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CLAY MINERALS OF A GERMAN-TYPE MIDDLE TRIASSIC SEQUENCE, BORE HOLE NAGYKOZÁR 2, MECSEK MTS., S. HUNGARY

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ABSTRACT

The mineralogical composition of Middle Triassic sedimentary rocks in the bore hole sequence Nagykozár-2 and in few surface outcrops in the western Mecsek Mts. was investigated by X-ray diffraction methods. The composition of the bulk rock, insoluble residue and the <2 μm fraction was considered. Triassic sediments of the Mecsek Mts. Show remarkably analogous features with those of the German-type Triassic. Middle Triassic was deposited in a transgressive period of evolution of a flat coastal plain and later of a carbonate ramp environment.

Buntsandstein-type sandstones of Schythian age are overlain by Röt-type sediments. Red to green laminated siltstones of tidal flat facies contain the detrital clay assemblage of *illite (mica), Fe-Mg-chlorite*, and the detrital feldspars *K-feldspar* and *plagioclase*. Anhydritic evaporites alternating with dolomite and siltstone beds of coastal sabkha origin are characterised by illite and *Mg-rich chlorite* or *mixed-layer chlorite/smectite* of presumably neoformational origin. The carbonate mineral of the evaporites is dolomite sometimes associated by *magnesite*. *Corrensite, Mg-chlorite* and *illite* occur in the overlying marly limestones and dolomites of inner and mid ramp, periodically dysaerobic carbonate environment. The genesis of corrensite is connected with the restricted nature of this sedimentary basin.

Carbonate sediments analogous to Germanic Muschelkalk are represented by Middle Anisian to Middle Ladinian formations. They are mostly characterised by the dominance of the single clay mineral *illite-1Md* and by presumably authigenic *K-feldspar*. In lower part of the sequence a dolomitised variegated peritidal facies exists in which sometimes *kaolinite* may be enriched indicating subaerial weathering on the top of periodically emerging small carbonate sand bars. Another kaolinitic weathering seems to have taken place during the Middle Muschelkalk emersion.

In contrast to the Germanic Triassic, the Mecsek Mts. rocks underwent relatively strong burial diagenetic transformation which is reflected by the widths of the illite basal reflections (KÜBLER indexes). Another reason of sharpening of the illite reflections is the reorganisation in the evaporitic environment.

Analogies with the clay mineralogy of a formerly studied bore hole sequence in the Mecsek Mts., Pécs-IX. and with that of Triassic formations of the Germanic basin are discussed.

INTRODUCTION

Mineralogy of Middle Triassic clastic, evaporitic and carbonate formations of the Mecsek Mts. was studied by the present author using the material of the bore hole Pécs-IX (VICZIÁN 1990, 1992, 1993). X-ray diffraction analysis and microscopic petrographic observations revealed that facies relations are reflected by the clay mineralogy of these formations: in clastic siltstones a detrital illite + chlorite assemblage predominates, anhydrites and restricted basin marly limestones contain the Mg-rich assemblage of Mg-

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chlorite, corrensite and illite while other carbonate rocks are characterised almost solely by illite. Neoformations were interpreted using the low-temperature phase diagrams of LIPPMANN and analogies with sedimentary formations of the Germanic Basin were indicated.

Recently the similarity between the Triassic sedimentation of the Mecsek Mts. and of German-type basins of Europe was stressed by the detailed sedimentological and paleontological studies of TÖRÖK (1997b, 1998) and KONRÁD (1997, 1998). It was shown that the Lower Triassic conglomerate and sandstone sequence of the Mecsek corresponds to the Buntsandstein unit of the Germanic Triassic while Middle Triassic formations in Mecsek are analogous with the Röt and Muschelkalk units. There are much larger differences in the Upper Triassic formations of Mecsek and Keuper of the Germanic basin.

The aim of the present study is to analyse the mineralogical variations in another Triassic bore hole sequence in the Mecsek Mts, that of the well Nagykozár-2 in order to prove the relations observed in the bore hole Pécs-IX in another facies sequence of the same character. In addition, in view of the new sedimentological results, a more detailed comparison with the clay mineralogy of the Germanic Triassic is made possible by these studies.

GEOLOGICAL RELATIONS

The geological map of the Mecsek and Villány Mts. is shown in *Fig. 1*. The bore hole Pécs-IX is located in the main block of the western Mecsek Mts., a few km northwards from the city of Pécs. Bore hole Nagykozár-2 lies about 10 km SE from the bore hole Pécs-IX. Although there are important structural lines in between, the Triassic sequences in both bore holes are very similar. In the sequence of Nagykozár-2 Triassic is covered by Tertiary, Cretaceous and Jurassic sediments and fills the 675.0 to 1704.3 m depth interval. Triassic is underlain by Paleozoic formations.

The stratigraphic succession of the Nagykozár-2 sequence including the names of local lithostratigraphic units is shown in *Figs 3* and *4*, following the first description of the core material by BARABÁS-STUHL (1988). The definitions and descriptions of the lithostratigraphic units were made by RÁLISCH-FELGENHAUER and TÖRÖK (1993). BARABÁS-STUHL (1993) studied the stratigraphy of the sequence. In the bore hole Nagykozár-2 samples were taken only from the generally transgressive part of the sequence, from the *Patacs* until the *Zuhánya Formations*. TÖRÖK (1997b, 1998) interpreted the Middle Triassic evolution in the Mecsek Mts. as stages of the development of a carbonate ramp. According to this interpretation the pre-ramp stage is represented by the *Patacs Siltstone Formation*, the initial ramp by the *Magyarürög Evaporite Member*. *Hetvehely Dolomite Mb.* corresponds to inner ramp, *Viganvár Limestone Mb.* to mid-ramp while *Rókahegy Dolomite Fm.* again to inner ramp situation. The deepening started again during the deposition of the mid-ramp *Lapis Limestone Fm.*, the deepest outer ramp facies was that of the *Zuhánya Limestone Fm.* According to Konrád (1997, 1998) the deposition of the Zuhánya Fm. was followed by a sea level drop and temporary emersion as a consequence of tectonic movements. After this unconformity, members of the *Csukma Fm.*, *Kozár Limestone* and *Kán Dolomite* were formed in the territory of western Mecsek. These members are partly covered by the *Mánfa Siderite Mb.*, which indicates another period of emersion and subaerial weathering.

For comparison with the results of the above sequence, a few samples were analysed from surface localities in the western Mecsek area.

