Annales Societatis Geologorum Poloniae (1992), vol. 62: 149 – 167
PL ISSN 0208-9068

GIANT-SCALE CROSS-BEDDED MIOCENE BIOCALCARENITES IN THE NORTHERN MARGIN OF THE CARPATHIAN FOREDEEP

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Łaptaś, A., 1992. Giant-scale cross-bedded Miocene biocalcarenites in the northern margin of the Carpathian Foredeep. *Ann. Soc. Geol. Pol.*, 62: 149 – 167.

Abstract: Biocalcarenite bodies with giant-scale cross-bedding occur along the southern margin of the Góry Świętokrzyskie mountains which during the Miocene bordered the sedimentary basin of the Carpathian Foredeep from the north. The biocalcarenite bodies occur in a zone about 25 km long and up to 3 km wide; their thickness attains 35 m. The biocalcarenite bodies are tripartite in vertical section – they consist of bottomset, foreset and topset divisions. The individual tabular sets of cross-strata in the foreset deposits are up to 17 m thick. The foreset cross-strata dip steeply (average value of the maximum dip of the foreset strata is 27°) southward, that is towards the Carpathian Foredeep. The topset deposits consist of horizontally stratified biocalcarenites up to 5 m thick. The bottomset deposits are either cross-stratified in various directions or massive; locally they form lenticular slumped bodies with erosional bases. The biocalcarenite bodies were deposited in a nearshore zone at the northern margin of the Carpathian Foredeep during the tectonic uplift of the of the Góry Świętokrzyskie. A longshore current flowing from NEE to SWW carried bioclastic debris eroded from the nearshore area. The current crossed obliquely the edge of an initial escarpment that was probably an E – W-oriented synsedimentary fault scarp. The bioclastic debris fell down at the upper edge of the scarp and was laid down parallel to the south-dipping scarp at the angle of repose. The low specific weight of the biocalcarenites grains could facilitate the formation of the giant-scale cross-stratified bodies.

Key words: Giant-scale cross-bedding, biocalcarenite, Miocene, Carpathian Foredeep

Manuscript received 2 March, 1989, revised accepted 24 February 1992

INTRODUCTION

The studied biocalcarenites belong to the sequence of Badenian siliciclastic sediments and limestones in the northern part of the Carpathian Foredeep (Central Paratethys). They occur south of the Góry Świętokrzyskie mountains (in many geological papers referred to under their translated name – the Holy Cross Mountains). During the Badenian, this part of the basin was a gulf open eastward, toward the Podolia, and closed on the west, near Kraków (Rögl & Steininger, 1984, p. 185).

