Acta Mineralogica-Petrographica, Szeged, XXIV/2, 315—337, 1980

DIAGENETIC AND LITHIFICATION PROCESSES OF RECENT HYPERSALINE DOLOMITES ON THE DANUBE-TISZA INTERFLUVE

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SUMMARY

In the hypersaline lacustrine dolomite and dolomite mud profiles of the Danube-Tisza-Interfluve four members can be distinguished on the basis of formation, composition, diagenesis and lithification. In the three lower members, i. e. in the dolomitic limestone and dolomite the starting phase of anadiagenesis, in the upper dolomite mud the syndiagenesis take place. The latter lithification is one of the most important factor of syndiagenesis. The formation, evolution, filling processes of pores, the chemical composition of the filling material as well as their crsytal forms depend on these processes and change according to their affects.

INTRODUCTION

The dolomite formation of sodaic lakes lying among the dunes of the blown-sand area of the Danube-Tisza-Interfluve has been dealt with in particular [MOLNÁR, B., M. MURVAI, I., 1975, 1976; MOLNÁR, B., M. MURVAI, I., HEGYI—PAKÓ, J., 1976; MOLNÁR, B., 1979]. It has been stated that the early diagenetic dolomite formation is produced by the evaporisation caused by drought, by the CO_2-depriving effect of plants and by the admixture of freshwater of considerable quantity deriving from the autumn precipitation.

In the Danube-Tisza-Interfluve two rock types of dolomite occur. In the northern parts and in the existing sodaic lakes dolomite muds soft and plastic in wet state, and loose crumble in dry state are known. Mainly in the southeastern part of the Danube-Tisza-Interfluve and in the warmer sodaic lakes being now covered partly by the wind-blown sand, hard dolomite is found at the bottom of the carbonate profiles and in the upper parts loose dolomite mud similar to that mentioned above, can be found. Accordingly, in case of dolomites of the Danube-Tisza-Interfluve the diagenetic and lithification processes take place in sight of us and this provides a fair opportunity to study this very significant sedimentological changes of carbonate formation.

The pores of carbonate rocks are considerably modified during lithification. To elucidate this process, it is highly significant from the point of view of the hydrocarbon and water reserving carbonate rocks. Further, the chemistry of carbonate rocks is strongly connected to the chemistry of the water from which the rocks were deposited. The carbonate formation of closed lake basins may provide information on the changes of chemistry and water table of the former lake, on the measure of evaporization and on the climatic changes.

In Hungary numerous terrestrial lacustrine carbonate intercalations are known, e. g. in the Permian formations of the Mecsek Mountains, in the Lower Eocene strata of the Transdanubian Central Mountains or in the Pannonian and Pleistocene formations of the Tolna Hills [ÁDÁM, L. ,MAROSI, S., SZILÁRD, J., 1959; FORGÓ, L., MOLDVAY, L., STEFANOVITS, P., WEIN, GY., 1966; SZENTES, F., 1968; ÁDÁM, L., 1978]. These are to be processed and may provide useful paleogeographic relationships, too.

In the following the diagenetic and lithification processes of the carbonates of the Danube-Tisza-Interfluve will be demonstrated.

CONCEPT OF DIAGENESIS AND LITHIFICATION

In the Hungarian literature the *diagenesis* is called in general *lithification*. Accordingly, the hardening to rock-state, i. e. the lithification is only a part-process of diagenesis.

A. In the international literature a lot of definitions of *diagenesis* are known. It is especially hard to find common view when concerning the limits of diagenesis. Most of the concepts, however, agree that the processes between the states of deposition and metamorphism are understood as rock diagenesis.

In general, diagenesis includes all the physical, physico-chemical, chemical and biological changes which follow in the sediments at low temperatures and pressures, i. e. mostly near the surface. In case of a given sediment, however, diagenetic processes can be determined already in the sedimentation cycle and in the weathering cycle, respectively.

Recently, several authors dealt with the diagenesis of carbonates and carbonate rocks [BRICKER, O. P., 1971; BATHURST, R. G. C., 1970, 1971; CHILINGAR, G. V., BISELL, H. J., WOLF, K. H., 1967; FAIRBRIDGE, R. W., 1967; FOLK, R. L., 1965, 1974; FRIEDMAN, G. M., 1964, 1975; MILLIMAN, J. D., 1974; and PRUDY, E. G., 1968].

According to FAIRBRIDGE, R. W. [1967] the diagenesis consists of three phases: 1. syndiagenetic; 2. anadiagenetic; and 3. epidiagenetic phases.

The geochemical processes of the *syndiagenetic* phase is primarily controlled by the pore water of large quantity and lying between the mineral grains with changing bonding force.

The *anadiagenesis* is started by the burial deeper than in the previous case. The main process is the lithification. The liquid content of the sediment is strongly migrating in this phase and its total amount considerably decreases.

The *epidiagenesis* is the phase being subsequent to the uplift of the sediment (or rock). The main affecting factor is the downward migrating water being influenced by atmospheric effects.

According to CHILINGAR, G. V., BISELL, H. J., WOLF, K. H. [1967] the most important processes of the diagenesis of carbonatic sedimentary rocks are as follows: 1. Physical processes: compaction, drying, shrinking; 2. Physico-chemical processes: solution, leaching, discoloration, oxidation, reduction, re-precipitation, recrystallization, cementation, authigenic mineral formation, etc.; 3. Biochemical and organic processes: cave formation, formation of organic and inorganic compounds.

FÜCHTBAUER, H. [1974], MILLIMAN, J. D. [1974] and FOLK, R. L. [1974] classified the diagenetic processes as follows:

I. Destructive diagenesis, which as a result of biological of mechanical erosion and chemical solution produces the sedimentation of carbonates.

II. Constructive diagenesis, which produces the reformation and transformation of carbonates.

A species of the latter type is the *iso-chemical diagenesis* which does not change the chemical composition of the sediment. The early and late diagenetic cement formation are assigned to this type. Neomorphism denotes the recrystallization, e. g. from the greater crystals of biogenic shell fragments smaller crystals are developed or when during dissolution calcite is formed from aragonite. Finally, the selective processes, e. g. the encrusting solution processes are assigned to this group which produce stilolite and secondary porosity.

Another type of constructive diagenesis is the *allochemical diagenesis* when the sediment is transformed also chemically. Examples are the early or late diagenetic dolomitization, dedolomitization, the dissolution and transformation to calcite of the Mg-bearing calcite, clay mineral formation, zeolitization and the formation of authigenic minerals.

B. *Lithification*, i. e. the rock formation is considered in general to be one of the most important process of diagenesis. According to CHILINGAR, G. V., BISELL, H. J. WOLF, K. H. [1967] lithification is the assemblage of processes which transforms the newly deposited sediments into solid rocks. This transformation may take place in any phase of diagenesis. In the processes of lithification compaction, cementation, recrystallization, dolomitization and pressure solution are the most important factors.

The essential difference between the diagenetic and lithification processes is that the appearance of diagenesis is a function of the facies, and the structure of the sediment, respectively, i. e. this is specific; while lithification may occur in all sediments. Lithification can be considered to be one of the evolution phases of the rock which may follow at any time during diagenesis and due to nearly all diagenetic processes.

In the course of lithification of carbonate rocks the carbonate mud is transformed to hard carbonate rock during which the pore content decreases from original water-abundant 50—70% down to 2—3%. If in case of this process the role of compaction is subordinate, enormous carbonate quantities should be available to cementation. According to BATHURST, R. G. C. [1970] in case of fine grained carbonates the lithification should be traced back to the joint effect of cementation and neomorphism and it is fundamentally determined by the following processes.

1. Dissolution of the very fine-grained components and the predominance of greater components;
2. Transformation of aragonite into calcite;
3. Recrystallization of the high-Mg-calcite while the divalent magnesium remains in the pore water;
4. At the grain contact pressure solution occurs;
5. During cementation syntaxial growth occurs at the grain's surface.

The fact that what process plays the predominant role out of the processes enumerated above during lithification, depends always on the mineralogical features of the carbonate components, on their form and grain size, on the clay mineral and organic matter content as well as on the depth of deposition.

COMPOSITION AND TEXTURAL EVOLUTION OF THE CARBONATES OF THE DANUBE-TISZA-INTERFLUVE

Four characteristic carbonate profiles were chosen from the southeastern part of the Danube-Tisza-Interfluve *(Fig. 1)*. Out of them the Csólyospálos-South is a nature conservation area just because it is a sedimentologically rare and interesting geological formation as proved by the previous investigations [Mucsi, M., 1963; Molnár, B., 1979].

Three of the studied carbonate profiles overlie strongly ochre-spotted fine-grained blown-sand while the the Csólyospálos-North profile was deposited on black organic matter containing fine-grained blown-sand. The hydrochloric-acid-soluble part of the blown-sand amounts from 10 to 20%, in general.