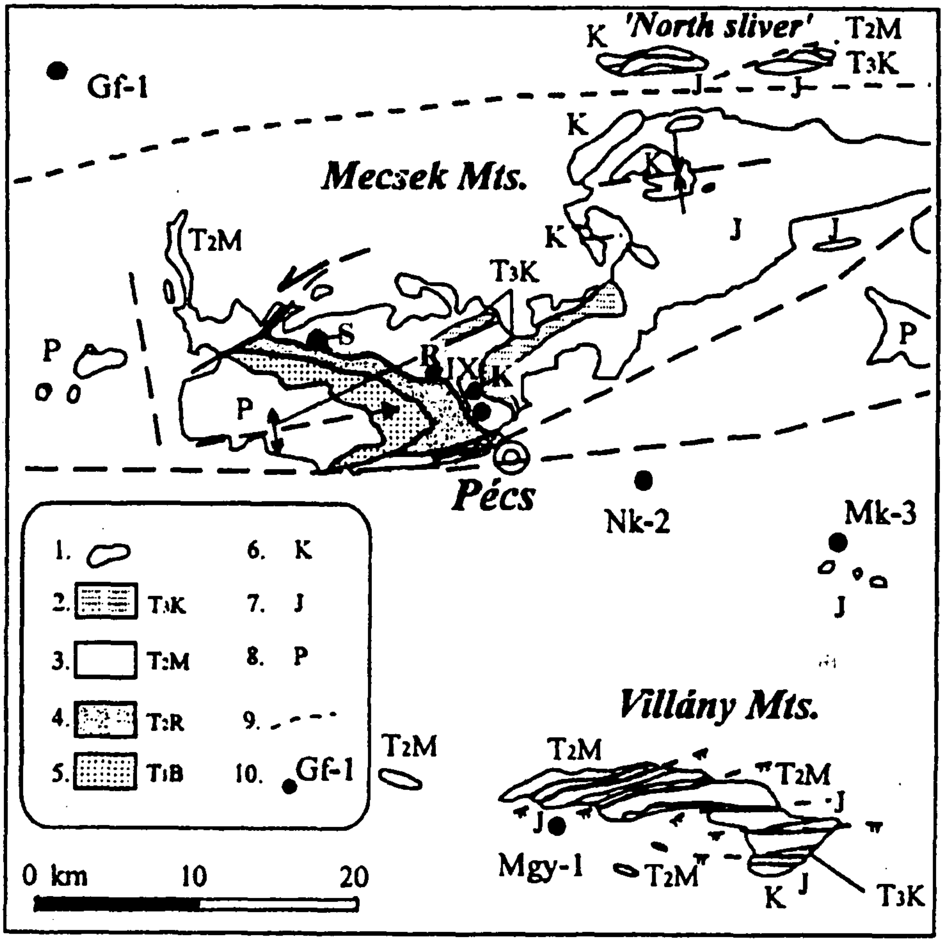


Fig. 1. Geological map of the surrounding of bore hole Nagykozár-2 (Nk-2) according to KONRÁD (1998). Some important bore holes and localities mentioned in the present study are shown.
IX: bore hole Pécs-IX; R: Remete-rét, K: Kis-rét, near the hill Misina at Pécs; S: Sás-völgy at Hetvehely. 1. Boundary of outcrop of Paleozoic and Mesozoic formations; 2. Upper Triassic detrital sediments; 3. Middle Triassic Muschelkalk-type carbonates; 4. Middle Triassic Röt-type formations; 5.Lower Triassic Buntsandstein-type Jakabhegy Sandstone; 6. Cretaceous; 7. Jurassic; 8. Paleozoic; 9. important structural line; 10. site of deep drillings and outcrop localities.

- One oncoidal limestone sample was taken from the locality *Kis-rét, Misina,* from the *Kozár Limestone Mb.* which is the uppermost member of the Mecsek Middle Triassic and a member of the Csukma Fm.
- Two samples were taken from the locality *Remete-rét, Misina,* from a special facies of the Rókahegy Dolomite Fm. containing branching stromatolitic forms. The occurrence was extensively studied and described by KONRÁD (1997).
- Three samples were taken from the locality *Sás-völgy* at the village Hetvehely, from an outcrop of the Hetvehely Dolomite and Viganvár Limestone Members.

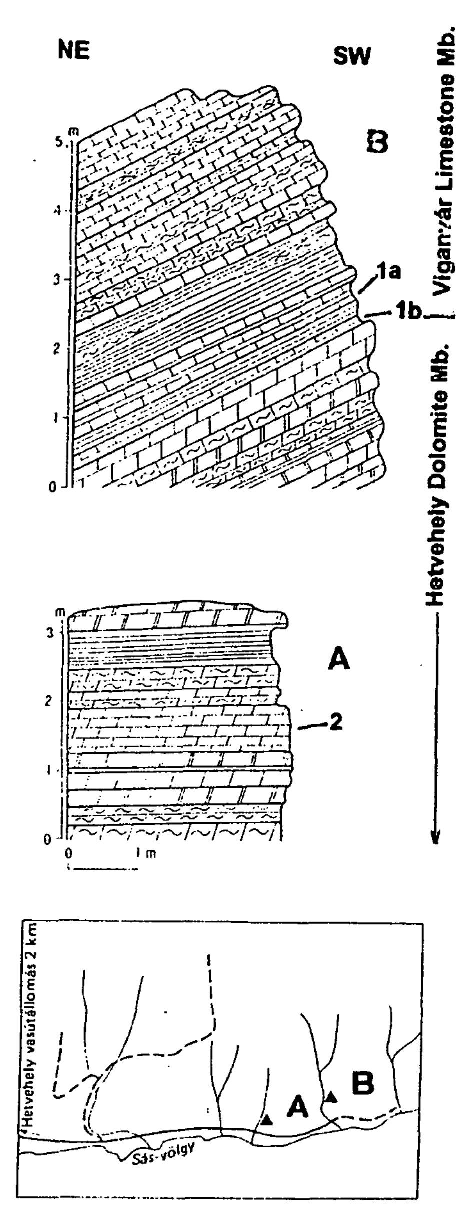


Fig. 2. Geological profiles of the outcrops A and B in Sás-völgy at Hetvehely, according to RÁLISCH-FELGENHAUER (1988a). The stratigraphic position of the samples taken is shown.

The geological relations of these localities, which are also stratigraphic key section, were described by RÁLISCH-FELGENHAUER (1987, 1988a,b). *Fig. 2* shows the profile and the sampling points of the locality Sás-völgy at Hetvehely.

SAMPLES AND METHODS

Field descriptions and microscopic examinations were made by RÁLISCH-FELGENHAUER. A total of 24 samples were taken for X-ray diffraction analysis, both bulk rock and the 3 % HCl insoluble residue were analysed.

Another set of samples was selected for detailed XRD study of the clay minerals in the <2 μm fraction. For the clay mineral analyses 9 samples were taken from the bore hole Nagykozár-2 and 6 samples from the outrcops mentioned above. Brief description and stratigraphic position of these samples is listed in Table 1. In each case, the <2 μm fraction was obtained by sedimentation after removal of the carbonate content by 3 % HCl. It was attempted to obtain the clay fraction of an anhydrite rock by repeated dissolution in distilled water, in a similar way as described by LIPPMANN and PANKAU (1988, p. 264). The complete dissolution of anhydrite was not achieved, however, it was possible to obtain a sufficiently enriched silicate fraction from which the <2 μm fraction was separated. Clay minerals were identified in oriented specimens of the < 2 μm fraction, in untreated and in ethylene gylcol treated form.

Semi quantitative XRD analysis was carried out by weighing selected reflections of the phases by intensity factors, according to standard methods used in the Hungarian Institute of Geology (RISCHÁK and VICZIÁN 1974, SZEMEREY-SZEMETHY 1976, KOMKOV et al. 1989, SIDORENKO et al. 1992). The width at half height of the first basal reflection of illite at 10 Å and of kaolinite at 7.2 Å was measured on smoothed curves after background

