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JURASSIC PALAEOGEOGRAPHY OF THE TRANSDANUBIAN CENTRAL RANGE (HUNGARY)

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Riassunto. La Catena Centrale Transdanubiana (CTR) è costituita da un allineamento di colline nel nord dell' Ungheria. Essa è formata soprattutto da rocce carbonatiche di età mesozoica con facies alquanto affini a quelle delle Alpi Meridionali e dell'Austroalpino. Il sistema Giurassico viene suddiviso in diverse formazioni costituite prevalentemente da calcari pelagici. I ritrovamenti abbondanti di ammoniti, raccolti strato per strato in numerose sezioni, consentono una risoluzione biostratigrafica eccellente.

Lo spessore delle formazioni giurassiche è solitamente basso, ma cambia lungo la catena. Da un massimo di 500 m nella porzione occidentale, passa a valori assai variabili nella parte centrale (10-400) (montagne del Bakony), per ridursi a meno di 100 m ad est (Gerecse). Nel settore del Bakony, le variazioni di spessore riflettono la topografia del fondo marino, assai articolata durante il Giurassico. La tettonica sinsedimentaria è dominata da faglie normali; blocchi ruotati e faglie listriche sono ipotizzabili solo ad oriente.

Si possono identificare cinque stadi principali nell'evoluzione paleogeografica:

1) Hettangiano superiore: prevalenza di bassifondi oolitici, ad eccezione di pochi siti senza sedimenti o con sedimenti di piattaforma strutturale.

2) Sinemuriano e Pliensbachiano: la disintegrazione tettonica da luogo alla formazione di paleoalti e fosse sottomarine, con sedimentazione condensata o non deposizione sui paleoalti e successioni sedimentarie più spesse e continue nelle fosse. I paleoalti sono contornati da un ventaglio di sedimenti rideposti, come brecce di scarpata, cocquine a brachiopodi, calcareniti a crinoidi, calcari silicei spiculitici, mentre calcilutiti pure o argillitiche prevalgono nelle parti più distali (Rosso Ammonitico).

3) Toarciano inferiore: sulla topografia precedente si sovrappone l'evento anossico tetidiano, con argilliti nere e depositi sedimentarii di Mn concentrati sul versante occidentale di alcuni paleoalti.

4) Giurassico medio e inizio del Giurassico superiore: prevalenza di radiolariti, i cui limiti sono entrambi eterocroni (da Aaleniano a Kimmeridgiano), con l'eccezione di alcuni paleoalti. L'assenza di carbonati dal Batoniano sommitale sino all'Oxfordiano inferiore indicherebbe che l'intera TCR si trovava sotto la CCD durante questo intervallo.

5) Giurassico terminale: la sedimentazione uniforme delle facies tipo Rosso Ammonitico e Biancone durante il Kimmeridgiano superiore ed il Titoniano è interrotta solamente durante il Titoniano inferiore da intercalazioni locali di brecce di pendio e di calcari biodetritici grossolani. Questi vengono interpretati come le ultime manifestazioni di movimenti tettonici sinsedimentari lungo le faglie che delimitano i paleoalti.

Sulla base delle affinità paleogeografiche durante il Giurassico, la TCR è immaginata come la prosecuzione esterna e settentrionale della piattaforma/plateau di Trento, situata a nord del futuro lineamento insubrico. Tuttavia la disintegrazione tettonica in blocchi e le differenze di subsidenza inziarono prima in questo comparto, dando luogo ad una topografia più' articolata in questo settore del margine passivo della Tetide.

Abstract. The Transdanubian Central Range (TCR) is a flattened range of hills in northern Transdanubia (Hungary), formed mainly by Mesozoic carbonate rocks showing strong facies similarities with the Southern Alps and the Austroalpine domain. The Jurassic system is divided into several formations of predominantly pelagic limestones. Ammonoids are frequent and were collected bed-by-bed in numerous sections, providing an excellent biostratigraphic resolution. The thickness of the Jurassic system is usually small but changes along the strike of the TCR. It reaches a maximum thickness of 500 m in the western part; is very variable (10-400 m) in the central segment (Bakony Mts.) and rather low (less than 100 m) in the east (Gerecse). In the Bakony segment, the thickness variation reflects the strongly dissected topography of the Jurassic sea-floor. Synsedimentary tectonics is dominated by normal faults; tilted blocks and listric faults may be inferred only in the east.

Five main steps were identified in the palaeogeographic evolution:

1) Late Hettangian: carbonate oolitic shoals prevail, except for a few sites where non-deposition or neritic sediments occur.

2) Sinemurian and Pliensbachian: tectonic disintegration resulted in an intricate pattern of submarine horsts and intervening basins, with condensed sedimentation or non-deposition on the horsts and thicker, continuous sedimentary sequences in the basins. The submarine topographic highs are surrounded by aprons of redeposited material (scarp breccias, brachiopod coquinas, crinoidal calcarenites, spiculitic cherty limestones), while pure or argillaceous limestones (Rosso Ammonitico) prevail in the distal areas.

3) Early Toarcian: the Tethys-wide anoxic event is superimposed on the previous submarine bottom topography; the resulting black shales and sedimentary Mn-ores are concentrated on the western sides of some horsts.

4) Dogger to Early Malm: radiolarites with heterochronous lower and upper boundaries (Aalenian to Kimmeridgian) prevail, except for the top of some submarine topographic highs. The absence of uppermost Bathonian to Lower Oxfordian carbonates suggests that the whole TCR sunk below the CCD in those times.

5) Latest Jurassic: the uniform deposition of Rosso Ammonitico and Biancone in the Late Kimmeridgian and Tithonian is interrupted only in the Early Tithonian by local intercalations of scarp breccias and coarse biodetrital limestones. This is interpreted as the

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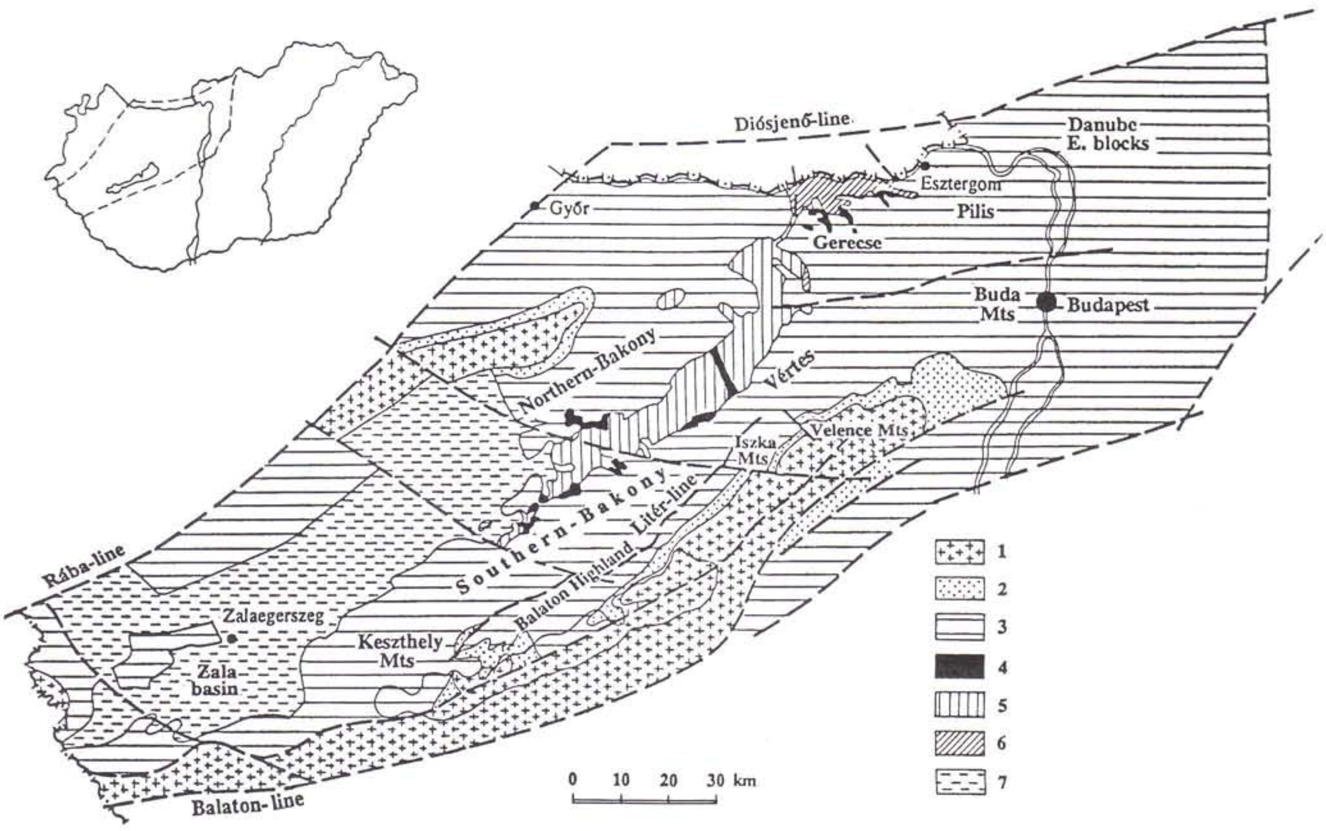

