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EVIDENCE OF HYPERSALINE SEDIMENTARY ENVIRONMENT IN DINANTIAN CARBONATE DEPOSITS IN AREA OF KRZESZOWICE NEAR KRAKÓW

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Abstract: Pseudomorphs after evaporites and evaporite-solution breccias were found within the Dinantian limestones exposed north of Krzeszowice. Also other indicators of increased water salinity were identified: (a) occurrence of restricted and specific fossil assemblage, (b) presence of crusts of coniatolite and coniatoid types, (c) occurrence of laminated dolomicrites. Sedimentary features indicate back-barrier environment of low energy (lagoon).

Key words: Dinantian, evaporites, salinity indicators, pseudomorphs.

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INTRODUCTION

Dinantian carbonate sediments contain as a rule only traces left after primary evaporite minerals, in forms of various pseudomorphs and evaporite-solution breccias. Only recently, the criteria for correct identification of these sediments have been defined. This triggered an avalanche of papers reporting new occurrences of evaporite facies within the Dinantian shelf sediments of western Europe (Table 1).

Table 1 indicates that practically all carbonate shelves of Variscan geosyncline in western Europe were situated during the Dinantian in the climatic zone favouring formation of evaporites, i.e. the zone where potential evaporation exceeded meteoric water supply. Of course, the excess evaporation is not always sufficiently intensive to allow evaporite minerals to precipitate. Dinantian carbonate facies of saline environments have been known for a long time. This complies with the common belief that in the Dinantian the whole Europe was situated within tropical zone (e.g. Bless *et al.*, 1984) typified by high air temperatures and relatively low precipitation. This is inferred, among others, from the widespread occurrence of caliche crusts within the discussed sediments. It is obvious that climatic fluctuations might have occurred during such a long time span (Wright, 1980) but the dry periods definitely prevailed in the Dinantian over the humid ones.

Formation of evaporite sediments need a particular morphology of sedimentary

Table 1

Occurrences of evaporite facies on the shelves of Variscan geosyncline in Western Europe

Country	Age of sediments	Types of pseudomorphs	Type of basin	Authors
Wales	Visean	calcite and dolomite after gypsum, evaporite-solution breccias	sabkha	Bhatt, 1975
England	Visean	anhydrite	deep basin	George *et al.*, 1976
Ireland	Visean	calcite after anhydrite	sabkha	Brandon, 1977
Spain	Upper Visean	silica and calcite after anhydrite, evaporite-solution breccias	lagoon	Lastra, 1978
Ireland	Visean	silica after anhydrite	sabkha	Brunton & Mason, 1979
Belgium	Visean	silica after anhydrite	sabkha	Hennebert & Hance, 1980
Belgium	Visean	calcite after selenite and anhydrite	subtidal and sabkha	Swennen *et al.*, 1981
Belgium	Lower Visean	calcite after anhydrite and gypsum, evaporite-solution breccias	sabkha	Swennen *et al.*, 1982
Belgium	Visean	calcite and silica after anhydrite and gypsum, evaporite-solution breccias	deep basin	Jacobs *et al.*, 1982
Wales	Visean	calcite after gypsum	sabkha	Wright & Wright, 1982
Ireland	Visean	calcite after anhydrite and gypsum	sabkha	Griffith & Wilson, 1982
Belgium	Lower Visean	calcite and silica after anhydrite, evaporite-solution breccias	sabkha	Poels & Preat, 1983
Belgium France Holland	Visean	calcite and silica after anhydrite and gypsum, evaporite-solution breccias	deep basin and sabkha	Rouchy *et al.*, 1984
West Germany n. Aachen	Visean	calcite after selenite	subtidal	Paszkowski unpublished

basin. The latter condition was fulfilled periodically in various regions of the shelf of the Variscan geosyncline in western Europe. This is result of tectonic events occurring in the geosyncline (subsidence variable in time and space) as well as of eustatic changes in the world ocean. With those large-scale agents one should relate simultaneous (e.g. in the Lower Visean) formation of evaporite facies in distant localities situated on the opposite sides of the Variscan geosyncline.

The pseudomorphs after evaporite minerals and evaporite-solution breccias, used by the present authors to infer about primarily evaporite character of the Dinantian carbonate sediments near Krzeszowice, are not confined in Poland to the Dinantian strata. Their presence is a common phenomenon in marine carbonate formations of various age. The traces left by evaporites were found for example in the Eifelian strata of the Góry Świętokrzyskie Mts., in form of siliceous pseudomorphs after nodular anhydrite (Narkiewicz & Olkowicz-Paprocka, 1983). Also, in the Zechstein strata of the Gałęzice syncline occurrence of siliceous and calcitic pseudomorphs after calcium sulphates was documented (Bełka, 1978). Moreover, in the immediate vicinity of the present study area, near the village of Miękinia, the authors found calcified gypsum sediments within the Roethian strata (so-called "crystalline limestone").

DINANTIAN EVAPORITES IN POLAND

So far, the Dinantian evaporites have been known in Poland in three main areas (Fig. 1). Evaporite sediments were first described in borehole sections of the Visean carbonate strata in the Koszalin—Chojnice zone, Western Pomerania (*A* in Fig. 1)

