraminifers, crinoids and some ammonites are worth mentioning. According to Görög (2003) the majority of the foraminifers are of inbenthic- and hyaline-type. Dolostone and limestone breccia beds with small size sub-angular quartz pebbles contain rare fragments of colonial corals restricted to the southern margin of the Mecsek Zone (Császár et al. 2007).

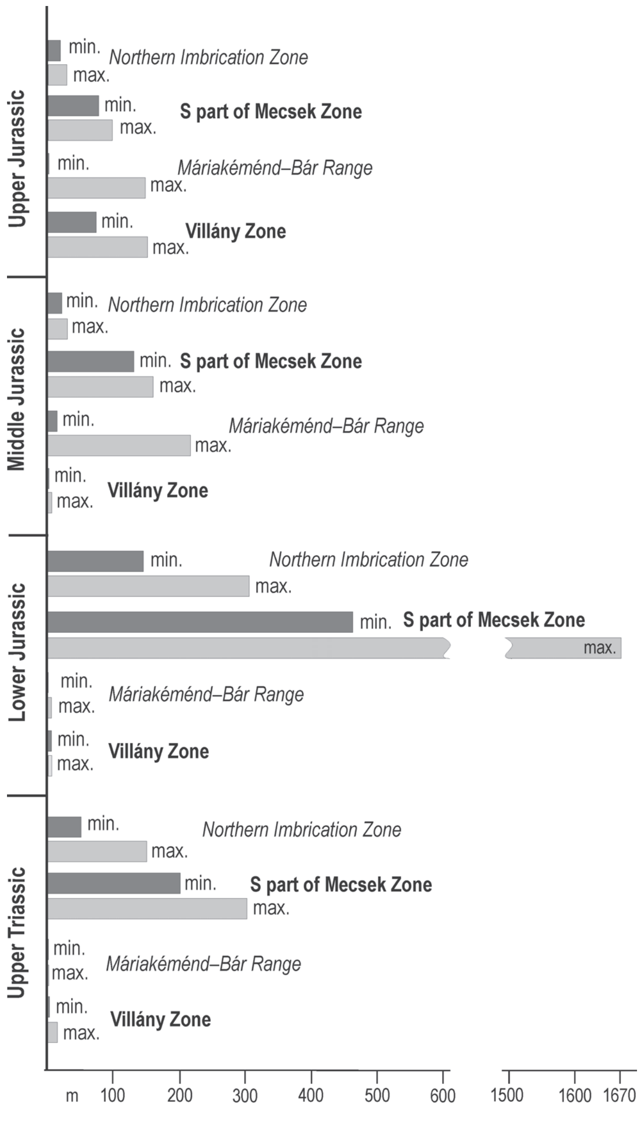


Fig. 4. Comparison of sedimentary sequences of the Mecsek and Villány Zones and Subzones by series from the Upper Triassic up to the Upper Jurassic.

The Upper Sinemurian to Lower Pliensbachian, silty or even fine-grained sandy calcareous marl is developed in Allgäu facies typical for the Helvetic Zone. The thickness of the Hosszúhetény Calcareous Marl Formation ranges between 300–400 m. It is frequently intercalated by crinoidal limestones with chert nodules of sponge origin. The source rocks of the scarce breccia layers are in part intraformational, in part Middle Triassic in origin. Its fossil content is poor. In addition to the crinoids, a few brachiopods, ammonites and benthic foraminifers are found. The foraminifers (Görög 2003) indicate a deeper, off-shore environment with a higher oxygen content, but less nutrient flux than in the bedrock of the Vasas Marl.

In the Upper Pliensbachian and Lower Toarcian the clayey limestone and calcareous marl turn mainly into sandstone (Mecseknádasd Sandstone Formation). It is characterized by 0.6–2.0 m thick sedimentary cycles, the bases of which may start with breccias or coarse- to fine-grained sandstones and the tops finish with silty marls, siltstones and, clayey limestones. The sandstone beds are often crinoidal and/or siliceous. Breccia beds are relatively frequent in the lower beds and very scarce in the upper ones. The components also include Lower Jurassic sedimentary rocks. The formation is poor in fossils but a few horizons are enriched in brachiopods, ammonites, and hyaline benthic foraminifers which indicate well oxygenized, neritic, ***deep sublittoral to bathyal environments***. The formation is restricted to the southern part of the Mecsek Mountains where its thickness can reach 900 m.