Within the carbonate profiles the following strata members can be distinguished:

a) The carbonate profiles start everywhere with sandy carbonate of looser structure containing red ferriferous precipitations of 10 to 30 cm, which possesses a hydrochloric-acid soluble part of 30 to 60%, the value increasing upwards *(Fig. 1)*.

b) The next member is a light—grey hard carbonate rock of 15—30 cm thickness showing macroscopically homogeneous fabric; its hydrochloric-acid-soluble part is always above 50%, in some cases this amounts to 80%. Because of its peculiarities this member was used as foundations matter in the neighbourhood and in a few cases it is used recently, too.

c) The light-grey carbonate rock is over- and underlain by a darker-grey carbonate rock which is very hard and containes carbonate matter above 80%, it shows well-developed bedding planes (its folk term is "pechmeg").

d) The closing member of the carbonate profiles is a 40—60 cm thick loose light-grey carbonate mud being crumble in dry state; its hydrochloric-acid-soluble part varies between 30 and 80% showing an upward decreasing tendency. The upper part of the profiles became soil in a thickness of 10—25 cm.

15 characteristic samples were taken from each members and detailed different sedimentological analysis were carried out on them (*Fig. 1.* I. 1—15, Table 1).

X-ray diffractometric records were made on all the 15 typical samples. The characteristic X-ray records are seen in *Fig. 2.* Only the sections of the curves are demonstrated which reflect first of all the composition of the carbonates. When evaluating the curves by profile sections it can be seen that in the loose sandy carbontae containing ferriferous precipitations, i. e. in the member *a*, calcite predominates but considerable dolomite quantity can also be identified as proved by the sample No. 1 of Kömpöc. In harmony with the macroscopic appearance, it contains also quartz and feldspar (*Fig. 2.* sample No. 1).

In the light-grey hard carbonate, i. e. in the member *b* the same minerals predominate, only the quantity of feldspars is somewhat less (*Fig. 2*, samples No. 4—6).

The composition of the darker-grey hard carbonate ("pechmeg"), i. e. of the member *c* is different as proved by the two X-ray records (*Fig. 2.* samples No. 8 and 9). In the sample deriving from the Kömpöc-South outcrop dolomite shows smaller while calcite greater quantities. In the sample of the Kömpöc-North outcrop (sample No. 9) dolomite is also significant in addition to calcite.

As it was shown, above the "pechmeg" considerable change could be recognized macroscopically. The harder formation is replaced in member *d* by carbonate mud of looser structure. According to the X-ray records, in its compositions changes follow, too. As against the calcite and dolomite identified is the samples above in these samples dolomite predominates (*Fig. 2.*, samples No. 11—15).

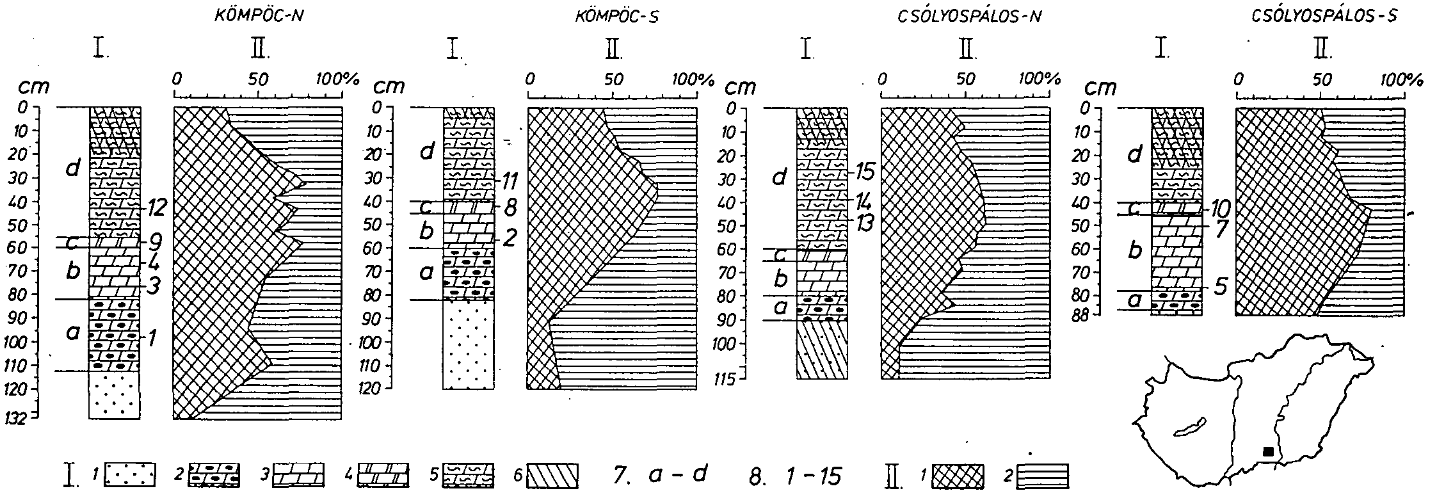

Fig. 1. Formations of the investigated carbonate profiles of the Danube-Tisza-Interfluve. — I. 1 — fine-grained sand; 2 — sandy, limy dolomite and dolomitic limestone of looser structure containing ferriferous precipitations; 3 — light-grey hard dolomite; 4 — dark-grey hard dolomite ("pechmeg"); 5 — light-grey dolomite mud; 6 — humic strata; 7a—d — indication of the carbonatic members within the profile; 8. 1—15 — site and number of samples of the profile. Numbers are the same as in Table 1.
II. 1 — hydrochloric-acid-soluble; 2 — insoluble in hydrochloric acid.

TABLE 1

Position and number of samples within the profiles chosen for investigation

Position of sample within the profile	No. of sample	Location of sample
Light-grey dolomite mud	15	Csólyospálos-N, upper 5 cm of the 25—50 cm
	14	Csólyospálos-N, middle 5 cm of the 25—50 cm
	13	Csólyospálos-N, lower 5 cm of the 25—50 cm
member *d*	12	Kömpöc-N 40—45 cm
	11	Kömpöc-S 30—35 cm
Dark-grey hard dolomite	10	Csólyospálos-S, 60—65 cm
("pechmeg")	9	Kömpöc-N, 60—65 cm, fine-stratified
member *c*	8	Kömpöc-S, 40—45 cm
Light-grey hard dolomite	7	Csólyospálos-S, top of the bank (c)
	6	Csólyospálos-S, bottom of the bank (b)
member *b*	5	Csólyospálos-S, bottom of the bank (a)
	4	Kömpöc-N, 60—82 cm (a)
	3	Kömpöc-N, 60—82 cm (b)
	2	Kömpöc-S, 45—60 cm, from the upper part
Sandy, looser dolomite and dolomitic limestone of looser structure containing ferriferous precipitations member *a*	1	Kömpöc-N, 82—102 cm

Parallel with the X-ray diffractometric records derivatographic (DTA) records were also made from the same samples. The results obtained from the sandy carbonate (*a*-member) containing ferriferous precipitation) and from the light—grey hard carbonate (*b*-member) are quite similar. The values concerning the $CaCO_3$ varies between 71 and 77%, those of $MgCa(CO_3)_2$ between 19.4 and 22.3%, i. e. within rather narrow range. Out of the double endothermal peak of dolomite the first one is rather poorly-developed, the second one, however, is characteristic (*Fig. 3.*, samples No. 1—6).

The $CaCO_3$-value of the dark-grey hard carbonate (*c*-member) decreases down to 65.1 to 66.6%, the dolomite value increases up to 26.5 to 32.1% (*Fig. 3*, samples No. 8—9). The samples No. 9 of the Kömpöc-N outcrop, the X-ray diffractometric record of which showed also intense dolomite peak, is characteristic and shows well-developed double endothermal dolomite peak (*Fig. 3*, sample No. 9).

The curves of carbonate muds show more intense double endothermal peaks (*Fig. 4*, samples No. 11—15). In harmony with the X-ray records, the values of $CaCO_3$ and $CaMg(CO_3)_2$ vary between 36.1 to 65.6 and 34.8 to 59.0%, respectively, i. e. within rather wide range and the value of the latter considerably increases. It is worthy of note that the first endothermal peak of dolomite is found at lower temperature, i. e. between 715 and 735 °C than usual. As to literature data, two reasons may be responsible for this phenomenon, i. e. either the weaker degree of crystallization of the presence of water-soluble salts may produce it [Berg, L. G., 1943; Földvári—Vogl, M., 1958; Füchtbauer, H., Goldschmidt, H., 1965; Müller G., 1969; Müller, G., Irion, G., Förster, U., 1972; Müller, G., Wagner, F., 1978; Földvári, M., 1974].