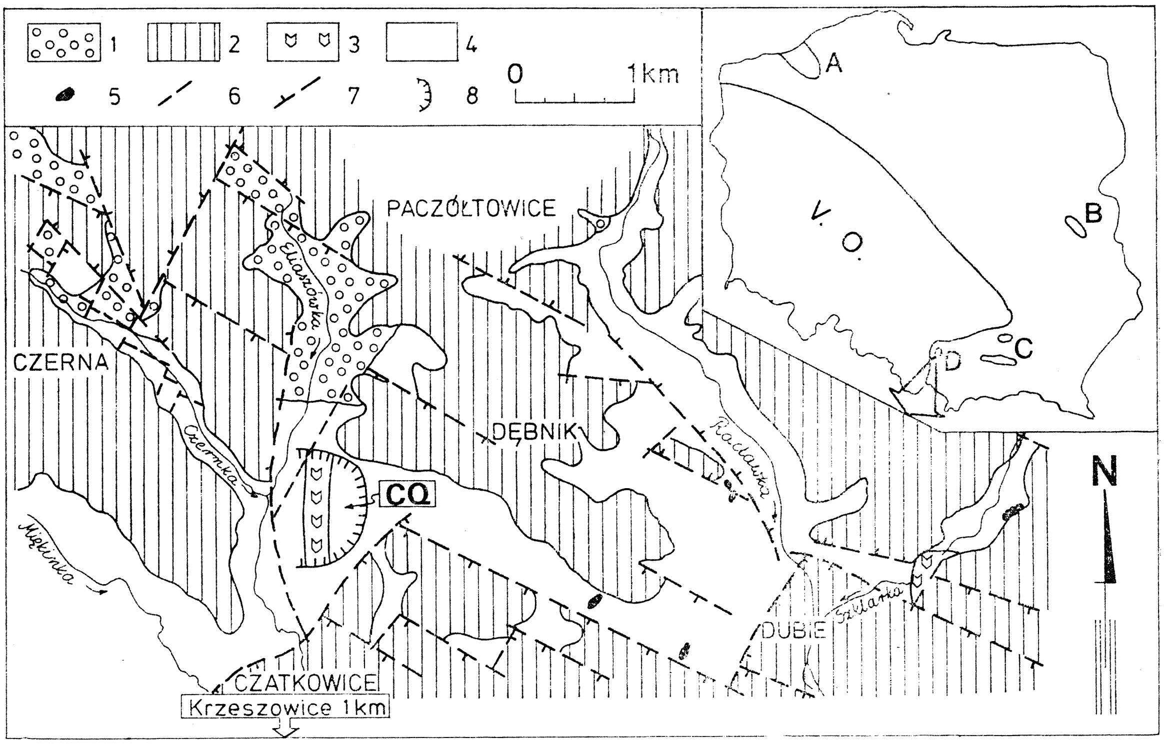

Fig. 1. Map illustrating distribution of evaporites in Poland (upper right insert) and geological sketch of the Dębnik area (according to Bogacz, 1980, changed): *A* — Koszalin—Chojnice zone, *B* — part of the Lublin trough, *C* — Carpathian Foredeep (area Bochnia—Tarnów and area to SE of Busko Zdrój), *D* — Dębnik area, *V. O.* — area of Variscan orogene; *1* — fenestral-coniatoid series; *2* — Permo-Mesozoic cover; *3* — outcrops of the complex H (southern zone); *4* — undivided pre-Permian sediments; *5* — magmatic intrusions; *6* — Variscan faults; *7* — faults rejuvenated during Alpine orogeny; *8* — quarries; *CQ* — Czatkowice quarry

where stratiform or nodular anhydrite aggregations were found (Dadlez, 1978). The Lublin trough (*B* in Fig. 1) is another area of occurrence of the Dinantian evaporite facies. Nodular concentrations of anhydrite were found here within variegated terrigenous sediments and dolomites of the Hulcza Formation which overlies the faunally documented Famennian (Miłaczewski, 1981). The above series does not contain stratigraphic indices and thus one cannot exclude its Lower Carboniferous age. The third area of evaporite occurrence is the Carpathian Foredeep (*C* in Fig. 1) where in numerous bore-holes between Bochnia and Tarnów and also to the southeast of Busko Zdrój, the nodular and stratiform anhydrite deposits were ascertained within the Dinantian carbonate sediments (W. Moryc, personal communication). Such distribution of the Dinantian evaporites suggests that the conditions favourable for evaporite formation existed periodically along nearly whole Polish segment of the Variscan geosyncline shelf.

DINANTIAN EVAPORITES OF KRZESZOWICE AREA

Above 1100 m thick sequence of the Dinantian carbonate sediments is exposed in the vicinity of Krzeszowice. The detailed biostratigraphic division of this imposing rock complex is not yet accomplished. The existing reports are partially contradictory and are not sufficiently supported by detailed field evidence (Alexandrowicz & Mamet, 1973; Gromczakiewicz-Łomnicka, 1974; Zajączkowski, 1975).

Sedimentological analysis of the Dinantian section exposed in the vicinity of Krzeszowice (Fig. 2) showed the presence of carbonate sediments formed in distinctly different sedimentary environments. Pelagic "basin" sediments occur here (black marly spiculites with cherts, containing Culm-type fauna and numerous trace fossils of *Zoophycus* type) as well as extremely shallow-water or even subaerial facies (e.g. paleosols of caliche type).

Some of the informal lithostratigraphic units distinguished by Paszkowski (1983) reveal features of the sediment formed in the basin of increased water salinity. Complexes B, E, H and I belong to this category there but unambiguous traces of evaporites were ascertained only within the complex H (Fig. 2). The following evidence implies increased water salinity during formation of these strata:

a) restricted biota with dominance of forms resistant to high salinity, i.e. calcispheres, ostracods and vermiform gastropods,

b) abundance of algal sedimentary structures, which suggests conditions inhibiting development of grazers of algal mats (mainly herbivorous gastropods),

c) presence of laminated carbonate crusts of the coniatolite type and of the coated grains of the coniatoid type, particularly in the complexes H and I,

d) occurrence of laminated dolomicrite sediments (only in the complexes B and H).

It must be noted that inferring about increased water salinity when basing on only one of the above criteria, may lead to serious errors, as for example restricted fauna may result also from euxinic conditions in the basin.

The traces of evaporite presence occur merely in section of the complex H. This complex is built of more than 200 m thick series of carbonate rocks. It is perfectly exposed in the limestone quarry "Czatkowice" and in the valley of Szklarka river, where it constitutes the core of the Szklarka brachysyncline (the latter subdivision by Bogacz, 1980). The complex is built predominantly of mudstones and wackestones,

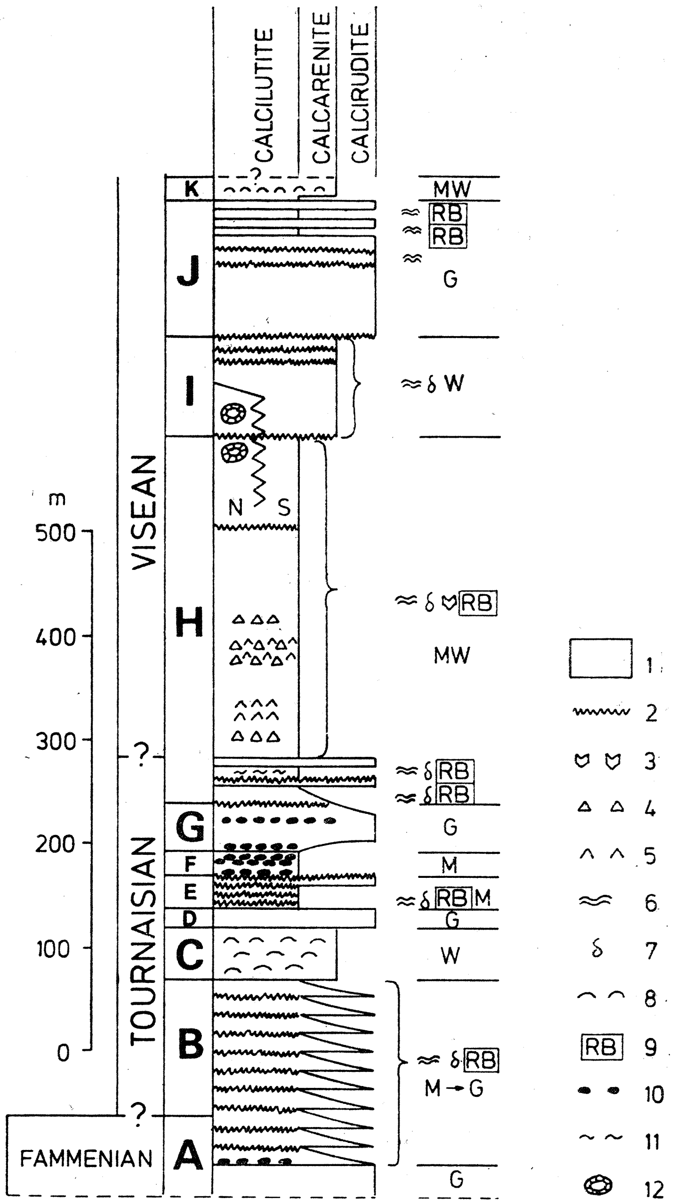

Fig. 2. Generalized compiled section of the Dinantian strata exposed north of Krzeszowice: *1* — carbonate rocks in general; *2* — main horizons of subaerial exposure; *3* — traces after evaporites, in general; *4* — horizons of evaporite-solution breccias; *5* — pseudomorphs after evaporite minerals; *6* — algal structures; *7* — vermiform gastropods; *8* — brachiopods coquinoid limestone; *9* — restricted fossil assemblage (calcispheres, ostracods, blue-green algae); *10* — cherts; *11* — intercalations of clayey rocks; *12* — coniatolites and coniatoids, symbols of Dunham's rock classification: *M* — mudstone, *W* — wackestone, *G* — grainstone

which suggests low-energy, presumably lagoonal sedimentary environment. The latter opinion is further supported by the shallow-water sedimentary structures. In the upper part of the complex, to the north of Krzeszowice, certain facies variability along the S—N direction is present. In northern area, the upper part of the complex H and the lower part of the complex I are developed in fenestral-coniatoid facies (Paszkowski, 1986) formed in generally shallower and more energetic waters (Fig. 1). The occurrence of traces of evaporites in the complex H is confined to southern area and boundary between both above areas is located near the mouth of Rudnica gorge (eastern tributary of the Eliaszówka river). To the south of this boundary, numerous traces left after evaporites are visible within the complex H. Coniatoids dispersed in the micritic matrix occur sporadically and are presumably delivered by storm events from the northern area.