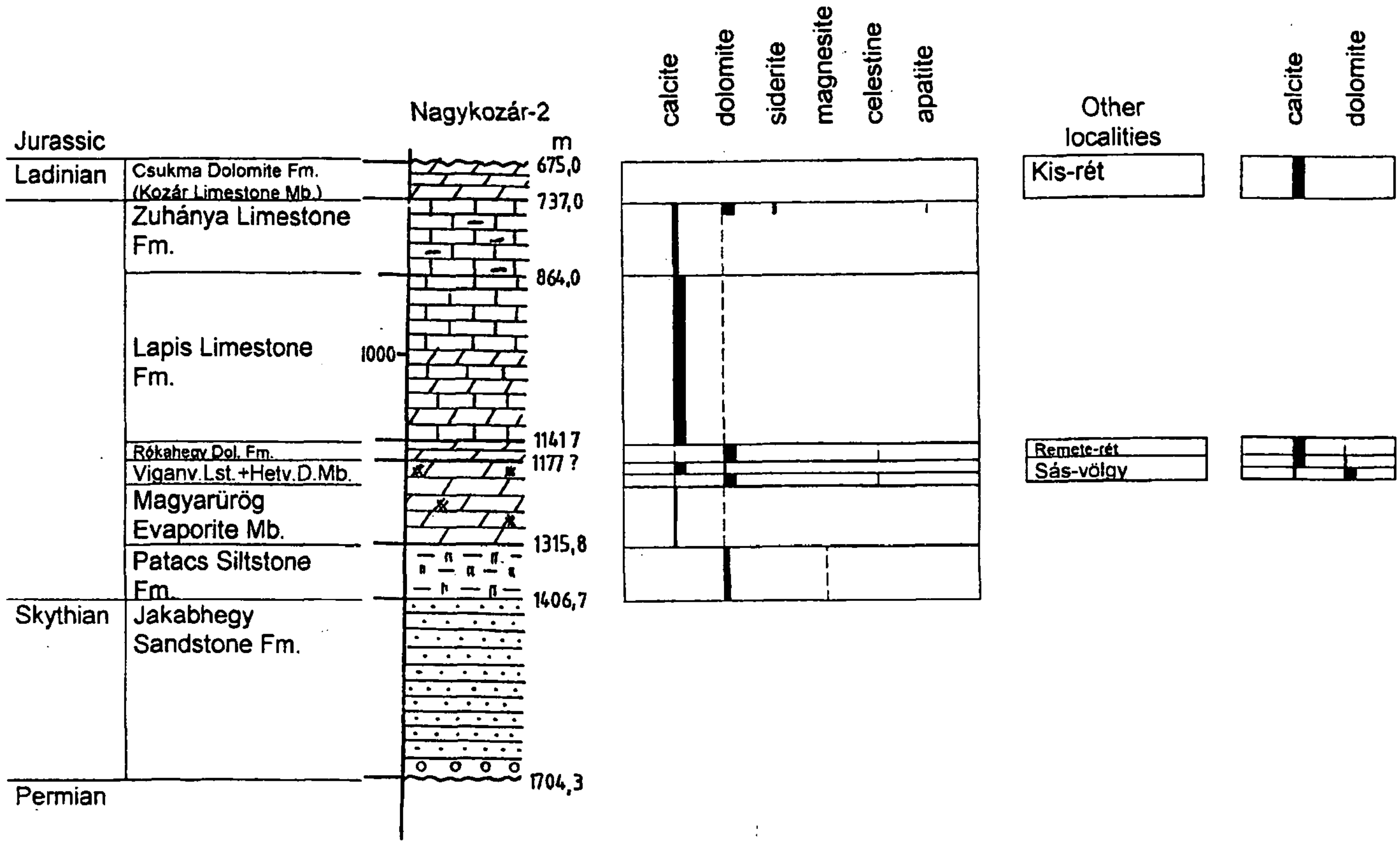


Fig. 3. Frequency of carbonate and related minerals in stratigraphic units of the Triassic sequence in bore hole Nagykozár-2 and in other localities in Mecsek Mts. Semi-quantitative abundance of the minerals is shown by the thickness of the corresponding line, see the legend to fig. 4. Stratigraphic succession and lithology according to BARABÁS-STUHL (1988).

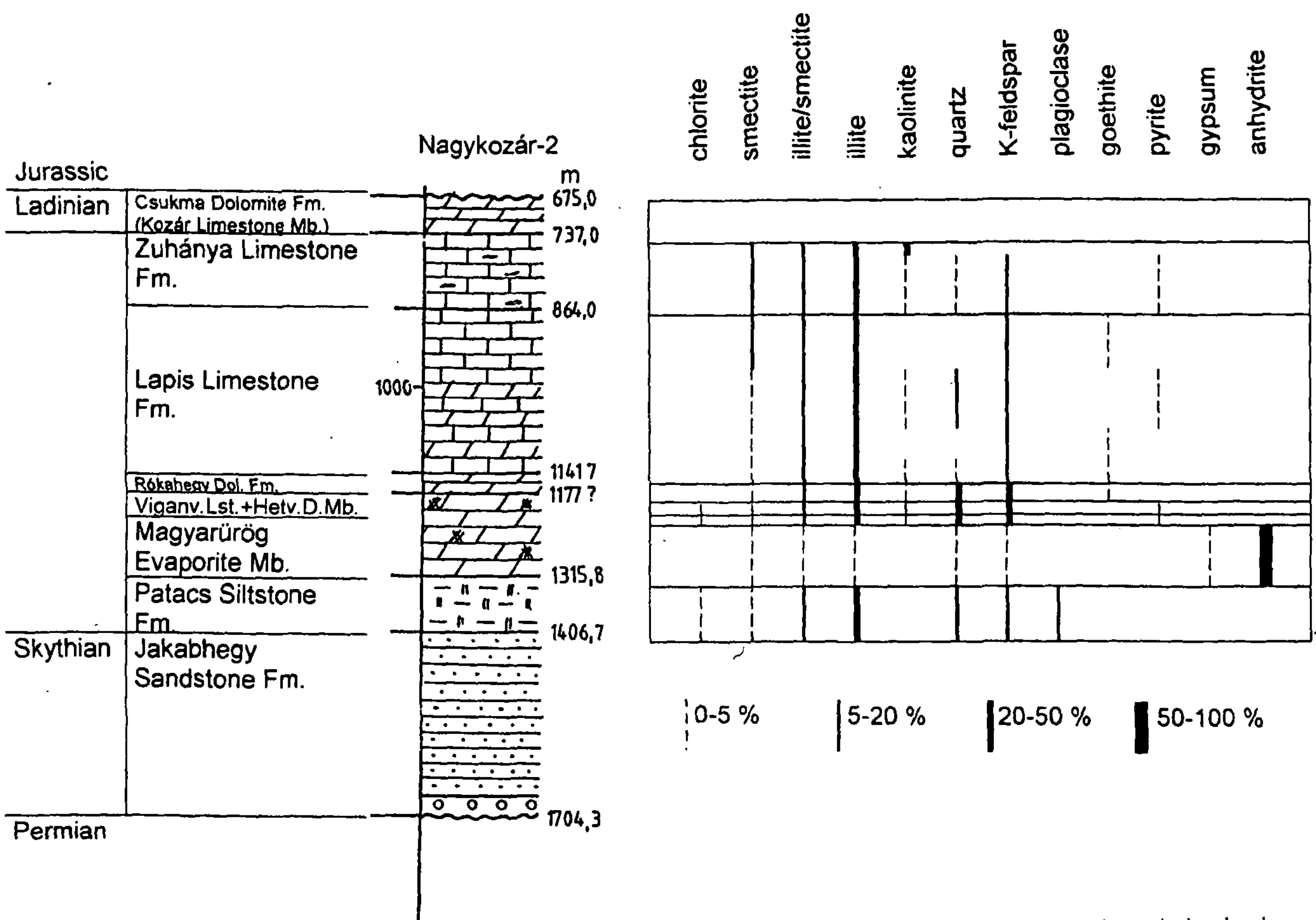


Fig. 4. Frequency of minerals in the insoluble residue in stratigraphic units of the Triassic sequence in bore hole Nagykozár-2. Semi-quantitative abundance of the minerals is shown by the thickness of the corresponding line. Stratigraphic succession and lithology according to BARABÁS-STUHL (1988).

correction. Normally, the polytypism of illite was determined on random powder specimens of the insoluble residue and of the <2 μm fraction, in some cases special side-filled sample holder was used in order to enhance non-basal reflections.

The XRD analyses of the samples from Remete-rét and Kis-rét were made by P. KOVÁCS-PÁLFFY and K. BARÁTH (1996), the others by I. VICZIÁN and Á. ÉNEKES (1993). M. FÖLDVÁRI (1996) analysed the Remete-rét and Kis-rét bulk samples by thermal methods (unpublished reports).

RESULTS

The variation of the carbonate minerals in the Middle Triassic section of the Nagykozár-2 sequence and of other localities in Mecsek Mts. is shown in *Fig. 3.* The composition of the insoluble residue in Nagykozár-2 is shown in *Fig. 4.* The figures are generalisations of the primary semi-quantitative data for a particular stratigraphic units.

Carbonate minerals

Considering the *Röt-type* formations, the carbonate mineral is exclusively dolomite, in the Lower Anisian Patacs Siltstone Fm. and Magyarürög Evaporite Mb. In the Magyarürög Mb., however, anhydrite may be accompanied by magnesite instead of dolomite. The occurrence of magnesite in analogous horizons of the bore hole Pécs-IX was discussed in detail by VICZIÁN (1992). Dominantly *dolomite* occurs in the Hetvehely Dolomite Mb., there is, however, a little calcite, both in the bore hole samples and at Sás-völgy.

