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ANISIAN TERRESTRIAL SEDIMENTS IN THE BÜKK MOUNTAINS (NE HUNGARY) AND THEIR ROLE IN THE TRIASSIC RIFTING OF THE VARDAR-MELIATA BRANCH OF THE NEO-TETHYS OCEAN

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Key-words: Bükk Mts., lake sediments, fluviatile sediments, braided river, half-graben, rifting, Southern Alps, Dinarides.

Abstract. In recent years detailed sedimentological and biostratigraphical investigations have revealed Anisian terrestrial sediments in three sections of the Bükk Mountains. In the northern part of the mountains fluviatile sediments were recognised while in the southern part lake deposits were observed.

Based on the stratigraphical position and microfacies analyses of the resedimented grains, two terrestrial events can be reconstructed. The age of the younger is late Pelsonian–early Illyrian?. This can be correlated with the Richthofen Conglomerate in the Dolomites. The age of the older terrestrial event could not be established exactly but it must have happened either in the Pelsonian or in the Aegean–Bithynian; consequently it may correlate either with the Voltago or with the Piz de Peres Conglomerate in the Dolomites. The terrestrial sediments in the Bükk Mountains are parts of a volcano-sedimentary succession, which is characteristic of the updoming part of a rifting area. Terrestrial sediments in the southern part of the mountains represent the deepest part of the half-grabens, which originated during the course of the rifting.

The present paper gives an overview of the Anisian–Lower Ladinian terrestrial sediments in the Southern Alps–Dinarides and considers their formation during the Triassic rifting of the Vardar-Meliata branch of the Neo-Tethys.

Riassunto. Il dettagliato studio sedimentologico e biostratigrafico ha recentemente messo in evidenza la presenza di sedimenti continentali in tre sezioni delle Bükk Mountains. Nella parte settentrionale delle montagne sono stati osservati sedimenti fluviali, mentre a sud sono presenti sedimenti lacustri.

In base alla posizione stratigrafica ed alle microfacies dei granuli risedimentati, sono riconoscibili due eventi continentali. L'età del più recente è probabilmente Pelsonico superiore-Illirico inferiore. Questo può essere correlato con il Conglomerato di Richthofen nelle Dolomiti. Invece l'età dell'episodio più antico non può essere definita con precisione e può essersi verificato sia nel Pelsonico che nell'Egeico-Bitinico. Di conseguenza può essere correlato sia con il Conglomerato di Voltago oppure con quello del Piz de Peres nelle Dolomiti. I sedimenti continentali delle Bükk Mountains fanno parte di una successione vulcano-sedimentaria che è caratteristica della parte rilevata in un contesto di rifting. I sedimenti continentali della porzione meridionale delle montagne rappresentano la parte più profonda dei semi-graben, che si sono formati durante il rifting. Sulla base di una rassegna dei sedimenti continentali dell'Anisico-Ladinico inferiore delle Alpi Meridionali e delle Dinaridi viene valutata la loro modalità della loro formazione durante il rifting Triassico del ramo Vardar-Meliata della Neo-Tetide.

Introduction

Anisian terrestrial sediments within thick platform carbonate successions are well-known in the Dolomites and they are also well-documented (Farabegoli & Levanti 1982; De Zanche et al. 1993; Senowbari-Daryan et al. 1993; Gianolla & Jacquin 1998; Gianolla et al. 1998). However, although Anisian terrestial sediments in the Bükk Mountains are mentioned in the literature (Balogh 1964; Pelikán 1993) there is no detailed documentation about them. The aim of this paper is to describe the Anisian terrestrial sediments (two occurences out of the three were earlier unknown) in the Bükk Mountains, to show their role in the Triassic evolution of the mountains and to make a comparison with the coeval terrestrial sediments of the Southern Alps and Dinarides.

Today, the Bükk Mountains are located in the NE part of Hungary (Fig. 1). In the Triassic they was situated NW of the Dinarides, in the neighbourhood of the Julian Alps and the Southern Karawanks, on the southern shelf of the Vardar-Meliata branch of the Neo-Tethys (Balogh 1964; Kovács 1984; Haas et al. 1995; Dercourt et al. 2000; Ziegler & Stampfli 2001).

The central part of the Bükk Mountains was affected by very low to low grade metamorphosis, so sec-

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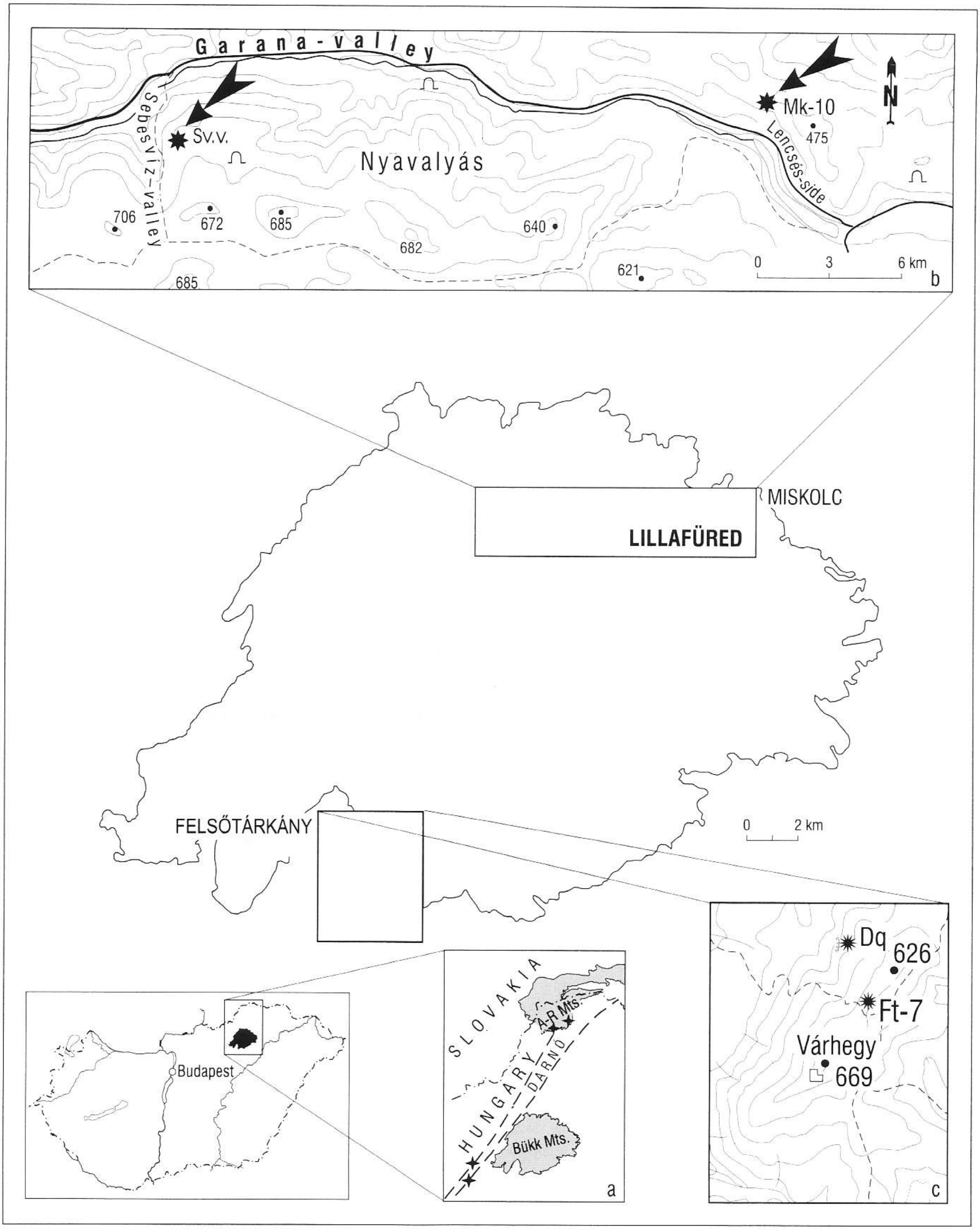


Fig. 1 - Location map of the studied areas. 1/a. Bükk Mts., D: Darnó-zone, AR: Aggtelek-Rudabánya Mts. 1/b. Geographical position of the Sebesvíz Section (Sv.v.), and borehole Miskolc-10 (Mk-10). 1/c. Geographical position of borehole Felsőtárkány-7 (Ft-7), and the dolomite quarry of Várhegy (Dq).

tions suitable for sedimentological investigations can be found only on its margins. Sedimentological investigations of three Triassic sections revealed Anisian terrestrial sediment occurrences, out of which two are situated in

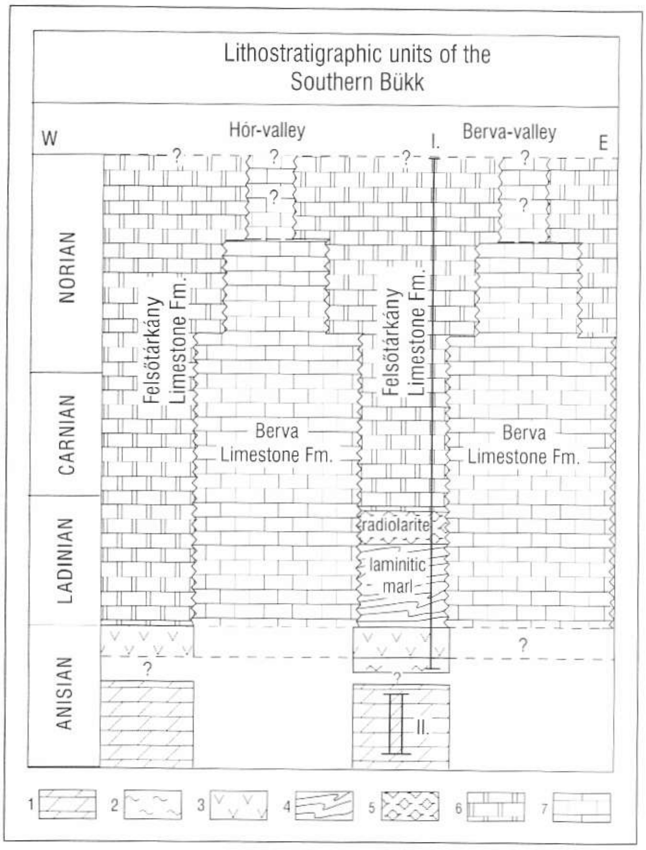


Fig. 2 - Stratigraphic setting of borehole Felsőtárkány-7 (I) and its footwall (II). Legend: 1. dolomite (Hámor Dolomite Fm.), 2. lacustrine marl, 3. Szentistvánhegy Metaandesite Fm, 4. laminitic calcareous marl, 5. radiolarite, 6. cherty limestone (basin facies: Felsőtárkány Lst. Fm.), 7 platform carbonate (Berva Lst. Fm.).

the northern part, while one in the southern part of the mountains (Fig. 1b,c). Triassic sedimentation of the Bükk Mountains was controlled mainly by extensional tectonics (Velledits 1998a). The evolution of the volcano-sedimentary succession of the mountains follows the evolution of the updoming part of a rifting area (Dixon et al. 1989) from the Anisian.

Since at the moment there is no formally accepted definition of the Anisian/Ladinian stages and their boundary, the article mainly follows the scheme proposed by Mietto & Manfrin (1995).

Sections

For a detailed description of the outcrops revealing the Anisian terrestrial sediments of the Bükk Mountains see Velledits (1999, 2000). In the present paper only the most important facts are given below.

Borehole Felsőtárkány-7

Geographical position: south of the village of Felsőtárkány, in the NW ridge of the Vár Hill (Fig. 1c). The stratigraphic setting of the terrestrial sediments in borehole Felsőtárkány-7 can be seen in Fig. 2.

The borehole stopped in the terrestrial deposits. Consequently, the basal part of the terrestrial deposits and the underlying formation are unknown. Most probably, after a short unexplored interval Hámor Dolomite occurs. The dolomite can be studied in the neighbourhood in a quarry on the Vár Hill, south of Felsőtárkány (Fig. 1c). It consists of peritidal features (e.g. algal mats, algal domes (Fig.3a), and huge (1–4 cm) oncoids), and subtidal dolomite beds, which are rich in foraminifera. (Table 1, the forams were identified by A. Bérczi-Makk). The age is Pelsonian. (Fig.3b-e).