Some regularities are apparent in the distribution of the evaporite traces:

a) they most frequently cap shallowing-upwards sequences typical of the sabkha environment (Pl. I) (*cf.* Brunton & Mason, 1979).

b) they often occur within the top parts of beds which in their lower parts contain colonies of vermiform gastropods (Pl. II: 1) and algal biosedimentary structures (mainly stromatolites),

c) the calcareous sediment directly embedding post-evaporite forms is usually very fine grained and frequently shows lamination; occassionally it is dolomicrite. In such sediment, the only fossils determined were calcispheres and ostracods.

Pseudomorphs after evaporites are in form of discontinuous layers, laminae or flat and isometric nodules up to 30 cm thick. Their most characteristic feature is lateral variability which makes difficult correlating of particular horizons between the sections. One can differentiate three main types of pseudomorphs:

1. Pseudomorphs in calcilutite sediment after dissolved lath-shaped or prismatic anhydrite crystals, from 0.3 to 10 mm in diameter (Pl. II: 2), which often form grape- and rosette-like aggregations. Those parts of rocks which contain dispersed crystals form discontinuous layers with diffuse boundaries.

2. Pseudomorphs in form of flat and isometric nodules, up to 20 cm thick (Pl. III: 1). They usually form discontinuous horizons in which particular nodules are oriented with their longer axes along the sediment lamination. Their boundaries are sharp and they are surrounded by the aureole of dispersed pseudomorphs of the type 1. Occasionally the flat nodules reveal features of mechanical deformation which they underwent in unconsolidated sediment. They are thrusted over each other, broken or crushed, whereas the surrounding sediment shows distinct plastic deformations.

3. Layered pseudomorphs forming layers from several milimeters up to 30 cm thick, are usually composed of several milimeters thick laminae separated from each other by thin films of micritic sediment. They often form assemblages of several layers revealing enterolithic structures (Pl. III: 2).

All three types of pseudomorphs are composed of aggregate of coarse-sparitic calcite (which frequently exhibits polysynthetic twinning) and various types of silica. One finds here mainly isometric fine-crystalline quartz and radial concentrations of fibrous varieties of chalcedony: quarcine and lutecite (length-slow chalcedony *sensu* Folk & Pittman, 1971; see Pl. IV: 1), which minerals are typical of silicified evaporites (West, 1964; Folk & Pittman, 1971; Arbey, 1980). Relatively rare are radial quartz aggregates with characteristic zonal distribution of microscopic anhydrite inclusions (Pl. IV: 2), as well as aggregations of isometric quartz grains coated with quartz of palisade structure (Pl. V: 1), the latter being formed by filling of pore space with silica (*cf.* Arbey, 1980).

In most cases, it is possible to note certain zonation of secondary minerals within the pseudomorphs of the first and second types. Silica minerals with only minor admixture of micritic and fine-sparitic calcite are concentrated most commonly near walls of the pseudomorphs, and in the case of flat or isometric nodules, mainly in their bottom parts. The central parts of the pseudomorphs are usually filled with coarse-sparitic calcite, although one occasionally encounters pseudomorphs filled either nearly exclusively with SiO_2 minerals or exclusively with sparitic clacite without traces of silicification.

Contrary to the above discussed, in the layered pseudomorphs there is observed dominance of quartz, quarcine and lutecite over sparitic calcite. These forms are usually more strongly silicified and they often reveal net structures, typical of pseudomorphically replaced evaporites (West, 1964).

Both, pseudomorphs after dispersed crystals and presence of preserved relics (inclusions), indicate that anhydrite was the primary evaporite mineral of the discussed strata (*cf.* Arbey, 1980; Poels & Preat, 1983). The primary anhydrite grew in form of loose euhedral crystals beneath the sediment surface. Aggregation of these crystals led subsequently to formation of more compact structures devoid of micritic matrix. In consequence, flat and isometric nodules were built, composed of anhedral anhydrite (West, 1964; Butler *et al.*, 1982). The rate of nodule growth was the highest along the sediment lamination, i.e. related to the anisotropy of non-lithified sediment. Lateral expansion of individual nodules led to collisions resulting in their deformation, breaking, thrusting over each other etc. In case of layered anhydrites, formed in course of proceeding accretion and compaction of the sediment or by crystallization directly beneath the sediment surface, the lateral expansion resulted in enterolithic structures (West, 1965).

The present results suggest a two-stage diagenetic replacement of the evaporite sediments. The first, occurred during the early stage of diagenesis and consisted in partial dissolution of anhydrite and its gradual replacement by silica (*cf.* Poels & Preat, 1983) of probably biogenic origin (*cf.* Chowns & Elkins, 1974). This is indicated by zonation of the secondary minerals. The silicification usually commenced at the outer faces of the crystals or nodules and gradually proceeded towards the centres. This produced aggregates of fine-crystalline quartz and radial concentrations of quarcine and lutecite. The process was the fastest in the layered anhydrites, which is evidenced by their nearly complete silicification. This was presumably due to greater feasibility of silica migration within the evaporite layers, as compared with nodules or dispersed anhydrite crystals.

The second stage of replacement occurred during advanced diagenesis and resulted in complete leaching of evaporites and filling of the residual voids with blocky sparite.

EVAPORITE-SOLUTION BRECCIAS

All investigated sedimentary breccias included in the solution breccias show similar structures. They are composed of two elements: angular or deformed clasts with diffuse edges and abundant micritic matrix. The thickness of layers is variable and attains 50 cm, and the clast diameters are up to 15 cm. The structure of these breccias suggests irregular lithification of sediment overlying the evaporite during its dissolution. Presumably, these sediments were composed of layers being at different stages of consolidation that, during their collapse, led to crushing of more rigid parts and their dispersion within the plastic weakly consolidated micrite.

There are three main types of relations between the solution breccias and evaporites in the sediments of the complex H:

1. The breccias occur immediately above the layer with pseudomorphs, which suggests incomplete dissolution of the primary sulphates or the primary presence of admixtures of better soluble chlorides.

2. Pseudomorphs after calcium sulphates occur within micrite matrix of the breccia, whereas in the vicinity of breccia they are absent.

3. There are no evaporite relics whatsoever, both, within and outside of breccia. Close similarity to the breccias encountered in the above described situations, allows one to infer that these are also evaporite-solution breccias (*cf.* Middleton, 1961).