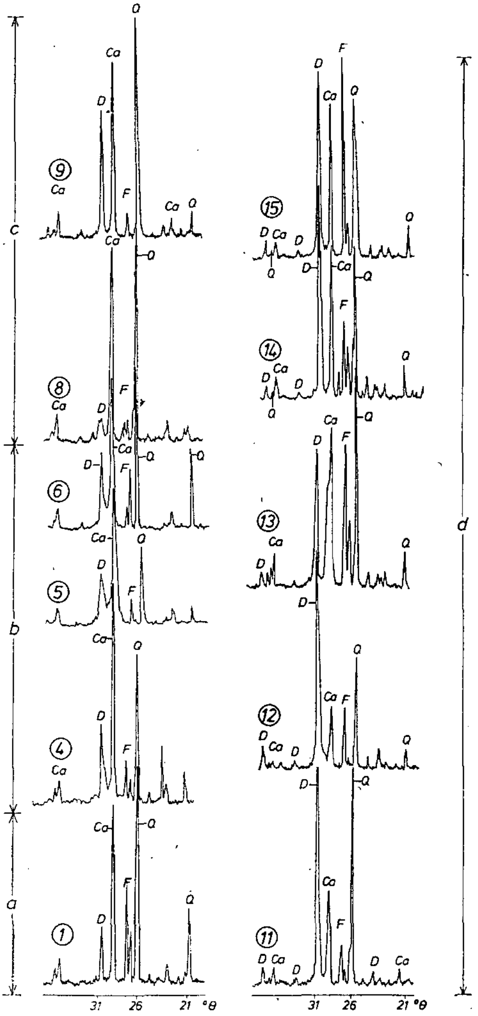

Fig. 2. X-ray diffractometric records of different members (a—d) of the studied profiles. Recording conditions: CuK$_\alpha$, Ni-filter, 32 kV, 24 mA, 2Θ/min. Numbers are the same as in Table 1; D=dolomite, Ca=calcite; F=feldspar, Q=quartz.

Since according to the investigations of the carbonates of the Danube-Tisza-Interflüve, protodolomite (or high Mg-calcite), i. e. dolomite of less ordered structure or of weaker crystallization degree, even in case of more elongated X-ray diffractometric records, only the second reason could be taken into account. Carbonates were precipitated from strongly alkalic sodaic lakes where out of the water-soluble salts the $NaHCO_3$ and Na_2CO_3 are always present [Molnár, B., M. Murvai, I., Hegyi—Pakó, J., 1976; Molnár, B., 1979]. The temperature decrease of the first endothermal peak could be caused by these salts. Füchtbauer, H. (Professor of the Geological Department of the Bochum University) analyzed also this material. Based on his X-ray records he stated that the values of dolomite mud are as follows: $Ca_{0,55}Mg_{0,45}$, consequently, as to their composition these are calcium dolomites. Their order-line is 35.2° (2Θ), i. e. these are medium-ordered and real dolomites. According to Füchtbauer the calcium surplus is the evidence of the in situ formation. These results agree with our ones and prove them.

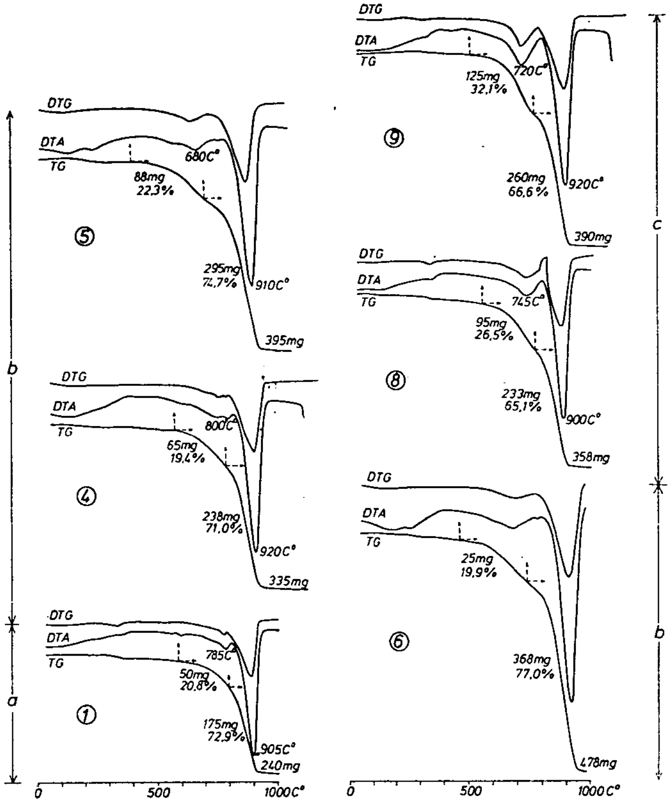

Fig. 3. Derivatographic records of the members a—c of the studied profiles. — DTG = derived thermogravimetric change; DTA = differential thermal analysis; TG = thermogravimetric change. Sensibility: DTG 1/10, DTA 1/10, TG 500 mg, duration: 100 min.; heating speed 10°/min. Number of samples is the same as in Table 1.

Perpendicularly of the “stratification” thin section and scanning electron microscopic pictures were made from the typical samples. In order to distinguish between calcite and dolomite the thin sections were coloured by Na-alisarine-sulfonate. Evaluating the results by strata members the following could be stated:

According to the evaluation of Folk’s texture elements the thin section of the member *a* contains micrite of 64.1% [Folk, R. L., 1959] (*Fig. 5.*, sample No. 1). According to colouring the major part of micrite is limy material. Dolomite spots occur only in size below 1 mm. The quantity of the detrital eolian quartz and feldspar grains is considerable, i. e. 23% (Plate I/1). In the sample there are in several percent lime grains and unfilled pores.

The matrix fills the interparticle space. The proportion of detrital grains is so high that according to the Dunham’s classification the rock is assigned to wackestone

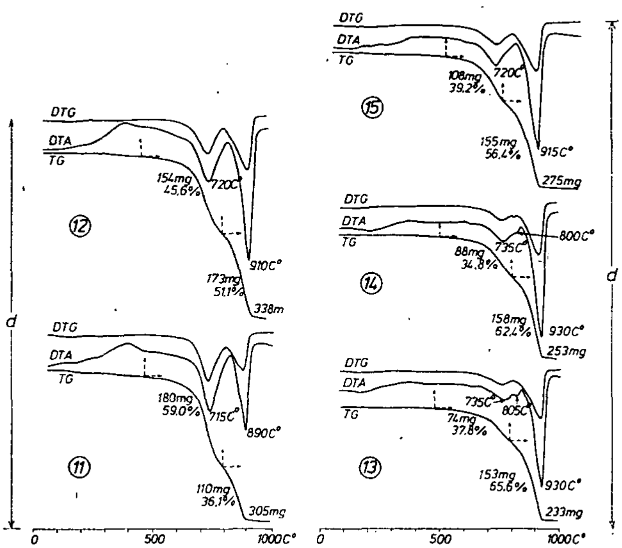

Fig. 4. Derivatograms of the member *d* of the investigated profiles. Recording conditions: see in Fig. 3. Numbers of samples are the same as in Table 1.

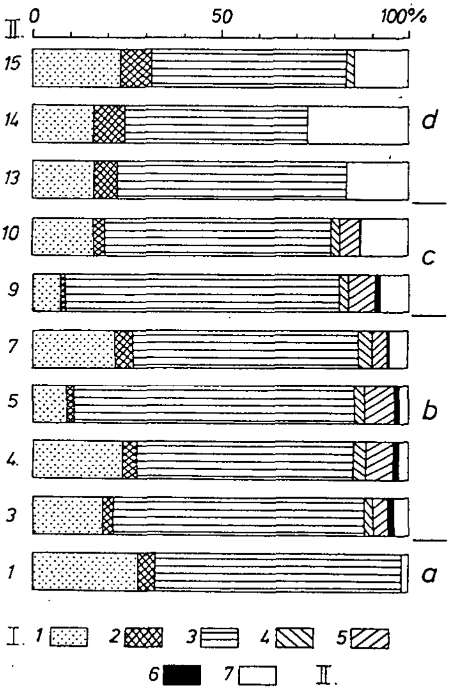

Fig. 5. Fabric constituents of thin sections determined by means of the FOLK-method.
I. 1 — quartz and other detrital grains; 2 — carbonatic detrital grains; 3 — micrite; 4 — microsparite; 5 — sparite; 6 — bioclastics; 7 — unfilled pores.
II. 1—10 — No. of thin section (the same as in Table 1); a—d: indication of the individual members.

category and shows the so-called mud-supported deposition structure ([DUNHAM, R. J., 1962].