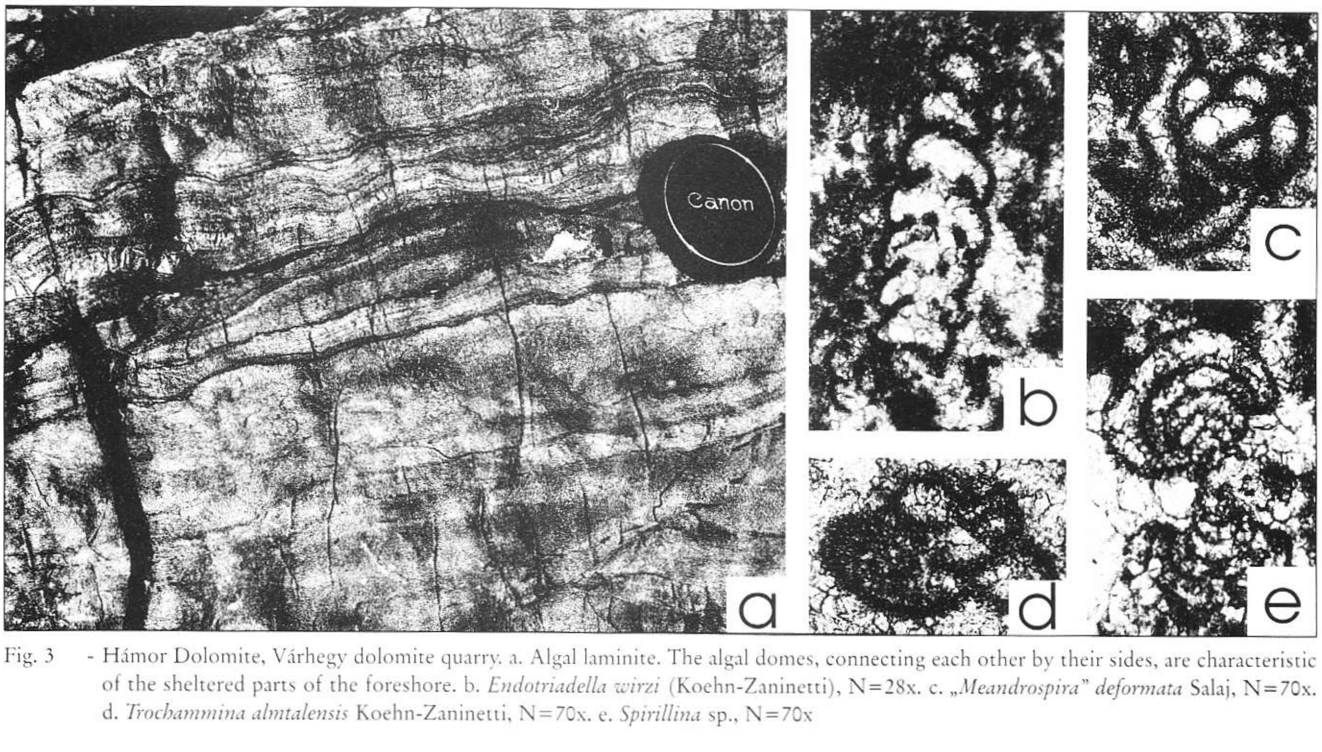


Fig. 3 - Hámor Dolomite, Várhegy dolomite quarry. a. Algal laminite. The algal domes, connecting each other by their sides, are characteristic of the sheltered parts of the foreshore. b. *Endotriadella wirzi* (Koehn-Zaninetti), N=28x. c. *„Meandrospira" deformata* Salaj, N=70x. d. *Trochammina almtalensis* Koehn-Zaninetti, N=70x. e. *Spirillina* sp., N=70x

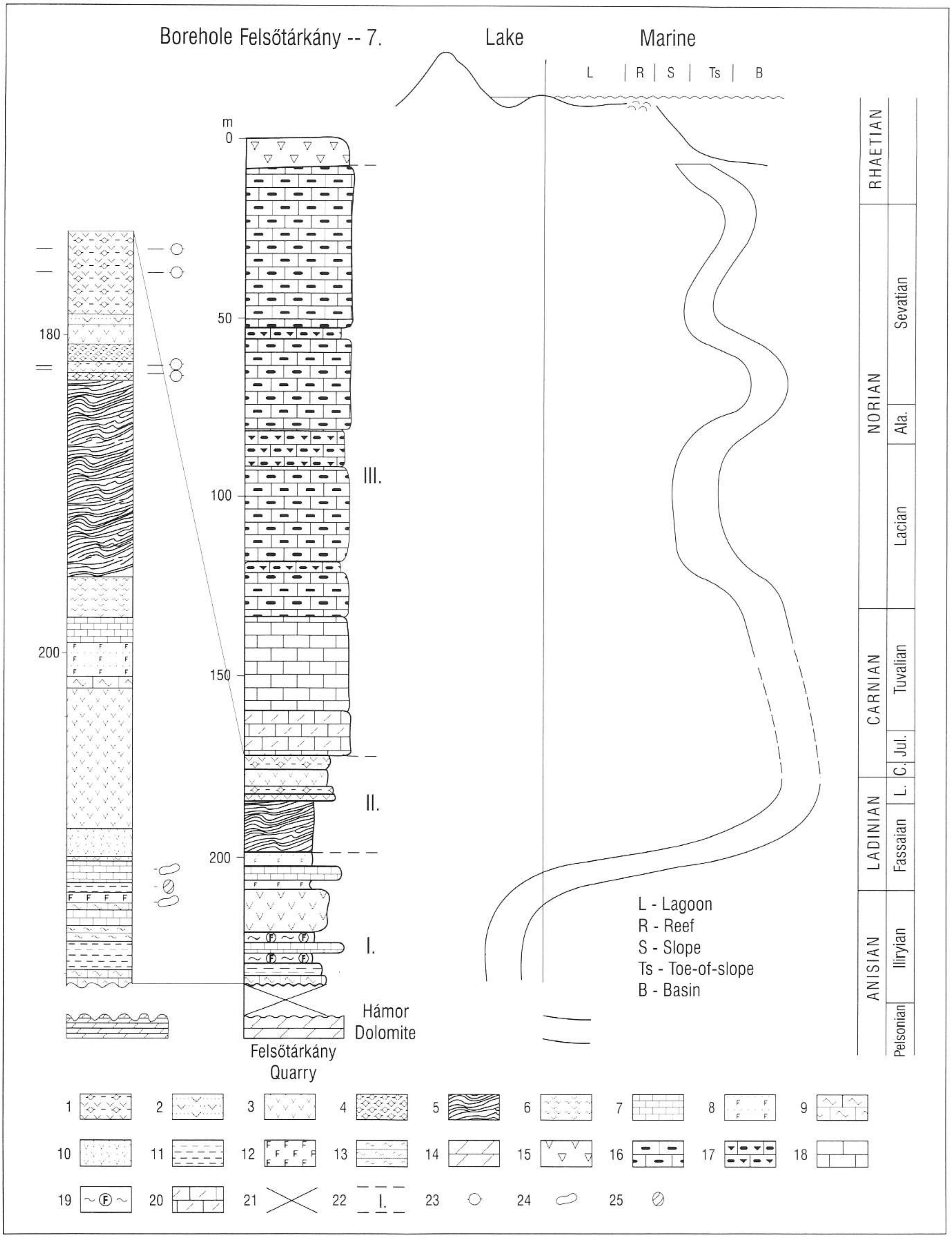


Fig. 4 - Sequence and facies of borehole Felsőtárkány-7. Legend: 1. siliceous, tuffaceous, weathered claystone, 2. weathered tuff, 3. volcanic tuff, 4. radiolarite, 5. laminitic calcareous marl, 6. tuffaceous bioturbated marl, 7. freshwater limestone, 8. sandstone rich in feldspar, 9. marl, calcareous marl, 10. strongly weathered, reworked volcanic fragment, 11. red clay, 12. calcareous marl with feldspars 13. sandy marl rich in green minerals, 14. dolomite (Hámor Dolomite Fm.), 15. talus, 16. cherty limestone (Felsőtárkány Lst. Fm.), 17. lithoclastic intercalation (Felsőtárkány Limestone), 18. limestone of basin facies without chert, 19. Marl rich in resedimented volcanic clasts 20. dolomitised limestone, 21. lack of information, 22. Sedimentation units, 23. radiolaria, 24. ostracode, 25. chara.

	Borehole: Ft-7	**Radiolaria**	**Age**
Hanging wall	173.6	*Muelleritortis cochleata* *Spongoserrula rarauna*	Longobardian Muelleritortis cochleata zone
	175.5	? *Muelleritortis* sp.	Longobardian
	182.9	*Oertlispongus inaequispinosus* *Baumgartneria* cf. *retrospina* *Falcispongus calcaneum*	Late Fassanian
Footwall	**Hámor Dolomite**	**Foraminifera** *Earlandinita oberhauseri* *Endotriadella wirzi* *Haplophragmella inflata* "*Meandrospira*" *deformata* *Spirillina* sp. *Trochammina almtalensis*	Pelsonian

Tab. 1 - The most important fossils, and ages of the footwall and hangingwall of the lake sediments.

		Dasycladaceae	**Foraminifera**	**Age**
Steinalm Lms. (footwall)	116,8 m		*Pilammina densa*	
	114,5 m	*Physoporella pauciforata gemerica* *Physoporella pauciforata pauciforata* *Physoporella pauciforata undulata* *Teutloporella peniculiformis*	*Diplotremina astrofimbriata* *Ebdoteba* sp. *Meandrospiranella* sp. *Trochammina almtalensis* *Variostoma* sp.	Pelsonian

Tab. 2 - The most important fossils of the footwall of the fluviatile sediments (borehole: Miskolc-10)

The sequence of the borehole can be divided into three units (Fig.4):

Unit I (231.0-199.4 m): marl, calcareous marl, sandstone, and claystone represent a lacustrine depositional environment. Different facies of a lacustrine environment could also be distinguished (Fig. 5). The terrestrial sediments contain volcanic (both lava and tuffite) interlayers (224.1-172.1 m). The volcanic material indicates an andesitic-rhyolitic composition. In the sample from 207.6 m it can be observed that the volcanic material was plastic when it reached the lake. Extinction of the plagioclases indicates that they originated from acidic extrusive rocks (Árgyelán, B.G., personal communication). Tuffs with pumice were found at the following depths: 224.5 m, 217.0 m, 212.5 m, 203.8 m. The analyses of volcanic rocks revealed that the majority of them originated from an effusive pyroclastic series. They are tuffs containing pumice, but the tiny diameter of the grains suggests a distal origin.

Unit II: laminitic, calcareous marl (199.4-183.9 m) representing an euxinic basin. This is overlaid by radiolarite (183.9-183.3 m, 182.9–181.3 m). Between the two radiolarite layers tuffitic marl can be found. The age of the radiolarite (Table 1) is upper Fassanian-Longobardian (personal communication from the late L. Dosztály).

Unit III: cherty limestone (172.1-8.0 m) that was formed in a well-oxygenated intraplatform basin. Some types of microfacies represent autochthonous sediments (e.g. radiolarian, filament mud, packstone), whereas other types represent allochthonous ones. The latter form distinct layers (levels) between the pelagic sediment (crinoidal packstone, conglomerate-breccia levels).

The cherty limestone was deposited in the time interval between Late Ladinian-Early Carnian and Early Rhaetian. (The estimation of age determination is based on forams and conodonts. The latter was dertermined by S. Kovács).

Interpretation:

- The age of the terrestrial sediments in borehole Ft-7 is most probably upper Pelsonian-lower Illyrian.
- Deposition of the terrestrial sediments was partly contemporaneous with the volcanic activity.
- The lake sediments were formed on the deepest part of a half graben (Velledits 2000) which came into being due to the Middle-Upper Triassic rifting.
- A subsidence curve (Fig. 4), reconstructed from the sedimentary sequence of borehole Ft-7, indicates an updoming (late Pelsonian-Early Ladinian) with coeval volcanic activity (Unit I). The uplift is followed by rapid subsidence (Unit II), which slowed down in the Late Ladinian (Unit III).

Borehole Miskolc-10 (Zsófiatorony)

Geographical position: 10.5 km NW of the village of Lillafüred, at the Lencsés side (Fig.1b).

The stratigraphic setting of the borehole can be seen in Fig. 6.

The section of the borehole can be divided into four units (Fig.7):

Unit I (120.0-99.9 m): Steinalm Limestone:

Light-grey limestone and dolomite in which three microfacies types can be distinguished:

1: Dasycladaceaen wacke-, packestone: (116.8 m and 116.4 m).

In a micritic matrix, Dasycladaceaen (determined by O. Piros) and Foraminifera (Table 2) indicate a Pelsonian age.

2: Foraminiferal packstone (114.50-114.65 m).

In a micritic matrix, a massive occurrence of a single foraminifer species *Pilammina densa* (Pantić) can be observed (Pl.1, Fig.1). The texture is grain-supported. The age is upper Pelsonian-lower Illyrian.

Remark: around the Pelsonian/Illyrian boundary, a layer that contains only one foraminifer species, *Pilammina densa*, can be found in many sections. This layer can be found in the German epicontinental basin (Lower Silesia, middle part of Poland Glazek 1973) and in the Tethys in Slovenia (Ramovš 1975). It represents a 4 m thick horizon containing mainly *P. densa*), Montenegro (Pantić 1965), Karakaya Basin (Altiner 1993). A similar microfacies is known from the Alsó Hill (Aggtelek-Rudabánya Mts., NE Hungary; Bérczi-Makk 1996), and from the Danube-Tisza Interfluve area (Bérczi-Makk, A., personal communication).

3: Dolomite mudstone (105.0 m).

The uppermost part of the Steinalm Limestone is totally dolomitised.