CONIATOLITES AND CONIATOIDS

Specific types of structures produced in hypersaline conditions are laminated crusts and coated grains which occur in the studied section solely in the complexes H and I — fenestral-coniatoid facies (Fig. 2) (Alexandrowicz & Mamet, 1973; Paszkowski, 1986). Within this more than 100 m thick series, there are observed several limestone horizons composed of grains up to 10 cm in diameter with laminated cortices built originally of aragonite (Pl. V: 2). These limestones are of grainstone type and they usually lie over fenestral algal mats and stromatolites. In these sediments common are also traces of vadose diagenesis (tepee structures, voids filled with vadose microcrystalline silt and microstalactite cements). Similar recent sediments are described from the saline lagoons of the Persian Gulf (Purser & Loreau, 1973) and ancient examples of similar sediments are known from the Dinantian of South Wales (Wright, 1981) and Permian of Guadalupe Mountains (Esteban & Pray, 1983). They are interpreted as structures precipitated from sea water of increased salinity in the vadose and phreatic zones.

Inversed grading observed in some coniatoid grainstone layers may suggest that a part of strata described here reveal characters of vadoids. The sediments of the fenestral-coniatoid series resemble closely strata of the Calcare Massiccio Formation of the Lower Jurassic in the Apennines (Bernoulli & Wagner, 1971) where they were also interpreted as lagoonal sediments formed by increased water salinity or as sediments produced in vadose conditions.

CONCLUSIONS

Sediments, which indicate increased salinity in the Dinantian sedimentary basin of the Krzeszowice area, indicate climatic conditions permitting evaporative concentration of sea waters in this part of the basin. Conclusions regarding the paleoclimate agree with those found in literature (e.g. Bless *et al.*, 1984). An important new aspect of the present study isareconstruction of paleogeographic situation favouring intensive evaporation. The facies analysis, based on exposures and several bore-holes from the Kraków-Silesia region, allowed the present authors to reconstruct paleogeography during deposition of the complexes H and I (Lower and Middle Visean;

Fig. 3). The studied area was situated then near the inner side of the barrier separating carbonate platform in the south from the deep basin in the north. The fenestral--coniatoid facies constitutes presumably sediments of that barrier (shelf-crest *sensu* Esteban & Pray, 1983), while sediments containing evaporites were deposited within sabkha or lagoon (Paszkowski, 1986), (Fig. 3).

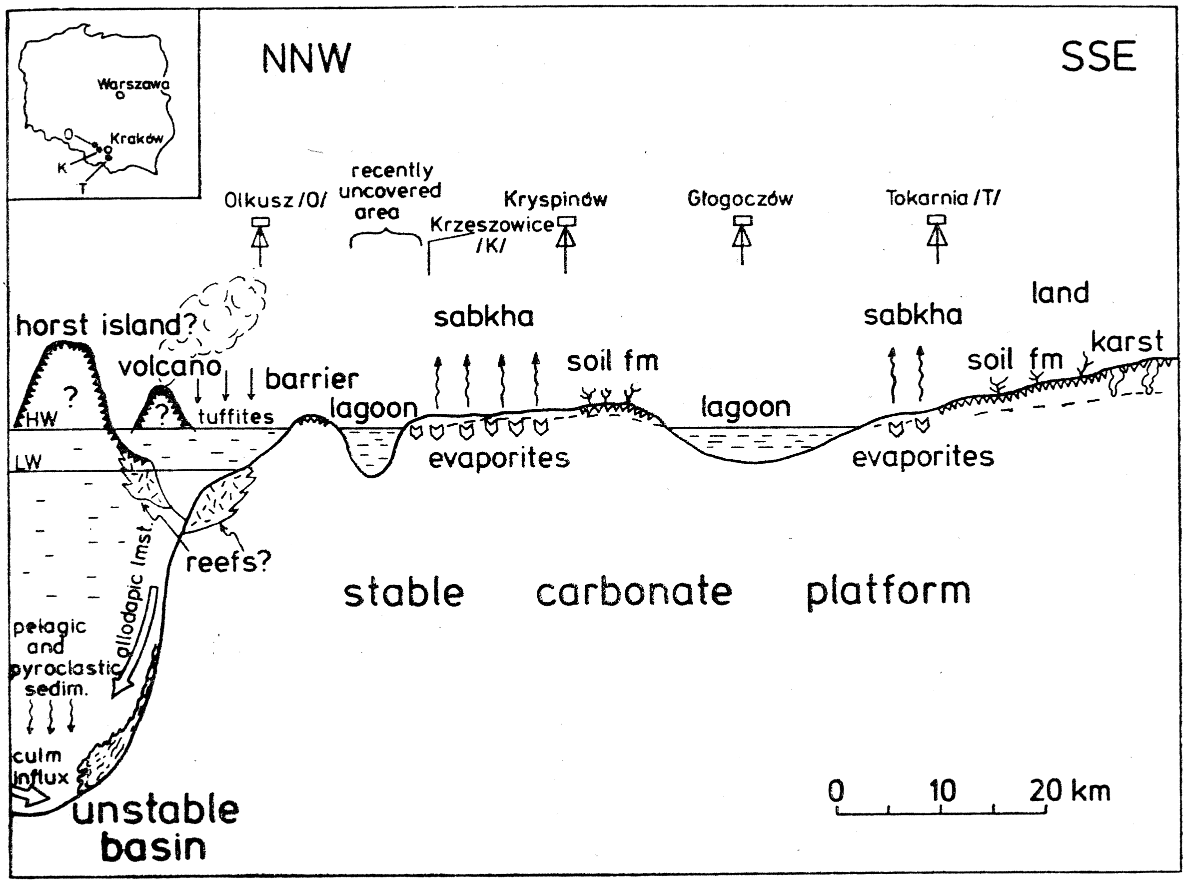

Fig. 3. Simplified idealized cross-section along the line Olkusz—Tokarnia across the sedimentary basin in lower Visean (partially conceptual). Data from exposures and bore-holes of which only selected are indicated. Solid dentate line denotes areas subjected to intesive erosion; light dentate line denotes areas of subaerial sedimentation

The established criteria of identification of the pseudomorphically replaced evaporites and reconstruction of succession of diagenetic alterations, offer possibility of distinguishing traces of evaporites in marine carbonate sediments of different ages.

Besides unequivocal evidence of the original presence of evaporite minerals within the studied sediments, also several other indicators of increased water salinity were identified:

a) occurrence of specific fossil assemblage consisting exclusively of vermiform gastropods, calcispheres, ostracods and algae of *Porostromata* family,

b) presence of crusts of coniatolite and coniatoid types,

c) occurrence of laminated dolomicrites.

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Streszczenie

DOWODY NA HIPERSALINARNE ŚRODOWISKO SEDYMENTACJI WĘGLANOWYCH UTWORÓW DINANTU REJONU KRZESZOWIC KOŁO KRAKOWA

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W ciągu ostatniego dziesięciolecia gwałtownie wzrosła ilość doniesień o występowaniu nowych stanowisk utworów facji ewaporatowych w węglanowych osadach dinantu Europy Zachodniej. Z Tabeli 1 wynika, że praktycznie na wszystkich szelfach węglanowych geosynkliny waryscyjskiej Europy Zachodniej panowały okresowo warunki umożliwiające powstawanie minerałów ewaporatowych.

Także na terenie Polski stwierdzono obecność utworów ewaporatowych w osadach dinantu Pomorza Zachodniego, Zapadliska Przedkarpackiego oraz prawdopodobnie na obszarze Rowu Lubelskiego (Fig. 1).

Analiza sedymentologiczna ponad 1100-metrowej serii osadów dinantu odsłoniętej na N od Krzeszowic wykazała obecność niewątpliwych śladów po ewaporatach. Są to kalcytowo-krzemionkowe (kwarc, kwarcyn, lutecyt) pseudomorfozy po listewkowych i pryzmatycznych kryształach, płaskurach, gruzłach lub warstwach anhydrytu oraz brekcje powstałe w wyniku rozpuszczania minerałów ewaporatowych.