In most cases the proportion of the detrital gains is higher than that of the evaluated samples. The distribution of the matrix and grains is unequal and very changing. E. g. the ferriferous precipitations contain less grains than their environment (Plate I/2). Thus, in case of these samples the measurements could not be carried out since within the sample areally very different results could be obtained. The more granular parts reach already the grain supported fabric structure of DUNHAM.

According to the scanning electron microscopic records the micrite consists of anhedral crystals (Table I/5). Most of the pores is of plant of interparticle origin [CHOQUETTE, PH. W., PRAY, L. C., 1970] (Plate I/1). The latter ones were generated in the manner that the carbonate precipitating from the solution did not fill a part of the interparticle space. The process of filling the pores has started. The filling material is always microsparite or sparite which based on the scanning electron microscopic pictures is a fibrous calcite elongated in the c-axis (Plate I/3—4).

If the member *a* contains fossils, this consists of mainly morphologically unbroken shells being filled by ferriferous micrite.

The member *b* shows fabric development being much more uniform than that of the member *a* (Plate I/6) The detrital grains show more uniform distribution Out of the fabric elements the micrite varies between 57.6 and 74.4% (*Fig. 5.*, samples No. 3—7). Based on colouring the matrix consists of calci- or dolomicrite but dolomitic calcimicrite also occurs. The quantity of detrital quartz and feldspar varies between 9.0 and 28.5%. This member contains also grains of detrital $CaCO_3$, pore-filling microsparite, sparite as well as bioclastics, all these amounting to several percent, and the pores are unfilled to some major extent than in case of member *a* (Plate I/6, Plate II/1—2). Dolomite euhedral also occur. According to the DUNHAM's classification the member *b* is assigned to the mud supported wackestones. On the basis of scanning electron microscopic records the micrite consists of anhedral crystals (Plate II/6).

The pores are very different considering both their shape and their origin. Numerous varieties occur. e. g. plant-generated pores consisting of different tubes or branching tubes being arranged irregularly and independent of the stratification, horizontal shrinkage pores nearly perpendicular of the stratification (Plate II/3), particle, interparticle as well as solution pores (Plate II/5). The picture of Plate II/2 shows the pore within the mollusc shell.

The filling of the pores is also different similarly to their shape and origin. All the varieties showing no filling up to total filling can be found (Plate II/2, and II/5, Plate III/1—2). Filling starts in general with microsparite and is continued by druse calcite of sparite size. The material of filling is concentrically precipitated at the walls of the pores (Plate II/4).

The pores within the mollusc shells were generated as follows: only a part of the original carbonate mud flowed into the shell, the other part remained empty. The mud within the shell could also shrink during micrite formation, thus the lower part of the shell is filled by dolomicrite in general, while in the upper the later diagenetic micro-calcisparite of calcisparite are found.

The shrinkage pores are of horizontal position and parallel with the pore's walls ferriferous precipitation can be observed. Similar pores and phenomena were described by FISCHER [1964] in the Alpine Triassic. The ferriferous precipitation has been regarded as a product of precipitation caused by the hydrometeorological differences between the summer and winter seasons. In our case the same can be assumed with high probability. The solution pores were generated by the subsequent solutions.

Fossils occurring in member *b* consisting mainly also of gastropods, are unbroken or occur as fragments. The gastropod shells are found often in non-horizontal, i. e. in oblique or vertical position (Plate II/2). Rarely Charales oospores also occur.

The fabric of the member *c* is rather varied (Plate III/3—6; Plate IV/14). It consists of micrite of 60.0 to 73.0% (*Fig. 5*., samples 9 and 10). Based on colouring, in sample No. 9 the matrix is dolomicrite, in sample No. 10 calcimicrite and dolomitic calcimicrite. In sample No. 9 the detrital quartz and feldspar amounts not more than 7%, this is the least value obtained so far. In sample No. 10 their amount is only 16%. The quantity of detrital carbonate grains is several percent. As compared to those observed till now, the great percentage of pores is a considerable change, which is fairly demonstrated by the fabric pictures under microscope. The pore-filling microsparite, sparite and bioclastics show nearly the same quantity as earlier. The member *c* is assigned also to the mud supported wackestones.

Proved by the scanning electron microscopic pictures, the micrite consists of subhedral crystals (Plate IV/2).

Within the whole carbonate profile the pores are most varied here, in all aspects. Their macroscopic appearance has been dealt with MOLNÁR, B., [1979]. According to the microscopic analyses the following species of pores occur. The pores discussed earlier, i. e. the plant-originated (produced mainly by rhizoids), the shrinkage, gas and intra-shell pores are accompanied by a new variety. This is the so-called protected or shelter pore which is generated as follows: the carbonate mud cannot flow into the downward lying convex shell fragment, thus a shelter pore is generated (Plate III/4) [CHOQUETTE, PH. W., PRAY, L. C., 1970]. The gas pores within the member are quite beautiful. Based on numerous observations these show isomeric forms in the wet carbonate mud. In the course of drying, i. e. during lithification these are deformed and get the irregular shape (Plate III/6, Plate IV/1). In this member the interparticle pores are subordinate.

The filling of pores is also rather varied. All the kinds including the unfilled up to the totally filled pores can be found (Plates III/3, 4, 6; Plate IV/1, 3, 4). In the shrinkage pores lying parallel to each other it can be observed in the so-called sheet cracks that the incompletely consolidated carbonate mud flowed into the pore from the top. The material of filling is similar to that observed till now. In the unfilled part mostly druse calcite occurs (Plate IV/3, 4; Plate V/1). Along the walls of the shrinkage pores the ferriferous precipitations are also frequent.

Major part of fossils is represented by unbroken gastropod shells, but fragments also occur. The unbroken shells are of horizontal deposition. The frequent Charales oo-spores, however, are of different imbedding positions (Plate IV/1).

In the carbonate mud (member *d*) micrite varied between 48 8 and 60.1% (*Fig. 5*., samples No. 13—15). Under colouring it proved to be always dolomicrite. The detrital quartz and feldspar occurred between 16.0 and 23.5% with upward increasing values. As against the so far predominating grain size of 0.1 to 0.2 mm, the detrital grains of the carbonate mud are finer, i. e. mostly between 0.02 and 0.06 mm (Plate V/2, 3, 4). The percentgae of the finer-grained detrital carbonates also increased and varied between 6.5 and 8.5%. As against the mainly eolian detrital carbonatic extraclasts, these grains are probably interclasts which in the course of total drying of lakes the wind took up from the incompletely consolidated bottom and redeposited again. According to the SEM photos the dolomicrite-matrix consists predominantly of euhedral crystals (Plate V/5).

The pore-filling microsparite and sparite are absent in this member. These occur only in minimal quantity in the soil zone as a result of soil formation. The quantity of the unfilled pors is highly increased. Especially high values are obtained (17.0—27.0%) below the soil horizon, and higher values can be found also in the soil part than in the deeper parts of the profile (*Fig. 5*., samples No. 13—15).

In the carbonate mud the shrinkage, plant and especially the gas pores predominate (Plate V/2, 3, 4, 6). It can be observed in the thin sections the pore formation and the formation of their shape, respectively, is in progress now, too.

Out of the fossils the Charales rhizoid is significant in addition to the gastropod shells mentioned earlier. This is probably due to the fact that the decomposition process did not eliminate them in the rock.

DIAGENETIC AND LITHIFICATION PROCESSES OF THE CARBONATES OF THE DANUBE-TISZA-INTERFLUVE

Before analyzing the diagenetic and lithification processes, let us study the demonstration of fabric elemenets in the Folk's triangle diagram. According to Folk when demonstrating the microcrystalline, allochemical and sparic calcite proportion of carbonate rocks, three basic carbonate types can be distinguished according to the individual ranges [Folk, R. L., 1959]. To demonstrate the carbonate studied according to the original imagination, it was troublesome that the allochemical and terrigenic detrital grains could not be distinguished unambiguously. Further, the pore-filling microsparite and sparite are produced by diagenetic processes, as it will be discussed later.

Thus, the demonstration was modified, i. e. in the first point (I) the micrite, in the second (II) comprehensively the detrital quartz, feldspar, the intra- and extraclastic grains as well as the bioclastics, while in the third point (III) the proportions of the pore-filling microcalcisparite and calcisparite, as well as that of the unfilled pores are demonstrated *(Fig. 6)*.

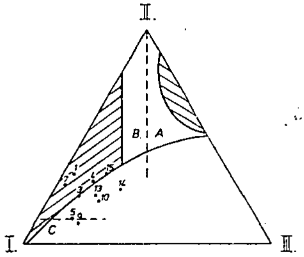

Fig. 6. Demonstration of the Folk's fabric elements of carbonates of the Danube-Tisza-Interfluve in triangle diagram.
I. micrite; II. detrital grains, quartz, feldspar, other carbonatic grains and bioclastics; III. sparite and microsparite, pore-filling sparite and microsparite; unfilled pores; 1—15, No. of thin sections, numbers are the same as in Table 1.