Unit II (99.9-87.3 m): The terrestrial clastic sequence is made up of an alternation of three rock types: A, conglomerate/

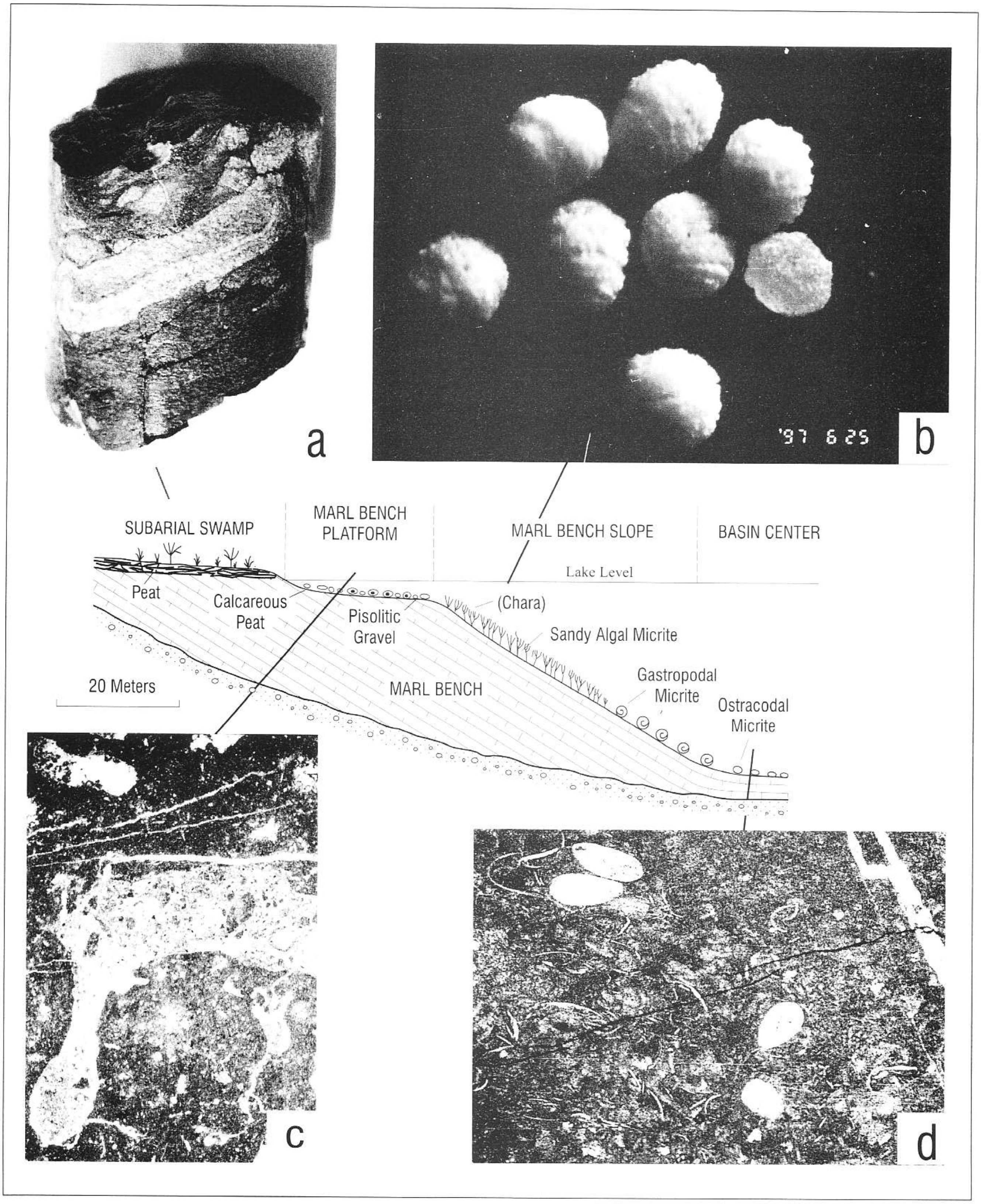


Fig. 5 - Lacustrine sediments. In the middle of the figures the model of Murphy and Wilkinson (1980) summarises the different lacustrine sedimentary environments and their characteristic sediments that can be well-correlated with the rock types and facies of borehole Felsőtárkány-7. a. Calcareous marl, rich in organic matter. Sediment of the swamp on the lake shore. (221.3–221.4 m). Diameter of the drill core is 6 cm. b. Chara carpolites, obtained from the marl via hydrochloric dissolution. According to recent observations (Murphy and Wilkinson 1980), Chara banks colonise the steeper upper part of the slope. (223.3 m). N=50x. c. Calcareous marl with microkarst phenomena. The former cavity (passage of a root or a burrowing organism) was further expanded by the subsequent dissolution. Slope sediment situated close the nearshore raise above the sea level occasionally. (222.8 m). N=14x. d. Ostracodal wackestone. Freshwater to highly brackish water forms (*Darwinula sp., Pulviella? sp., Lutkevichinella?* sp.), derived from the deepest part of the lake were identified from the insoluble residue. Det. M. Monostori. (222.0 m) N=14x.

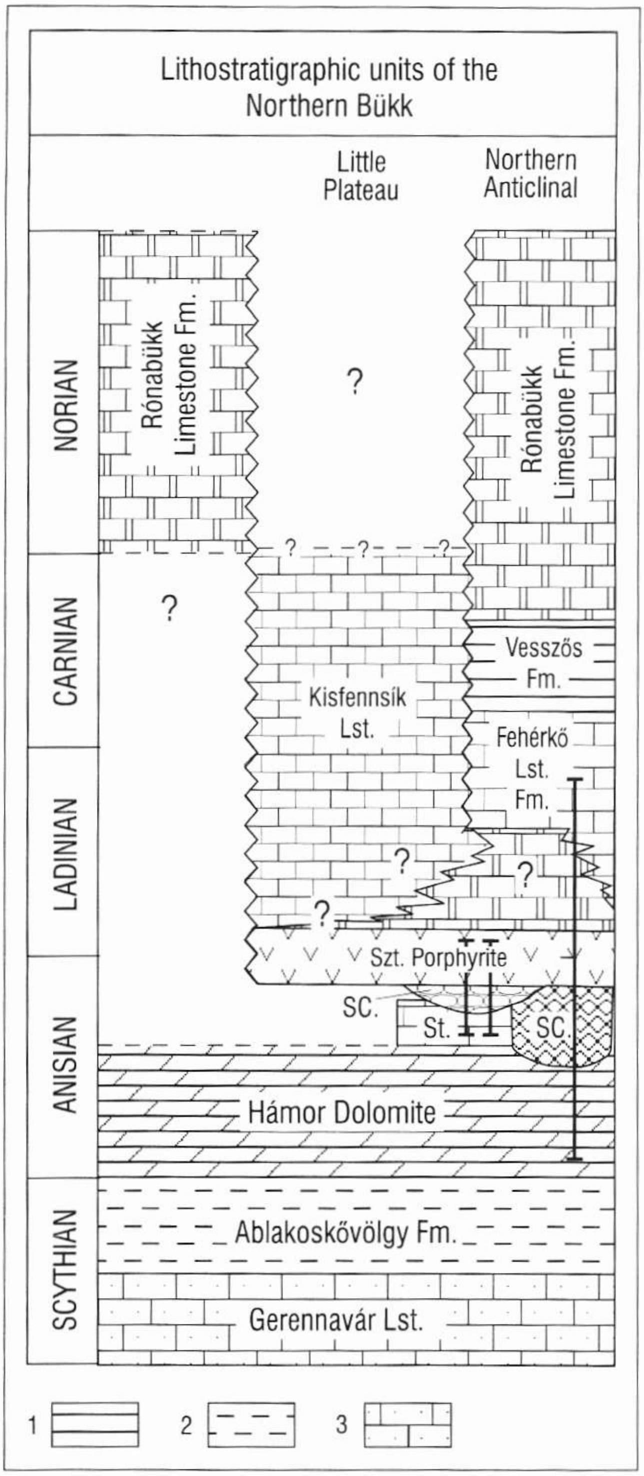


Fig. 6 - Stratigraphic setting of the studied layers of the Sebesvíz Section and borehole Miskolc-10. Legend: Some items are the same as on Fig. 2. Differences are as follows: 1. marl (Vesszős Fm.), 2. sandstone, clayey marl, calcareous marl (Ablakoskővölgy Fm.), 3. oolitic limestone (Gerennavár Lst. Fm). St: Steinalm Limestone, SC: Sebesvíz Conglomerate, I: borehole Miskolc-10, II: studied layers of the Sebesvíz Section.

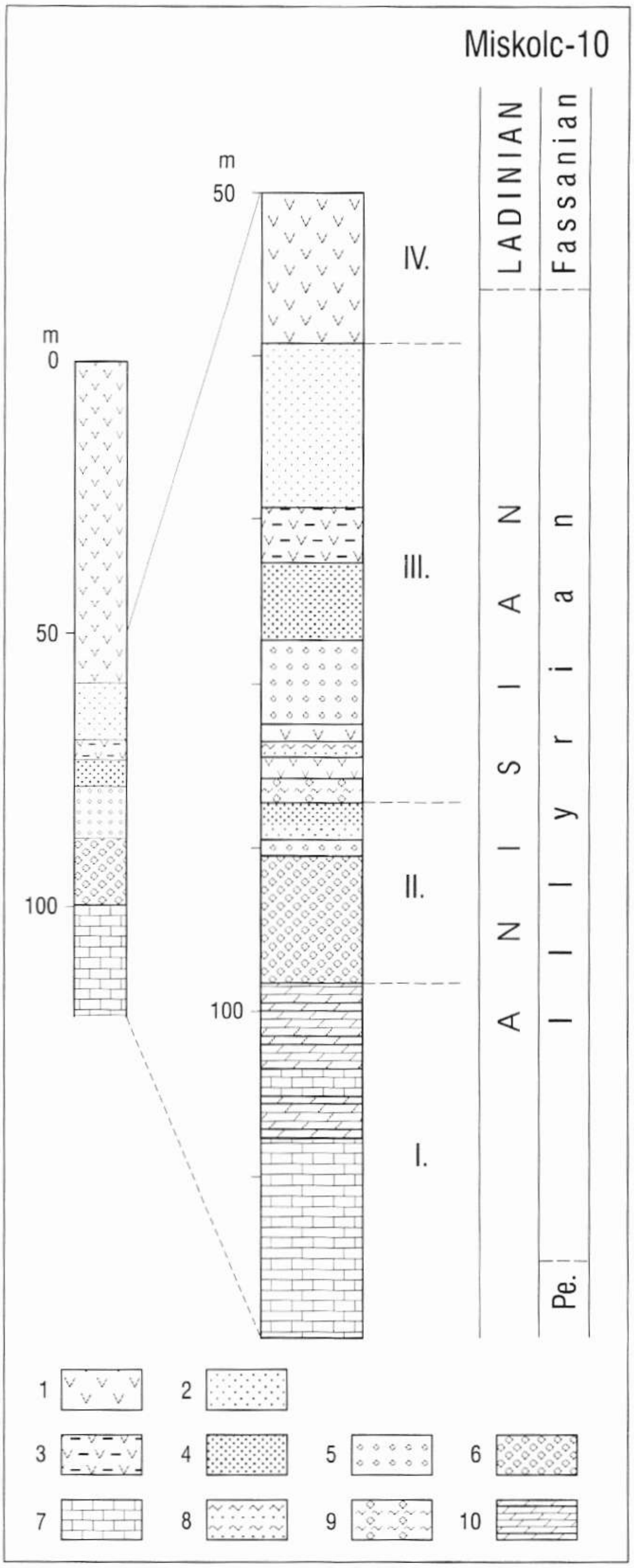
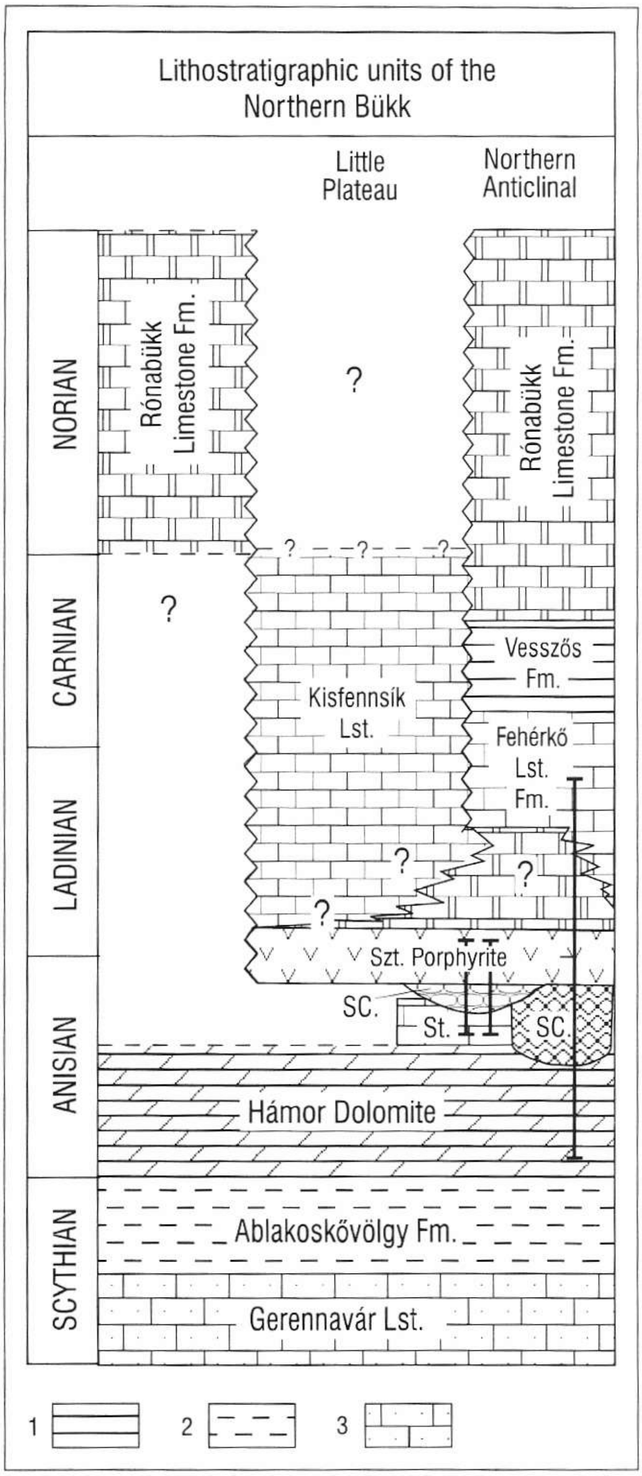