Within the *Muschelkalk-type* formations the dominant carbonate minerals are calcite in the Lapis and Zuhánya Limestone Fms and alternatively calcite or dolomite in the Viganvár Mb. and Rókahegy Fm. According to TÖRÖK (1998) "the dolomitized beds are peritidal inner ramp deposits" whereas limestones were formed in deeper, mid or outer ramp environment. No carbonate mineral was found in one red siltstone sample from the Rókahegy Fm. which is probably the product of temporary emersion. At Remete-rét, the textural elements of the stromatolite-like structures in the Rókahegy Fm. always contain a few per cents of dolomite in addition to about 80 % calcite. The carbonate phase of the oncoidal Kozár Limestone at Kis-rét consists only of pure calcite.

There are interbeddings in the Lapis and Zuhánya Limestone Fms where the total carbonate contents are only 40 to 70 % and the carbonate phase consists of both calcite and dolomite. Such rocks may be called dolomitic calcareous marlstones. Frequently *dolomites* are *Fe-varieties* in those marly layers. Thin marlstone films were considered by TÖRÖK (1998) as products of 'background' sedimentation. There are also relatively pure carbonate rocks which consist partly of calcite and partly of dolomite, both of practically stoichiometric composition. Dolomitisation and dedolomitisation processes in dolomite-mottled limestones of the Zuhánya Limestone Fm. were studied in detail by TÖRÖK (1997a). A special *calcite + dolomite + siderite* carbonate assemblage was found in the uppermost sample of the Zuhánya Fm (751.5 m).

Minerals in the insoluble residue

The variation of non-carbonate minerals (silicates, sulphates) will be considered in the composition of the 3 % HCl insoluble residue.

Quartz reveals peculiar distribution. In the lower clastic formations of Röt type, up to the Hetvehely Dolomite Mb., quartz makes 20 to 40 % of the insoluble residue which is the normal composition of detrital terrigeneous sediments. In the Muschelkalk-type sediments, however, quartz is very low or even missing in the carbonate-free fraction (see e. g. *fig. 5*).

In most cases *K-feldspar* exceeds quartz, its amount being about 20 % of the insoluble residue throughout the section. The unusual, relatively even intensity distribution of the main reflections shows that there is no tendency of preferred orientation, unlike the most detrital K-feldspars which usually exhibit a strong 3.24 Å line (*Fig. 5*). *Plagioclase* is restricted only to the lowermost clastic Patacs Siltstone Fm., it is missing in other formations.

Clay minerals are the most frequent minerals in the silicate fraction. 40 to 60 % of the silicate fraction in Röt-type sediments and 60 to 80 % of silicate fraction of quartz-poor Muschelkalk-type rocks are clay minerals. Their composition is rather uniform: the dominant clay mineral is almost exceptionally *illite*. The broadening of the illite basal reflection toward higher d values is interpreted as mixed-layer illite/smectite and smectite. The polytypic modification 1Md always dominates over a minor portion of 2M, 2M being sometimes completely missing (*Fig. 5*). It has to be emphasised that this is the case in the insoluble residue of the rocks which means that the abundance of illite-1Md is not the product of the laboratory enrichment of the fine size fractions, but the property of the bulk rock itself. There is more regular variation in the distribution of other clay minerals: *chlorite* occurs in the lower detrital formations up to the Hetvehely Dolomite Mb. Higher on in the sequence chlorite is replaced by kaolinite but its amount is usually low. There are

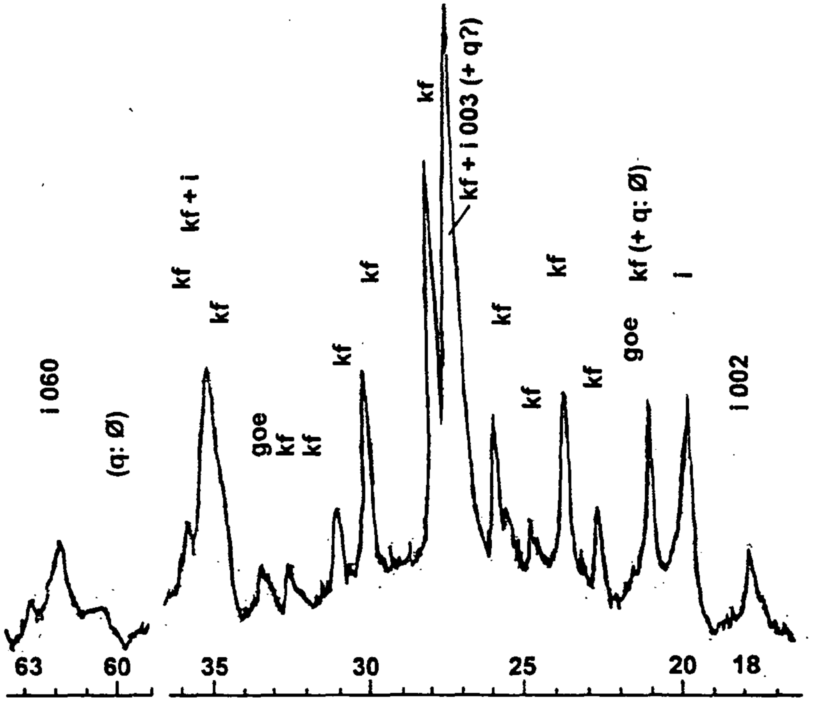


Fig. 5. X-ray diffraction pattern of non-oriented powder specimen showing the non-basal reflections and weak 002 and 003 basal reflections of illite-1Md and the strong reflections of potassium feldspar in the ranges 17 to 36 and 59 to 63 °2Θ. The presence of little goethite and the absence of quartz lines is indicated. Nagykozár-2, 884.7 m, 3 % HCl insoluble residue of dolomitic calcareous marl, Lapis Fm.

few exceptionally high *kaolinite* contents, the maximum is 40 % in the uppermost sample of Zuhánya Fm. (Nk-2. 751.5 m).

There is indication of *corrensite* in the bulk composition of a carbonate-free anhydritic siltstone at 1192.3 m depth but it could not be detected in the insoluble residue. Corrensite was found also in the bulk composition of a dolomite at 1191 m and in two bulk limestone samples of the Sás-völgy locality (Hetvehely and Viganvár Mbs, respectively).

Goethite and *pyrite* occur in alternating intervals in the carbonate rocks and in their marly and silty intercalations. Usually their presence is shown by the yellowish, brownish or grey colour of the rocks, respectively. The abundance of goethite seems to correlate with the quartz-poor and quartz-free and – surprisingly – also with the kaolinite-poor intervals of the Muschelkalk-type sequence.

Sulphate minerals, especially *anhydrite* and minor portions of *gypsum* are concentrated in the Magyarürög Mb. Almost pure anhydrite rocks of more than 80 % anhydrite content may occur. It is interesting that sporadic occurrences of *celestine* are restricted to the overlying Hetvehely Dolomite Fm.

Clay minerals in the <2 μm fraction

Table 2 contains the composition of the <2 μm fraction. The following clay minerals can be distinguished:

Smectite. Smectite was identified by the expansion to 17.0 Å upon treatment with ethylene glycol. There are only subordinate quantities in the Viganvár Mb. and Rókahegy Fm., the most being 9 % of the <2 μm fraction in the stromatolitic limestone at Remete-rét.

Illite. The dominant clay mineral in the whole section of Middle Triassic is illite. In most cases the clay mineral fraction is parctically monomineralic consisting only of illite. Similarly to the bulk rock and to the insoluble residue, illite is mostly of the disordered 1Md polytypic modification. Illite-1Md was identified by the strong reflections at d = 4.5 Å and 2.6 Å and by the absence of other non-basal reflections. Weak non-basal reflections indicate minor amounts of modificaton 2M in most samples an 1M in a few cases. The 001 basal reflection has some broadening towards lower °2Θ values which can be interpreted as a few per cent of smectite interlayering in addition to stacking disorder. Broadening was expressed by the „illite crystallinity" (IC) values according to KÜBLER (1990). IC values vary in the range of 0.50 to 0.90 °2Θ, expectionally low values were found in the anhydritic evaporite rock (Nk-2. 1343 m, 0.40 °2Θ) and in the highly kaolinitic clay fraction of a dolomite in the Rókahegy Fm. (Nk-2. 1150 m, 0.34 °2Θ).