Based on this figure, the carbonates of the Danube-Tisza-Interfluve are assigned to the group of microcrystalline allochemical and microcrystalline orthochemical carbonates. This means that in the course of deposition the energy of motion of the sedimentation medium was low while the precipitation was rapid [Folk, R. L., Land, L. S., 1975].

As it has been referred to in the introduction, due to the higher total salt content of the lakes and to the Mg^{++}/Ca^{++} ratio of 7 to 12 the carbonates of the Danube-Tisza-Interfluve precipitate as high Mg-calcite and are transformed into dolomite in the early diagenesis [MOLNÁR, B., 1979].

The particular diagenetic and lithification processes of the different strata members can be evaluated as follows:

The loose sandy-lime dolomite containing ferriferous precipitations and the dolomitic limestone derive from the water infiltrating through the cover of higher carbonate content. This is proved also by the increased significance of the ferriferous precipitation here. The downward filtrating carbonatic solution filled the sand of the bottom, first of all the space among the sand particles. This caused the phenomenon that the quantity of the detrital matter is highest in this part, and the distribution of the detrital and carbonic matter is unequal. The dolomite occurring in higher horizons was transformed to certain extent during dissolution and downward filtration. The downward moving water might have high Mg-content after these processes, the concentrated salt quantity, however, was absent, thus in the sediments lime plays also an important role in addition to dolomite, consequently, in case of certain patches it can be called also dolomitic limestone.

The pore filling is always of $CaCO_3$ content also here as well as in higher levels of the profile. When analyzing the average sample under laboratory conditions this is responsible for the fact that both the X-ray-diffractometric and the derivatographic curves indicate not pure dolomite. In the sample the primary dolomicrite and the secondary pore-filling microcalcisparite and calcisparite cannot be mechanically separated before the analyses. The separation could be performed only in thin sections by means of colouring with Na-alisarine sulfonate.

Based on the above facts it is obvious that in this member why the interparticle predominate over the gas pores.

The light-grey hard dolomite (member *b*) is an independent geological formation. The detrital grains got the dolomite as extraclasts in addition to the dolomicrite precipitating from the lake's water. The diagenetic pore-filling microcalcisparite and calcisparite play more important role than in the previous member. Thus, the X-ray diffractometric and derivatographic records do not show considerable difference as compared to the previous member though $CaCO_3$ plays here much less important role. This is proved also by the fact that in the matrix fairly well-developed dolomite euhedral occur.

The attention should be called to two kinds of pores, i. e. the occurrence of shrinkage pores which from here downwards becomes common, and the exsolution pore which is generated by the dissolving effect of the subsequent solutions. Its formation is probably caused by the downward filtrating water which generated also the member *a*. The pores within the gastropod shells showing geopetal structure are also worthy of note.

The ferriferous precipitations occurring parallel with the walls of the shrinkage pores reflect the differences of hydrometeorology, occasionally of vegetation characterizing the different seasons. The matter of the ferriferous spots of the member *a* may derive from the dissolution of them.

In the course of deposition of the member *c*, i. e. fo the "pechmeg" a sudden change followed as compared to the conditions before. This is also indicated by the bedding plane developed between the members *b* and *c*. In the "pechmeg" there is the greatest quantity of micrite matrix and the smallest proportion of the detrital grains. This fact as well as the cementation are responsible for the phenomenon that this is the hardest member though the pores and especially the macroscopic pores show very high proportions. In the upper bedding plane of the "pechmeg" a lot of drying cracks can be observed [MOLNÁR, B., 1979]. The fossil shrinkage collapses are also frequent. Similar phenomenon can be observed in the recently drying lake bottom in the loose carbonate mud [MOLNÁR, B., KOPECZKY, A., 1979]. There is a great number of shrinkage and gas pores of microscopic size.

Consequently, the "pechmeg" accumulated very rapidly. Meanwhile the lakes were often dried. In the lake's life probably this period is most extreme concerning the climatic conditions. This is proved by the liquid carbonate mud intruding into the shrinkage pores or into those formed after drying.

A new and significant change followed in the course of deposition of the loose carbonate mud (member *d*) overlying the "pechmeg". As it was demonstrated, the proportion of pores is greatest in this member, and these pores are unfilled. Thus, the X-ray diffractometric and derivatographic records show the characteristic dolomite composition of the matrix and calcite seems to be subordinate.

While in members *a* and *b* the matrix was fairly well cemented and the rock was hardened during pore filling, here the rock remained loose just because of the lack of rock saturation accompanying the pore-filling cementation. Thus, in the members *a* and *b* the lithification is in a progressed state. In these members the diagenesis, in the carbonate mud the lithification can be observed. In the carbonate mud only shrinking and drying took place, as well as compaction proceeded.

This gradual lithification is demonstrated also by the fact that the Charales did not decompose here and is rather frequent, while in the deeper members it is rather rare. The change of the shape of gas pores shows the same process. These are more or less isometric when the lakes are drying and the carbonate mud is wet; later parallel with drying and carbonate mud compaction, their shape becomes irregular. Disturbing the bottom mud of sodaic lakes of the Danube-Tisza-Interfluve huge quantity of gas is released in form of bubbles. Shrinkage pores are developed also in this loose state.

The pores of the carbonates of the Danube-Tisza-Interfluve are assigned to the fabric selective pores (except the shrinkage pore) being generated in the so-called eogenetic zone (classification according to CHOQUETTE—PRAY). Shrinkage pores may be fabric selective or not.

It is characteristic of the pores of the eogenetic zone that these are generated by processes starting from the surface or near-surface. According to their size the pores can be assigned to the micro- (<0.065 mm), meso- (0.065—4.0 mm) and rarely to the mega-pores (4.0—32.0 mm) [CHOQUETTE, PH. W., PRAY, L. C., 1967].

According to the classification of diagenesis of FAIRBRIDGE [1967], the *dolomite muds* of the Danube-Tisza-Interfluve show *syndiagenetic processes.* According to BATHURST [1970], too, in this phase great quantities of water is released being bound with changing force between the particles, and this produces the shrinking and compaction of the sediment and the change of shape of the pores, first of all of gas pores.

Dolomites are in the starting phase of *anadiagenesis*. The main factor is the completion of their lithification. The liquid content of the sediment is considerably migrating, thus the former carbonate mud is saturated, then hardened and pore-filling is also started. As it has been stated, the latter consists of microcalcisparite or calcisparite as against the dolomicrite of the matrix and this is caused by the slower crystallization resulted in by the different i. e. lower Mg^{++}/Ca^{++} ratio of the pore waters [FOLK, R. L., LAND, L. S., 1975]. The smaller Mg/Ca ratio of the pore water and lower Mg-content may be produced by the consumption of Mg^{++} during the early diagenetic dolomite formation. Magnesium is present in the pore water though in smaller quantities than before. This is proved by the fibrous and druse calcite crystals growing at the pore walls perpendicularly of it and being *elongated in their c-axis* [MOLNÁR, B., 1979].

In this state drying and shrinkage take place out of the diagenetic physical and cementation out of the physico-chemical processes of CHILINGAR *et al.* [1967].

Out of the diagenetic processes of FÜCHTBAUER, MILLIMAN and FOLK the constructive allochemical diagenesis predominates. This causes the early diagenetic transformation of the primary high Mg-calcite into dolomite [MÜLLER, G., IRION, G., FÖRSTER, U., 1972; FÜCHTBAUER, H., 1974; MILLIMAN, J. D., 1974; FOLK, R. L. 1974; MOLNÁR, B., 1979].

The lithification and diagenetic processes of carbonates of the Danube-Tisza-Interfluve are in many aspects similar to those of the similar formations of Shark Bay (Western Australia) or of Coorong Lagoon, Southern-Australia [LOGAN, B. W. CEBULSKI, D. E., 1970; LOGAN, B. W , 1974; LOGAN, B. W. *et al.*, 1974; ALDERMAN, A. R., SKINNER, H. C. W., 1957; SKINNER, H. C. W., 1960; 1963; SKINNER, H. C. W., SKINNER, B. J., RUBIN, M., 1963] VON DER BORCH, C., 1965; Further, similarities can be conluded concenning the carbonate formations of the Persian Gulf and Bahama Islands [PRUDY, E. G., 1963 (SHINN, E. A., GINSBURG, R. N., 1964; PURSER, B. H., (ed., 1973)].

Our investigations have been based on the concept that the present is a key to the geological past. The further aim is the practical use of the results, after the stable isotope determinations of $C^{12}/^{13}$ and similar investigation of carbonate formations of other areas.