Fig. 7 - Sequence of borehole Miskolc-10. Legend: 1. volcanite (Szentistvánhegy Porphyrite), 2. sandstone, 3. aleurolite with reworked volcanic clasts, 4. granule (2–3 mm), 5. microconglomerate (2–5 mm), 6. conglomerate, breccia (0.5–8 cm), 7. limestone, 8. clayey calcareous marl, 9. calcareous marl with limestone clasts, 10. dolomite.

breccia; B, red sandstone; C, ochre sandy clay. This sequence was deposited by a braided stream. The conglomerate/breccia layers represent the channel fill, the red sandstone interlayers and the sand bar between the channels, while the yellowish-brown sandy clay layers were deposited as floodplain mud.

A: Conglomerate/breccia (Pl.1,Fig.h):



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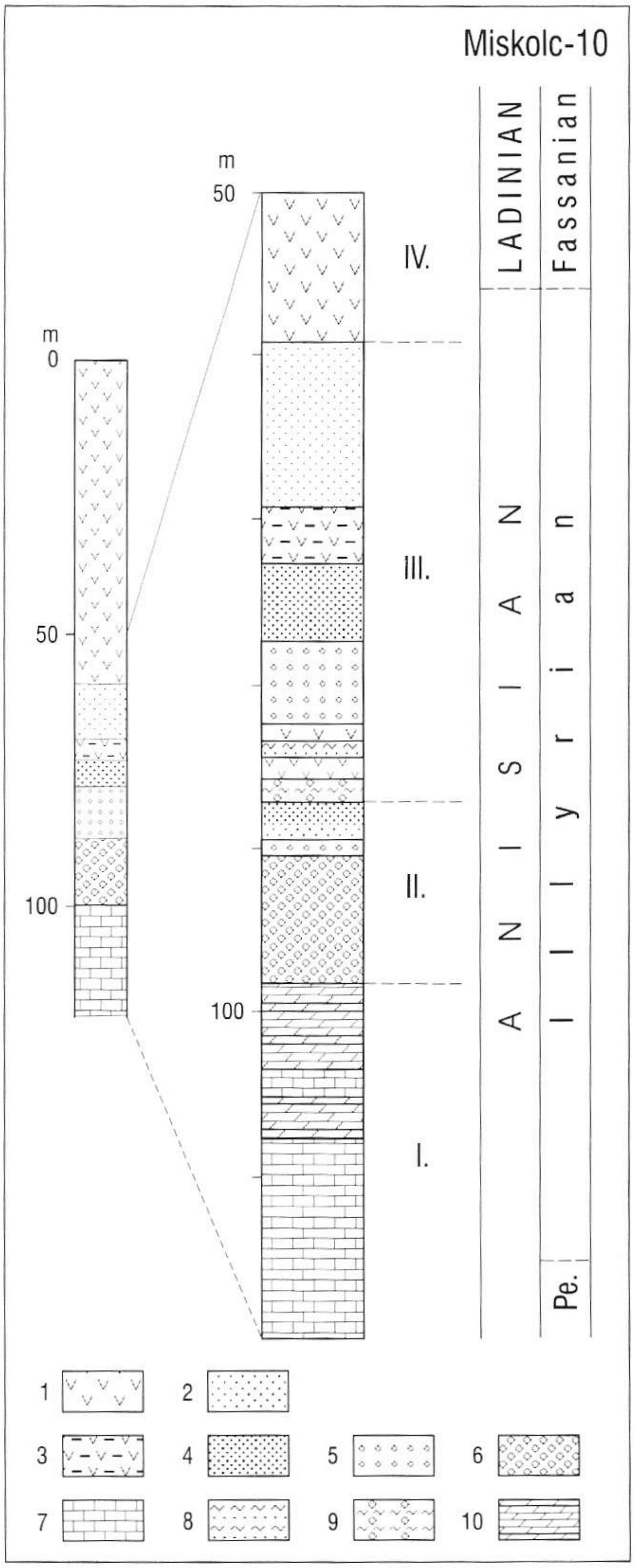

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A: Conglomerate/breccia (Pl.1,Fig.h):

Borehole: Miskolc-10				**Sebesvízvölgy section**		
MF of the resedimented pebbles	**Fossils**	**Facies**	**Age**		**Fossils**	**Age**
Dolomite pebbles						
1. Homogenous dolomite				1.		
2. Foraminiferal mudstone	*Endoteba* sp. *Meandrospira deformata* *Meandrospira dinarica* *Meandrospirella samueli* *Tolypammina gregaria*	lagoon	Pelsonian	2	*Polypammina* sp. *Nodosaria* sp.	
3. Foraminiferal grainstone	*Meandrospira dinarica* *Tolypammina gregaria*	sand shoal	Pelsonian	3	Meandrospira deformata *Rephax* sp. *Tolypammina gregaria*	Early Anisian
4.Oolitic grainstone		sand shoal		4		
5. Peloidal packstone		lagoon		5	*Hoyenella sinensis* *Meandrospira pusilla*	Early Anisian
6. Mikrobial stromatolite		lagoon				
7. Mudstone with bivalve shells		lagoon				
Limestone pebbles:						
8. Radiolarian, sponge spicule wackestone		basin				
9.Crinoidal packstone		toe of slope				
10 Claystone grains						

Tab. 3 - Microfacies, fossils and ages of the resedimented grains of the Sevesvízvölgy Conglomerate (borehole: Mk-10, and Sebesvízvölgy section).

– The thickness of the beds varies between 0.4 and 5.4 m (5.4 m, 0.4 m, 1.2 m, 0.6 m, 1 m).

– Clasts of the conglomerate/breccia beds are only slightly rounded, suggesting a proximal source area. The structure is grain-supported. Most of the redeposited clasts are dolomite, but limestone and clay pebbles also occur in a small quantity. The grainsize varies between 2 mm and 8 cm.

– The spaces between the pebbles are filled with red or yellow clay. At 89.95 m and above, tiny grainlets of volcanic origin occur among the pebbles and their diameter is only a few mm.

– Both normal and reverse gradations occur, but the latter is rare.

The material (dolomite, limestone, claystone) and the microfacies of the pebbles are different (Table 3). The dolomite pebbles originate from different environments of a lagoon (subtidal, peritidal) and from the sand shoal facies. Foraminifers are evidence of Pelsonian age.

Limestone pebbles: compared to the dolomite grains the preservation of limestone grains is better, and they occur in a smaller quantity. The microfacies of the limestone grains indicate basin and slope facies.

The quantity of the claystone grains is very low and their diameter varies between some mm and some cm.

In the samples between 89.95–89.8 m, pebbles of 1–2 mm in diameter appear and in these plagioclase lathes can be seen. Based on their extinction angle the basic origin can be also excluded.

Unit III (87.3–48.5 m): fine-grained clastic sediments (e.g. sandstone, conglomerate).

This interval of the borehole was investigated by examining selected representative samples:

86.6–86.5 m: dolomite pebbles in a marly matrix.

In comparison with Unit II, there is a lower quantity of pebbles. The texture is matrix-supported. In the ochre marl matrix, slightly rounded dolomite pebbles occur in a small quantity. It is most likely that the sediment is the product of a gravity mass movement, presumably a debris flow mudstream (Sztanó, O. personal communication).

83.0 m: fine-grained pyroclastic rock.

The colours of the respective grains are white and violet and their average diameter is 2–3 mm, but some grains reach even 8–10 mm. 90% of the grains are zonal plagioclase, 10% are dolomite. The matrix is altered volcanic glass. The rock suggests coeval volcanic activity.

79.0–77.9 m: brownish violet microconglomerate.

The diameter of the pebbles varies between 2–8 mm, 95% of the grains are andesite (aphanitic andesite), 5% are carbonate. The carbonate pebbles are coated with clay film. The matrix is altered volcanic glass. It is most probable that the sediment is the product of a gravity movement, a former lahar (Szabó, Cs. personal communication).

76.5 m: coarse-grained sandstone.

The size of the clasts varies between 2 and 8 mm and the texture is oriented. The colours of the respective clasts are violet-red, white, green. The quantity of the volcanoclasts is smaller than in the former sample. It may indicate the recurrence of the fluvial deposition during a break of volcanic activity.

70.6 m and 68.3 m: arkose.

It is is violet in colour. The majority of the grains are plagioclase. Since their contour is intact they may have originated in the near vicinity. A single cm-sized hyalite fragment was also encountered.

48.5 m: volcanite with carbonate pebbles.

Occurring in a light green matrix, violet spars appear with an irregular contour. The spars have a thin dark green rim. The framework of the rock consists of plagioclase lathes and between them carbonate fragments can be seen. The rim of the carbonate grains is altered. The rock is a product of a lava flow. Between the volcanic components the carbonate grains represent the sediments that were ripped up and incorporated by the lava flow.

Unit IV (48.5-0 m): green volcanic tuff.

Interpretation:

Between the deposition of the lagoonal sediments of Unit I (Steinalm Limestone) and the terrestrial sediments of Unit II, the area was lifted up. Due to the tectonic activity significant differences in the relief occurred in the late Pelsonian and this resulted in an intense erosion which provided the material of the conglomerate/breccia layers of the second unit.

A microfacies investigation of the redeposited pebbles (Unit II) revealed that dolomite and limestone pebbles originated not only from a former carbonate platform but also from a basin. Consequently, we can conclude that before the uplift the basement was differentiated. The plagioclase at 89.95-89.5 m (crystal tuff) indicates coeval volcanic activity. On the basis of the investigation of the plagioclase, a basic rock-type origin can be also excluded.

The finer-grained rocks of Unit III suggest a levelling of the relief. A gradual decrease in the resedimented sedimentary materials in the borehole section (Stage III) indicates the beginning of intense volcanic activity (Unit IV).

Sebesvízvölgy Section (Fig. 8)

Geographic position: half-way between the villages of Bánkút and Lillafüred, on the southern side of the Garadna Valley (Fig. 1b).

The stratigraphic setting of the section can be seen in Fig. 6.

Unit I: platform dolomite (Hámor Dolomite). No fossils were found in this section.

Unit II: Sebesvízvölgy Conglomerate (Pl. 2, Fig. a).