Kaolinite. Kaolinite is missing in the lower clastic units (Patacs Siltstone Fm. and Magyarürög Evaporite Mb.) and is a minor component (0-2 %) in the carbonate rock units. The only expection is a dolomite sample in the Rókahegy Dolomite Fm. where kaolinite amounts to 35 % of the <2 μm fraction (Nk-2. 1150 m). Kaolinite is here well crystallised, it has very sharp basal reflection (width of 001 at half height: 0.34 °2Θ), similarly to the low IC value of illite.

Chlorite. Chlorite is normal Fe-Mg-chlorite. Mg-chlorites, typical in the bore hole Pécs-IX, were not found here. In the bore hole Nagykozár-2 chlorite is a minor component throughout the section, it seems to be a little more abundant in the lower clastic horizons. It is enriched in a single case, in silty fraction of the magnesite-bearing anhydrite rock in the Magyarürög Mb. (Nk-2. 1343 m). In the lower clastic horizons chlorite is accompanied by irregular mixed-layer chlorite/smectite.

Irregular mixed-layer chlorite/smectite. The mineral occurs in the anhydrite (Nk-2. 1343 m), in minor amounts also in a similar rock in the Patacs Fm. (Nk-2. 1346 m), as well as in the clay fraction of a Hetvehely Mb. dolomite sample at the outcrop Sás-völgy.

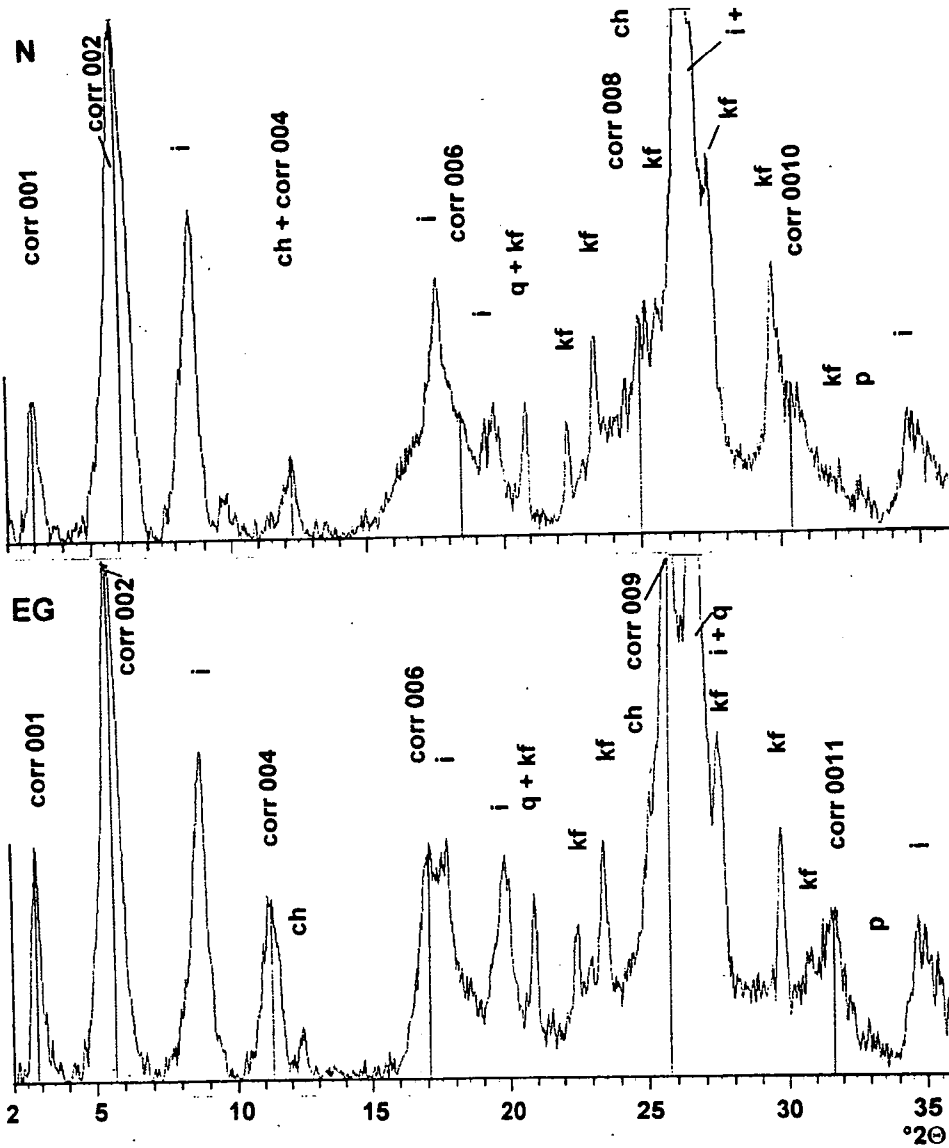


Fig. 6. Background corrected X-ray diffraction pattern of a corrensite-bearing mineral assemblage. Oriented specimen of untreted material („N") and after ethylene glycol treatment („EG"). Nagykozár-2, 1191 m, <2 µm fraction of clayey dolomite, Hetvehely Mb. Legend: corr: corrensite, ch: chlorite, i: illite, q: quartz, goe: goethite, kf: potassium feldspar, p: pyrite.

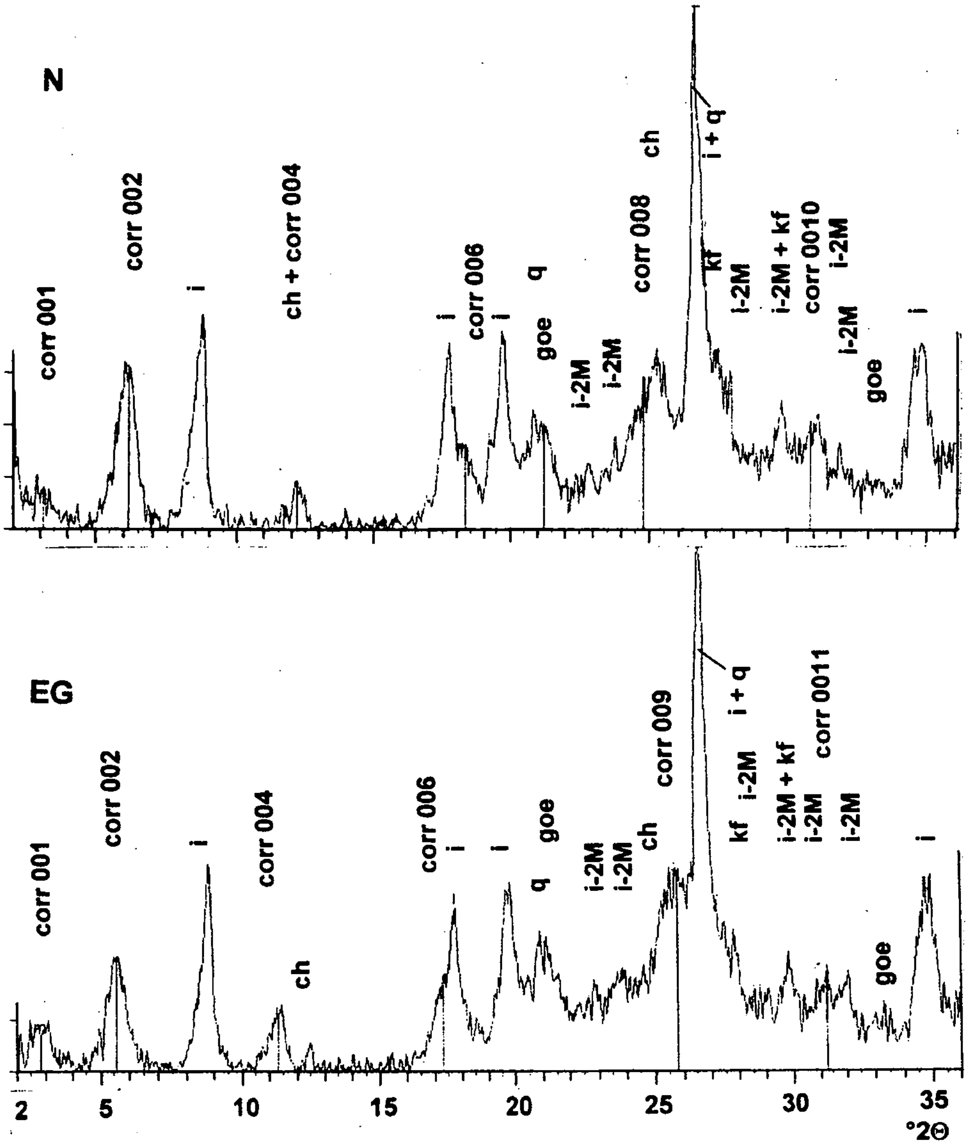


Fig. 7. Background corrected X-ray diffraction pattern of a corrensite-bearing mineral assemblage. Oriented specimen of untreated material ("N") and after ethylene glycol treatment ("EG"). Sás-völgy at Hetvehely, sample 1a, <2μm fraction of dark grey clayey limestone, Viganvár Mb. Legend: see fig. 6.