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Manuscript received, July 28, 1979.

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EXPLANATION OF PLATES

PLATE I

Microscopic and SEM photos of the sandy dolomite and dolomitic limestone (member *a*, photos 1—5), and of the light-grey hard dolomite (member *b*, photo 6.) of looser structure, containing hypersaline lacustrine ferriferous precipitations (Danube-Tisza-Interfluve).
(Photos were made from thin sections and preparates perpendicular of "stratification").

1. Kömpöc-N, 82—102 cm. Biogenic pores in dolomicrite matrix between quartz grains, partly filled by calcisparite. 1 N, M = 50 x.
2. Same location: iron spot in which the proportion of detrital grains is less than in the environment 1 N, M = 10 x.
3. Same location: SEM-photo of a broken surface. Left: pore-filling fibrous calcite; Middle: matrix Right: part of a quartz grain. M = 1000 x.
4. Same location: SEM picture of sparite and fibrous calcite pore filling between detrital grains, on etched surface. M = 540 x.
5. Same location: SEM picture of calcimicrite matrix consisting of anhedral crystals, in broken surface. M = 6000 x.
6. Csólyospálos-S. Fabric of the bottom of light-grey hard dolomite bank. Cross-section of partly filled biogenic pores in dolomicrite matrix and gastropod shell fragments. 1 N, M = 10 x.

PLATE II.

Microscopic and SEM photos of the hypersaline lacustrine light-grey hard dolomite (member *b*) of the Danube-Tisza-Interfluve.

1. Kömpöc-N. 60—82 cm. Partly filled biogenic pores and detrital quartz grains in dolomicrite matrix. 1 N, M = 100 x.
2. Same location: unfilled and smaller completely filled biogenic pores as well as gastropod shell cross-section showing geopetal structure. 1 N, M = 20 x.
3. Kömpöc-N 45—60 cm. Partly biogenic partly shrinkage (in the middle horizontally lying) pores. Parallel with the walls of shrinkage pores ferriferous accumulation occurs. 1 N, M = 20 x.
4. Csólyospálos-S. Upper part of the dolomite bank (sample *c*). Interpartcile pore between detrital grains originally unfilled by micrite, at the walls subsequent fibrous calcite filling has started. Smaller pores are completely filled by microsparite and sparite. 1 N, M = 100 x.

5. Csólyospálos-S. Lower part of the dolomite bank (sample *a*). Exsolution (?) pore in dolomicrite matrix filled subsequently by microsparite. 1 N, M = 100 x.
6. Csólyospálos-S. Lower part of the dolomite bank. (sample *b*). SEM-photo of the fabric of matrix consisting of anhedral crystals in broken surface. M = 1000 x.

PLATE III.

Microscopic and SEM photos on the hypersaline lacustrine light-grey dolomite (member *b*, photos 1—2) and on the dark-grey dolomite, i. e. on the so-called "pechmeg" (member *c*, photos 3—6) of the Danube-Tisza-Interfluve.

1. Csólyospálos-S. SEM picture of pores of different size on ground surface. M = 200 x.
2. Same location: SEM picture of the pore lying in the middle of Photo 1, under greater magnification (720 x).
3. Kömpöc-N. 55—60 cm. Completely filled (top) and unfilled (bottom) shrinkage pores. 1 N, M = = 20 x.
4. Same location: So-called shelter pores partly filled by fibrous calcite (bottom), and partly filled shrinkage pores (top). 1 N, M = 100 x.
5. Same location: Cross section of Charales oo-spore recrystallized. 1 N, M = 100 x.
6. Csólyospálos-S. Gas pores, at the walls with the starting fibrous filling calcite generation. 1 N, M = 100 x.

PLATE IV.

Microscopic and SEM photos on the hypersaline lacustrine dark-grey hard dolomite, i. e. "pechmeg" (member *c*) of the Danube-Tisza-Interfluve.

1. Kömpöc-N. Fabric of the fine-stratified hard dolomitie. In the dolomicrite matrix perpendicularly of stratification horizontal shrinkage (SK), rounded biogenic (RP) and irregular gas (GA) pores with different filling .Horizontally imbedded gastropod shells (G) and Charales oo-spore cross sections (0). 1 N, M = 9 x.
2. Same location: SEM picture of dolomicrite matrix consisting of subhedral crystals in etched surface. M = 6000 x.
3. Same location: SEM picture of druse calcite filling in broken suface. M = 360 x.
4. Same Location: SEM picture of shrinkage pore filled by druse calcite in etched surface. Around the pore filling quartz grains are shown. M = 100 x.

PLATE V.

Microscopic and SEM pictures on the hypersaline lacustrine dark-grey hard dolomite, i. e. "pechmeg" (member *c*, photo 1) and on the light-grey dolomite mud (member *d*, photos 2—6) of the Danube-Tisza-Interfluve.

1. Kömpöc-N. SEM picture of completely filled (in the middle) and partly filled (top-right) pores in etched surface. Filling matter is druse calcite. M = 100 x.
2. Csólyospálos-N. 25—50 cm, lowermost 5 cm. Irregular-shaped, gas-generated pores showing neither the beginning of filling. 1 N, M = 20 x.
3. Csólyospálos-N. 25—50 cm, middle 5 cm. Great, unfilled biogenic pore. 1 N, M = 20 x.
4. Csólyospálos-N. 25—50 cm, uppermost 5 cm. Great, irregular-shaped gas-generated pores; at the pore walls with very thin micrite coating as first indication of filling. 1 N, M = 20 x.
5. Csólyospálos-S. SEM picture of pore wall generated by roots and rhizoids respectively, in broken surface. The matrix consists of euhedral dolomite crystals. M = 6000 x.
6. Same location: SEM picture of absolutely unfilled biogenic pores inbro ken surface. M = 48 x.