There is a small coarse-grained crinoidal limestone body of 30–40 m thickness (Kecskehát Limestone Formation) developed within the Mecseknádasd Sandstone Formation. The depositional area is supposed to be an elevated part of the southern sub-basin.

During the Early Toarcian, the sedimentary environment became open marine, shallow bathyal, and later dysoxic to anoxic (Raucsik & Varga 2008) in harmony with the "global anoxic event". The sediment is grey to dark grey, organic rich silty marl, clay marl, fine-grained sandstone, calcareous marl, in part laminated siltstone (Rékavölgy Siltstone Formation). Its total thickness is 160 m. The formation is rich in fish remains, ammonites, belemnites, bivalves and foraminifers.

In the Villány Zone the best outcrop of the Lower Jurassic is situated on the Templom Hill at the village Villány (Vörös 2010) and it is represented by the 8 m thick Somssichhegy Formation (Figs. 3 and 4) deposited with gentle angular unconformity above the Upper Triassic Mészhegy Formation (Vörös 1990; Galácz et al. 2008). It consists of a lower detrital member and an upper biodetrital (crinoidal) limestone member. The rich ammonite association and brachiopods indicate that the age of the formation is Early Pliensbachian. The lower member is a product of a ***transgressive shallow marine***; the upper one is a ***sublittoral to shallow bathyal*** environment. The upper half of the lower member is called a "boulder bed" because boulder-size sandy limestone fragments are the major constituents in the pebbly and sandy limestone matrix. The lower member is capped by a 20–30 cm thick fossiliferous bed (ammonites, belemnites, brachiopods and petrified drift woods).

The upper part of the formation is well-bedded limestone with molluscs and sorted crinoid fragments. The Eodoceratacea ammonite fauna of the Somssichhegy Formation shows a close relationship with those of the Prealpine Sub-Briançonnais and the Pontides (Dommergues & Geczy 1989; Géczy & Galácz 1998). It is evidence that the Villány-Bihor Zone belonged to the Euro-Asiatic (or Euboreal) province situated on the European margin even in the Early Pliensbachian.

The thick Lower Jurassic succession of the Mecsek Mountains developed continuously in a deepening environment, while it is lacunose and thin in the Villány Hills (Fig. 4). It is worth mentioning that at the eastern end of the Villány-Bihor Zone (Bihor Mts) the Lower Jurassic resembles the Mecsek succession. It means that the one-time facies boundary was cut by the Late Cretaceous thrust plane.

Getting far from the siliciclastic source areas in the Middle Jurassic

There was no break in sedimentation in the Mecsek Zone in the Early and Middle Jurassic (Fig. 3). The anoxic Rékavölgy Siltstone Formation continuously developed into the bathyal Komló Calcareous Marl Formation of Aalenian–Bajocian age (Fig. 4). The transitional beds are dark grey platy marl replaced upward by alternating beds of grey, spotted, calcareous marl, marl and clayey limestone 50 to 500 m in thickness. The most typical fossils are tiny bivalves (*Bositra*), but other bivalves and scattered chronozone-indicator ammonites (Vadász 1935) also occur. The water depth was bathyal, deepening upwards in harmony with the decreasing amount of siliciclastics. In the Bathonian, the sedimentation of the Jurassic succession shows a radical change. The thick grey clayey or sandy succession typical of the European margin, is replaced by the red or variegated, nodular Óbánya Limestone Formation. This is the first occurrence of the so-called "ammonitico rosso" facies characteristic for the Tethyan Province. The 10–15 m thick formation was formed in a medium to deep bathyal environment. It is very rich in ammonites and belemnites, although some brachiopods and bivalves also occur. According to Galácz (1995), the deposition of the formation is restricted to the Bathonian. The microfauna (foraminifers and ostracods) suggest an off-shore, deep-water environment with relatively poor nutrient supply.