Mixed-layer chlorite/smectite in the sample Nk-2. 1343 m can be recognised by shifting of the first basal reflection from 14.5 Å to 15.7 Å and of the second basal reflection from 7.1 Å to 7.8 Å upon glycolation. The Sás-völgy sample contains a more disordered variety: in the glycolated sample there is a broad transition between the basal reflection of chlorite at 14.5 Å and that of smectite at 17.0 Å. It seems so that there are several transitional steps from irregular chlorite/smectites to well ordered corrensite.

Corrensite. This regular variety of mixed-layer chlorite/smectite occurs in a grey dolomite sample in the Hetvehely Mb. (Nagykozár-2 = Nk-2. 1191 m) and in a dark grey limestone sample of the Viganvár Mb. at the locality Sás-völgy. Corrensite can be recognised by the integral sequence of the basal reflections (BAILEY 1982) as it is shown in *figs 6* and *7* and in Tables 3 and 4.

K-feldspar. In each case, clay minerals are accompanied by relatively high contents of K-feldspar in the <2 µm fraction. Its abundance in the fine fraction shows that the mineral itself is generally fine-grained.

TABLE 1

Description and stratigraphic position of samples taken for analysis of the <2 µm fraction

Locality Depth, m or Sample No.	Formation or Member	Rock
Nagykozár-2		
1143	Rókahegy Dolomite	*Limestone,* light grey, with thin, yellowish marly interbeddings
1145	Rókahegy Dolomite	*Dolomite* marl, dark brownish red, thin lamination
1150	Rókahegy Dolomite	*Dolomite,* yellowish grey, in voids rhombohedral crystals and white dusty material
1177	Viganvár Limestone	*Limestone,* grey, with thin, wavy, dark grey marly interbeddings
1179	Viganvár Limestone	*Dolomitic* calcareous marl, with many thin, wavy, dark grey marly interbeddings
1181	Hetvehely Dolomite	*Dolomite,* grey, with thin, dark grey marly interbeddings
1191	Hetvehely Dolomite	*Dolomite,* dark grey, homogeneous, thin lamination, with smooth layer smooth layer surface
1343	Magyarürög Evaporite	*Magnestic* anhydrite, contorted beds of pink anhydrite, dark grey marl and light carbonate
1346	Patacs Siltstone	*Dolomitic, anhydritic siltstone,* thin, light dolomite, anhydrite and ark grey silty layers
Kis-rét		
1.	Kozár Limestone	*Ocoidal limestone,* dark grey oncoids of cm size, between oncoids: dark brown
Remete-rét		
1.	Rókahegy Dolomite	*Stromatolitic limestone*, „lower layer": dark grey, massive, homogenous
2.	Rókahegy Dolomite	*Stromatolitic limestone*, „upper layer": bright black biogene structures, light brown matrix
Sás-völgy		
1a.	Viganvár Limestone	*Limestone,* dark grey, homogeneous, layered
1b.	Hetvehely Dolomite/ Viganvár Limestone	*Limestone,* light grey, thin layers with even surface
2.	Hetvehely Dolomite	*Dolomite,* grey, with dark grey marly layers and spots, authigenic breccia (?)

TABLE 2

Clay mineral composition (%) and IC values of the <2 μm fraction

Locality Depth, m or Sample No.	Smectite	Illite (+Illite/ Smectite)	Kaolinite	Chlorite	Chlorite/ Smectite	Corrensite	IC, °2Θ
Nagykozár-2							
1143	1	99	tr.				0.79
1145	tr.	98	1	1			0.56
1150	tr.	65	35				0.34
1177	tr.	98	1	1			0.78
1179	tr.	97	2	1			0.72
1181		98	2				0.86
1191		61		6		33	0.68
1343[1]		64		23	13		0.40
1346		95		4	1		0.79
Kis-rét							
1.		97		3			0.49
Remete-rét							
1.		98		2			0.66
2.	9	89		2			0.68
Sás-völgy							
1a.		75		6		19	0.53
1b.	2	98					0.58
2.		90		7	3		0.54

[1] Dissolved in distilled water

TABLE 3

lx d(001) (Å) values for corrensite, sample Nk-2. 1191 m, <2 μm fraction

001	*l x d(001) (Å)* Untreated	*l x d(001) (Å)* Ethylene glycol
001	29.4	30.7
002	2 x 14.54 = 29.08	2 x 15.55 = 31.10
004	4 x 7.23 = 28.92	4 x 7.81 = 31.24
006	6 x 4. 81 = 28.86	6 x 5.19 = 31.14
008	8 x 3.57 = 28.56	
009		9 x 3.456 = 31.10
0010	10 x 2.938 = 29.38	
0011		11 x 2.822 = 31.04

TABLE 4

lx d(001) (Å) values for corrensite, sample Sás-völgy 1a, <2 μm fraction

001	*l x d(001) (Å)* Untreated	*l x d(001) (Å)* Ethylene glycol
001	29.0	31.1
002	2 x 14.43 = 28.86	2 x 15.88 = 31.76
004	4 x 7.25 = 29.00	4 x 7.78 = 31.12
006	6 x 4.84 = 29.04	6 x 5.15 = 30.90
008	8 x 3.59 = 28.70	
009		9 x 3.456 = 31.10
0010	10 x 2.897 = 28.97	
0011		11 x 2.813 = 30.94

DISCUSSION

Clay mineral zones

Considering the composition and that of the insoluble residue, the following clay mineral associations can be distinguished in the sequence of Nagykozár-2:

Illite + chlorite + chlorite/smectite: This is typical in clastic rocks of the Patacs Siltstone and Magyarürög Evaporite Fms. Mg-rich chlorites found at Pécs-IX did not occur in the present study. Perhaps they correspond here to mixed-layer chlorite/smectites.

Corrensite + illite + chlorite: Corrensite is restricted to some layers of the Hetvehely, Viganvár Mbs, in each case occurring in "unclean" clayey limestones or dolomites.

Illite + illite/smectite (+ smectite), with minor kaolinite and chlorite: This illite dominated association is typical in all carbonate rock formations from the corrensite-free layers of the Hetvehely Dolomite and Viganvár Limestone upwards, in the Rókahegy, Lapis and Zuhánya Fms.

Illite + kaolinite: There are relatively high kaolinite contents in some layers of the Rókahegy Dolomite Fm. and in the uppermost sample of the Zuhánya Limestone Fm. In the latter case kaolinite seems to replace the otherwise abundant K-feldspar.

The composition of the samples taken from surface outcrops fits well into this scheme:

At *Sás-völgy* the Hetvehely Dolomite sample seems to belong to the lower clastic clay assemblage, the limestone at the Hetvehely/Viganvár boundary to the illite-dominated association and the Viganvár Limestone to the corrensite-bearing one.

The stromatolitic limestone samples of Rókahegy Fm. at *Remete-rét* belong to the illite-dominated association.

The composition of the oncoidal limestone sample at *Kis-rét* shows that the illite-dominated association continues up to the Middle Ladinian Csukma Fm., i. e. up to the uppermost Triassic formation represented in the bore hole Nagykozár-2.

Comparison with the bore hole Pécs-IX and with other Middle Triassic occurrences in Mecsek Mts.