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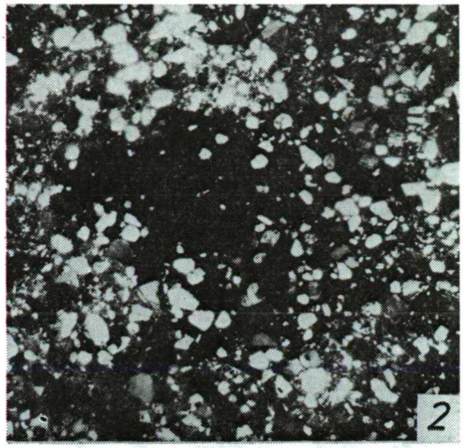
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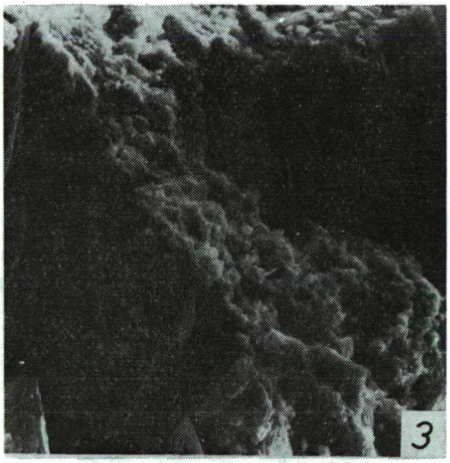
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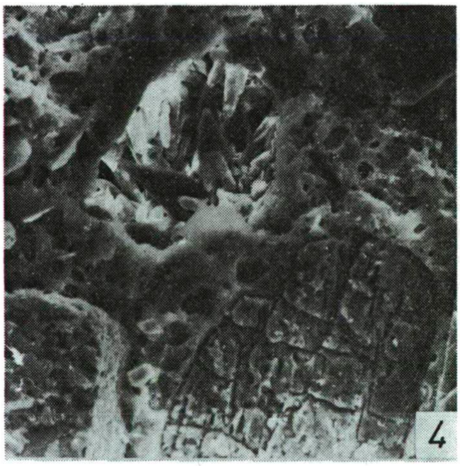
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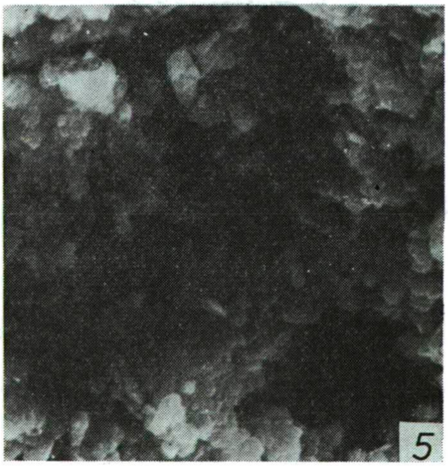
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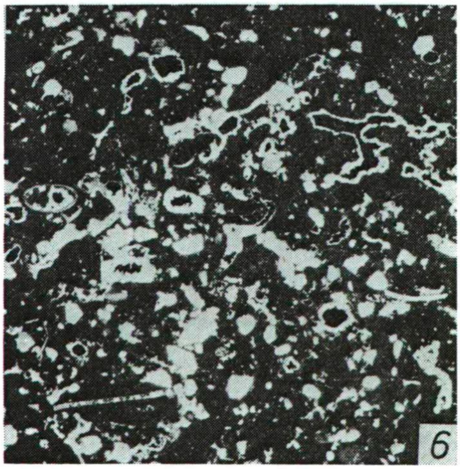
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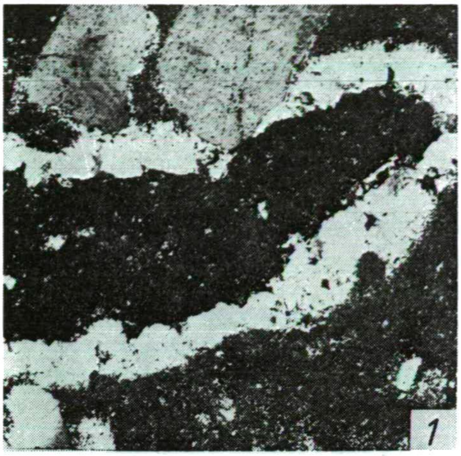
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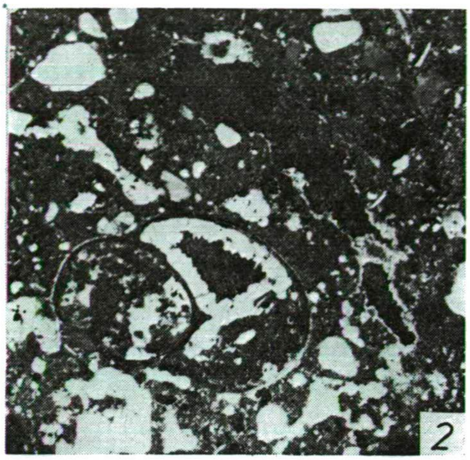
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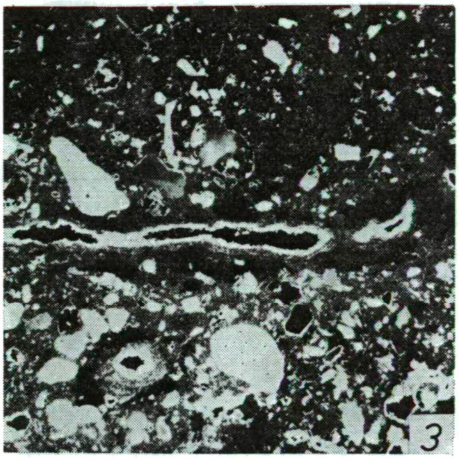
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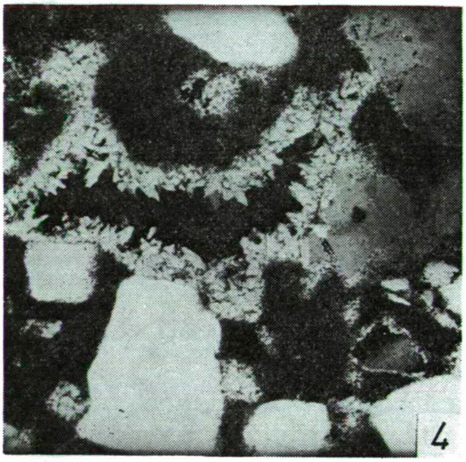
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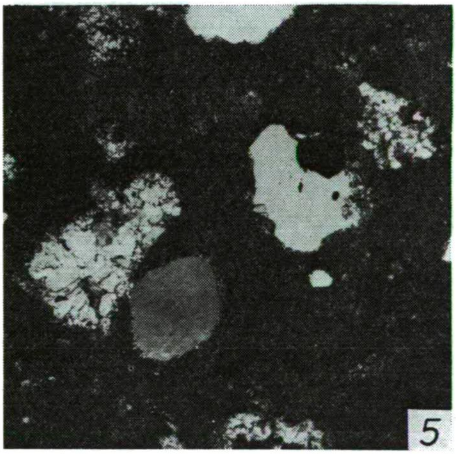
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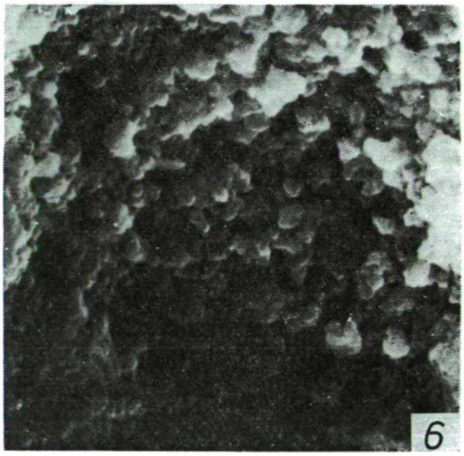
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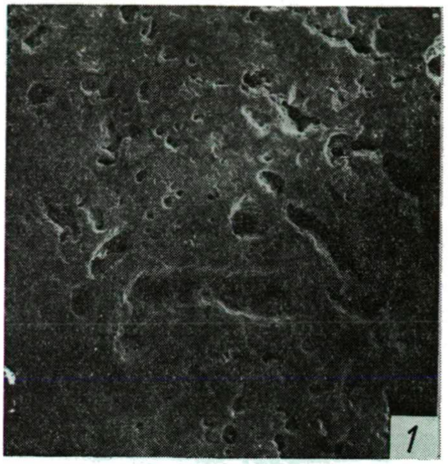
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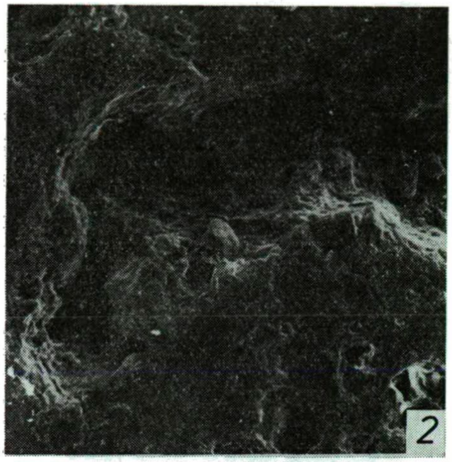
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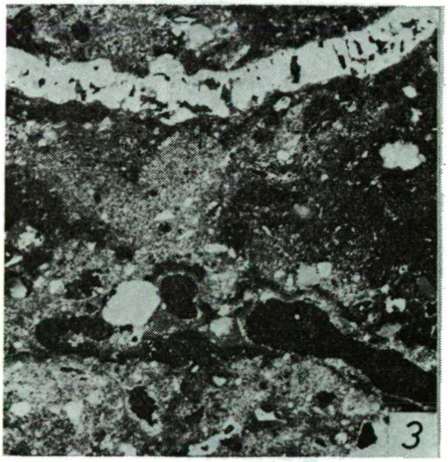
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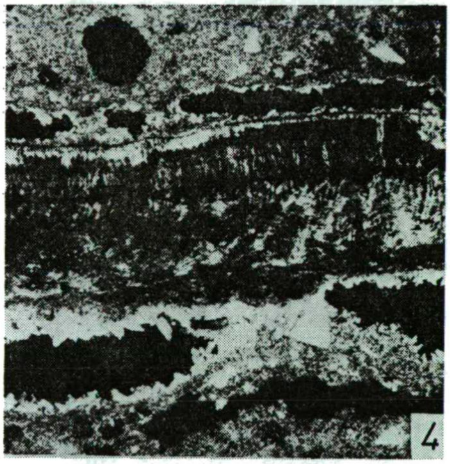
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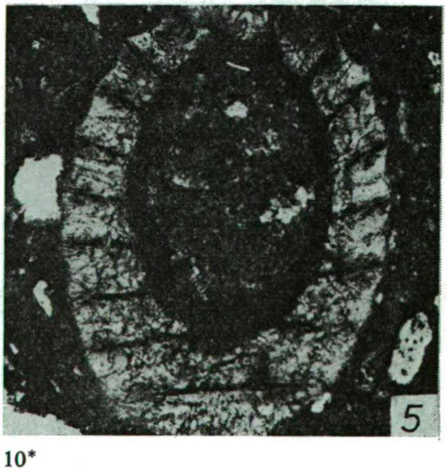
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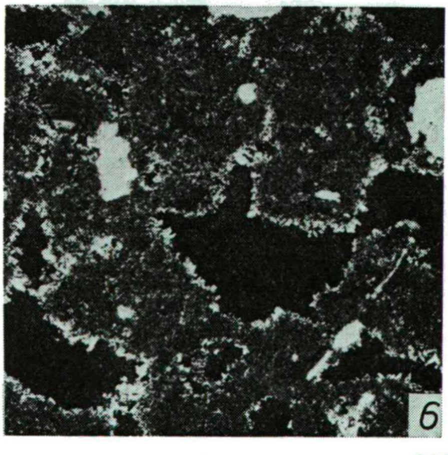
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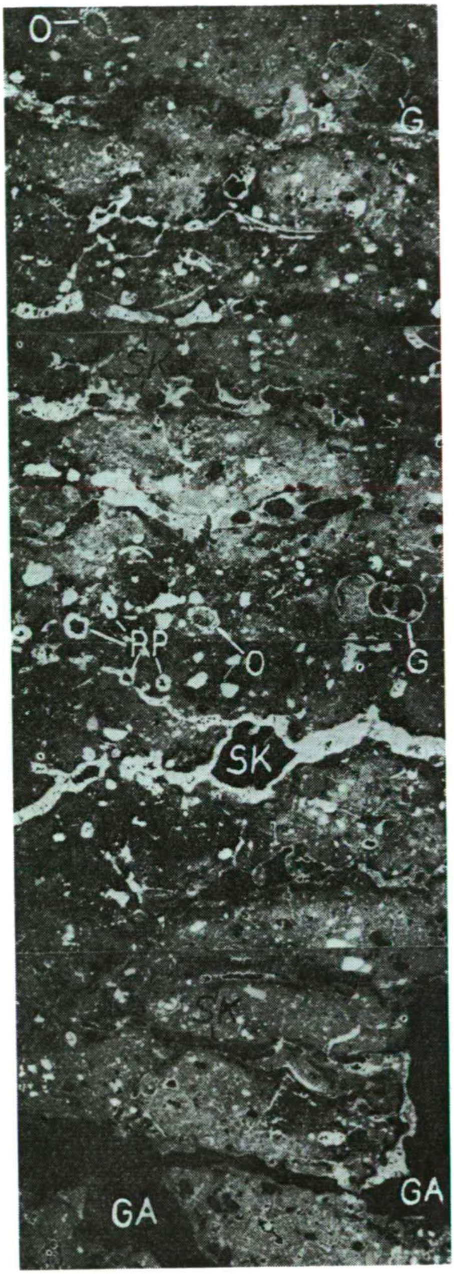