Wyniki przeprowadzonych badań sugerują, że minerały ewaporatowe wzrastały pierwotnie pod powierzchnią osadu, a następnie w trakcie diagenezy ulegały stopniowemu rozpuszczaniu i zastępowaniu najpierw przez minerały z grupy SiO_2, a potem przez kalcyt.

Oprócz niewątpliwych śladów obecności minerałów ewaporatowych w obrębie badanego profilu (Fig. 2) stwierdzono wiele innych wskaźników podwyższonego zasolenia wód basenu sedymentacyjnego. Należą do nich:

1) występowanie charakterystycznego zespołu skamieniałości składającego się z ślimaków wermetoidalnych, małżoraczków, kalcisfer oraz struktur pochodzenia glonowego typu stromatolitów i trombolitów;

2) obecność laminowanych skorup i ziarn obleczonych typu koniatolitów i koniatoidów;

3) występowanie laminowanych dolomikrytów.

Na podstawie cech strukturalnych badanych utworów i przestrzennego ich rozmieszczenia ustalono, że osady ewaporatowe tworzyły się w obrębie sebhy lub laguny. Była ona oddzielona od otwartego morza barierą budowaną przez osady facji fenestralno-koniatolitowej (Fig. 3).

EXPLANATIONS OF PLATES

Plate I

Example of complete sequence of sabkha sediments. From the bottom: *a* — limestone with dispersed oncoids, *b* — algal mat and LLH stromatolite, *c* — fenestral mat, *d* — silicified layer (pseudomorphs after anhydrite). The lower part of sequence represents sublittoral environment, the middle part — littoral environment, and the upper part — supralittoral environment. Czatkowice quarry, 145 m above the bottom of the complex H. Bar corresponds to 2 cm

Plate II

1 — Fragment of bioherm of vermiform gastropods. Inside tubes septa are visible. In the centre there is embryonic chamber (protoconch) of thin micritic walls, fixed to the shell of adult individual. Racławka valley, complex B. Thin section, unpolarized light

2 — Pseudomorphs after lath- and prism-shaped anhydrite crystals (type 1). Czatkowice quarry, 145 m above the bottom of the complex H. Thin section, unpolarized light

Plate III

1 — Flat nodules of calcified anhydrite (type 2 — at the top) resting on algal mat. In the centre — pseudomorphs after loose anhydrite crystals. Czatkowice quarry, 145 m above the bottom of the complex H.

2 — Siliceous pseudomorphs after layered anhydrite (type 3), partially of enterolithic structure. Czatkowice quarry, 90 m above the bottom of the complex H

Plate IV

1 — Radial aggregations of fibrous quarcine crystals in pseudomorphs after euhedral anhydrite. Czatkowice quarry, 145 m above the bottom of the complex H. Thin section, crossed nicols

2 — Radial aggregation of quartz crystals with zonally distributed anhydrite inclusions. Czatkowice quarry, 90 m above the bottom of the complex H. Thin section, crossed nicols

Plate V

1 — Isometric quartz coated with palisade quartz. Czatkowice quarry, 90 m above the bottom of the complex H. Thin section, crossed nicols.

2 — Example of coniatolitic crust developed on the fragment of coniatoid limestone. Visible are: lamination with a system of palisade calcite crystals perpendicular to it and individual coniatoids. Eliaszówka valley, fenestral-coniatoid series. Thin section, unpolarized light