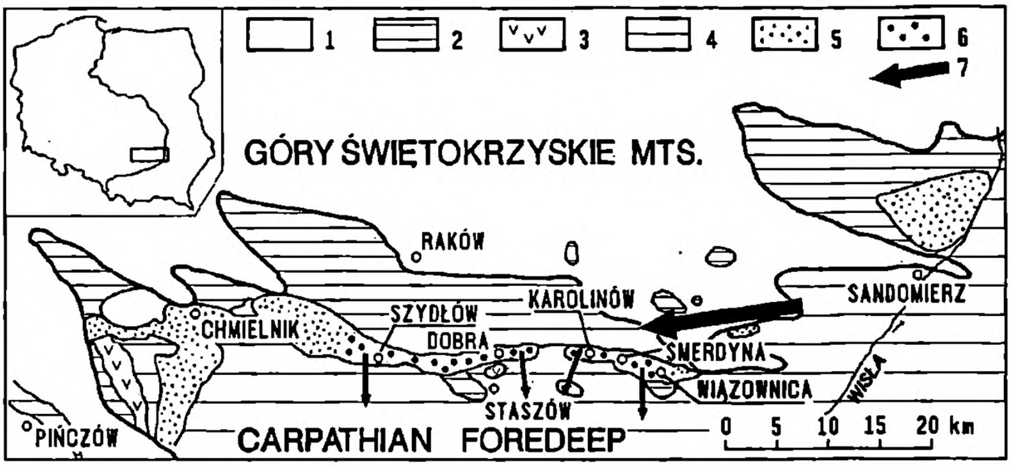

Fig. 1 Setting of the Badenian biocalcarenite bodies at the northern margin of the Carpathian Foredeep basin. Geological data from Radwański (1973) and geological maps 1:50 000 of Senkowicz (1958) and Romanek (1958) - modified. *1* – deposits older than Miocene; *2-6* Miocene: *2* – Pińczów formation (including red-algal-bryozoan limestones), *3* – Krzyżanowice formation (including gypsum), *4* – Machów formation, *5* – Chmielnik formation, *6* – biocalcarenite bodies in Chmielnik formation (arrows show mean dip azimuths of giant-scale cross-strata, *7* – inferred course of Badenian longshore current across area of probable primary extent of red-algal-bryozoan limestones of Pińczów formation

The biocalcarenites were called "detrital limestones" (Radwański, 1973; Rutkowski, 1976) and their origin was variously interpreted. The steeply dipping foreset strata were misinterpreted as an evidence of a tectonic dip of the Miocene deposits; Czarnocki (1923) maintained that the Miocene deposits in this area form a flexure striking parallel to the structural strike of the Góry Świętokrzyskie (Czarnocki, 1923, p. 3). Radwański (1973) attributed the origin of the cross-stratified limestones to the tectonic tilting of the nearshore "Miocene accumulation platform". Rutkowski (1976) concluded that these sediments were laid down "below an abrasion platform", by currents directed from the shore toward the basin. Czapowski (1984) considered the detrital limestones as barrier deposits.

This paper presents the description and sedimentological interpretation of the biocalcarenite bodies. The author studied the biocalcarenites in the main area of their occurrence, i.e. near Staszów, from Szydłów in the west to Smerdyna on the east (Fig. 1), in large quarries, whose walls are up to 20 m high and 1,000 m long.

GEOLOGICAL SETTING

STRATIGRAPHY

No formal lithostratigraphical scheme has been yet established for the Miocene sediments in the Carpathian Foredeep. The biocalcarenites described

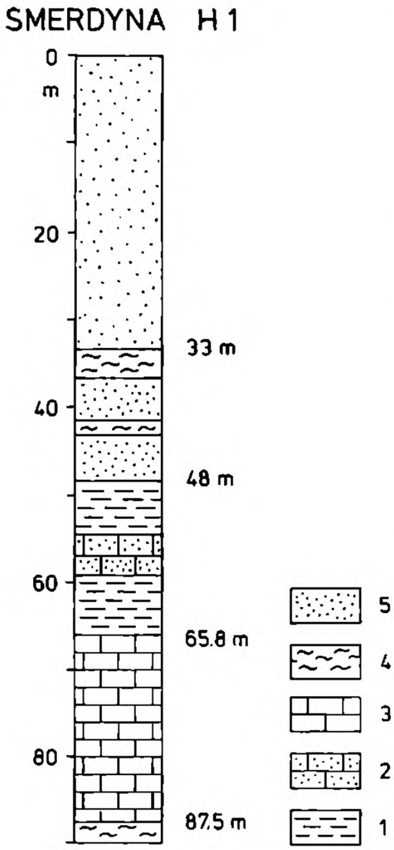

Fig. 2 Section of borehole Smerdyna H-1 at Karolinów. *1* – marls, *2* – sandstones, *3* – red-algal-bryozoan limestones of Pińczów formation, *4* – clays, *5* – biocalcarenite bodies

in this paper belong to the so called Chmielnik formation, described by Alexandrowicz *et al.* (1982 – a proposal of lithostratigraphical division) as Upper Badenian-Lower Sarmatian gravels, sands, conglomerates, sandy limestones and detrital limestones. Recently, Dudziak & Łaptaś (1991), basing on the study of calcareous nannoplankton, dated the Chmielnik formation at the Middle Miocene zones NN5 and NN6, i.e. the Badenian of the Paratethys (see Vass, 1986).

A deep water equivalent of the Chmielnik formation are the sandy and clayey sediments of the Machów formation (Alexandrowicz *et al.*, 1982); the two formations interfinger laterally.

Both formations overlie Middle Badenian evaporite sediments of the Krzyżanowice formation – gypsum in the nearshore part of the basin, and salt-bearing sediments locally in the central part (Alexandrowicz *et al.*, 1982).