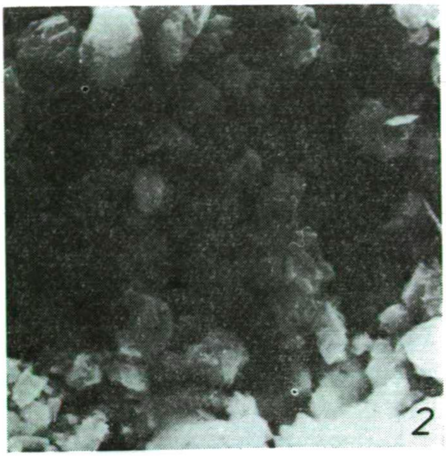
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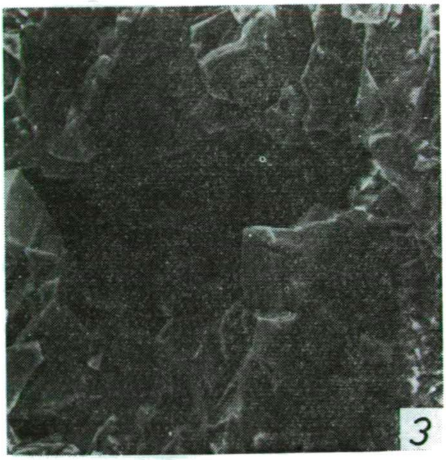
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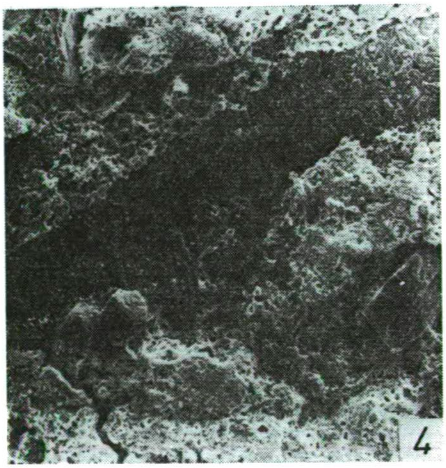
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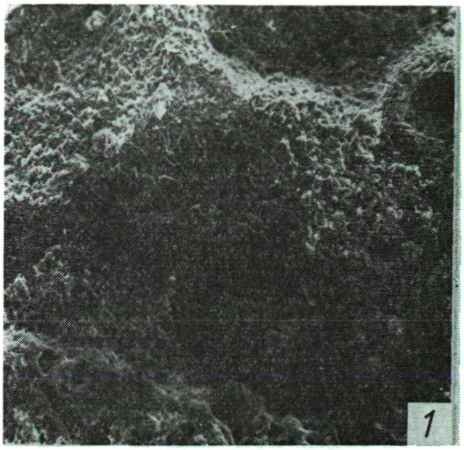
PLATE V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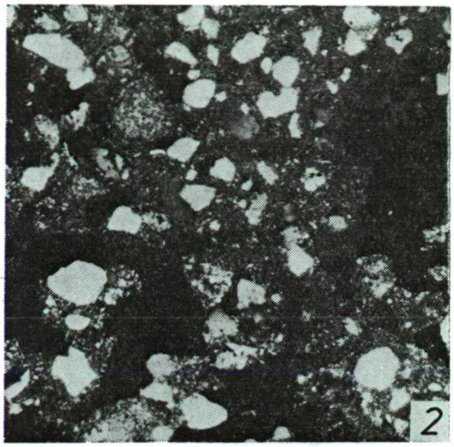
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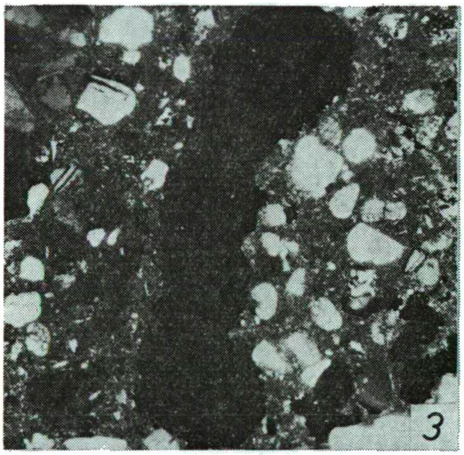
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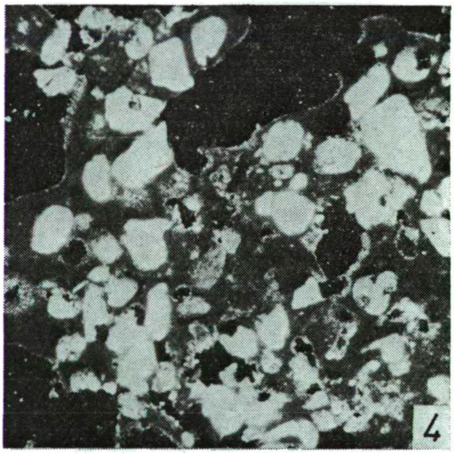
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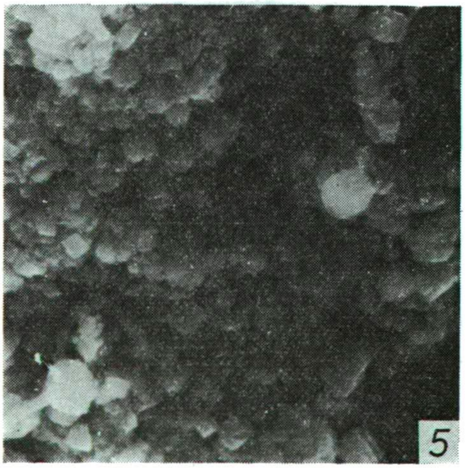
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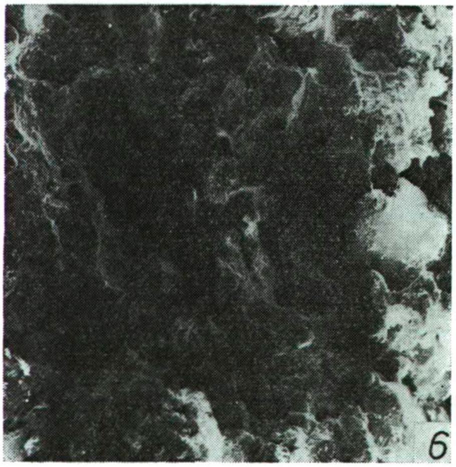
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