The lithological differences indicate further deepening of the bathyal environment during the Callovian to Early Kimmeridgian deposition of the Fonyászó Limestone Formation (Fig. 3). The nodular Óbánya Limestone is substituted after rapid transition to the lower member of the Fonyászó Limestone Formation. It is red and greenish-grey, well-bedded, often platy limestone, marl or calcareous and siliceous marl with pale green, thin clay, clayey marl and marl intercalations of tuff (?) origin with angular volcaniclastics in the host limestone (Császár 2002). The upward increasing frequency of the chert nodules indicates continuous deepening of the basin. The prevailing *Bositra* content characteristic for the 20 m thick lower member interval gave place upwards to the radiolarians, while the frequency of the rest (ammonites, belemnites, brachiopods, bivalves and foraminifers) did not change considerably. The age of the lower member is Callovian to earliest Oxfordian.

The Middle Jurassic (Figs. 3 and 4) in the Villány Zone is represented by the condensed, unique Villány Limestone Formation of 0.5 m thickness deposited after a long break in sedimentation above the Somssichhegy Limestone Formation. It is known from its type locality called Templom Hill quarry, east of Villány village (Lóczy 1915; Kaszap 1963; Vörös 2010, 2012). Its lithology and ammonite association is documented by Géczy & Galácz (1998). The majority of the 133 ammonite taxa and the reworked rock fragments are encrusted by deep-water stromatolite. This bank represents the Upper Bathonian and almost the whole Callovian. Its foraminiferal and ostracod content is reported by Görög et al. (2012). The formation is also known from the Rózsabánya quarry, Máriagyűd above the Middle Triassic dolomite and in the Magyarbóly Mb-1 borehole as an intercalation within a thick crinoidal limestone body.

Bathypelagic and platform carbonate in the Late Jurassic

The upper 25 m part of the typical Fonyászó Limestone Formation (Raucsik 2012b) is composed of cherty limestone, cherty calcareous marl and radiolarite. They are enriched in radiolarians and cadosinids but ammonites, belemnites, brachiopods, bivalves and foraminifers may also be found. The age of the upper part of the formation is Oxfordian–Early Kimmeridgian. The depositional environment of the formation is ***deep bathyal*** but there is a craggy change in lithology and sedimentary environment in time and space as well. The succession is getting more grey, more cherty and/or clayey to the north and north-east direction in the Mecsek Zone (Bérczіné et al. 1997) especially in the Alföld, but within the Mecsek Mts too.

The upper part of the Fonyászó Formation is Oxfordian–early Early Kimmeridgian. It is replaced upwards by the variegated nodular Kisújbánya Limestone Formation with a few red and grey chert nodules of ***open marine*** origin. It was formed in the Kimmeridgian–Early Tithonian. *Saccocoma*, radiolaria, *Cadosina* and *Stomiosphaera* are its prevailing microfossils, the macrofossils (ammonites, belemnites) are subordinate. The thickness of the formation is approximately 20 m.

In the 110 m thick Márévár Limestone Formation of Maiolica facies, plenty of calpionellids were identified. The lower member of the formation consists of well-bedded, cherty, clastic limestone with intraformational breccia beds, while the upper member is thinner bedded, occasionally with internal laminar structure, although it may contain some calcareous marl, or even thin clay beds. It is generally poor in megafossils (ammonites and belemnites), but their frequency increases southward. The formation contains pelagic microfossils (*Saccocoma* in the basal layers, radiolarians in the middle and upper part, while calpionellids may occur in the entire section). As a general tendency in the Middle and Upper Jurassic of the Mecsek Zone the thickness of the Márévár Limestone Formation deposited above the dissected basement decreases southward in accordance with the general shallowing tendency. The ca. 18 m thick southernmost Zengővárkony section is condensed, thin- to thick-bedded, and rich in microfossils, with almost all calpionellid zones and subzones. Its mixed and condensed nature is determined by a southward ***shallowing water depth***. The age of the formation is Late Tithonian–Early Hauterivian (Nagy & Szinger 2012).

There is a fundamental change in the composition of the Jurassic succession of the Villány Hills from the Upper Jurassic: the highly lacunose and condensed Lower and Middle Jurassic is replaced above a hardground by the thick-bedded or even massive Upper Jurassic limestone (Szársomlyó Limestone Formation — Figs. 3 and 4) at least 300 m in thickness. There are significant differences among the nappe units in facies and thicknesses as well. The basal beds of the formation are barren in megafossils but rich in planktonic foraminifers. Higher in the sequence ooidal and sponge-, brachiopod- and belemnite-bearing limestone intercalate into the *Saccocoma*-bearing beds. In the upper part of the formation *Tubiphytes*, coral, green algae and limestone fragments deriving from ***shallow marine platform*** occur more and more frequently.