The evaporite formations are underlain by red-algal/bryozoan/foraminiferal limestones and marls ("Pińczów limestones" or "Lithothamnium limestones") and sandy deposits (Lower Badenian Pińczów formation of Alexandrowicz *et al.*, 1982). These sediments could shed organic calcareous material for the studied biocalcarenites of the Chmielnik formation during the uplift of the Góry Świętokrzyskie.

LITHOLOGY

The biocalcarenites of the Chmielnik formation are built of rounded fragments of red-algal thalli (including rhodoliths) and fragments of bryozoan colonies (Pl. IV: 1, 2, 4). Less numerous are discoidal foraminifers, serpulae and fragments of pelecypod shells. In addition to the organic debris there occur well rounded limestone fragments. The dominant grain size (0.5 - 1.5 mm) falls in the range of coarse sand, coarser grains, up to 2 cm, occur sporadically.

Fine quartz sand grains (0.1 - 0.3 mm) occur as a small admixture (the biocalcarenites include only about 2% of HCl insoluble components).

The bulk of the clastic material in the biocalcarenites is derived from the

Pińczów formation (mainly from red-algal/bryozoan/foraminiferal limestones), laid down earlier in the same basin. Older clastic material (Jurassic and Cretaceous limestones and quartz sand) is derived from the land area of the Góry Świętokrzyskie.

The studied biocalcarenites are friable, porous and they split readily along the planes of stratification. Cement is sparse, it occurs as thin rims (0.01 - 0.03 mm) consisting usually of two parts (Pl. IV: 4): an inner rim of fibrous cement, indicative of marine phreatic conditions; and outer finely crystalline drusy cement that forms in vadose conditions – "dogtooth cement" of Flügel (1982, p. 70). The spaces among the cement-rimmed grains are void. The grains themselves, mainly the fragments of red-algal thalli, are also porous.

STRUCTURE OF THE BIOCALCARENITE BODIES

Distinctive lenticular bodies of cross and horizontally stratified biocalcarenites, up to 30 m thick (Fig. 2), occur (Fig. 1) over a distance of about 25 km in an irregular belt up to 3 km wide, parallel to the feet of the Góry Świętokrzyskie.

The biocalcarenite bodies display a tripartite structure: their uppermost parts consist of horizontally stratified topset packages, up to 5 m thick; their main middle parts consist of giant-scale cross-stratified foreset packages (5 to 20 m thick), and the lowermost parts are variously developed bottomset deposits, up to 15 m thick.

TOPSET DEPOSITS

Topset deposits are rarely visible, probably they were largely removed by later erosion. They occur at the tops of some outcrops, as horizontally stratified biocalcarenite packages above the steeply inclined foreset cross-strata. The regularly spaced horizontal strata are 10 to 20 cm thick and are built of limestone grains of fine sand to fine gravel size. No internal lamination or gradation was observed within the strata. The base of the topset deposits is erosional, the foreset cross-strata are truncated by a flat erosional surface, horizontal or slightly inclined (up to 5°) to the south. The topset strata overlie this surface concordantly (Pl. III: 1, 2).

FORESET DEPOSITS

The foreset deposits are steeply dipping sets of giant-scale cross-stratified biocalcarenites, usually more than 5 m thick. In most quarries the foreset deposits are incompletely exposed, without their tops and bottoms (Pl. I: 1).

The total thickness of the foreset deposits seems to vary between 5 and 20 m. The greatest thickness of the giant-scale cross-stratified foreset deposits was observed at Smerdyna; it equals 17 m with the top not exposed.

The azimuths of dip of the foreset cross-strata fall between 150° and 230°, and the average value of the maximum dip of foreset strata is 27°.

A typical set of the foreset giant-scale cross-strata is built of two alternating types of strata referred to respectively as A-type strata – thicker and finer-grained, and B-type strata – thinner and coarser-grained (Pl. II: 2).

A-type strata are 20 to 40 cm thick. They are planar, parallel to one another. No lateral bending was observed in these strata. Their continuity exceeds the outcrop limits (tens of metres along the dip and up to a hundred meters along the strike). The strata are built of medium-grained to very coarse-grained sand.