Fig. 1 - Location map of the Transdanubian Central Range showing surface and subsurface distributions of the pre-Tertiary rocks. Legend: 1: Pre-Permian, crystalline (magmatic and metamorphic) rocks, 2: Permian, 3: Triassic, 4: Jurassic, 5: Lower Cretaceous (in predominantly carbonate facies), 6: Lower Cretaceous (in flysch facies), 7: Upper Cretaceous. (after Haas & Budai, 1995).

last manifestation of synsedimentary tectonic movements along the faults bordering the submarine horsts.

Based on palaeogeographic similarities and analogies in Jurassic times, the TCR is visualized as the northern foreground of the Trento platform/plateau (lying north of the later Insubric lineament), where the block-tectonic disintegration and differential subsidence started earlier and resulted in a bottom morphology more dissected than in the South Alpine part of this west Tethyan passive margin.

Introduction.

The Transdanubian Central Range unit of western Hungary provides a good opportunity to trace Jurassic palaeogeography, because it was spared, apparently, by the Alpine compressional phases. The outcropping parts of the range are dominated only by normal faults and less numerous strike-slip faults. On the other hand, the interpretation of deep seismic and geoelectric profiles highlights deep-seated subhorizontal thrust planes, which may suggest allochthony for the whole range (Ádám et al., 1984; Horváth & Rumpler, 1984). However, even if the range is a mega-nappe, it would lie in an uppermost nappe position, without perceptible internal shortening.

Probably due to the mid-Cretaceous nappe emplacement, the range acquired a gentle synform structure with a SW-NE axis, parallel to its strike. The elevated northwestern and southeastern limbs suffered intensive subsequent erosion, and therefore the Jurassic sedimentary rocks were preserved only in the narrow (10 to 20 km wide) axial belt in the hills of the Gerecse, Vértes and Bakony. Other occurrences are known as subsurface continuation to the southwest, in the Zala basin, where they are penetrated by a few boreholes (Fig. 1).

For sources of stratigraphic and sedimentary historical data the reader is referred to some review papers written on the Mesozoic of the Transdanubian Central Range: Galácz & Vörös, 1972; Galácz et al., 1985; Kázmér, 1986; Galácz, 1984; 1988; Galácz & Vörös, 1989.

The Jurassic history of the Transdanubian Central Range.

Prior to the Jurassic history of the range, the Triassic evolution produced varied sedimentary sequences, terminating in an almost uniform, shallow-water carbonate platform extending to the entire area (the Dachstein Limestone platform) (Vörös et al., 1990; Haas, 1994; Haas & Budai, 1995).

The Jurassic is dominated by calcareous lithofacies. Limestones are most common, but marls and radiolarian cherts occur as well. Two types of succession appear: so-called continuous sequences ("basinal sequences"), and successions with repeated depositional hiatuses ("condensed sequences" i.e. successions deposited on submarine topographic highs). The latter record only some stages or ammonite zones, being interrupted by gaps marked by ferromanganese-encrusted hard-grounds. These sequences were developed as paraconformable successions of pelagic red limestones of reduced thickness. Ages and spans of the hiatuses vary in time; i.e. there were no specific periods of general non-deposition or major submarine erosion. On the other hand, in the thicker continuous sequences with less stratigraphic condensation, most of the ammonite zones are present throughout.

A chronostratigraphic scheme (Fig. 2) shows the lateral variations and relationships of the Jurassic formations in the Transdanubian Central Range. This diagram is based on the papers mentioned above, and on our own field experience and data.

The Triassic/Jurassic boundary is drawn at a facies change within the shallow marine, Bahamian-type carbonate platform complex. Here the Lofer cyclothemes and the associated intertidal fossils of the uppermost Triassic Dachstein Limestone disappear, and ooidal-oncoidal, brachiopod-bearing carbonates appear. This unit is the Kardosrét Limestone Formation ("Dachstein-type Limestone" auctt.), which is considered Hettangian in age (Dulai, 1993).

This facies change records a very significant event, i.e. the breakup of the former, wide carbonate platform. The disintegration produced a pattern of elevated and more depressed depositional sites and the bottom topography influenced significantly sedimentation processes for most of the Jurassic.

In the northeastern areas (Vértes and Gerecse Hills) the oncoidal-ooidal limestone is missing, and in some places (e.g. in Tata) the Dachsteinkalk is overlain paraconformably by foraminiferal and crinoidal micritic limestone (Pisznice Limestone). This formation is widespread throughout the entire area, and comprises mainly