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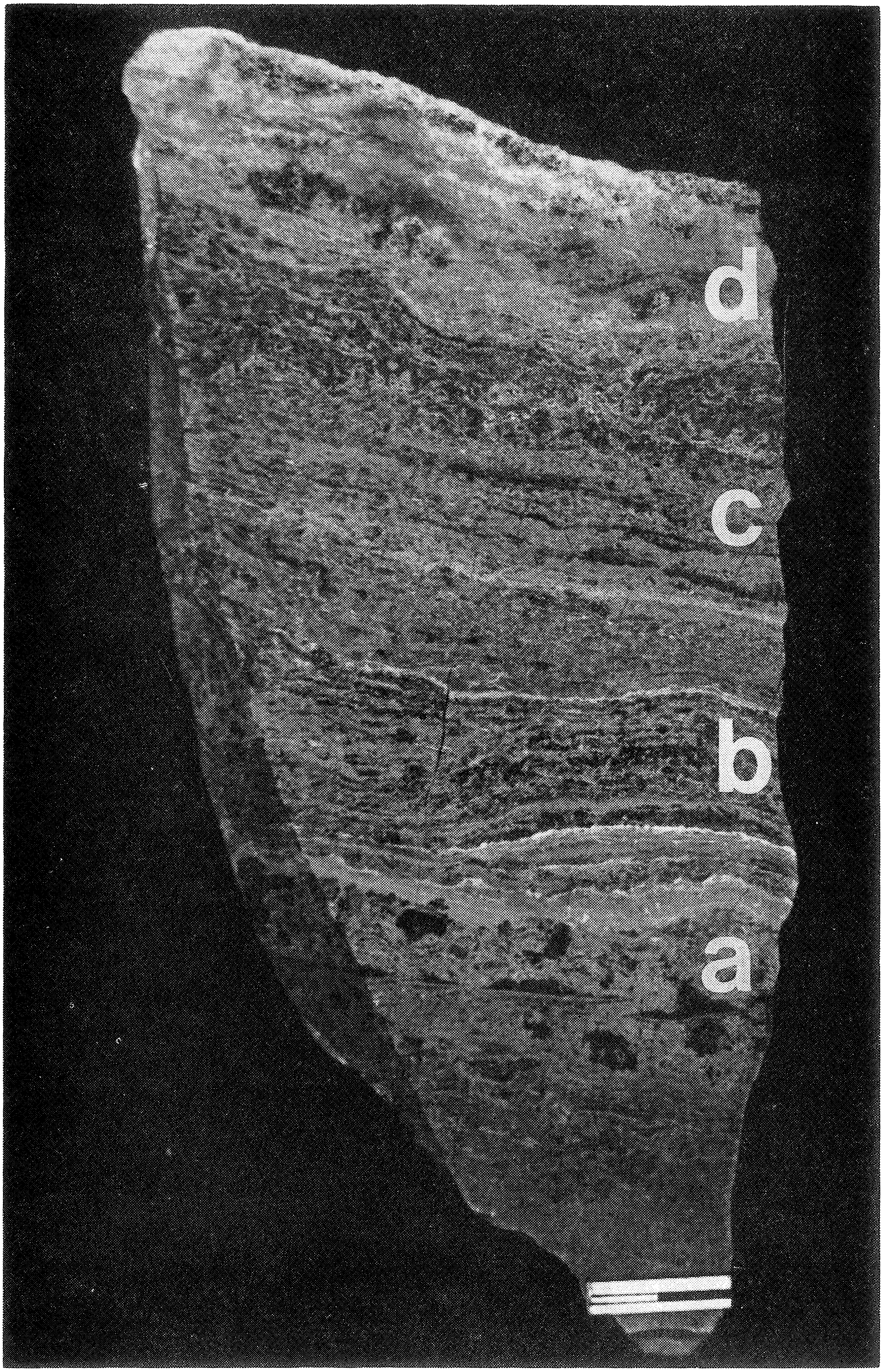
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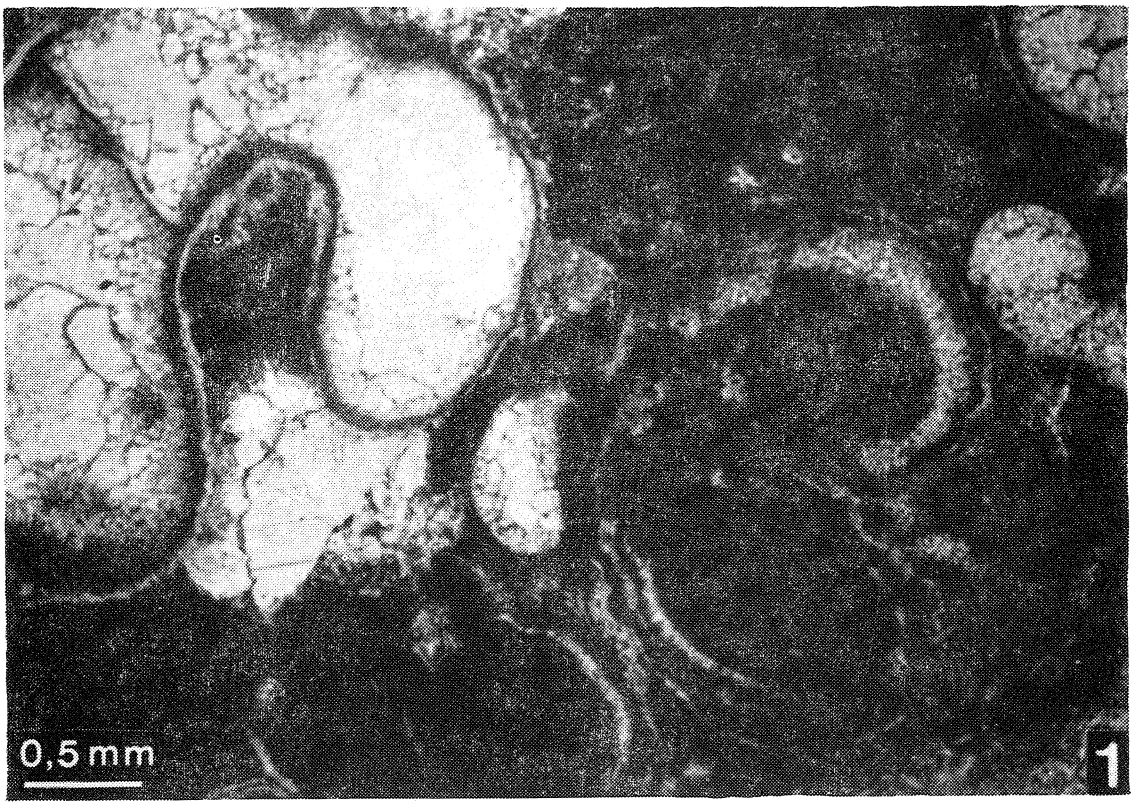
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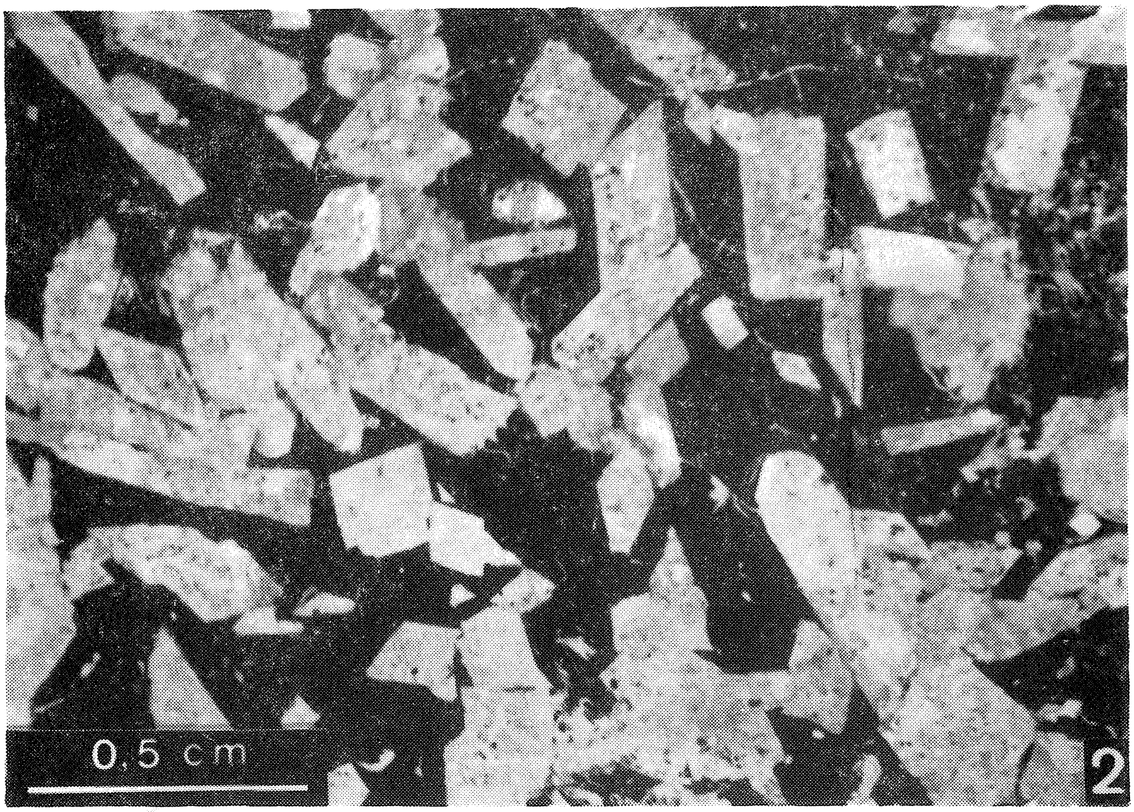