B-type strata 2 to 10 cm thick, are coarser grained – from very fine to medium gravel (up to 2 cm in diameter). The grains are poorly rounded, whole shells of oysters and pectenids as well as larger rhodolith fragments are frequent. The strata are perfectly continuous only in the direction of dip. Laterally, the gravelly strata change in thickness, so that some of them pinch out in 2 - 3 m and are replaced by other similar strata. So it seems that the B-type strata are narrow tongues, a few metres in width.

Individual strata of the A and B types or their sets alternate in the foresets. A general rule in the structure of the giant-scale foreset cross-strata is the rhythmical alternation in the grain-size of the carbonate material – sand-size material in A-type strata, and gravel-size material in the B-type strata.

The grains of quartz sand occur as a small admixture in the material of both types of cross-strata (up to 2% of HCl insoluble components). These grains are well rounded, 0.1 - 0.3 mm in size, regardless of the grain-size of the host biocalcarenite.

Terminations of cross-strata

As was already mentioned, most exposures show only the middle part of steeply dipping, flat, parallel foreset cross-strata, hence the data on the lower and upper terminations of the foreset strata are fragmentary.

Where the topset strata are exposed, one can see that the foreset cross-strata are truncated at top by a flat erosional surface, horizontal or gently dipping to the south. No marked relief was observed on this surface. Exceptionally (e.g. in the southeast part of the quarries at Smerdyna) non-erosional tops of the giant-scale cross-strata are preserved, gradually passing upwards to horizontal topset strata (Fig. 3; Pl. I:2).

Where the bottom of the foreset deposits is exposed one can see that the basal contacts of foreset cross-strata are tangential (most A-type strata) or angular (most B-type strata). A few A-type and B-type strata pinch out against the bottom or before reaching it (Figs 4, 7B).

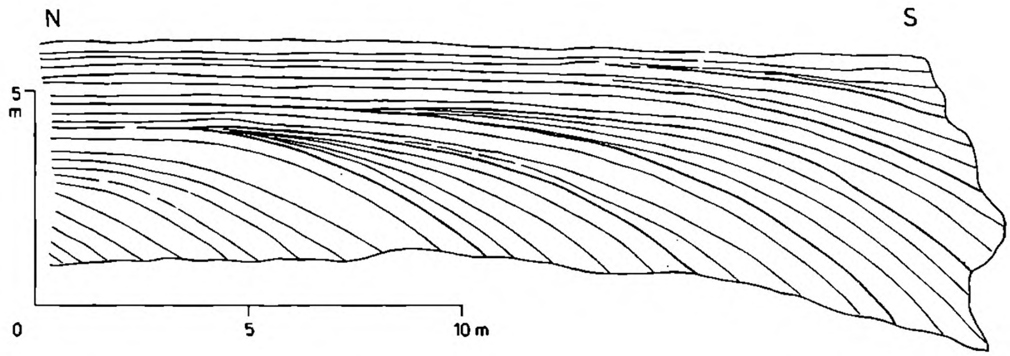

Fig. 3 Non-erosional boundary between topset and foreset deposits. Note convex-up shapes of cross-strata. Smerdyna

Disturbances of cross-stratification

Intrastratal plastic deformation of the foreset cross-strata is occasionally observed near the top of the foreset deposits. Some groups of strata are folded within a generally non-folded sequence (Fig. 5). The thickness of the folded part of the foreset strata attains up to 6 m, and the deformations may continue (or repeat) laterally over a distance of a hundred metres.

Erosional channels are exceptionally found in the lower part of the foreset deposits (e.g. at Karolinów). The channel shown in Fig. 6 and Pl. III: 2 is about 1 m deep, and it was observed for ca. 7 m along its axis. It is filled with trough cross-stratified biocalcirudite B-type strata. The axis of the trough dips at ca. 15° towards the south (azimuth 185°).

BOTTOMSET DEPOSITS AND SUBSTRATE OF GIANT-SCALE CROSS-STRATIFIED BODIES

Only top parts of the bottomset deposits are known from outcrops; these are massive or low-angle cross-bedded biocalcarenites.

Massive, lenticular biocalcarenite beds, up to 4 m thick are visible at the bottoms of some quarries at Karolinów (Figs 6, 7) and Szydłów. The visible extent of the lenses in the direction of dip of the overlying foreset cross-strata does not exceed 30 m, and in the transverse direction they can be observed for more than 10 m (to the outcrop limits). The lenses have flat tops gently dipping to the south, and uneven, convex-downward bottom. The grain size is from 1 mm to several centimetres, well mixed (Pl. IV: 3). The lower boundaries of the lenses are erosional. The described features are indicative of the mass-flow origin of the biocalcarenite lenses.