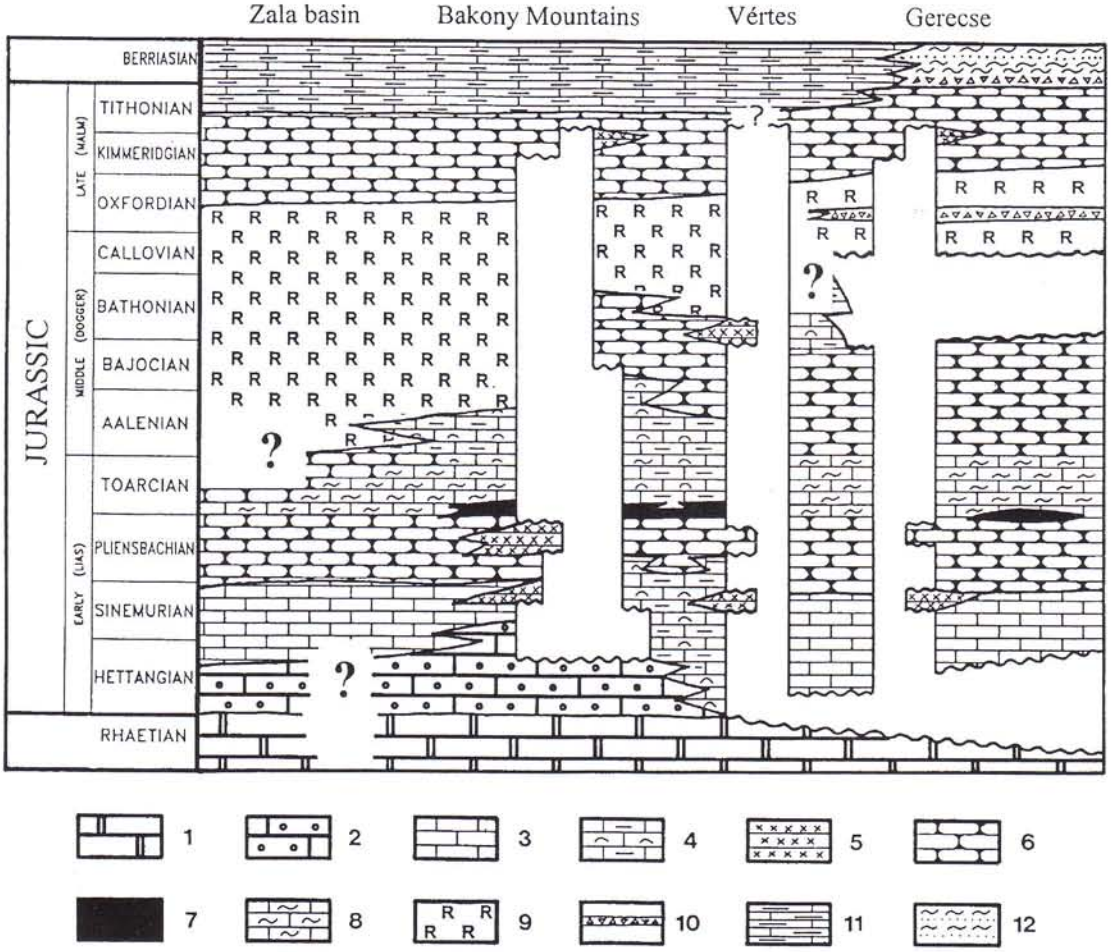

Fig. 2 - Chronostratigraphic scheme showing the uppermost Triassic to lowermost Cretaceous formations of the Transdanubian Central Range. Legend: 1: Dachstein Limestone, 2: Kardosrét Limestone, 3: Pisznice Limestone, 4: Isztimér Formation (Lower Jurassic) and Eplény Formation (Middle Jurassic), 5: Hierlatz facies, including Lower (Hierlatz Limestone s. str.), Middle and Upper Jurassic (Szélhegy Limestone) formations, 6: Ammonitico Rosso facies, including Tüzkövesárok Limestone (Lower Jurassic), Tölgyhát Limestone (Middle Jurassic) and Pálihálás Limestone (Upper Jurassic), 7: Úrkút Formation (black shale, Mn-ore), 8: Kisgerecse Formation (Ammonitico Rosso marl), 9: Lókút Radiolarite, 10: "Oxfordian breccia", 11: Biancone or Maiolica facies, including Mogyorósdomb and Szentivánhegy Formations, 12: Felsövadács Breccia and Bersek Formation (flysch), blank: sedimentary gaps.

the Lower Sinemurian. In the eastern and western ends of the range it passes gradually to a mostly reddish, sometimes nodular mudstone of "Rosso Ammonitico" facies (Tüzkövesárok Limestone). More varied Lower Jurassic lithologies can be found in the central segment, where the topography was dominated by submarine highs. The transitional zones between the horsts and the basins are characterised by scarp breccias and biodetrital limestones (Hierlatz Limestone) showing decreasing grain-size towards the basins. Fine-grained redeposited sediments, such as well-bedded cherty and crinoidal limestone (Isztimér Formation) were deposited on the floor of the basins.

The Toarcian stage is usually represented by clayey marls with calcareous nodules (marly Rosso Ammonitico = Kisgerecse Formation), but in some regions black, laminated shales with manganese carbonates (Úrkút Formation) were deposited. This formation is referable to the Early Toarcian anoxic event. The most complete record of this anoxic event is the nearly 40 m thick laminated black shale of Úrkút, where mining activity was established, based on the manganese content of the shale. A similar succession is known around Eplény. Elsewhere, the products of the anoxic event appear as a thin, dark, laminated interlayer (e.g. in Lókút, Bakony Mts, see Galácz & Vörös, 1989), or as a thin bituminous black clay (e.g. in Tölgyhát Quarry, Gerecse Hills) within the calcareous sequence, or as a significant hiatus (e.g. Bánya Hill in the Gerecse, see Jenkyns et al., 1991).

The Liassic facies pattern prevailed into the Middle Jurassic. In the northeast (Gerecse) and southwest (Zala basin) rather condensed Rosso Ammonitico-type limestones persist (Tölgyhát Limestone Formation), whereas in the Bakony segment much thicker, siliceous, fine-biodetrital limestones (Eplény Formation) are dominant. Another feature of the Middle Jurassic is the reappearance of neptunian dyke infillings and scarp breccias, which seem to be restricted spatially to the margins of the horsts and temporally to the Bajocian (Bakony) and to the Bathonian (western Vértes). These are interpreted (Galácz, 1988) as the sedimentary records of rejuvenated movements along the margins of the submarine horsts. The movements repeatedly lessened the size of the horsts, slicing down more and more parts at greater depths.

The next important formation, the Lókút Radiolarite has perhaps the widest temporal and spatial distribution in the Transdanubian Central Range: the formation of these cherts and siliceous marls started in the Bajocian (in some places even in the Aalenian) and lasted until the Oxfordian (locally until the Kimmeridgian). The radiolarite shows some significant differences in lithofacies in the Bakony and in the Gerecse Hills and Tata. In the Bakony the dominant lithology is a siliceous marl with thinner or thicker massive chert beds, and the succession shows conspicuous heterochrony in the carbonate/radiolarite/carbonate facies changes, i.e. both at the lower and upper lithologic boundary. On the other hand, in the Gerecse Hills and on the Tata horst the radiolarite is usually thinner (2 to 3 m), and the massive chert beds consist of almost pure silica. In the latter area the radiolarite seems to be restricted to a narrower time interval: it overlies a dissolved surface of Upper Bajocian limestone, and is followed by a lowermost Kimmeridgian limestone (Főzy, 1993). Radiolarian studies show also that in this area the chert is restricted only to the Oxfordian (Dosztály, L. pers. comm., 1996).

The Upper Jurassic above the radiolarite is represented by rather uniform pelagic limestones. In some localities a thin, smectite-rich clay bed is present at the radiolarite-limestone transition. The Pálihálás Limestone of Rosso Ammonitico facies comprises the Kimmeridgian to Early Tithonian time interval, and in very few places in the Bakony and Gerecse Hills it interfingers with "Hierlatz-type" biodetrital calcarenites (Szélhegy Limestone). The Upper Tithonian Maiolica- or Biancone-type white micritic limestones (Mogyorósdomb Limestone) show a continuous transition to the Cretaceous, except for the Gerecse area, where the Berriasian and the Neocomian are represented by detrital (flysch-like) sediments.

Relative thickness variations.

Several details of the Jurassic history summarised above were described and discussed in papers dealing with the palaeogeography and evolution of different parts of the Transdanubian Central Range (e.g. Konda, 1970; Mészáros, 1971; Fülöp, 1971 and 1976; Vígh, 1961; Galácz & Vörös, 1972; Vörös, 1974 and 1986; Haas et al., 1984), but summaries encompassing the whole range are rare (e.g. Kázmér, 1987; Schmidt et al., 1991, only for the Early Jurassic). The present work is the first attempt to deal with the subject in a comprehensive manner. Thus we believe that the tectono-sedimentary evolution of the range could be better understood and illustrated by an interpreted thickness-diagram drawn along the strike of the range (Fig. 3). This diagram was constructed from borehole data, individual sections, and explanatory notes of geologic maps (scale 1:20,000) published by the Hungarian Geological Institute. The zero (reference) line at the top of the diagram is set at the Jurassic/Cretaceous boundary. Some descriptions and interpretations are necessary to clarify certain details. The following remarks address specific peculiarities of the picture.