The upper part of the Szársomlyó Limestone Formation in the eastern continuation of the Bóly Basin (Nagybaracska B-27 and B-28 boreholes) is present. It is rich in colonial organisms, mainly corals and bryozoans but green algae and *Tubiphytes* are also frequent. The sedimentary environment is partly lagoonal, and partly resembles the reef slope. Based on calpionellids the age of the upper part of the borehole B-28 (417.0–465.0 m) is Late Tithonian–Berriasian (Császár 2002).

The Villány-Bihor Zone became land in the Berriasian and in traps of the karstified surface pisoidic bauxite accumulated (Harsányhegy Bauxite Formation). It was followed by a slow transgression the product of which was an Urgonian carbonate platform in the entire Villány-Bihor Zone. A compressional tectonic movement put an end to this kind of sedimentation in the Albian when the first imbrications and nappes were formed in the Tisza Unit.

Peculiarities of the Jurassic sedimentation on the Máriakéménd–Bár Range

The Jurassic formations in the Máriakéménd–Bár Range (MBR) located between the Mecsek Mts and the Villány Hills (Figs. 2 and 4) have been known since 1912 (Lóczy Jr. 1912), but their correct age is still debated. Their petrographic data were introduced by Schlemmer (1984), Raucsik (1996), and Császár (2012). Formally the MBR is an E-NE–W-SW oriented subsurface range below the Neogene succession between the Ellend Basin to the north and the Bóly Basin to the south, but lithologically similar types of rock are found close to the southern margin of Mecsek Zone at Pusztakisfalu, next to the large listric (and strike-slip) fault. The best outcrops of the range are found north of Máriakéménd and Versend. Out of ca. 20 boreholes, only six cut the Jurassic and reached the underlying Middle Triassic carbonate formations (Fig. 5). It means there is no Upper Triassic on the MBR. There are only two boreholes (Máriakéménd Mk-3 and Somberek Smb-1) in which Lower Paleozoic metamorphite was reached below the Triassic.

Four different types of Jurassic are known in the MBR. In spite of the proximity of the Mecsek Zone (Fig. 3), the Jurassic successions are more similar to those of the Villány Zone therefore it is considered to be the part of this one. In the Pusztakisfalu Pk–III borehole the oldest Jurassic sediment is the Aalenian red, coarse-grained crinoidal limestone (Pusztakisfalu Limestone Formation) with brachiopods and belemnites. The formation is impregnated by oxidic iron ore with metamorphic rock fragments in the basal beds. The extent of the formation is restricted to the Pusztakisfalu and Apátvarasd environs with a thickness of approximately 50 m.

In the MBR sensu stricto the following rock types are typical: pale grey or greenish-grey platy, crinoidal limestone frequently containing grey chert nodules and in certain horizons thin green clay intercalations. In thin sections many sponge spicules and *Bositra* shell fragments and a few benthic foraminifers can be recognized. The formation is well outcropped in a quarry south of Máriakéménd after which it is called the Máriakéménd Limestone Formation (Raucsik 2012c). The thickness of the formation exceeds 250 m in the Somberek Smb-1 borehole (Fig. 5). From the lithological point of view, it is similar to the lower part of the Szársomlyó Limestone Formation discovered in the Szoborpark (Park of Statutes) at the eastern end of the Harsány Hill. In the borehole Nagybaracska B-28 the lowermost two beds within the 700–708 m interval are crinoidal, *Bositra*-bearing and siliceous (Császár 2002), therefore it can also belong to the Máriakéménd Limestone Formation.