The data obtained in the present study are in full agreement with the results received from the bore hole Pécs-IX (VICZIÁN 1992, 1993). The stratigraphic range is slightly different. The sequence starts in both cases with Lower Anisian, but at Pécs-IX the lower clastic members are more pronounced while in the present study the carbonate-rich upper formations up to the Middle Ladinian are more represented.

Similar features in both bore holes are the absence of *calcite*, the permanent presence of *dolomite* in the evaporitic members, the occurrences of *magnesite* in these evaporitic rocks and of *celestine* in the Hetvehely Dolomite Mb. Similar are the *clay mineral* zones. Illite crystallinity (IC) values found in evaporitic and normal-salinity formations vary in the same range in both profiles.

Among the *feldspars* the K-feldspar is dominant in almost the whole sequence in the present study while at Pécs-IX neoformation of albite was observed in the lower part of the sequence.

The absence or low concentration of quartz in the Muschelkalk-type carbonate rocks is a new result.

The enrichment of *kaolinite* in the Rókahegy Fm. was not observed before. The appearance of *siderite* and *kaolinite* in the uppermost sample of the Upper Anisian

Zuhánya Fm. resembles the occurrence of kaolin, siderite-bearing kaolin in the bore hole Komló K-LXXII (NAGY and RAVASZ-BARANYAI 1968). These special kaolinite-bearing rocks belong to the stratigraphic unit Mánfa Siderite Mb. which immediately overlies the Kozár Limestone Fm. (RÁLISCH-FELGENHAUER and TÖRÖK 1993), however, no corresponding stratigraphic horizons occur in the well Nagykozár-2. Similarly, kaolinite-rich "green clay" interbeddings are known from other Upper Anisian occurrences in the western Mecsek Mts. (WÉBER 1965, 1978). In spite of the lithologic similarity, these formations are not contemporaneous. All these occurrences belong to a stratigraphically higher level, the top of the Kozár Fm., while the sample of the present study represents a former emersion period after the deposition of the Zuhánya Fm.

Comparison with the German Triassic basin

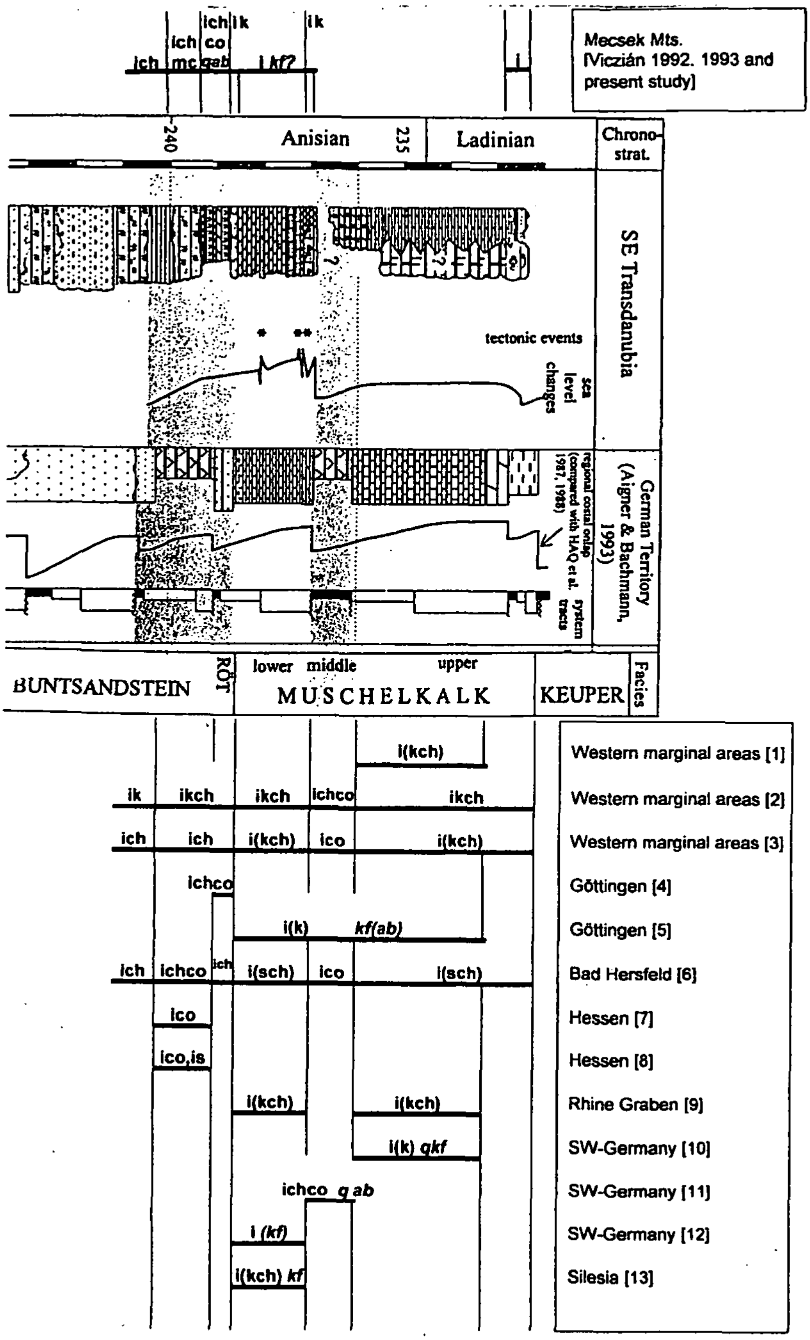
Mineralogy provides further evidences of the similarity between the facies and stratigraphic relations of Mecsek Mts. Lower and Middle Triassic formations and the German-type basins which was discussed in detail by KONRÁD (1997, 1998) and TÖRÖK (1997b, 1998). Mineralogical data were collected from the literature and the typical clay mineral assemblages were determined for stratigraphic horizons in the German Triassic basin (*Fig. 8*).

Middle to Upper Buntsandstein and silty clastic members of *Röt (Upper Buntsandstein)* contain the detrital illite+chlorite assemblage, similarly to the Mecsek Mts. clastic formations. *Evaporitic* members of the Röt contain normally corrensite but corrensites have been found also in other restricted basin sediments in Germany. In Hungary, corrensites were found only in restricted basin marly limestones and dolomites while true evaporitic anhydrite rocks seem to contain Mg-chlorite or chlorite/smectite. Authigenic quartz and albite were found in carbonates in Mecsek Mts.

Lower and Upper Muschelkalk is always characterised by dominant illite and authigenic neoformations of potassium feldspar and to a lesser amount albite. It was shown first by FÜCHTBAUER as early as in 1950. Kaolinite and chlorite contents are normally subordinate in limestones of the basin, there are higher kaolinite and chlorite contents in the untypical marginal formations in Luxemburg and adjacent areas. The authigenic feldspars and the illitic clay minerals of the Silesian Muschelkalk are well documented by MICHALIK (1991). Corresponding limestone members of the Mecsek sequence contain practically only illite and the authigenic formation of potassium feldspar is suspected. Middle Muschelkalk is evaporitic in many places in Germany containing corrensite, similarly to the Röt saline formations. KONRÁD supposes that there is an unconformity in the same horizon in Mecsek which is possibly shown by the elevated kaolinite content in the uppermost underlying sample.

Genesis of clay minerals

Genetical problems were extensively studied by the present author in connection with the bore hole Pécs-IX (VICZIÁN 1990, 1992, 1993). In the present study, the similarity between the two sequences was found. It is not necessary, therefore, to repeat the whole argumentation of the previous papers. In the following only new aspects of composition and the results of recent sedimentological analyses are discussed in detail.



Mecsek Mts.
[Viczián 1992, 1993 and present study]
ich
ich mc
ich co qab
ik
i kf?
ik
i
240
Anisian
235
Ladinian
Chrono-strat.
SE Transdanubia
tectonic events
sea level changes
German Territory (Aigner & Bachmann, 1993)
regional costal onlap (compared with HAQ et al. 1987, 1988)
system tracts
BUNTSANDSTEIN
RÖT
lower
middle
upper
MUSCHELKALK
KEUPER
Facies
Western marginal areas [1]
Western marginal areas [2]
Western marginal areas [3]
Göttingen [4]
Göttingen [5]
Bad Hersfeld [6]
Hessen [7]
Hessen [8]
Rhine Graben [9]
SW-Germany [10]
SW-Germany [11]
SW-Germany [12]
Silesia [13]
i(kch)
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Fig. 8.