1. The Kardosrét Limestone is widespread in the Zala basin and in the Bakony (but missing at Misefa,

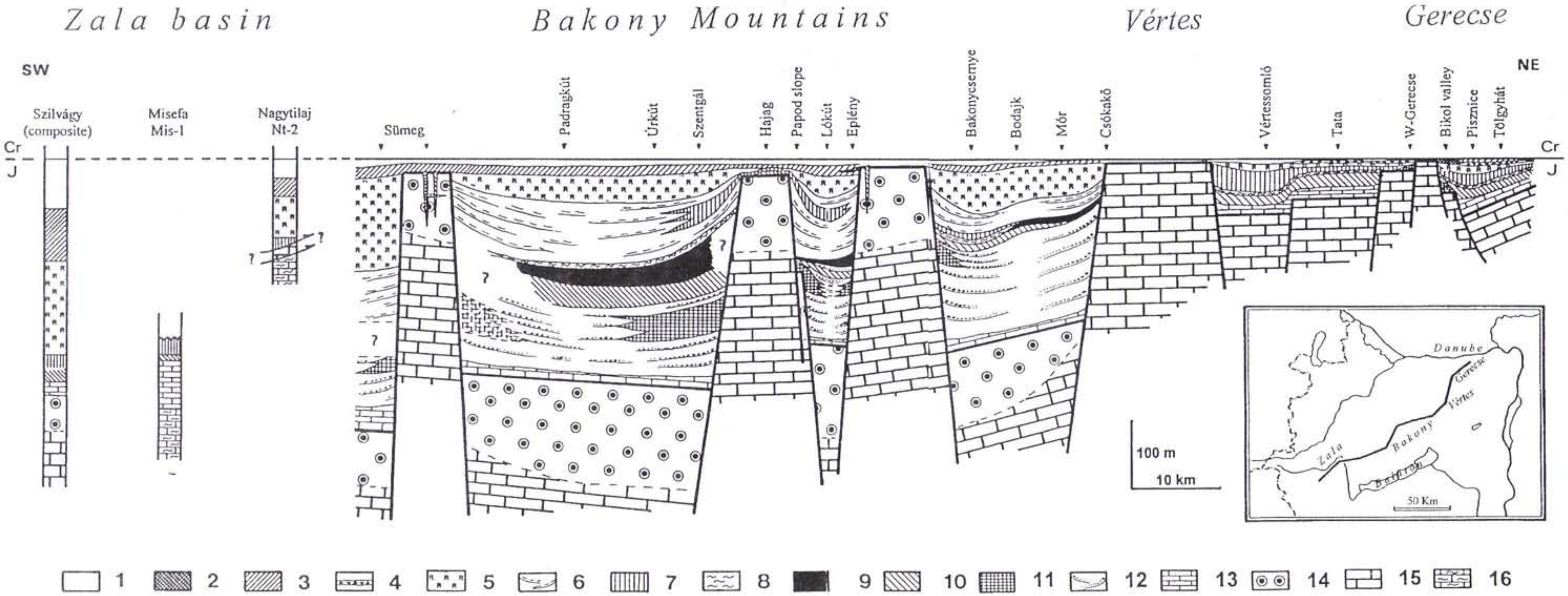

Fig. 3 - Jurassic lithologic units of the Transdanubian Central Range showing their thickness variations along a SW to NE profile. Further explanation in the text. Legend: 1: Maiolica or Biancone facies, 2: Szélhegy Limestone, 3: Pálihálás Limestone, 4: "Oxfordian breccia", 5: Lókút Radiolarite, 6: Eplény Formation, 7: Tölgyhát Limestone, 8: Kisgerecse Marl, 9: Úrkút Formation, 10: Tüzkövesárok Limestone, 11: Hierlatz Limestone, 12: Isztimér Formation, 13: Pisznice Limestone, 14: Kardosrét Limestone, 15: Dachstein Limestone (Upper Triassic), 16: Kössen Formation (Upper Triassic). Sources: Bérczi-Makk, 1980, Körössy, 1987 and 1988, Haas et al., 1984; Mészáros, 1976a and 1976b; Csima & Mészáros, 1976; Konda, 1970, 1985, 1987, 1988a and 1988b; Knauer et al., 1982; Bernhardt & Peregi, 1983; Bernhardt, 1983; Fülöp et al., 1960 and 1965; Fülöp, 1976; Vigh, 1961.

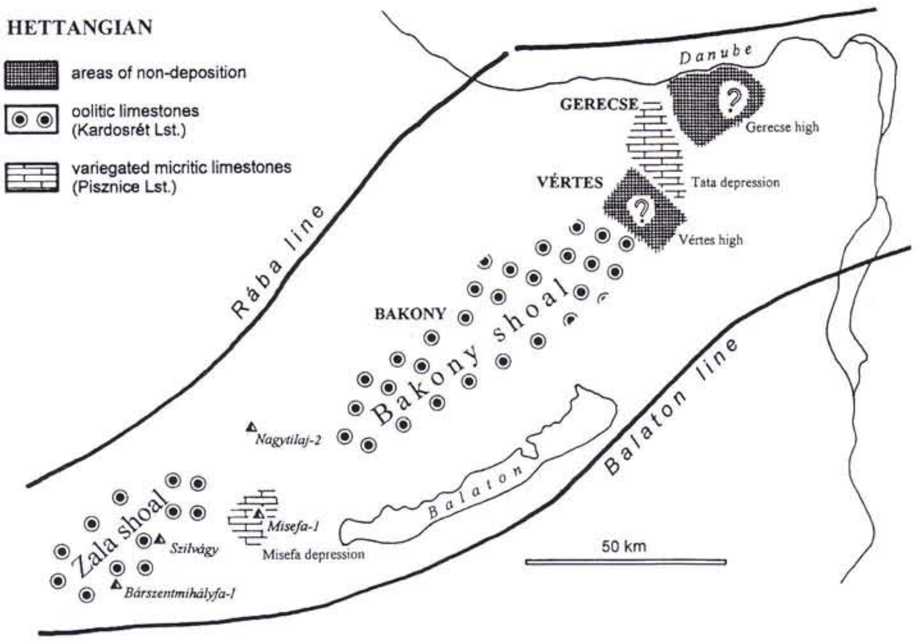

Fig. 4 - Palaeogeography of the Transdanubian Central Range in the earliest Jurassic (Hettangian). The predominance of oolitic shoals.

together with the Dachsteinkalk): this indicates the presence in these areas of extensive carbonate shoals in the Hettangian, in contrast with the Vértes and Gerecse, where non-deposition or substituting foraminiferal wackestones are recorded.

2. Tectonic blocks (submarine topographic highs) are prevailing in the Bakony segments, with condensed sedimentation on top, and thick, partly redeposited sediments between blocks. Note the thinner Liassic basinal deposits in Zala. The Vértes-Gerecse segment still seems to be a more or less coherent, slowly subsiding block with a thin, pelagic Liassic sequence.

3. Toarcian black shales (with Mn-ore) seem to be confined to the western slopes of some submarine horsts (Tölgyhát, Mór, Eplény, Úrkút), probably reflecting an oxygen minimum zone in the water column. Red marly limestones are deposited in the deeper parts. This suggests only minor tilting of the basin floors; no perceptible tilting on the tops of the topographic highs.

4. First evidences of rotational block faulting (listric faults) are recorded in the Middle Jurassic: see the Gerecse asymmetric basin in the northeast. A similar interpretation is possible for the Vértessomló-Tata zone, and for the Zala basin (where the radiolarite and the Upper Jurassic limestone show considerable westward thickening - if the interpretation of the borehole data is reliable).

5. The tilting of the basin floors follows a consistent northeastward pattern, which may suggest a NE creep and stretching of the continental crust, i.e. a northeastern deep (oceanic ?) basin.

6. The reduced and uniform thickness of the latest Jurassic sediments may provide evidence of general tectonic quiescence and equalized bottom topography. Minor exceptions are the redeposited calcarenites along the margins of some horsts, indicating local rejuvenation of vertical movements in the early Tithonian.

Palaeogeographic evolution.

Five intervals were selected and illustrated with regional maps to describe and interpret the Jurassic palaeogeographic features of the area. In the selection of these time slices, preference was given to the intervals providing the most informative pictures, i.e. informative in providing details for the local situation, and also more generally for tracing wider connections.