In the eastern part of the MBR, the Máriakéménd Limestone is underlain by a marl sequence from which it develops continuously with alternation of calcareous marl, clayey limestone and crinoidal limestone. In the Somberek Smb-1 borehole the thickness of this clayey limestone and calcareous marl is close to 30 m. Schlemmer (1984) classified the succession under the Komló Calcareous Marl on the basis of

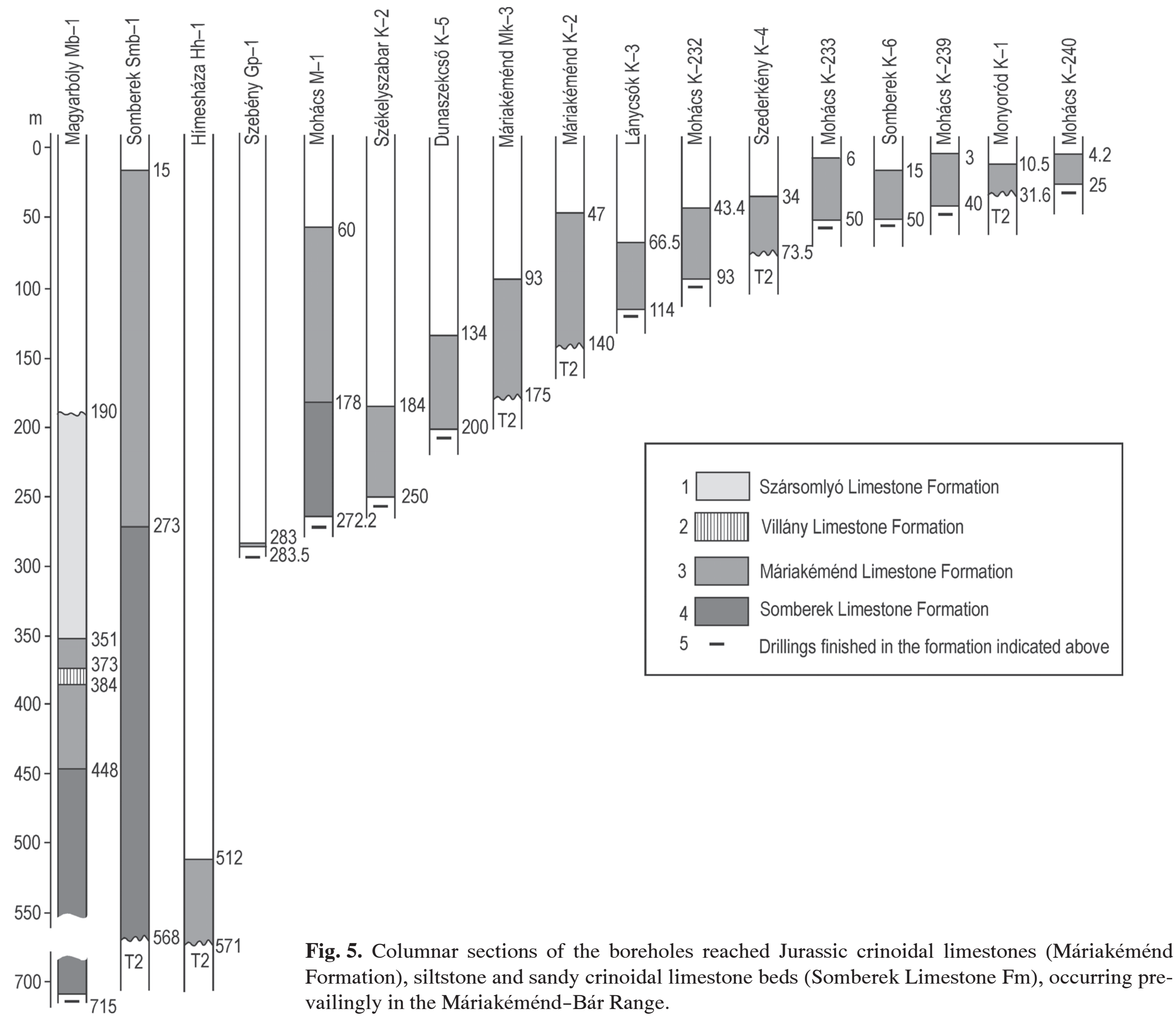


Fig. 5. Columnar sections of the boreholes reached Jurassic crinoidal limestones (Máriakéménd Formation), siltstone and sandy crinoidal limestone beds (Somberek Limestone Fm), occurring prevailingly in the Máriakéménd–Bár Range.