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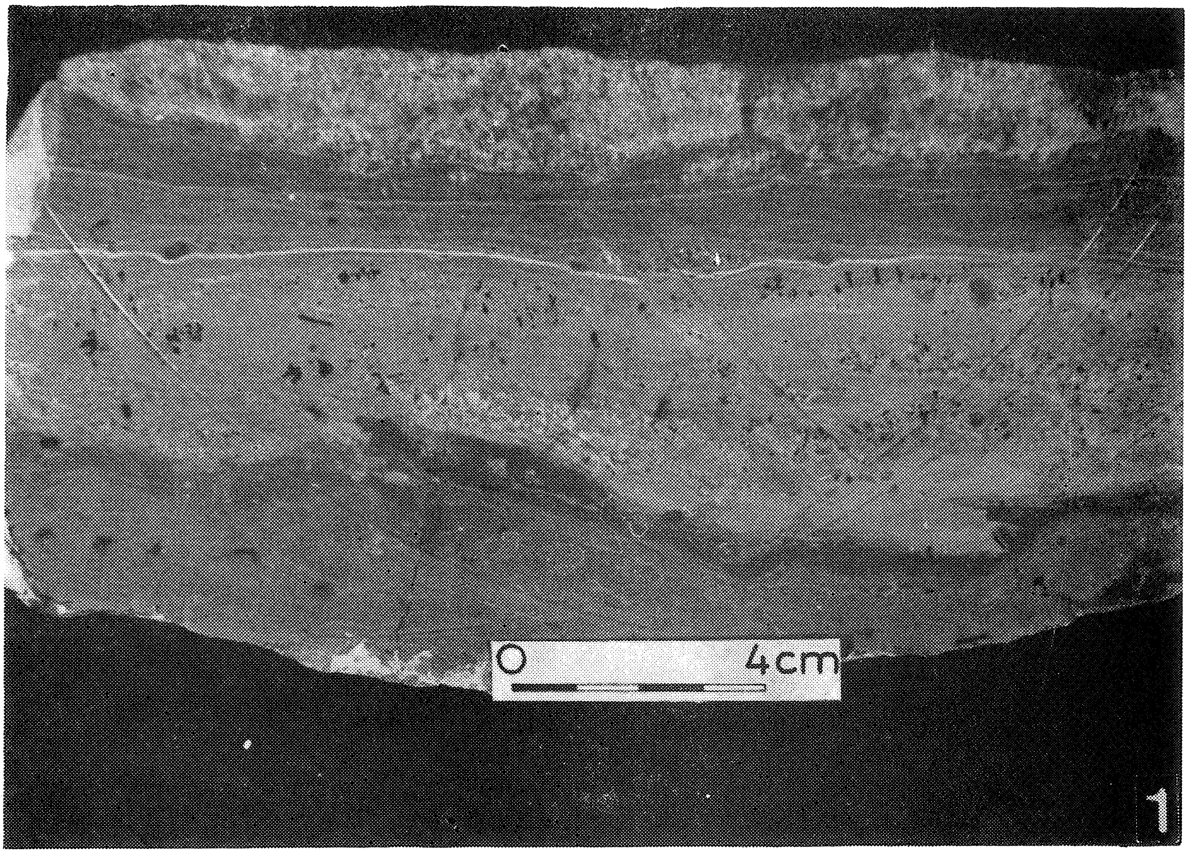
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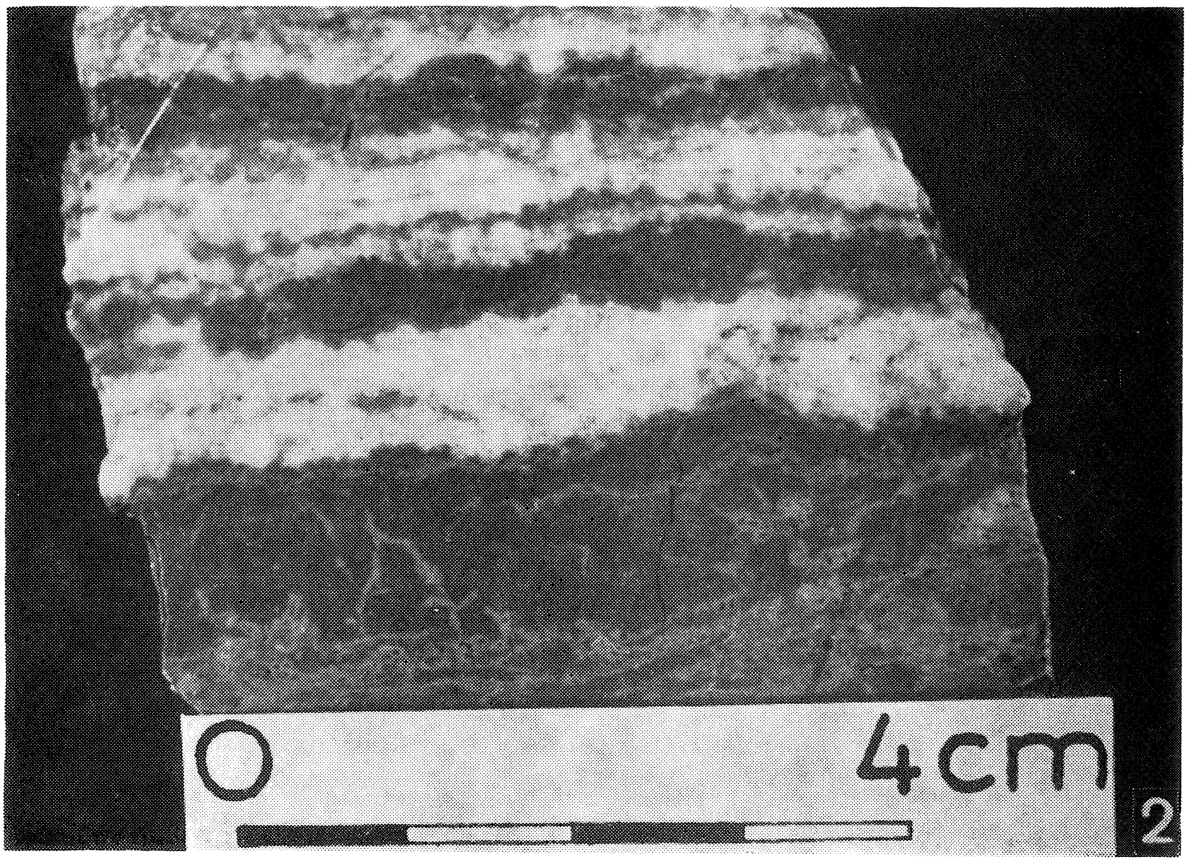
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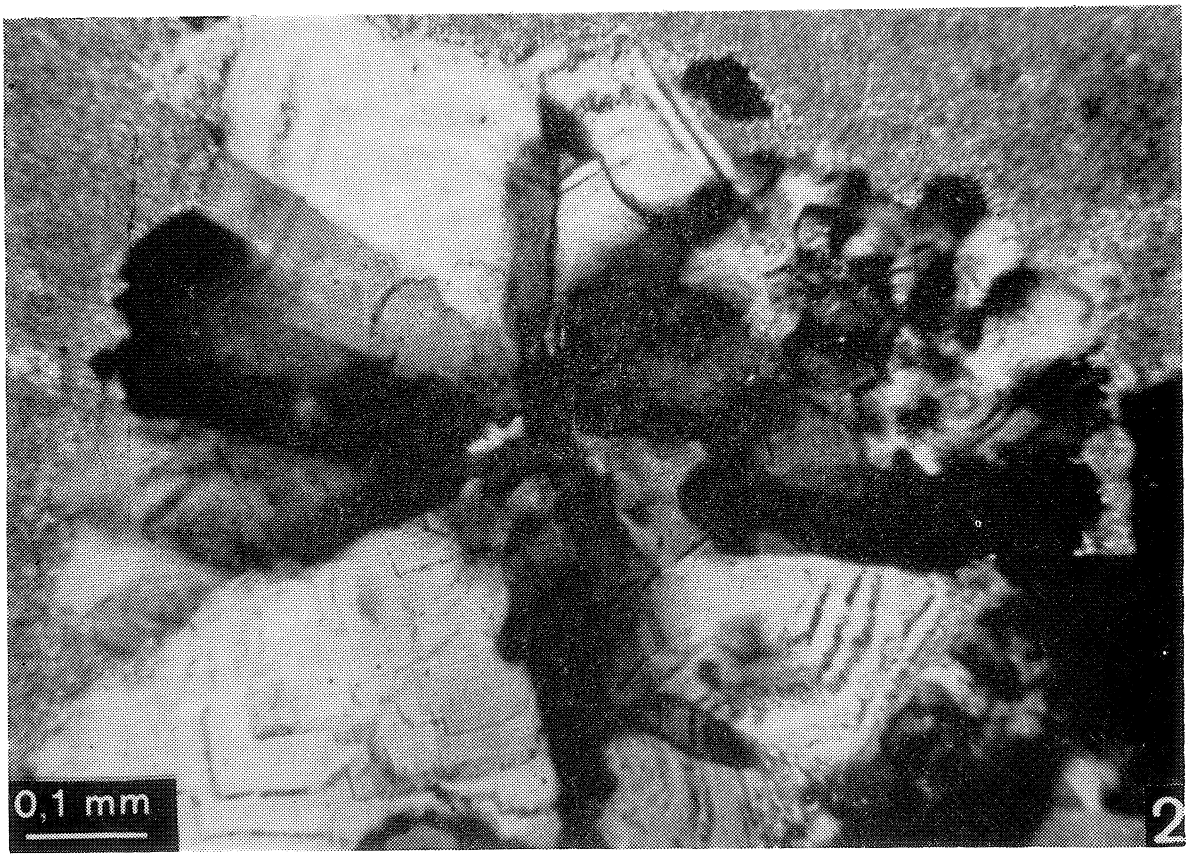