Hettangian (Fig. 4).

Calcareous sedimentation dominated the Zala and Bakony segments in the earliest Jurassic. Extended oolite shoals (Kardosrét Limestone) formed, associated with lower-energy leeward deposits (Haas et al., 1984). The areal distribution of higher-energy and protected environments was distinguished based on the size of the oncoids and composition of the local faunas (brachiopods and gastropods) (Dulai, 1993). The end of the shallow-water Kardosrét Limestone sedimentation, i.e. the drowning of the carbonate shoal, corresponds to the end of the Hettangian, because the age of the earliest ammonite faunas from the overlying red limestones belongs to the basal Sinemurian, Bucklandi Zone (e.g. in Lókút: Géczy, 1972). The single exception within the Zala-Bakony segment is Misefa, where the Kardosrét Limestone (and the Dachsteinkalk) is missing, and the Rhaetian Kössen beds are directly overlain by deeper-water Liassic carbonates.

In the northeastern parts (Tata and Gerecse Hills) of the Transdanubian Central Range the Kardosrét Limestone is missing, and the Dachstein Limestone is

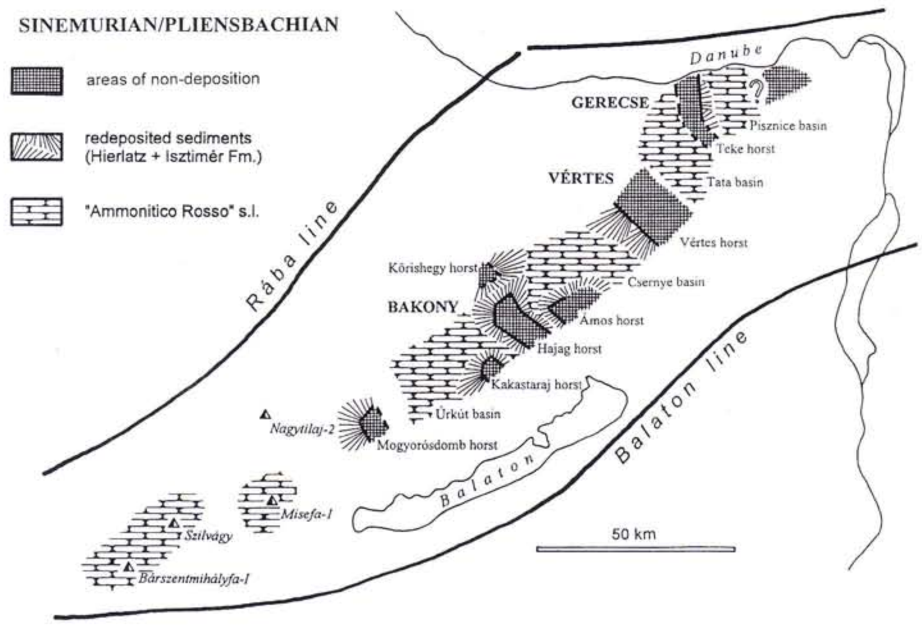

Fig. 5 - Palaeogeography of the Transdanubian Central Range during the Sinemurian and Pliensbachian. The onset of the "horst/basin" pattern.

overlain by a pink limestone with some crinoid remains (Fülöp, 1976). Its basal beds are dated to the Upper Hettangian in Tata (Géczy in Fülöp, 1976). In the Gerecse Hills the pink limestone above the Dachsteinkalk, sometimes bearing brachiopods or crinoids, is Upper Hettangian in age (Vígh, 1961).

Sinemurian/Pliensbachian (Fig. 5)

A bottom topography characterised by elevations and intervening deeper basins was formed at this time. This pattern was likely due to differential subsidence of blocks bounded by normal faults, because a significant angular disconformity between the Kardosrét Limestone and its overlying beds was never found.

The tops of the submarine highs are characterised by the rather incomplete red nodular limestone sequences, interrupted by hard-grounds, which suggest non-deposition, submarine erosion or sediment removal. Near the margins, the horsts are deeply penetrated by neptunian dykes which are filled with material otherwise swept away (i.e. into the deeper basins) by currents. The fissure-filling materials are usually pink or red crinoidal limestones with other benthic organisms, i.e. brachiopods, gastropods, bivalves.

Different types of biocalcarenites and allodapic limestones, sometimes with evidence of redeposition (e.g. gradation, current-related cross-bedding, see Galácz & Vörös, 1989) characterise the basinal sequences. Common rock-types are coarse- or finer-grained crinoidal limestones (Hierlatz limestone, see Vörös, 1991), which were deposited near the submarine fault zones, sometimes as the matrix of scarp breccias (e.g. in Kericser, Géczy, 1971). The crinoidal limestones show finer grain size toward the inner parts of the basins, and become interfingered with well-bedded red limestones or grey cherty limestones (Isztimér Formation).

The uneven bottom topography remained the main controlling element of deposition for the entire Jurassic, and even for the Early Cretaceous in the Transdanubian Central Range. The surface areas of the topographic highs became smaller in time, thus the maximum areal distribution of submarine highs can be traced in the Sinemurian and Pliensbachian. Most topographic highs drawn on the map were identified by incomplete and condensed sequences, but some (e.g. the Körishegy horst) were inferred from the occurrence and distribution of proximal, coarse biocalcarenites.

Early Toarcian (Fig. 6).

The Toarcian marks an important change in the Liassic sedimentation. In the Lower Toarcian Falciferum Zone laminated black shales connected to an anoxic event appear. Interestingly, these anoxic sediments (black shale complexes or thin anoxic clay interbeds) seem to be confined to the western side of the horsts. This apparent asymmetry is possibly related to the geometry of the basins.

The anoxic event is probably the beginning episode of a more general change in the sedimentary evolution, because above the black shale or the equivalent non-sequence, marls occur, replacing the limestones which dominated the former Lower and Middle Liassic sequences. This red, nodular marl (Kisgerecse Formation) is most characteristic in the Gerecse Hills (Géczy, 1984), but occurs also in the Bakony (Bakonycsernye: Géczy, 1961, Úrkút: Géczy, 1968, etc.). The marl sedimentation is restricted stratigraphically to the Lower and Middle Toarcian, because in the uppermost part of

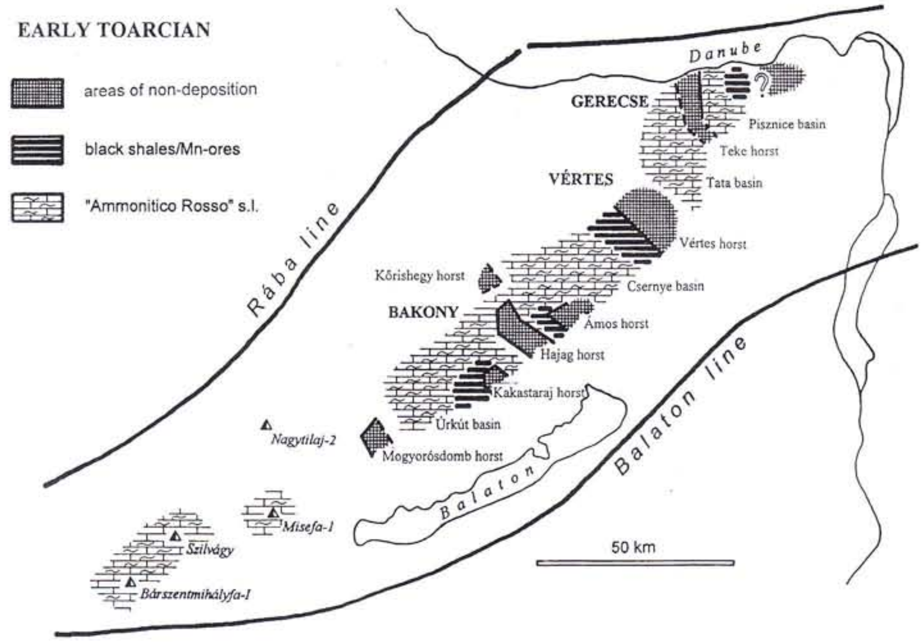

Fig. 6 - Palaeogeography of the Transdanubian Central Range in the Early Toarcian. The "black shale event"; bottom topography reflecting the position of the anoxic layer.

the stage a Rosso Ammonitico-type limestone returns everywhere in the successions.