After an erosion surface the Sebesvíz Conglomerate follows and it has a thickness of 34 m (since the stratal dip is uncertain, its thickness could be 51.3 m if a higher angle is taken into account). Pebbles of 2-15 cm in diameter float in a grey, calcareous matrix. In the lower part of the conglomerate, in two (20 and 60 cm thick) horizons, the matrix is red clay and the grains are angular and unsorted. In the matrix of the conglomerate, Al-chlorite and pyrophyllite were indicated by X-ray analysis. These two minerals - together with a large amount of haematite - suggest heavy lateritic

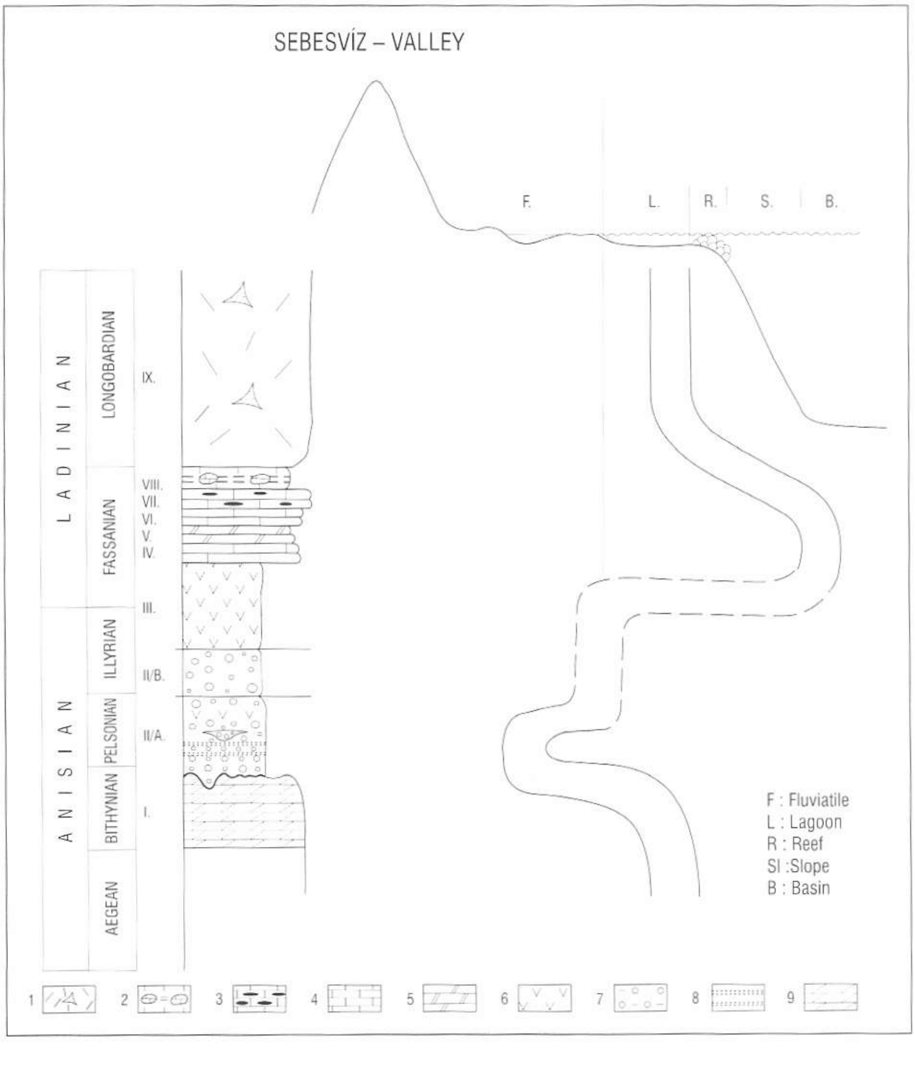

Fig. 8 - Anisian–Ladinian layers and facies curve of the Sebesvíz Section. Legend: 1. white massive limestone (Fehérkő Lst. Fm.), 2. light grey limestone, in certain horizons limestone clasts in red clay matrix, 3. dark grey cherty limestone with shale and radiolarite intercalations, 4. dark grey laminar limestone, 5. white dolomite, 6. volcanite (Szentistvánhegyi Porphyrite), 7. conglomerate-breccia (Sebesvíz Conglomerate), 8. dolomite pebbles in red clay (Sebesvíz Conglomerate), 9. medium grey dolomite (Hámor Dolomite Fm.).

weathering (Kovács-Pálffy, P. and Viczián I., personal communication). Between the clay minerals the illite has a double nature: a part of it is a 2M-altered, clastic or already metamorphic product; its other part is badly crystallised and has a wide base reflection. The latter was smectite, thus the tuffaceous character of the original material cannot be excluded, either.

For the microfacies types and fossils of the resedimented pebbles see Table 3. The age is Aegean-Bithynian.

In the layer group, a 70 x 300 cm dish-shaped conglomerate represents channel sediments. In the middle part of the Sebesvíz Conglomerate, a maximum 4.8 m thick tuffitic volcanic intercalation can be found; its lower and upper boundaries are tectonic in the section. In the upper part of the conglomerate, claystone pebbles also occur among the resedimented pebbles. Accordingly, the erosion affected the footwall and the underlying rocks as well.

The shape of the clasts is very often angular and they do not show any particular order. The grains are similar to those in the lower part of the Sebesvízvölgy Conglomerate and they are complemented by clay pebbles. The latter most probably originate from the Ablakoskővölgy Formation that underlies the Hámor Dolomite (Fig. 6).

Facies: in the lower part the red, clayey matrix suggests lateritic weathering; according to the lithology the sediment can be interpreted as a fluviatile, flood-plain sediment. The dish-shaped conglomerate complex is a channel filling.

On the basis of foraminifera, the age of the dolomite pebbles is Early Anisian, their facies is lagoonal.

Unit III is the Szentistvánhegy Porphyrite. Unit IV (Pl. 2, Fig. h, i) is a thin-bedded limestone of basin facies. Its age is Ladinian/upper Fassanian on the basis of conodonts. This is followed by white dolomite (Unit V) and thin-bedded grey limestone (Unit VI), and then cherty limestone with radiolarite intercalations occurs (Unit VII). This is followed by light- grey limestone with red clayey limestone clasts (Unit VIII). Unit IX is a platform limestone with stromatactis that occurs en masse.

Interpretation

The Sebesvízvölgy Section indicates the following subsidence history: after the deposition of the lagoonal Hámor Dolomite (Unit I), the area was raised. Subsequently, or probably coevaly with the volcanic activity (Unit III), the area subsided rapidly (Units IV–VIII). The initial rapid subsidence had slowed down by the Late Ladinian. In the Late Ladinian, the sedimentation, due to the progradation of the platforms, continued on the platforms.

Current knowledge about the terrestrial sediments of the Bükk Mountains

Age: the main problem with the terrestrial sediments of the Bükk Mountains is that their age cannot be determined as precisely as that of those in the Dolomites. This is partly due to the subsequent tectonics, partly to the bad exposure conditions, and partly to the dolomite (which in some cases forms the footwall) that very frequently contains no fossils.

The dating of terrestrial deposits was based on the age of the underlying formation and on the age data of the resedimented pebbles.

Borehole Felsőtárkány-7: since the borehole stopped in the lake sediments, its footwall is unknown. However, according to the assumed stratigraphical position of the lake deposits their age is most probably late Pelsonian–Illyrian.

Borehole Miskolc-10: the underlying formation (Steinalm Limestone) contains upper Pelsonian–lower Illyrian fossils, so the terrestrial event must have taken place in the latest Pelsonian–early Illyrian.

The material, age, and facies of the resedimented pebbles are different. Among these were found Steinalm Limestone, dolomite (Hámor Dolomite) and shale most probably originated from the Ablakoskővölgy Formation (upper part of the Lower Triassic), and oolitic grainstone which most probably originated from the Gerennavár Limestone (lower part of the Lower Triassic). The grains originated not only from the directly underlying formation, but from deeper ones, too. Based on microfacies of the resedimented grains, we can assume that before the updoming the platform had been differentiated, so we have to take into consideration the coeval existence of platforms and basins.

Sebesvízvölgy: the footwall consists of Hámor Dolomite but we could not find any fossils in the studied outcrop. The age of the resedimented grains is Lower Anisian; their microfacies indicates a lagoonal origin. Only a few claystone grains were found and these probably originated from the Ablakoskővölgy Formation. Grains which could have originated from the Steinalm Limestone and the Gerennavár Limestone have not been found.

Comparing the material of the pebbles from the Sebesvízvölgy Conglomerate as well as from borehole Miskolc-10, we can assume that the pebbles represent two terrestrial events: one in the latest Pelsonian–early Illyrian, and probably another in the Lower Anisian or in the Pelsonian.

Volcanic activity is coeval with the Anisian terrestrial sediments. In the lacustrine marl sediments, reworked volcanic rock fragments as well as resedimented minerals can be found. In the sample from Ft-7: 207.6 m, it can be seen that the material was still plastic when it entered the basin. The material from which the clasts originated was originally felsitic (glassy). Its remnants are mineralised with clay and contain plagioclase phenocrysts. On the basis of the extinction of the plagioclase, the grains are almost certainly derived from acidic extrusive rocks (Árgyelán, B.G., personal communication). The volcanic rocks are derived from a pyroclastic series that came into being due to explosive volcanism. Based on their petrographic character, they are pumiceous tuffs, the fine grain size of which indicates a distal facies. On the basis of the thin sections, their genetic classification cannot be carried out. They may be members of a dispersed pyroclastic series connected to a Plinian-type, or the distal parts of an ignimbrite series (Harangi, Sz. personal communication).

Traces of volcanic activity can be found between the Upper Anisian–Ladinian sediments of the Bükk Mountains.

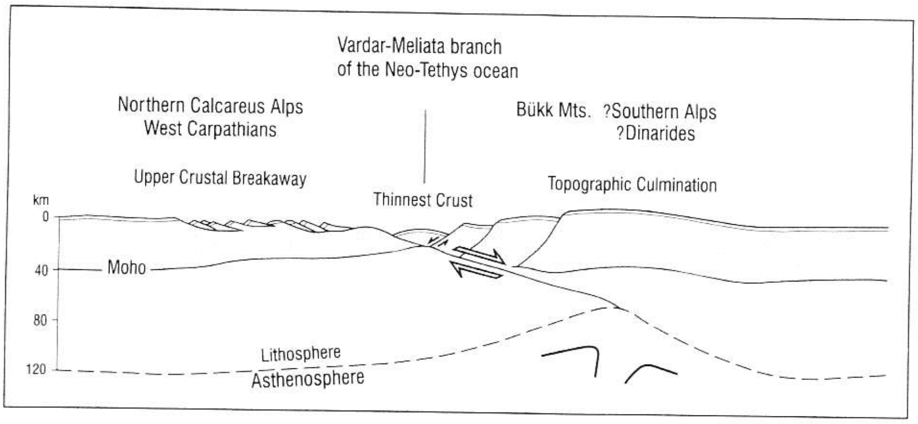

Fig. 9 - Position of the Alpian and Dinaridic units during the Triassic rifting of the Neo-Tethys. The lower part of the Figure depicts the modified simple shear model (Dixon et al. 1989). See text for explanation.

Role of the Anisian terrestrial sediments of the Bükk Mountains in the rifting of the Vardar-Meliata branch of the Neo-Tethys-ocean

Terrestrial sediments in the Bükk Mountains are part of a volcano-sedimentary series which is characteristic for the updoming part of a rifting area (Velledits 1998/a; 1998/b; 2000). According to Dixon et al. (1989) and Allen and Allen (1990), this part of a rifting area is characterised by topographic culmination and by bimodal volcanism (Fig. 9). Above the upwelling of the asthenosphere the crust is updoming and the area is uplifted. The respective occurrences of the volcanism and uplifting probably coincided (Coleman et al. 1983 in Dixon et al. 1989). Shortly after the uplifting, reworking of clastic sediments from the uplifted areas began and gradually even the deeper layers were eroded down to the crystalline basement. These clastic layers are not always very thick and do not extend over the whole area. Leeder and Gawthorpe (1987) established that extensional tectonism produces characteristic half-graben/tilt-block systems. These basins have a profound influence on the geomorphology and on facies distribution. In their models, in the deepest parts of the continental half-grabens, either a lake can be found or flows a river.

From point of view of subsidence, two different stages can be distinguished in the evolution of a rifting area. The synrift or mechanical subsidence stage is characterised by the breaking up of the crust along faults. During this period the subsidence is very rapid. It is followed by the post-rift or thermic cooling stage, then the subsidence of the crust is slow and is controlled by the cooling of the crust.

According to the paleogeographic reconstructions of Kovács (1984), Haas (2001: Fig. 7), and Ziegler & Stampfli (2001: Figs. 3, 5) the Bükk Mountains were situated on the Southern shelf of the opening Vardar-Meliata branch of the Neotethys ocean.

Based on sedimentological, biostratigraphical, geochemical and petrological analyses, we can follow the different stages of an updoming part of a rifting area in the Triassic sediments of the Bükk Mountains. After the pre-rift stage (Hámor Dolomite, and Steinalm Limestone), the territory was uplifted (terrestrial sediments).

In the Southern Bükk Mountains the evolution of a half-graben between Anisian–Rhaethian can be followed (Velledits 2000, figs. 7-8). In the late Anisian a terrestrial half-graben came into being with a lake in the deepest part. This evolved into a carbonate shelf half-graben due to the subsidence of the rifting. (Above the Anisian lake sediments we can find cherty limestone in the Norian-Rhaethian).

After and partly coevally with the uplift, an acidic volcanic event took place. The petrographical character of the volcanic rocks shows that the Middle Triassic volcanic rocks represent magmatic activity related to extensional episodes (Harangi et al. 1996). The volcanic activity was followed by a rapid subsidence of the crust. In the course of a few million years the crust subsided by a minimum of 500-600 meters. In the late Fassanian the late Anisian lake sediments were covered by laminitic marl and radiolarite. Later, this rapid subsidence slowed down and cherty limestone was deposited during the thermal cooling stage.

The duration of the different evolutionary stages (taking into account the dates of Gradstein et al. 1995) are as follows: the updoming stage lasted from the Aegean/Bithynian boundary until the Pelsonian/Illyrian boundary. The duration was approximately 3.3 million years. The syn-rift stage lasted from the Pelsonian/Illyrian boundary until the Fassan/Longobardian boundary, lasting 4.7 million years. For the duration of the post-rift stage only an estimated value can be given due to the lack of information about the Jurassic sediments of the Bükk Mountains. At the Triassic/Jurassic boundary the subsidence is low, and continous. Most probably the slow subsidence continued until the Bajocian/Bathonian boundary. The Bükkzsérc Formation (oolithic limestone) represents the early occurrence of compression. The assumed boundary between the Bajocian/Bathonian probably took place at the end of the post-rift stage and it lasted for something like 51.3 million years.