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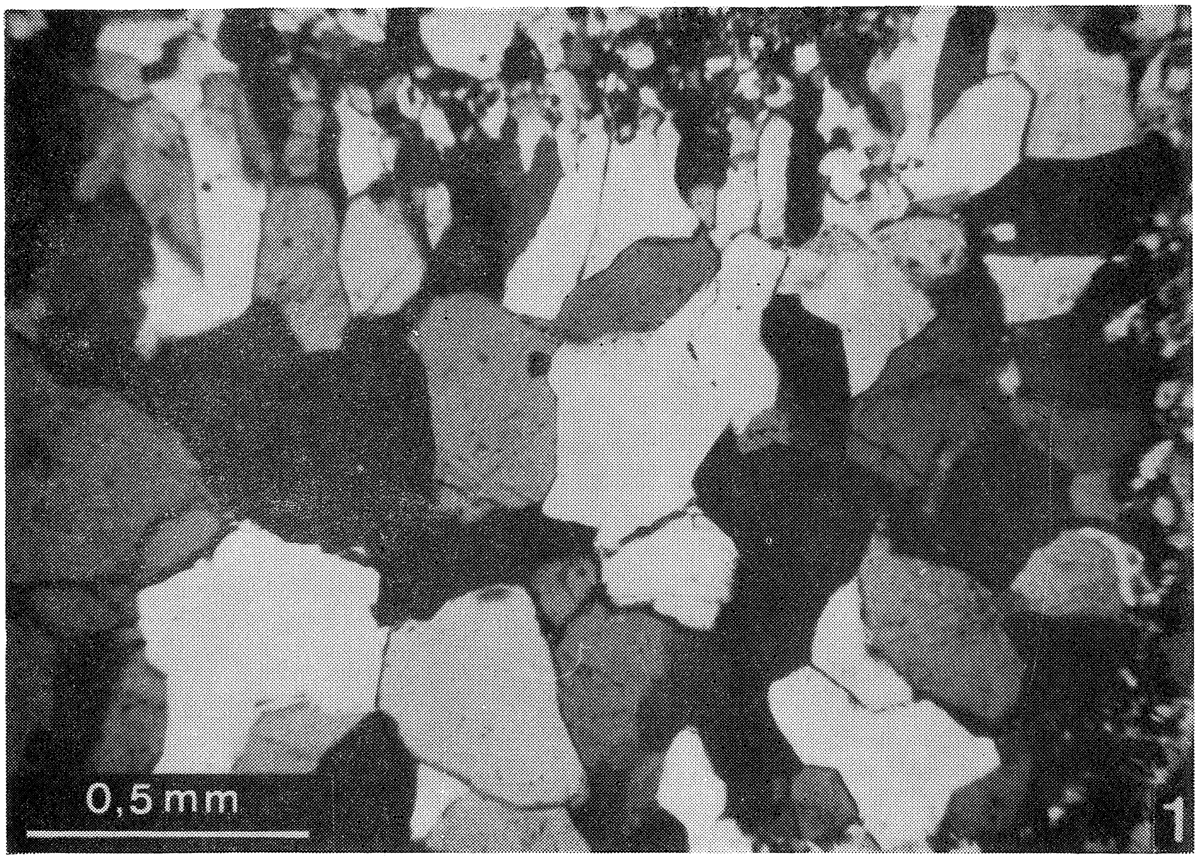
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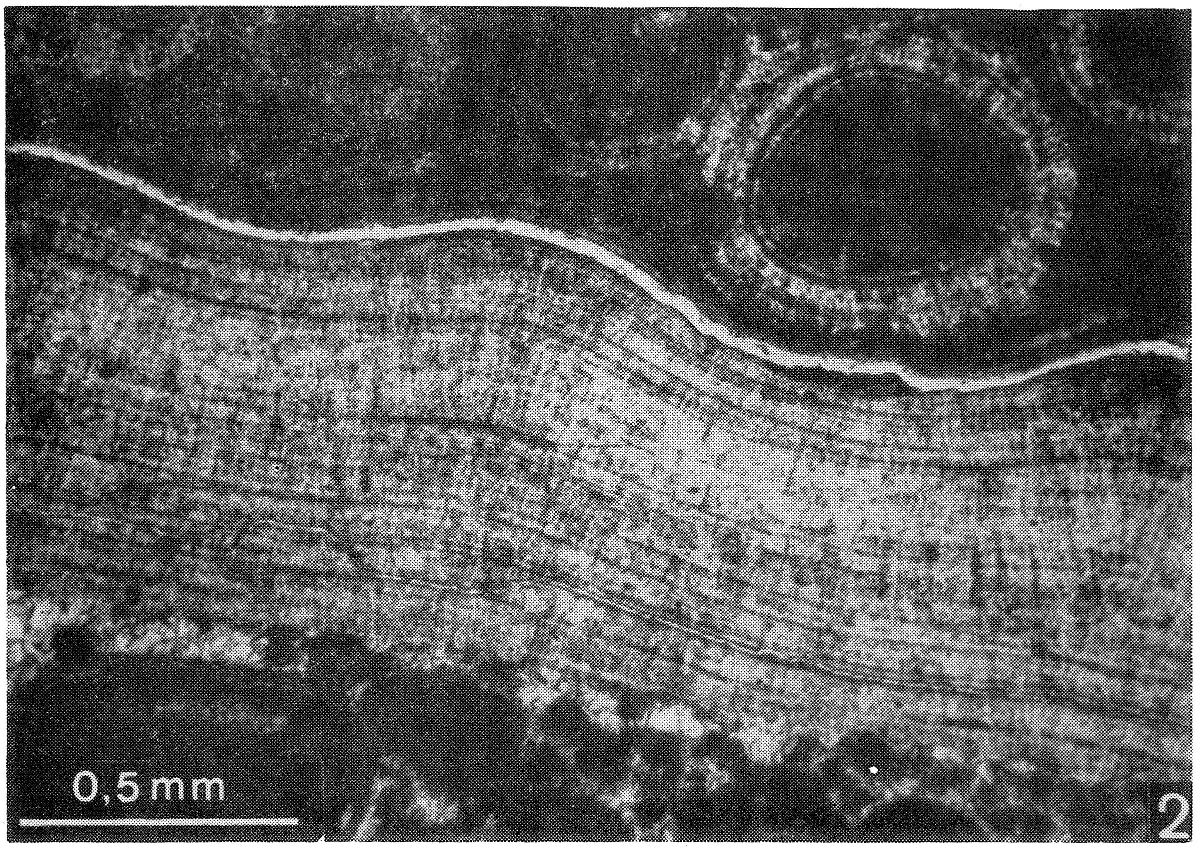
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