Bathonian/Callovian (Fig. 7).

This time interval is dominated by the deposition of the radiolarite. Although it is referred to as the "Radiolarite event" even in some recent work (e.g. Bencze et al., 1990, p. 72), the onset of this siliceous sedimentation is far from synchronous. Géczy (1968) was the first to indicate the heterochrony of the calcareous/cherty lithologic change in the Bakony Mts. Recent studies revealed that the radiolarite appears earlier in the basinal areas: in Úrkút the age of the limestone beds below the radiolarite is uppermost Toarcian or lowermost Aalenian (Géczy, op.cit.), in Csernye it is lowermost Bajocian (Géczy, 1961) and in Lókút it is Upper Bajocian (Galácz, 1976). In the latter localities the lithologic change is gradual, the limestone or calcareous marl becoming increasingly siliceous, with more and more intercalations of chert nodules and banks toward the radiolarite proper. On the other hand, in the sequences of the topographic highs, the abrupt appearance of the radiolarite is significantly younger, being Upper Bajocian in the Közöskút ravine (Galácz, 1991), or Upper Bathonian in Gyenespuszta (Galácz, 1980). Interestingly, the radiolarite does not appear at all in the successions of some submarine highs and the Liassic or Middle Jurassic rocks are directly overlain by Upper Jurassic limestones (e.g. Tobánypuszta: Fülöp. 1964; Somhegy: Galácz, 1976). Clay seams of tuffaceous origin appear at the boundary between the radiolarite and the overlying limestone, or in the uppermost part of the siliceous sequence.

Our interpretation of the situation described above seems plausible for the Transdanubian Central Range. The subsiding bottom, with differentially elevated blocks, reached the calcium-carbonate compensation depth at different times. Basins were the first to reach the depth where radiolarian oozes could replace lime mud, then some lower horsts followed, while others never reached this realm and remained the elevated sites where sediment subsolution and/or removal occurred. The subsidence to greater depths was preceded in most places by a renewal of vertical movements along the slopes of the horsts, as calcarenites and scarp breccias, reappearing in the Late Bajocian, indicate (see Galácz, 1988). The uneven bottom topography enhanced the differential accumulation of the rock-forming radiolarian tests: they were swept into deeper parts, resulting in different thicknesses and various silica/carbonate ratios in the local radiolarite successions.

The situation seems to be different in Tata and in the Gerecse. In the sections studied, the age of the uppermost limestone beds underlying the radiolarite is Upper Bajocian (Fülöp, 1976; Galácz, 1984), and the radiolarite is pure, bedded chert with reduced thickness (usually 2 to 3 m). Local differences in the basement topography may be supposed for this area as well, since in many places a brecciated limestone intercalation lies within or on top of the Gerecse radiolarite. This thin (usually less than 1 m) calcareous breccia was interpreted as debris flow on an uneven basement.

Early Tithonian (Fig. 8).

The pelagic calcareous sedimentation resumed after the radiolarite deposition. The beginning of limestone deposition was also heterochronous, but the temporal differences were shorter (see Főzy, 1987; 1993). The former, repeated tectonism which reduced the surfa-

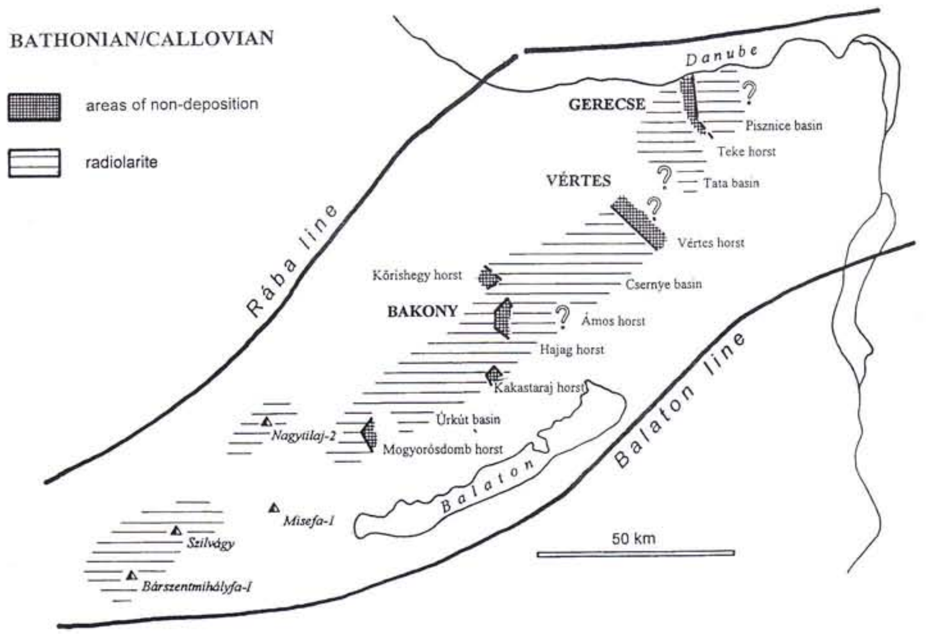

Fig. 7 - Palaeogeography of the Transdanubian Central Range during the late Middle Jurassic and early Late Jurassic. The period of decreasing horsts and onlapping pelagic sediments.

ce areas of the submarine highs continued also in the Tithonian. The rejuvenation of movements along the faults bordering the still existing horsts resulted in scarp breccias and redeposition of biocalcarenites. The best examples are megabreccias in Tithonian pelagic limestone matrix in the Eperkéshegy (Galácz & Vörös, 1989), and the coarse-grained, white biocalcarenite ("Tithonian Hierlatz limestone") in some localities of the Bakony. The latter is probably equivalent to the Szélhegy Limestone in the Gerecse (Főzy et al., 1994).

As a result of these and previous movements along the faults, some of the formerly elevated highs sunk definitively to greater depth. The entire and generally deep bottom was covered by calcareous sediments: Rosso Ammonitico-type nodular limestone (Pálihálás Limestone) or white marly, cherty limestone (Mogyorósdomb Formation - Maiolica or Biancone).

Comparison with the Southern Alps and the Austroalpine domain.

Similar or analogous counterparts to several Jurassic formations of the Transdanubian Central Range have been known for a long time in the Southern Alps or in the Austroalpine domain. The main similarities are listed below:

Taking into account the sedimentary setting, the lowermost Jurassic Kardosrét Limestone of the Transdanubian Central Range is somewhat analogous to the Sedrina Limestone of eastern Lombardy (M. Albenza - Sebino area: Gaetani, 1975) and to the lower part of the Calcari Grigi of the Trento Platform. Common characteristics are the sequential position overlying productive latest Triassic platform complexes (Dolomia Principale - Conchodon Dolomite - Dachstein Limestone) and a similar oolitic-oncoidal texture. The considerable differences in thickness (the Kardosrét Limestone and the Sedrina being thinner, i.e. less than 200 m) come from an age difference: the Kardosrét and Sedrina Limestones seem to be restricted to the Hettangian, while the Calcari Grigi formation of the Trento Platform extends to the top of the Sinemurian and the Pliensbachian in the northern and southern sectors, respectively (Bosellini et al., 1981). This close similarity suggests a possible relationship between the three regions, probably due to a common depositional domain where, in the Hettangian, similar shallow-water carbonates were formed. Later, the Trento Zone remained in a platform environment, while its western continuation (eastern Lombardy) drowned in the Sinemurian, when the accumulation of extremely thick marly and cherty limestones (Medolo Group) began (Sarti et al., 1992; McRoberts, 1994; Picotti & Cobianchi, 1996). The drowning of the Transdanubian Central Range happened at about the same time, but much thinner limestone sequences were deposited.