In North-East Hungary in the neighbourhood of the Bükk Mountains such units can be found which were deposited on different parts of the Vardar-Meliata branch of the Neo-Tethys ocean (Kovács 1984) . The Triassic sequence of the Bükk Mountains was deposited on the updoming side, while the sequence of the Aggtelek Rudabánya Mountains was deposited on the opposite (breakaway) side of the ocean (Velledits 1998/a, 1998/b). Small remnants of the ocean are represented by the ophiolites in Bódva Valley and Darnó Hill (see Fig. 1a and Fig. 9). The evolution of these three parts of the rifting ocean can be correlated very well. The Anisian Steinalm Limestone is present in the Bükk Mountains and in the Aggtelek-Rudabánya Mountains. After the sedimentation of the Steinalm Limestone the area of Bükk Mountains was uplifted. Simultaneously with the uplift the inner parts of the Aggtelek-Rudabánya Mountains nearer the rift axis (Bódva and Szőlősardó units) subsided. During the Middle-Upper Triassic, parallel with the strike of the rift axis, a larger and larger area gradually drowned in the Aggtelek-Rudabánya Mountains.

In the Middle Ladinian, 4.7 million years after the uplift of the Bükk Mountains between the two shelves (each having a different evolution history), a new ocean opened and its remnants are represented by the ophiolithes of the Bódva Valley and Darnó zone (Réti 1985, 1988; Dosztály & Józsa 1992).

The Triassic development of the units of North-East Hungary justify the asymmetric rifting model of Wernicke (1981, 1985) and Dixon et al. (1989).

Terrestrial sediments in the Southern Alps - Dinarides

Anisian terrestrial sediments are also known from the Southern Alps, from the area lying north of the Southern Alps, and from the Dinarides.

They seem to be characteristic of the southern shelf of the opening Vardar-Meliata ocean, to the northern continental shelf of the Gondwana. However, they are missing from the greatest part of the Northern Calcareous Alps and from the Western Carpathians - that is, from the northern shelf of the opening Vardar-Meliata branch of the Neo-Tethys ocean (Fig. 10). Consequently, the presence of the Anisian terrestrial sediments in the Bükk Mountains confirms its palaeogeographic connections with the Dinarides and the Southern Alps (Fig. 10).

A comparison of the Anisian terrestrial sediments is made more difficult by the fact that they knowledge about them is uneven. In some cases only the substage of their age is known, and sometimes their zone/subzone is known as well. It happens also that the age of the same formation is determined differently by different authors.

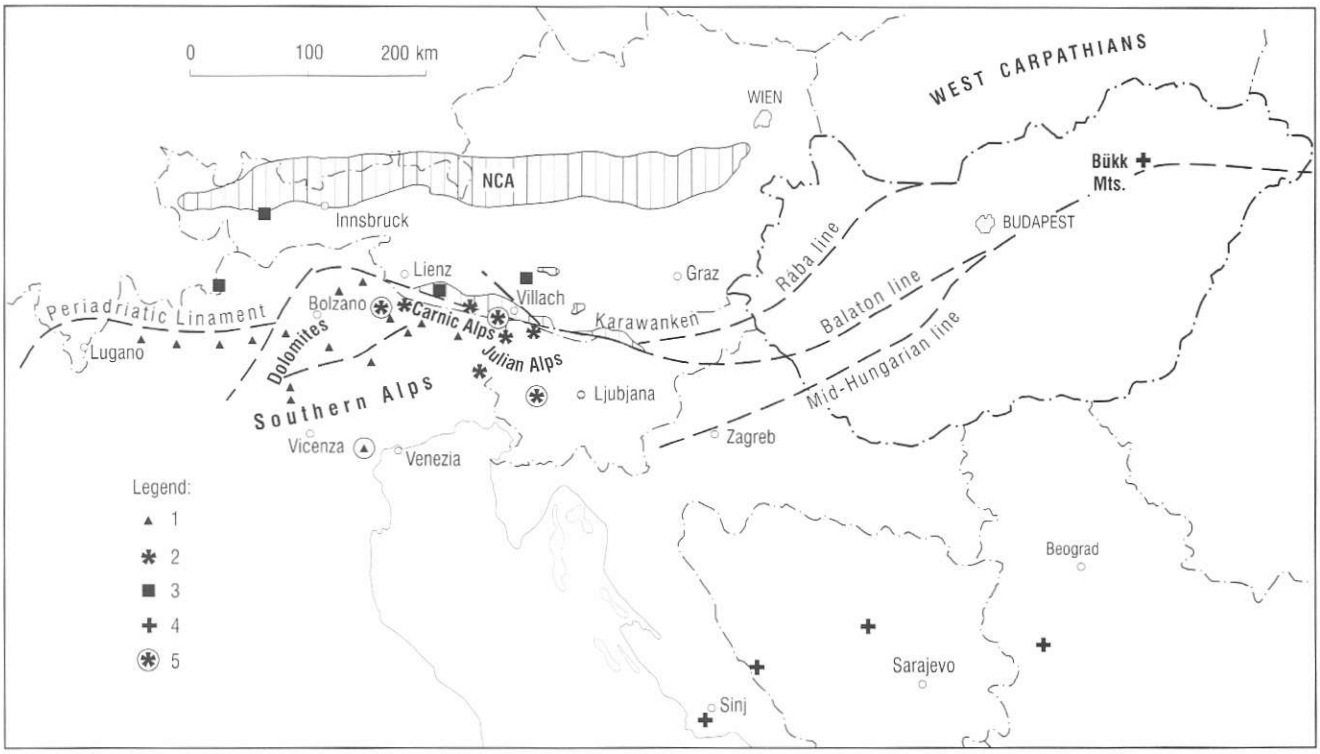

Fig. 10 - Distribution of the Anisian–Lower Ladinian terrestrial sediments. The figure shows that the Anisian terrestrial sediments are concentrated on areas south of the opening Vardar-Meliata branch of the Neo-Tethys ocean, and are missing from the NCA and WNC. (The Bükk Mts. came into their present day position only in the Neogene). Legend: 1. Anisian age (3 horizons), 2. upper Illyrian–Lower Ladinian (Ugovizza Breccia 2), 3. Pelsonian age, 4. without exact age, 5. very intensive erosion: the Anisian conglomerate is deposited on Carboniferous/Permian layers. The map was compiled on the basis of the results of Gianolla et al. (1998), Brandner (1984), Čar & Skaberne (2003), Cerny I. (1977), Farabegoli E., & Levanti D. (1982), Farabegoli et al. (1985), Fois E. & Jadoul F. (1983), Jadoul F. & Nicora A. (1986), Krainer K. & Lutz D. (1995), Marjanac T. (2000), Mostler H. & Krainer K. (1994), Protić et al. (2000), Radoičić R. (1990), Trubelja (2003) and Velledits (1998/a).

Southern Alps

Lombardy

Opinions on the origin of the terrestrial sediments of Lombardy vary. Gianolla et al. (1998, Fig. 4) describe terrestrial sediments from three levels (Bithynian/Osmani subzone, Pelsonian/Cuccense subzone, and Illyrian/Trinodosus subzone) that are parallel with the coeval terrestrial sediments of the Dolomites. Sea level changes is believed to be the primary factor of their origin.

Despite to this, according to Gaetani et al. (1998), the sedimentation of Lombardy was mainly influenced by episodes of transpression and transtension, with widespread volcanism and local uplifts in the Middle Triassic, linked indirectly to the opening of Neotethys in the East. Middle Triassic series is characterised by thick carbonate succession (1.200–1.500 m) to the East and 500–1000 m to the West, where it contains major gaps. Gaetani et al. (1998) describe one supersequence from the Middle Triassic that is subdivided into two major composite sequences (A1 and A2–L1).

From the Anisian, the following terrestrial sediments were reported:

1, On the top of the A1 sequence, a minor sequence (A1/II) appears in Western Lombardy (Brembana Valley) in the Upper Anisian. Its lower boundary is marked by a disconformity with „terra rossa" and locally intraformational breccia in the basal „Peritidal Dolomites" (Upper Angolo Limestone).

In the Lake Como area, fan deltas prograded onto the carbonate bay (Bellano Formation) as a consequence of the increased siliciclastic supply. Lithic arkoses passing upward to feldspathic litharenites are explained by uplift of the basement as well as either volcanism or basin inversion.

2, In Western Lombardy, the lower boundary of the sequence A2–L1 is marked by a 3–5 km progradation of the Bellano Formation onto the underlying coastal flat. In Central Lombardy, it is marked by the subaerial exposure of the upper „Peritidal Dolomites". The sequence boundary is placed in the upper part of the Balatonicus zone.

3, Coevally with the Richthofen Conglomerate of the Dolomites, a sharp increase in clay supply appears a few meters above the base of the Prezzo Limestone, which is explained either by local uplift or coastal retreat.

Dolomites

Terrigenous sediments were described in 3 levels (Bechstädt & Brandner 1970; Assereto et al. 1977; De Zanche et al. 1992; De Zanche et al. 1993; Senowbari-Daryan et al. 1993; Gianolla et al. 1998):

- Piz da Peres Conglomerate, (Bithynian, Kocaelia zone/Osmani subzone);
- Voltago Conglomerate, (Pelsonian, Balatonites zone/Cuccense subzone – unnamed subzone 2);
- Richthofen Conglomerate (Illyrian, Paraceratites zone/Trinodosus subzone).

Pia (1937) had already established that during the Triassic, the Southern Alps were affected by synsedimentary tectonism and volcanism. The most significant erosion can be dated to the time of the formation of the Richthofen Conglomerate, when this unconformity deeply cut Anisian, Lower Triassic and Permian units. On the basis of the analysis of the pebbles of the Richthofen Conglomerate, Bechstädt & Brandner (1970) established that a more than a 400 m thickness of sediments was eroded at this time.

After the third uplift (the age of which according to Gianolla et al. 1998 is the Paraceratites zone/Trinodosus subzone), the rate of subsidence increases. The sequence boundary seems to correspond to a drowning unconformity caused by a strong increase in subsidence and in sea-level rise (Gianolla et al. 1998). In the late Illyrian, anoxic basins came into being, and in these bituminous carbonate rhytmites sharply overlie the previous carbonate ramp sediments.

Rüffer & Zühlke (1995) and Zühlke (2000) have presented some results from simple numerical basin modelling with respect to subsidence/uplift rates and primary control by sea-level changes or subsidence/uplift. According to them, sequence boundaries in large parts of the Southern Alps (eastern Dolomites, Lombardy), in the European epicontinental seas (SW-Germany), in the Arctic Sea (Barents Sea, Canadian Arctic), and in China correlate with each other. Numerical modelling for the Dolomites indicates that the origins of the Piz da Peres Conglomerate and Voltago Conglomerate in large areas of the eastern Dolomites were induced by sea-level changes, whereas the Richthofen Conglomerate of the western Dolomites and the Voltago Conglomerate in the Southern Dolomites were primarily controlled by tectonics.

Carnic Alps

Krainer & Lutz (1995) describe two different kinds of breccias with different ages from the Gartnerkofel–Zielkofel area. The first breccia horizon consists of *in situ* breccias composed of decimeter-large clasts derived from the Werfen Formation and these developed locally at the base. These breccias ('Werfen breccias') occur along small-scale synsedimentary scarp faults. Their age is Lower Triassic. These breccias and synsedimentary scarp faults most probably reflect the first beginning of Middle Triassic tectonics in the Southern Alps.

The second breccia horizon is the Uggowitz Breccia. Its maximum thickness is 40 m. According to the authors, its age is probably Late Anisian/Early Ladinian. The conglomerates are polymict, grain-supported and moderately to poorly sorted. Clasts are derived from the upper part of the Werfen Formation. Reworking of Anisian carbonates was not observed. The lower contact of many beds is erosive. A small volcanic dyke can be observed in the lower part of the Uggowitz Breccia at the Kammleiten, whereas in the upper part dark violet volcanic clasts are frequent.

The Uggowitz breccia is overlaid by a thin sequence of carbonate siltstones and sandstones (Kühweg Member). The Kühweg Member is followed by pelagic limestones and intercalated pyroclastics (Pietra verde) of the Buchenstein Formation.

Farabegoli & Levanti (1982) recognised three main levels of terrigenous erosion in Western Carnia. The resedimented grains are included: 1, in the lowermost Dont Formation: Pelsonian; 2, in the M. Bivera Formation: lower Illyrian; and 3, Ugovizza Breccia: upper Illyrian.

In the Eastern Carnic Alps, in the eastern part of the "Paleocarnic chain", only the Ugovizza Breccia appears (Fois & Jadoul 1983; Jadoul & Nicora 1986). This is deposited on the eroded surfaces of the Auernig Group of Permian–Carboniferous age, or on the eroded surface of the Werfen Formation. It consists of delta fans and terrigenous fluviatile deposits. The breccia is overlaid by Calcari di Pontebba, the age of which is Late Anisian (Illyrian, Trinodosus pp/Avisianus Zone).

The age of the youngest terrestrial sediment (Uggowitz Breccia II) is late Illyrian (Hungarites zone/Avisianum subzone) which is younger than the Richthofen Conglomerate of the Dolomites (Illyrian - Paraceratites zone, Trinodosus subzone, according to the zonation of Mietto & Manfrin 1995).