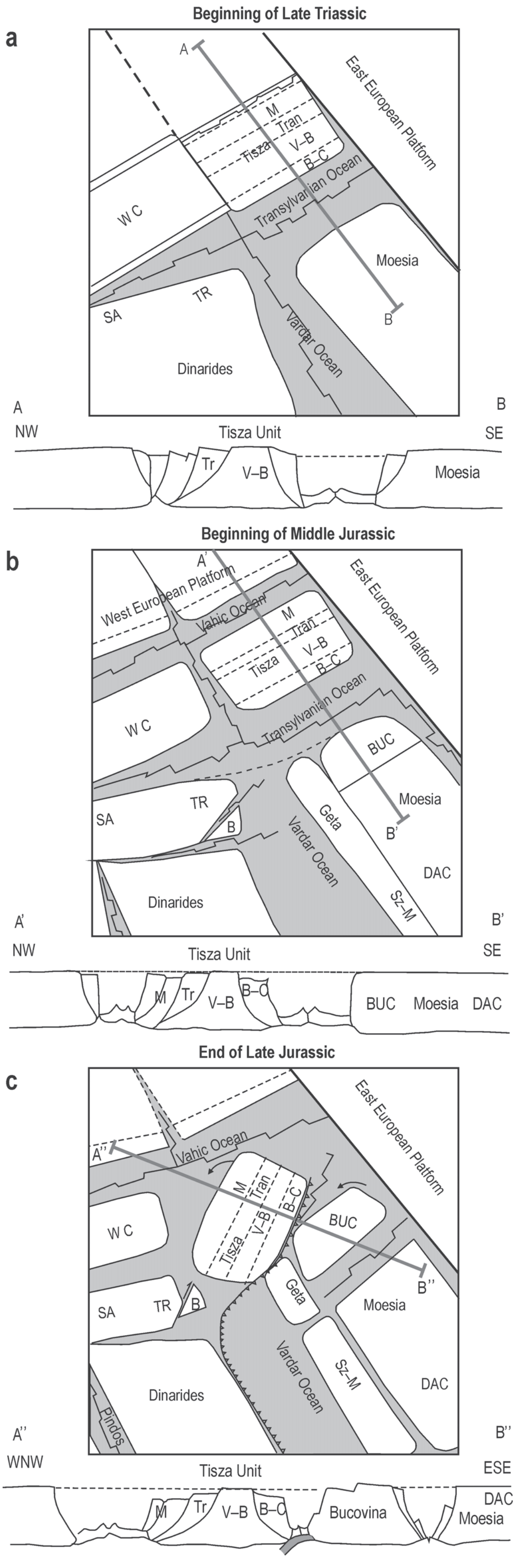
marl content. In addition to *Bositra*, radiolarians and ammonites the drill cores often contain echinoderm fragments, even crinoidal beds which are not characteristic for the Komló Formation. A similar succession is known at the lower part of Mohács (M-1 borehole), where the prevailing rock types are silty marl, silty calcareous marl, but — as subordinate components — crinoidal limestone intercalations also occur regularly. Surprisingly, east of the Villány Hills this kind of rock was described from the Magyarbóly Mb-1 borehole in the Villány Zone, the upper part of which resembles the Máriakéménd Limestone, while the lower one resembles the Somberek Formation (Fig. 5). Nevertheless the latter two formations can be considered as preliminary identification, but their precise classification requires further studies.

The succession of the Nagykozár Nk-2 borehole located to the west of the Ellend Basin lithologically, floristically and faunistically is different from the previous boreholes. According to the preliminary study it may include Late Jurassic and Early Cretaceous fossil assemblages. The neomorphic dolosparitic intercalations are clear indicators of strong tectonic influences; therefore the correct qualification of the succession requires detailed thin section studies.