Fig. 8. Comparison of typical clay and authigenic minerals in Lower to Middle Triassic rocks of Mecsek Mts. and of the German and adjacent Triassic basins. Stratigraphic correlation according to KONRÁD (1998).
Abbreviations of clay minerals: i: illite, ch: chlorite, mc: Mg-chlorite, co: corrensite, k: kaolinite, s: smectite. Authigenic minerals are written in *italics: q:* quartz, *kf:* K-feldspar, *ab:* albite. Minerals in brackets: about 10 to 20 % of total clay minerals.
References: [1]: MULLER et al. (1977) and MULLER (1978), [2]: SCHRADER in BERNERS et al. (1984), [3]:WAGNER (1989), [4]: LIPPMANN (1956), [5]: FÜCHTBAUER (1950), [6]: STROUHAL, HENDRIKS (1988), [7]: BÜHMANN, RAMBOW (1979), [8]: DOUBINGER, BÜHMANN (1981), [9]: GENG et al. (1996), [10]: LIPPMANN, SCHLENKER (1970), [11]: LIPPMANN, PANKAU (1988), [12]: LIPPMANN, BERTHOLD (1992), [13]: MICHALIK (1991).

I. Diagenesis

The degree of burial diagenetic transformation can be determined considering the mineral assemblage and the IC values. The scarcity of expanding smectites points *to medium to deep zones of burial.* Corrensites are typical diagenetic products. They are formed in the shallow burial stage in German Triassic-type environment, stable in the medium stage and may persist in the deep burial stage (LIPPMANN 1987, KÜBLER 1973, 1984).

Relatively high IC values in non-evaporitic formations (see Table 1), irregularly mixed-layer illite/smectites and chlorite/smectites exclude the onset of the anchizone. IC values are much higher than 0.42 °2Θ, which is the limit between diagenesis and anchizone (KÜBLER 1990).

The predominance of the illite-1Md polytipic from in the bulk rocks (*fig. 5*) shows that illites are not simply fine-grained detrital 2M micas. Much more probably they were partly expandable illitic weathering products which were reorganised in a potassium rich diagenetic environment. The nature and abundance of K-feldspar in carbonate rocks makes probable its authigenic origin (*Fig. 5*) which is another indication of a potassium-rich diagenetic environment. Lower IC values in evaporitic rocks show that the transformation started in these rocks during sedimentation or during early burial. The abundance of *illite* and *potassium feldspar* in the silicatic phase of carbonate rocks seems to be typical for the whole Muschelkalk-type upper half of the sequence. The transformation of illites may have lasted until the medium to deep zones of diagenesis. Authigenic potassium feldspars are considered to have been formed in Muschelkalk-type limestones from diagenetic pore waters enriched in K+ ions, after burial, without direct contact with the sea water (FÜCHTBAUER 1950, MICHALIK 1991).

Very probably the high *kaolinite* content of the dolomite sample from Nk-2, 1150 m is a diagenetic feature. Kaolinite is very well crystallised and even illite has sharper basal reflection then otherwise. Kaolinite might have crystallised from solutions *in open space* of abundant voids of this very porous dolomite.

II. Environment of deposition

The evolution of clay minerals of the French part of German Triassic basin and related basins in western Europe and Morocco was subject of the discussion given by MILLOT (1964) based on classical studies of LUCAS. He considered a continuous aggradational transformation of degraded illites both in time, from Lower Triassic to Keuper, and in space, from coastal facies to central areas of the basin. Now we can give a more differentiated picture of these relations in time, space and in terms of depositional environments within the German basin. This is true also for the Mecsek area, however, lateral variations cannot be recognised due to its very limited extent.

The *illite + chlorite* assemblage in lower clastic and members of the sequence seem to be normal terrigeneous detrital sediments derived from the nearby continent. The lack of kaolinite in the material indicates the lack of deeply weathered soil profiles in the source area. In view of the possible diagenetic transformation, it is possible, that there was a relatively high proportion of expanded clay minerals in the transported load.

Irregularly mixed-layer chlorite/smectites and Mg-chlorites occur in evaporites of coastal sabkha and marine lagoonal environments as products of chemical transformation in Mg-rich solutions.

According to experiences obtained so far from the Mecsek Mts., *corrensites* are typical chemical neoformations of less saline environments of restricted circulation, such as the carbonatic formations of the Hetvehely and Viganvár Members. According to LIPPMANN (1987) and LIPPMANN and PANKAU (1988), the crystallisation of corrensite needs solutions enriched in both Mg^{2+} and $(OH)^-$ ions. Its formation is favoured by the conditions of a restricted basin, which is a collector of alkaline waters derived from adjacent source areas.

According to the sedimentological analysis of TÖRÖK (1998) these formations were deposited on the northern margin of the Tethys in a mid- to outer-ramp setting in normal salinity marine environment. The carbonate ramp was very broad, at least several hundreds of kilometres away from continent and from the 'shelf edge' of the open Tethys ocean. The primary source area of the detrital sediments seems to have been the present territory of the Bohemian massif, both the continental and the marine areas were very flat, levelled terrains. Fossils and sediment types indicate warm and rather dry climate, close to 30°N paleo-latitude. The carbonate ramp lasted for a long time, for about 14 million years. All these conditions may explain the production of a terrigeneous, moderately weathered, fine-grained detrital material which contained primarily partly expanded illitic minerals, with a little kaolinite and quartz. LIPPMANN and BERTHOLD (1992) came to similar conclusions concerning the provenance of illite in the Muschelkalk of SW Germany. An earlier study (STÖRR et al. 1977) concluded that the development of a kaolinitic weathering crust on the surface of the Bohemian-Vindelician Massif started in the Upper Triassic and continued further in the Jurassic. In addition, the poverty in kaolinite and quartz and enrichment of illite in the Muschelkalk sediments in Mecsek Mts. may be due to the long transporting distance from the source area.

An important result of the sedimentological analysis is that hard reef-building organisms were missing and the dominant type of carbonate sedimentation was the accumulation of carbonate mud which remained soft relatively long due to the stirring action of storms. Storms stirred the whole water column both in inner and mid-ramp conditions. Goethite and pyrite containing beds probably indicate primary oxidation-reduction conditions of sedimentation.

The relative enrichment of *kaolinite* in the Rókahegy and in the uppermost Zuhánya Fms (except the diagenetic formation in pores of Rókahegy dolomite mentioned above) may be due to subaerial weathering during temporary emersion periods and inner ramp setting which was stressed by KONRÁD (1997b, 1998).

CONCLUSIONS

1. In the Mecsek Mts., during the Lower Anisian, evaporitic sabkha and restricted basin shallow marine conditions were favourable for the formation of irregular and regular mixed-layer smectite/chlorites. Corrensites occur in the marly carbonate rocks of the Hetvehely Dolomite and Viganvár Limestone Members.

2. From Middle Anisian till Middle Ladinian Muschelkalk-type carbonate sedimentation prevailed. The clay mineral of the limestones is illite accompanied by K-feldspar. Both minerals have been formed or reorganised in a potassium-rich diagenetic environment.

3. On the adjacent continent essentially illitic weathering crust developed in a levelled, relatively flat surface. The conditions for the development of a kaolinitic crust of weathering were first favourable in the Upper Triassic, however, during shorter elevation periods during the Middle Triassic partly kaolinitic weathering products may have developed (Rókahegy Fm. and top of Zuhánya Fm.).

4. The present investigations confirm the former results of the author regarding the clay mineralogy and diagenetic neoformations in a similar Middle Triassic rock suite in Mecsek Mts., the sequence of the bore hole Pécs-IX.

5. The typical clay minerals of the Mecsek Mts. Middle Triassic are very similar to the corresponding formations of the Triassic of German and adjacent basins which is another proof of the close genetic relations of both terrains. The difference is in the degree of diagenesis, which is weak in the German basin and reaches deep burial in Mecsek Mts.

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