Southern Karawanken

Above the dolomite (*Diplopora hexaster, Ph. pauciforata*), clastic sediments (conglomerate, sand, silt) appear (Cerny 1977). Their thickness varies between 30–60 m. Tuffite can be found at the base of the "Muschelkalk Konglomerate". Tuffitic material appears as a matrix, and as resedimented gravels. The terrestrial sediments are covered by basin carbonates.

According to Krainer & Lutz (1995) the South Alpine Karawanken Mountains shows most striking lithologic similarities to that of the Gartnerkofel area. The Late Anisian shallow water limestones (Contrin Formation) are covered by red pelagic limestones (Loibl Formation; Mostler & Krainer 1994). The latter formation is overlaid by volcanic rocks of andesitic to dacitic composition. The volcanics are covered by a basinal sequence, which is very similar to that of the Gartnerkofel area. The succession starts with polymict conglomerates of the Ugovizza Breccia, grading into sandstones and siltstones of turbidite origin (maximum thickness: 45 m.) This horizon is covered by the Buchenstein Formation (marly mudstones, cherty nodular limestones and pelagic limestones). The Ugovizza Breccia is situated between the early Fassanian Loibl Formation and the late Fassanian to Longobardian Buchenstein Formation (Mostler & Krainer 1994).

Julian Alps

Gianolla et al. (1998) described terrestrial sediments from four levels from the Southern Julian Alps (Piz da Peres CGM, Voltago CGM, Ugovizza Breccia, and Rio Gelovitz ss. 2). The first three are identical with the levels described in the Dolomites, while the youngest one corresponds to level 2 of the Ugovizza Breccia.

From the Northern Julian Alps only the two younger levels (Ugovizza Breccia 1, and Ugovizza Breccia 2) are known.

Farabegoli et al. (1985) describe three tectono-sedimentary cycles of second order: upper part of the Lower Triassic–Pelsonian, Pelsonian–lower Illyrian and upper Illyrian–Lower Ladinian. In the upper Anisian, the peritidal carbonate platform broke up and due to the uplift of the northern part of the area an E–W oriented ridge (Anisian Paleocarnic Ridge) developed. This is characterised by fluviatile deposits. In the lower Illyrian the ridge broke down and two basins were formed. In the upper Illyrian the southern basin subsided intensively and became a turbiditic basin. Still in the upper Illyrian, an intensive volcanic activity began on the ridge.

Areas adjacent to the Southern Alps

In these areas, sandstone and arkose represent the Anisian terrestrial sediments.

Lienz Dolomites

Brandner (1972) described two terrestrial events in the Anisian: a smaller one in the Lower Anisian, and a bigger one around the Pelsonian–Illyrian boundary. The second event is represented by a sandstone complex that is 150 m thick and consists of quartz–sandstone, partly with carbonate binding material and sandy marl. The author explains the occurrence of the sediments with tectonics.

From the areas below, Brandner (1984) mentions sandstones coeval with the Voltago Conglomerate (Pelsonian):

- Engadiner Dolomites (Follerkopf Formation, Dösegger et al. 1982 in Brandner 1984);
- the Southern margin of the western part of the Northern Calcareous Alps (Krabachjoch–Deckscholle, Imsterberg);
- Gurktaler Alps, "Licischen Fazies" (Tollman 1975 in Brandner 1984).

Dinarids

From the territory of the Dinarids, we have only a few exact data on either the age or facies of terrestrial sediments. Anisian and Ladinian terrestrial sediments are known in the areas listed below:

Idrija and Stopnik area

Terrestrial sedimentary rocks were formed in a tectonic trench as a consequence of the Lower and Middle Triassic tectonic activity in the area of Idrija and Stopnik. Among them, the Idrija tectonic trench with mercury ore deposits is the most important. It had started to form in the Lower Triassic. The first tectonic movements producing a flexure are marked by intraformation breccias in the upper part of the Lower Triassic dolomite (Placer & Čar 1977).

In the Upper Anisian the uniform Anisian dolomite platform, or ramp was cut by subvertical faults. Some blocks were uplifted and became partly dry land. Subareal weathering produced bauxitic sandy sediments (which are only partly preserved) and dolomitic clastic sediments that were mostly transported into a shallow sea (Čar & Čadež 1977).

In the Upper Ladinian, Longobardian, the area was differentiated into uplifted and subsided blocks. Some uplifted blocks were eroded down to the Carbonifrerous shale. The clastic sediments originating from the uplift are shale, sandstones and conglomerates, with distinct terrestrial horizons and volcanic rocks. In the other case the same type of conglomerates are deposited on the top of Triassic rocks of different ages. The conglomerates may reach a thickness of more than 600 m. In the Stopnik area they consist of pebbles of different types of limestone, dolomite, volcanic rocks, tuffs, tuffaceous sandstone and conglomerate. They represent mainly resedimented rocks of the Lower Ladinian and Anisian age. The sedimentary complexes of the Stopnik conglomerates were interpreted as alluvial fans and predominantly fan deltas (Čar & Skaberne 2003).

The whole area subsided at the end of Longobardian. The subsidence was accompanied by volcanic activity producing, apart from volcanic rocks, also tuffaceous sediments in which the youngest singenetic mercury ore was formed in Idrija. The tuffaceous sediments were covered by Cordevolian dolomite.

Dalmatia

At Muc, the Campilian Beds are covered by the Otarnic Breccia (Marjanac 2000). Its age is Anisian. The maximum thickness is 25 m. It is composed of very coarse debris and the matrix is sometimes bauxitic. It represents alluvial fan to fan-delta deposits. The breccia is overlaid by dolomite and this is followed by black carbonate clastics with lithoclasts, skeletal fragments and chert nodules, showing evidence of sliding and slumping. These sediments are overlaid by pyroclasts that are covered by black graded calcarenite–radiolarite and overlaid by clayey ash. Sediments of Ladinian age are represented by bituminous mass flow calcarenites, marls and breccia interbeds, containing abundant plant debris in addition to molluscs, echinoderms, corals and ammonoids.

According to Marjanac (2000), the Otarnic Breccia was deposited during a significant sea-level fall and associated emersion. The Late Anisian pyroclasts have been attributed to rifting (Belak 2000 in Marjanac 2000). It was interpreted as the result of a subaerial explosive volcanism. Large plant debris and coarse clastics suggest the proximity of an area covered with vegetation. The overlying sediments were deposited in shallow marine environments. The section indicates that the rifting failed after a short period of Middle Triassic volcanic activity and after it a shallow marine depositional regime was re-established, which lasted throughout the rest of the Mesozoic.

Radoičič (1987) states that Anisian block-faulting affected the entire Dinarides and was succeeded by polyphase volcanism (Anisian–Ladinian). Synsedimentary faulting was more intensive in the southern sector and began somewhat earlier – probably as early as the end of the Lower Triassic. The result was the uplift of a large region in the Dinaric Carbonate Platform (external zones). In the Late Anisian a large part of the Dinarides was characterised by the association of Han Bulog (ammonitic type facies) and bedded or nodular hemipelagic limestones and cherty limestones (Radoičič 1990). Ladinian is represented by the Porphyrite–Chert Formation – a group of magmatic rocks and bedded limestones with chert. In the Middle Carnian, a tectonic event caused emersion again. Radoičič (1990) mentions thick sequences of conglomerates and breccias of Anisian age from the Dinarides, but she gives no detailed description.

Jadar Block

Protić et al. (2000) gave an account the Podbukovi Conglomerates that lie between the Anisian Dolomites and the Lower Ladinian volcanics (Tronosa Formation).

Bosnian

Trubelja (2003) describes Middle Triassic bauxites that lie on the karst surface of the Middle Triassic dolostone and are overlaid by a grey bedded dolostone, marl, sandstone and a chert sedimentary complex of Upper Triassic age.

Conclusions

Age

Exact age data are known only from the Dolomites, Carnic Alps, Julian Alps and Karawanks. On this basis, the following statements can be made: in the Dolomites, terrestrial sediments were described in three levels (Gianolla et al. 1998; see their work mentioned previously in this paper). To the east of the Dolomites, in the Carnic Alps, Julian Alps and Karawanks, and in the neigbourhood of Idjija (N Dinarides) a younger conglomerate level also appears in the upper Illyrian–Lower Ladinian: Ugovizza Breccia 2 (Fig. 10).

Tectonics versus sea level change

All the authors cited in this paper emphasise the role of tectonics in the appearance of the Anisian terrestrial sediments between the thick platform carbonates (e.g. Assereto et al. 1977; Castellarin et al. 1979).

It varies what they thought the primary cause of the appearance of the Anisian terrestrial sediments was. Whether it was tectonics or sea-level oscillation. However, this supposition has changed in the course of time. In the 1970s and 1980s, the cited authors all considered that tectonics played the primary role, while in papers written in the 1990s many authors (De Zanche et al. 1992; De Zanche et al. 1993; Gianolla & Jacquin 1998; Gianolla et al. 1998) regard sea-level oscillation as being the prime factor in the formation of the terrestrial sediments and put their appearance to the boundary of the 3rd order cycles; even so they still stressed the the role of tectonics.

Based on the calculations of Rüffer & Zühlke (1995) and Zühlke (2000) it was proved that different parts of the Gondwana continental shelf were probably controlled by uplift in one place and by sea-level fall in other places.

The primacy of tectonics is implied by the following facts:

1) The terrestrial sediments-volcanites-pelagic sediments (with the exception of the occurrence in Dalmatia) occur together.

In several instances the Pelsonian/Illyrian terrestrial sediments are coeval with the volcanites or precede them directly. The volcanites are followed very frequently by pelagic formations, or with very thick carbonate platform series. These are replaced by shallow water carbonates only in the Longobardian.

This refers to the fact that the uplifting at the end of the Anisian was followed by the rapid subsidence of the crust which slowed down in the Late Ladinian.

This tendency can be very well observed in the Western Southern Alps (WSA), Dolomites, Carnic Alps, Southern Karawanks, Julian Alps and in the Bükk Mountains.

In the WSA Gaetani et al. (1998, Fig.4) described two periods with accelerated subsidence: the first in the Late Anisian, and the second in the mid-Norian. They explain it with tectonic activity.

In the Dolomites the Richthofen Conglomerate is covered by the shallow marine Morbiac-, and Contrin Formation. The overlying Buchenstein /Livinallongo Formation represents the pelagic sediments, which are heteropic with the thick Schlern platform carbonates. These sediments are replaced by platform carbonates in the Longobardian after the Wengen volcanites. Maurer (2000) pointed to the fact that the rate of subsidence considerably accelerated in the late Illyrian-Early Ladinian (Reitzi, Secedensis, Curioni zones). He estimates 200 Bubnoffs (m/Ma) for this period. Taking into consideration the fact that in the western Dolomites at the Reitzi/Secedensis boundary the platforms in the western Dolomites already reached a thickness of approximately 300 m (Maurer 2000), a subsidence for the period of Reitzi, Secedensis, Curioni zones of 600-700 m can be estimated. In the central Dolomites and Carnia, the subsidence is higher. At the Reitzi/Secedensis boundary the platforms already reach a thickness of 500-650 m. Consequently for the Reitzi, Secedensis, Curioni zones a subsidence of 900-1050 m can be estimated.

According to Maurer (2000) the subsidence slowed down in the Gredleri and Archelaus zones, reaching only 50 Bubnoffs.

Already Bosellini (1991, 1998) had suggested that in the Middle–Late Ladinian the subsidence "ceased suddenly over almost the whole Dolomite Region".

A similar tendency can be observed in the Bükk Mountains (Velledits 2000). The Upper Anisian lacustrine sediments are covered by laminitic calcareous marls deposited in an anoxic basin and these are overlaid by radiolarite of late Fassanian age. Radiolarite is followed by cherty limestone of Upper-Ladinian–Rhaetian age. Between the deposition of the terrestrial sediments and the radiolarite the subsidence of the basement was very rapid in the Bükk Mountains: i.e. more than 5–600 m metres during a few million years.

The movement of the crust is the same in both areas: i.e. emergence at the end of Anisian that is followed by rapid subsidence. The rapid subsidence slows down in the Middle-Late Ladinian. A subsidence of such a degree can be explained only by tectonic movements, though the rise in sea-level probably coincided with the subsidence of the crust. Due to the rapid subsidence after the uplifting, anoxic basins frequently came into being (e.g. in the Bükk: Velledits 2000 and the Dolomites: Senowbari et al. 1993). These were later replaced by well-oxygenated deep water sedimentation.

2) Discordance.

The younger terrestrial sediments (Richthofen Conglomerate, Ugovizza Breccia 2) were deposited frequently with a significant discordance on Permian or Carboniferous beds (Eastern Carnic Alps – Fois & Jadoul 1983; Jadoul & Nicora 1986; Idrija – Placer & Car 1977).

Angular discordance between the terrestrial sediments and their footwall has also been described several times (borehole Villaverla-1, AGIP – Gianolla et al. 1998; Western Carnic Alps – Farabegoli & Levanti 1982; Vicentinian Alps, Recoaro area: 5 to 20° unconformity – Barbieri et al. 1977).