No comparable Lower Jurassic formation exists in the Austroalpine domain. In this region, the platform carbonates of the Dachsteinkalk (or the Oberrhätkalk) are directly overlain in most places by red Jurassic limestones or Hierlatzkalk (see below).

Hierlatz Limestone: The Liassic brachiopod limestones along the margin of the Trento Platfom (e.g. at Sospirolo, Belluno) are only variants of the Calcari Grigi. The "Encrinite di Fanes" in the northern Trento Zone (see Masetti & Bottoni, 1978) is a simple crinoidal calcarenite without the peculiar lithologic characteristics of the Hierlatz Limestone, as defined by Vörös (1991). The only valid counterpart could be the brachiopod-rich "Broccatello d'Arzo", which occurs locally in western Lombardy (Lugano swell, see Bernoulli, 1964; Gaetani, 1975).

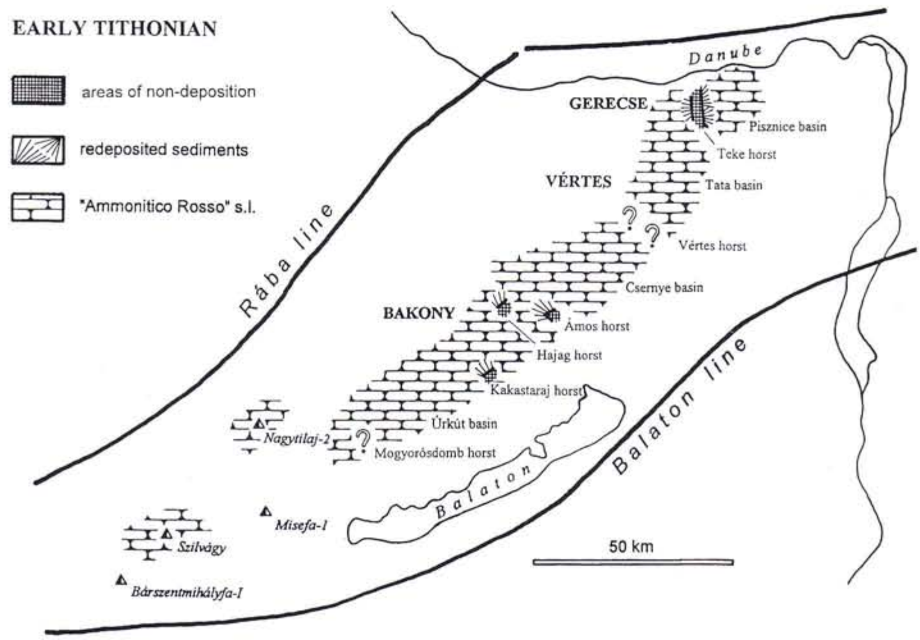

Fig. 8 - Palaeogeography of the Transdanubian Central Range in the Early Tithonian. The last rejuvenation of horst escarpments.

On the other hand, the Hierlatz Limestone is typical, frequent and definitely analogous in the Austroalpine domain (see Vörös, 1991).

In the upper portion of the Liassic comparable lithologies appear in the Southern Alps and in the Austroalpine domain as well. The red, nodular Tüzkövesárok Limestone of the Transdanubian Central Range is very comparable to the Rosso Ammonitico of Lombardy. As for the more calcareous Rosso Ammonitico of the Trento area, the difference is only chronostratigraphic. Because of the longer duration of the Calcari Grigi deposition, the change from shallow-water limestones to deeper-water carbonates took place later, after a significant hiatus. The red, nodular pelagic limestones are younger, since their deposition started in the Bajocian (Laub, 1994; Martire, 1996).

In the Austroalpine domain the Liassic Adnet Limestone is an almost perfect analogue to the nodular Tüzkövesárok Limestone, although their chronostratigraphic boundaries are partly different.

The Early Toarcian anoxic event resulted in comparable units in the Southern Alps, where black shales are known in some areas located mostly in the marginal parts of the Trento Plateau (Claps et al., 1995). The Late Toarcian lithologic change is also documented by the appearance of marls (Jenkyns et al., 1985). Much thicker (20-30 m) organic-rich laminated marls, locally with fish horizons are known in the thick basinal sequences of Lombardy (e.g. the lower part of the Sogno Formation in the M. Albenza region: Gaetani & Poliani, 1978).

In the Austroalpine domain Toarcian manganese ores have been mined (Germann & Waldvogel, 1971). The enrichment in Mn was probably connected to the anoxic event as it happens in the Bakony Mts. However, the Austroalpine localities are in the "Fleckenmergel" facies, which is unknown in the Transdanubian Central Range.

Late Middle Jurassic and Oxfordian siliceous sediments are widespread in the Southern Alps, either as radiolarites in the Lombardian Basin (see e.g. Jenkyns & Winterer, 1982, Bertotti et al., 1993), or as siliceous limestones in the external areas of the Trento region (Calcari selciferi à rincoliti: Laub, 1994).

A cherty radiolarite is known also in the Austroalpine regions, where the bulk of the formation is attributed to the Oxfordian (Böhm, 1992), although its chronostratigraphic boundaries may show considerable variation from mid-Bajocian to mid-Tithonian (Garrison & Fischer, 1969; Tollmann, 1976).

The Upper Jurassic smectite-rich clay beds in the Transdanubian Central Range suggest a volcanic origin and offer a correlation with the benthonitic seams of similar age in the Venetian Alps (Bernoulli & Peters, 1970).

The Upper Jurassic Rosso Ammonitico Superiore and the overlying Maiolica or Biancone of the Southern Alps are good analogues for the formations of similar age in the Transdanubian Central Range.

In the Austroalpine domain, the Upper Jurassic formations show considerable differences, with local reef units (Plassenkalk) and redeposited limestones (Barmsteinkalk).

The analogies and faunal similarities (discussed in Vörös, 1992 and 1993) mentioned above are somewhat stronger with the Southern Alps, especially considering the main features of the palaeotectonic evolution. The latter includes the processes of block tectonics, which resulted in a similar basin and horst pattern of the bottom topography, and repeated appearances of neptunian dykes and redeposited limestones (calcarenites, pelagic