Discussion

Paleoenvironmental and paleogeographical history of the Mecsek and the Villány-Bihor Zones

Until the end of the Middle Triassic the sedimentary environments of the Hungarian part of the Mecsek and Villány-Bihor Zones show minor differences. The situation fundamentally changed at the turn of the Middle and Late Triassic. According to several authors (Stampfli & Borel 2002; Gawlick et al. 2009) the break-up of Pangea and the opening of the Central Atlantic Ocean came about in the Early Jurassic time. It is hard to imagine that the radical change at the northern margin of the future Tisza Unit would have been independent of this event. At this time the Tisza Unit was situated on the southern margin of the European plate. The complete separation of the Tisza Unit from the European plate happened in the early Middle Jurassic as was proved by Géczy (1973) faunistically. Nevertheless the radical change started in the Late Ladinian (Fig. 3), namely in the Mecsek Zone when the marine carbonate sedimentation was replaced by fluvial siliciclastic sedimentation, while in the Villány



Zone the deposition almost stopped completely at that time as a consequence of the rifting. It means that the separation process started with initial rifting close to 60 Ma earlier. This is the moment when the formerly uniform northern part of the Tisza Unit started to disintegrate forming the Mecsek and the Villány-Bihor Zones. This separation is the beginning of the birth of the Ligurian–Penninic–Vahic Ocean (Fig. 6a). Due to the listric fault not only the Mecsek Zone tilted to the south but the Villány Zone as well. This is the reason why a relatively thick succession accumulated along the southern margin of the Mecsek Zone, while the northern margin of the Villány Zone was raised and served as a source area for the accumulation of the Upper Triassic and Lower Jurassic formations in the Mecsek Zone. In these formations Lower Paleozoic metamorphites and Triassic carbonate rocks form the conglomerate and breccia beds. The situation is proved by the Pusztakisfalu Pk-III borehole (Fig. 2), where Lower Paleozoic is overlain by the Middle Jurassic crinoidal limestone, whereas more to the south not only Middle Triassic carbonates are preserved but in a few cases the Upper Triassic Mészhegy Formation also occurs.

During the Early Jurassic the subsidence speeded up along the southern margin of the Mecsek Zone (Fig. 6b) as is indicated by the extraordinarily thick succession of the Mecsek Coal, the Vasas Marl and the Mecseknádasd Sandstone Formations, while in the Northern Imbrication Zone (Fig. 2) the thickness of the Lower Jurassic is much less. The north-western part of the Mecsek Zone must have been raised above the accommodation level and it acted as a major source for the siliciclastic sandstone beds, while carbonate clasts derived from the south. In the Early Jurassic, the southern side of the listric fault (northern margin of the Villány-Bihor Zone) still continued to act as a source area for the Mecsek Zone, where the deposition of the breccia and conglomerate intercalation continued. In the middle Early Jurassic, after a sub-aerial time interval the less elevated southern part of the Villány Zone became flooded and a few meters of siliciclastic sandstone and crinoidal limestone were deposited. As a result of the long lasting rifting process the Tisza Unit separated from the European continent in the Middle Jurassic and the sedimentation rate decreased by more than one magnitude in the Mecsek Zone. It is well documented by the decreasing grain-size in the Late Toarcian and early Middle Jurassic time, and even more clearly in the middle and late Middle Jurassic, when thin, really deep-water siliceous limestone and radiolarite were deposited in the entire Mecsek Zone. The process became even more conspicuous in the Early Cretaceous when the thinning process turned into rifting in a broad belt of the Mecsek Zone

Fig. 6. Paleogeographic sketch maps showing the changes of the geodynamic position of the Tisza Unit from the Late Triassic (**a**), beginning of the Middle Jurassic (**b**), end of Late Jurassic (**c**) (after Plašienka 2000, modified). **B** — Bükk Unit, **B–C** — Békés-Codru Zone, **BUC** — Bucovinian Unit, **DAC** — Dacides, **M** — Mecsek Zone, **SA** — Southern Alps, **Sz–M** — Serbo-Macedonian Unit, **TR** — Transdanubian Range, **Tran** — Transitional zone between the Mecsek and Villány Zones, **V–B** — Villány-Bihor Zone, **WC** — Western Carpathians.

producing even special (Mecsek-) type atolls (Császár 2002) up to the Albian.