In the Dolomites, on the Adige platform, pebbles of the Richthofen Conglomerate were deposited on an erosional surface: Werfen Formation (Lower Triassic) to Bellerophon Formation (Late Permian) (Brandner 1984, fig. 21).

3) The Anisian terrestrial sediments are distributed regionally. During the Pelsonian–Illyrian terrestrial sediments appear on the Gondwana northern continental shelf. The degree of erosion reaches up to several hundred metres (4–500 m) at some places. Nevertheless, on the northern margin of the Vardar-Meliata branch of the Neo-Tethys, in the Northern Calcareous Alps (NCA) and the Western Carpathians (WNC), huge parts of the carbonate platforms (Steinalm Lst.) were drowned at this time. The exact dating

for the platform drownings in the NCA and in the WNC has not been ascertained as yet. Pelsonian drowning events are described from the NCA by Schlager & Schöllberger (1973), Mandl (2000), and from the WNC by Mello et al. (1997). Reifling/Schreieralm/Nádaska Limestones of basin facies were deposited on the top of the lagoonal Steinalm Limestones. Another drowning event was described by Schlager & Schöllberger (1973) as "Reiflinger Wende". Lein (1987) described this with respect to the NCA, and Mello et al. (1997) made a similar description for the WNC. Neither terrestrial sediments no considerable volcanites are known from this interval either from the NCA or from the WNC.

Certainly, the sea-level oscillation affected sedimentation also in the Anisian (given that it is a continuous phenomenon). The terrestrial sediments are covered by a transgressive series (e.g. Morbiac Formation/Contrin Formation/Buchenstein Formation) which can also be well-explained by a rise in the sea-level. Probably the time of uplifting coincided with the lowstand. The degree of the subsidence following the greatest uplift, however, far exceeded the order of the eustatic sea-level rise.

The precise dating of the uplifting of the southern margin and the time of the drowning events on the northern margin of the Vardar-Meliata branch of the Neo-Tethys ocean are unknown as yet. Furthermore, it is today unclear whether the uplifting on the southern margin was coeval with the drownings on the northern margin, or whether the uplifting events preceded the drownings. What can certainly be established is that while on the southern margin the uplifting of platforms, the apparence of the terrestrial sediments and the presence of volcanites are characteristic, on the northern margin the drowning of platforms and the lack of volcanites are the most noticeable tendency. Therefore in the Anisian the development tendencies of platforms are contrasting in their nature.

Since the history of the development of the Bükk Mountains in the Anisian accords well with the assymetrical rifting of the Vardar-Meliata branch of the Neo-Tethys ocean (Velledits 1998/a, 1998/b), the origins of the dry land sedimentation of the Bükk in the Anisian can be linked to the elevation of the updoming wing. The similar features of the Anisian-Ladinian strata of the Southern Alps – Dinarides suggest they could have been close to each other in the Triassic. However, in order to determine the extent to which the rifting of the Vardar-Meliata branch of the Neo-Tethys ocean affected the development of strata of the Southern Alps-Dinarides in the Anisian-Ladinian, further investigations will be required.

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PLATE 1

Borehole Miskolc-10

a-c, g. Foraminifera and algae from the Steinalm Limestone:
a. *Pilammina densa* Pantić, Borehole Miskolc-10, 114.5–114.65 m. N= 70x.
b. *Meandrospiranella* sp., 116.4 m, N=70 x.
c. *Physoporella pauciforata* (Gümbel) *pauciforata* Bystrický, 116.4 m, N=28x.
d-f. Foraminifera from the reworked pebbles.
d. *Meandrospiranella* sp., 89.95–89.8 m, N=70x.
e. *Meandrospira dinarica* Kochanski-Devide & Pantić, 99.5 m. N=70x.
f. *Meandrospirella samueli* Salaj, 89.95–89.8 m. N=70x.
g. *Variostroma* sp., 116.8 m, N=28x.
h. Part of the conglomerate/breccia layers (Unit II). Fabric of the rock is grain-supported, size and roundness of the pebbles are varying. Grains of several different materials can be distinguished even with unaided eye.
i-j. Microfacies of the reworked pebbles:
i. Dolomite of grainstone fabric. The lithoclasts are surrounded by micritic edges. The grainstone fabric refers to high-energy environment of strongly agitated water. The rock was deposited in the facies of the moving calcareous sand dune on platform margin. 95.5m, N=40x.
j. Limestone pebble. Crinoidal packestone. Crinoid fragments in micritic matrix. In the upper left corner of the photo bryozoan fragment can be observed. It is a sediment of the deeper, mild water part of the lagoon or a sediment reworked from the platform to the basin. 95.5 m. N=28x.

PLATE 2

Sebesvízvölgy Section

a. Sebesvíz Conglomerate. Slightly rounded dolomite pebbles of varying size in red clayey matrix.
b. *Reophax* sp., N=70x.
c-d. *Tolypammina* sp., N=70x.
e. Grainstone. The original constituents were considerably altered subsequently. Inner parts of the intraclasts were dissolved, their moulds are filled in by dolospar. N=40x.
f. *Meandrospira deformata* Salaj, N=70x.
g. *Meandrospira pusilla* (Ho), N=70.
h. Unit IV. The terrestrial sediments and volcanites are followed by dark grey laminar limestone of pelagic facies. The limestone contains chert intecalations, its fabric became deformed due to subsequent tectonics.
i. Microscopic picture of Unit IV: filament, radiolarian wackestone. Radiolarians and pelagic bivalve shell sections in micritic matrix. The fossils are elongated in the same direction due to the subsequent tectonics. N=14x.

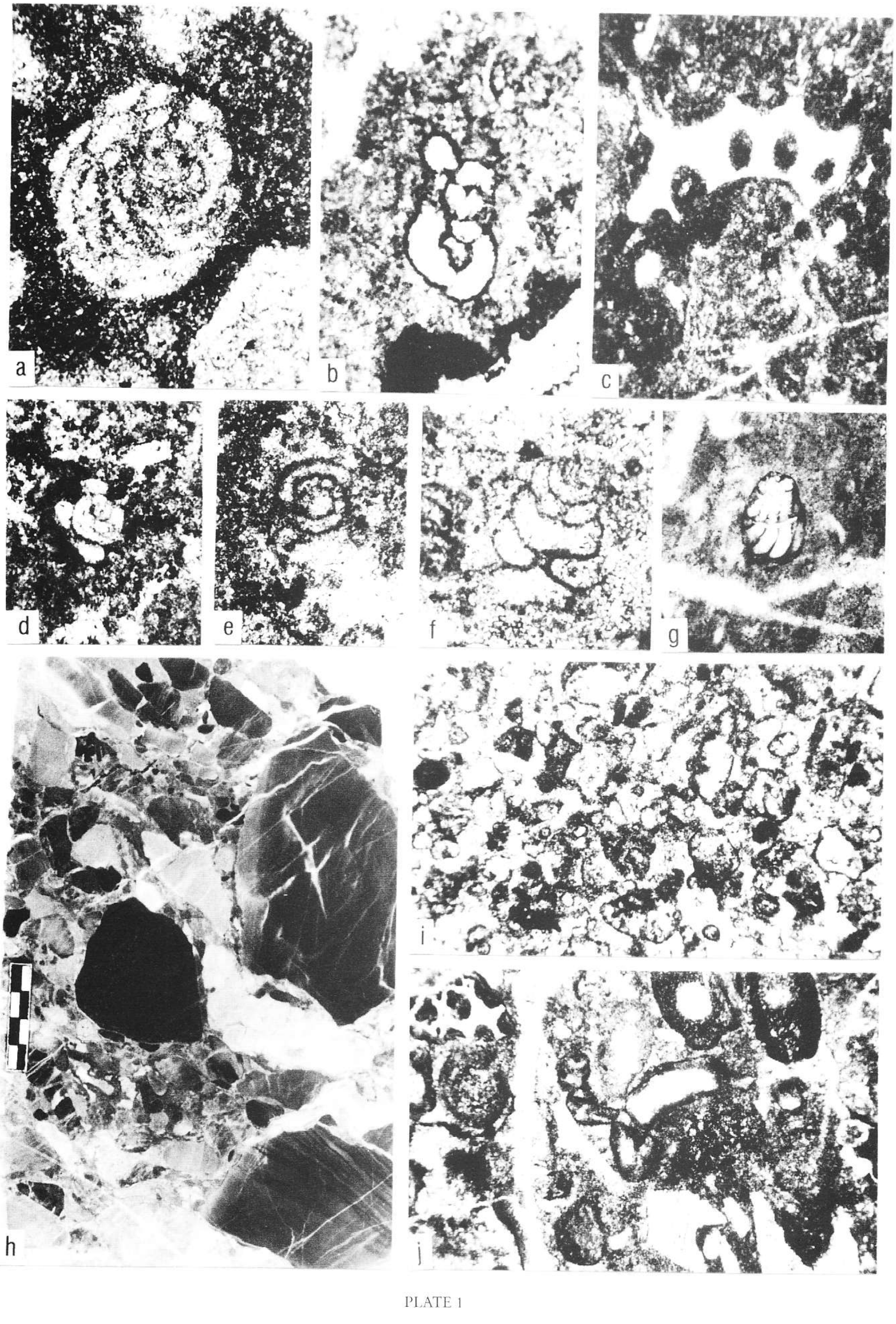

PLATE 1

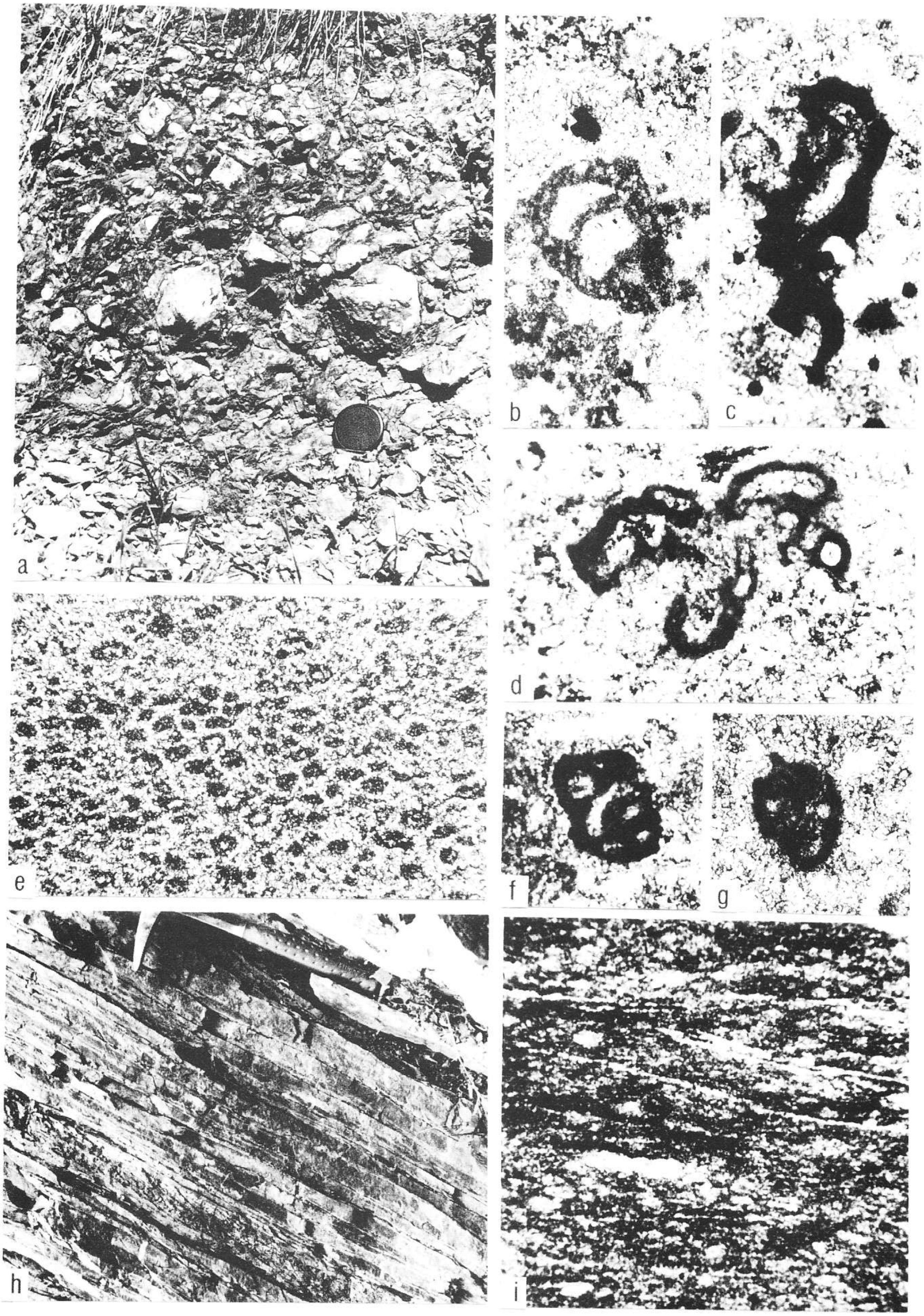

PLATE 2

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