The bottomset deposits below the mass-flow lenses were observed only at Karolinów. These are cross-stratified commonly at low angle, biocalcarenites, a few metres thick (Figs 6, 7). The values of both, the azimuths of dip and dip angles of in bottomset cross-strata are more variable than in the foreset de-

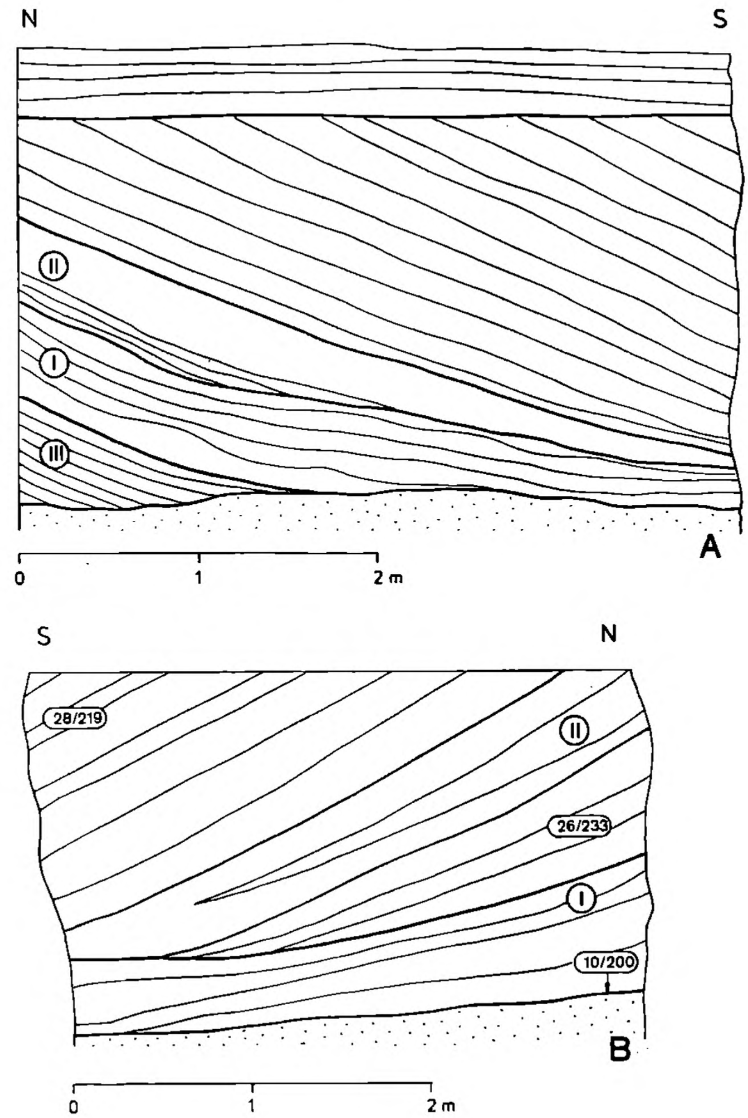

Fig. 4 Lower terminations of foreset cross-strata in Karolinów. Massive lenses of bottomset deposits (*dotted*) are visible at bases. Terminations: *I* – tangential; *II* – pinching-out; *III* – angular. Note horizontally stratified topset deposits in the upper part of A and erosional truncation of foreset strata. True dips and dip azimuths are marked at B.

posits. Similarly as in the foreset deposits, two types of strata may be distinguished. The thicker ones – 10 - 20 cm – are composed of fine to coarse sand grains, and the thinner ones with grains up to the fine gravel size. Both types of strata include increased amount of fine quartz sand (above 20%). The grain-size is generally smaller than in the foreset cross-strata.