The thinning process was much less developed in the Hungarian part of the Villány-Bihor Zone. It is shown by the highly lacunose sedimentation during the Middle Jurassic time — at least in the Villány Hills area. This phenomenon is discussed by Vörös (2012) and explained with the elevated position of the area. The northern, MBR part of the Villány-Bihor Zone was flooded in the late Early Jurassic or Middle Jurassic time only, when thick crinoidal, *Bositra-* and sponge spicule-bearing and cherty limestones, clay and marl were deposited. The eastern part of the MBR must have been an embayment this time keeping direct connection with the Mecsek Zone (see Komló Calcareous Marl). The Late Jurassic time was characterized by a shallowing tendency in the entire Alpine-Carpathian and Dinaric Realm (Gawlick et al. 2007, 2009), and it can be noticed also in the Mecsek Zone and in particular in the Bihor Mountains of the Villány-Bihor Zone (Bleahu et al. 1981). Within the deep bathyal Mecsek Zone, there are significant differences in the north-south direction including the Mecsek Mountains: the Northern Imbrication area was much deeper than the southern margin (Bérczíné et al. 1997). As a consequence of the first meeting (weak collision) of the Tisza and Geta tectonic units in the Late Jurassic the Villány-Bihor Zone (Fig. 6c) was characterized by a much shallower environment than the Mecsek Zone. The massive or thick-bedded limestone rich in reworked colonial organisms (corals, colonial algae, *Tubiphytes*) and lagoonal fossils such as green algae in the uppermost part of the Szársomlyó Limestone indicate a continuous shallowing tendency in the Villány Zone from the Oxfordian onward. The shallowing tendency of the Villány-Bihor Zone is even more striking in the Bihor Mts, at the eastern end of the zone (see Albioara Limestone and Cornet Limestone). The time of strong and final collision of the Tisza and Dacia Units (Fig. 6c) only started in the Albian.

Conclusions

The Late Triassic and Jurassic history of the Mecsek and Villány-Bihor Zones is determined by the separation of the Tisza Unit from the European Platform.

1. The first step of the separation is the formation of listric faults at the beginning of the Late Triassic which developed parallel to the Vahic Rift Valley, as the continuation of the North Penninic Rift Zone. This is the moment from which the Mecsek Zone (Karolinavölgy Sandstone) and the western part of the Villány-Bihor Zone (Mészhegy Formation) can be distinguished as different facies and tectonic zones within the independent Tisza Unit that was just born.

2. The formation of the listric fault at the southern margin of the Mecsek Zone continued and on the intensively subsiding block tilted to the south, a thick succession developed in the Hettangian–Early Sinemurian (Mecsek Coal) and also in the Late Sinemurian–Pliensbachian (Vasas Marl, Hosszúhetény Calcareous Marl and Mecseknádasd Sandstone). The carbonate pebbles and in part the siliciclastics too derived from the northern margin of the Villány-Bihor Zone, although the northern and north-western part of the Mecsek Zone also acted as a source area of siliciclastics for the Mecsek Basin.

3. Similar but less intensive events must have happened on the southern margin of the ancient Villány-Bihor Zone. As a consequence of the southward tilting, its northern margin rapidly uplifted, eroded and the Middle Triassic carbonate rocks, Upper Paleozoic siliciclastics and in part metamorphites were transported into the subsiding Mecsek Basin from the Late Triassic up to the early Middle Jurassic.

4. In the southern part of the Villány Zone after a certain-subaerial break in sedimentation a few meters thick siliciclastic and dolomitic sediment (Mészhegy Formation) accumulated in the Late Triassic and it was followed by highly lacunose clastic, bioclastic, fossiliferous marine sedimentation in the Early (Somssichhegy Formation) and the Middle Jurassic time (Villány Formation).

5. The Máriakéménd–Bár Range, the northern part of the ancient Villány-Bihor Zone was flooded by the sea in the Middle Jurassic only. The basement is prevailingly Middle Triassic carbonate, except the environs of Pusztakisfalu village where it consists of metamorphites. The patch reef zone must have developed in the northern part of the Villány-Bihor Zone from where platform elements (ooids) and reef-building organisms were transported to the north into the Mecsek Basin and to the south towards which the platform was prograded.

6. The first, weak collision between the Tisza and Dacia (Geta and Bucovinian) Units may have happened in the Late Jurassic, and can be recognized in the significant uplift of the Villány-Bihor Zone only. This process became more intensive in the late Early Cretaceous and this led to the first occurrence of flysch in the Villány-Bihor Zone.

7. More precise paleogeographical reconstruction is hampered by the Sub-Hercynian, Pre-Gosau and less intensively by the Miocene tectonic phases. This is the reason why the Mecsek and Villány-Bihor Zones were reduced to their recent width and the majority of younger Mesozoic formations were eroded.

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