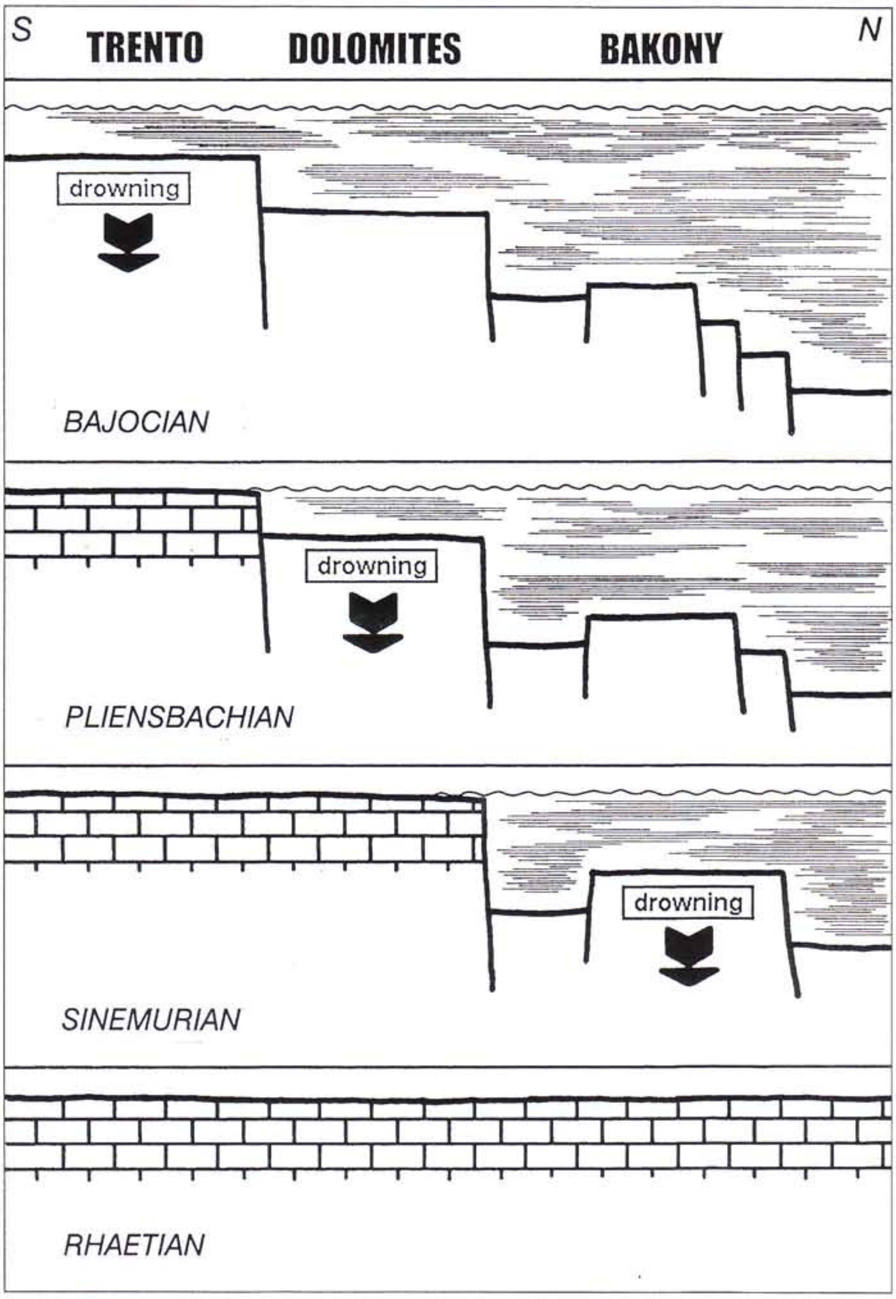

Fig. 9 - Sketch showing the main steps of the Jurassic palaeotectonic evolution of the continental margin along a south-north transect from Trento to Bakony. The South Alpine and the Transdanubian territories are envisaged as forming a continuous palaeogeographic domain. The drowning of the uniform Late Triassic carbonate platform started in the north (Transdanubian Central Range) in the Hettangian/Sinemurian, then the downfaulting and drowning prograded to the south.

oolites. Therefore, our interpretation that the Transdanubian Central Range was situated in the northern vicinity of the Southern Alps in Jurassic times (Galácz et al., 1985; Vörös, 1987 and 1993) is further supported by the present analysis. This agrees with palaeogeographic syntheses based on the previous (Permian, Triassic) facies pattern of the area (Majoros, 1980; Kázmér & Kovács, 1985; Vörös et al., 1990, Schmidt et al., 1991; Dercourt et al. 1993; Haas & Budai, 1995).

However, the attempt by Kázmér (1987) to trace the three main North-South trending palaeogeographic zones of the Southern Alps in the Transdanubian Central Range cannot be accepted. The correlation between the Gerecse Zone and the Belluno Trough is incorrect. Moreover, in the light of the data presented here, the Zala basin cannot be interpreted as an adequate continuation of the extensive Lombardian basin. On the other hand, the analogies between the Bakony and the Trento Zone seem to be strong and the western part of the TCR shows characteristics transitional to the Lombardian sequences.

Conclusions.

As a preliminary palaeogeographic conclusion, we visualize the entire Transdanubian Central Range as part of the Periadriatic region north of the Trento Zone. We believe that the elevated Trento Zone, this rather narrow (100 km) segment of the Southern Alpine domain, had a fan-shaped, northwardly extended foreslope, where the same palaeotectonic movements resulted in differently expressed sedimentary changes. The main difference was most probably the contrast in depth: the Transdanubian Central Range prevailed as a deeper, dissected plateau (i.e. a horst/basin system) for most of the Jurassic (Fig. 9). This topographic difference was manifested in the sedimentary facies of the TCR, which shares similarities with both the elevated Trento Zone and the deeper Lombardian basin.

At the end of the Triassic and at the beginning of the Jurassic (until the latest Hettangian) the entire region (Trento Zone + Transdanubian Central Range + eastern Lombardy) was dominated uniformly by oolitic shoals. The depth difference began around the Hettangian/Sinemurian boundary, when the Lombardian basement was drastically disintegrated: the rapid subsidence of the basins is documented by the several hundred metres-thick cherty limestone sequence (Moltrasio, Medolo). At about the same time, as the first step of the disintegration of the Trento - Transdanubian complex, the northernmost segment (Bakony s.l.) was downfaulted and became characterised by more pelagic and condensed sedimentation. Shortly after, at the end of the Sinemurian, when renewed block-faulting resulted in neptunian dykes and redeposited biocalcarenites in the Transdanubian Central Range, the northern block of the formerly uniform Trento Platform (now exposed in the Dolomites) subsided and the Calcari Grigi carbonate platform was covered by the "Encrinite di Fanes" of Pliensbachian age. At the end of the Pliensbachian, the remaining, southern part of the Trento Platform also shared the fate of the northern territories and the Calcari Grigi platform ended (Fig. 9).

The southern part of the Trento Zone kept its relatively elevated position in the latest Liassic and earliest Middle Jurassic, as indicated by the S. Vigilio Oolite rimming the Trento Plateau (Winterer & Bosellini, 1981). At the same time, the other areas were characterised by deeper-water sedimentation, mainly of Ammonitico Rosso-type. This was the result of a general deepening caused by extensional tectonics (see Bertotti et al., 1993 for the Southern Alps). The overall deepening was locally overprinted by movements of individual blocks along normal faults. The latter movements led to the formation of neptunian dykes, scarp breccias and coarse-grained biocalcarenites which are common both in the Southern Alps and in the Transdanubian Central Range. However, the significant thickness variations and the very complicated facies pattern in the Southern Alps (see e.g. in Martire, 1996) suggest a moderate depth, while the generally reduced thicknesses and more uniform lithofacies pattern of the Transdanubian region can be related to a deeper-water environment.

The water depth differences are more evident from the Middle Jurassic to the early Upper Jurassic sediments. The areal distribution of the radiolarite in the Lombardian basin and of the "calcari selciferi a rincoliti" and Scisti ad Aptici in the Trento Zone have been long understood to be regulated by the basic difference in depositional depth (see e.g. Bertotti et al., 1993). The thickness pattern of the radiolarites in the Transdanubian Central Range can be best explained by Baumgartner's suggestions (1987, 1990), which take into account the easy transport and redeposition of radiolarian skeletal particles from local submarine elevations to intervening basins. This represents a further step in interpreting the causes for the appearance or absence of radiolarites as a sediment in an area with a dissected bottom. Deposition and preservation of this sediment is only indirectly related to the enrichment of Radiolaria, which is best explained by upwelling and oceanic circulation patterns in the western Tethys (see De Wever et al., 1994; De Wever & Baudin, 1996).

The lithofacies similarity in the Upper Jurassic (i.e. uniform pelagic formations as Rosso Ammonitico limestone, then Maiolica- and Biancone-type siliceous limestones and calcareous marls) in the Trento Zone and in the Transdanubian Central Range suggests that in Late Jurassic - Early Cretaceous times the subsidence in the southern part of the region exceeded the values of the northern sector. This means that the Southern Alpine regions sank to a depth range where the differences in relative water depth did not play such a significant role in sedimentation, as indicated for the previous times.

The northernmost segment of the region, which was preserved as the Transdanubian Central Range, had a dramatic history in post-Mesozoic times, when the entire block was pushed northeastward to reach the Carpathian basin interior.

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