The lower part of bottomset deposits substrate of the whole biocalcarenite body were observed only in one borehole (Smerdyna H-1, Fig. 2) situated between Smerdyna and Karolinów. The biocalcarenite sediments are there 33 m thick. Clayey and sandy deposits, ca. 30 m thick, occur below the biocalca-

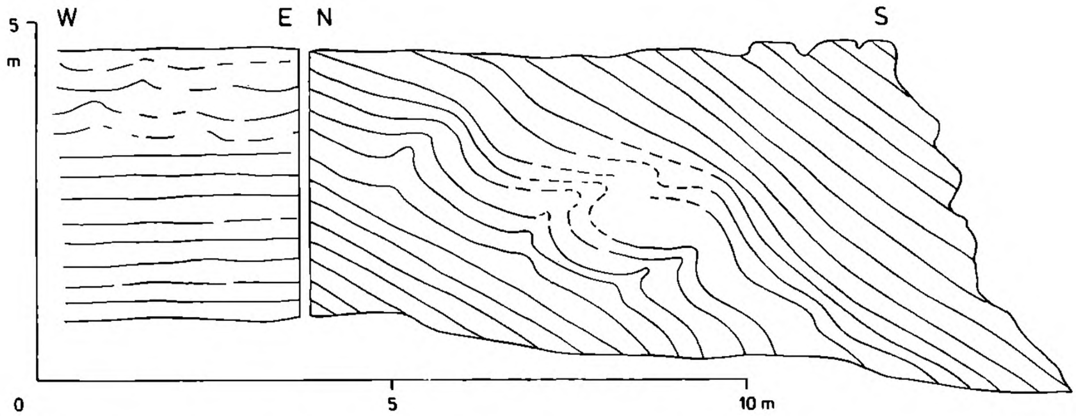

Fig. 5 Folded deformations of foreset cross-strata generated by slump on slope of foreset body. See text for discussion. Smerdyna

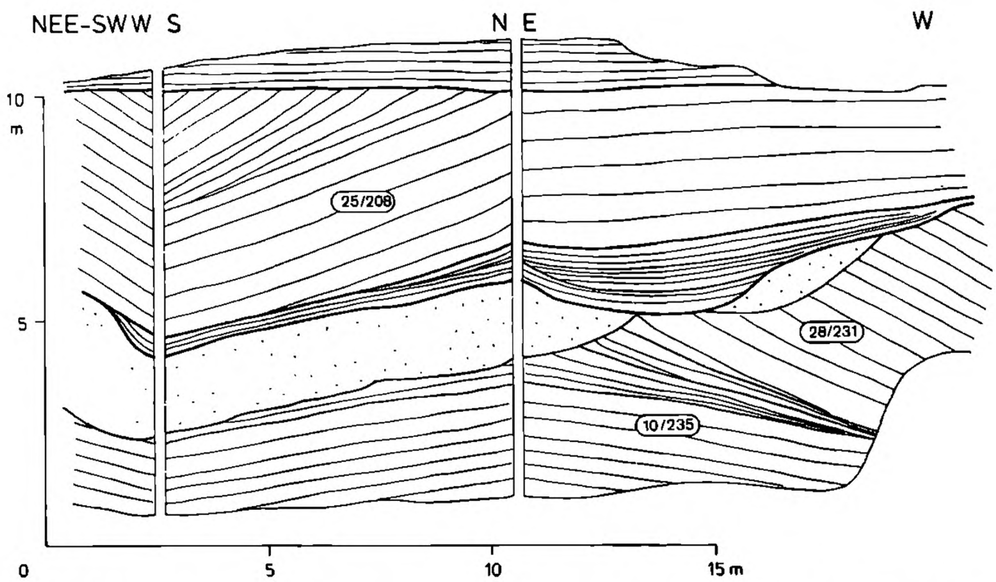

Fig. 6 Tripartite structure of biocalcarenite body. From the bottom of section: cross-laminateded sets and lenses of slumped material – upper part of bottomset deposits; giant-scale cross-stratified foreset deposits; horizontally laminated bottom part of topset deposits. Erosional trough is visible between bottomset and foreset deposits. True dips and dip azimuths are marked. Karolinów

renites. Both types of deposits alternate in the transition zone. The whole thickness of the bottomset deposits attains thus about 15 m.

Below the bottomset deposits and the clayey and sandy deposits, at the depth of 65 m, there lie red-algal limestones about 20 m thick, possibly belonging to the so called Pińczów formation. Their position is about 60 m lower than that of similar deposits cropping out to the north of the biocalcarenite bodies, between them and the feet of the Góry Świętokrzyskie.

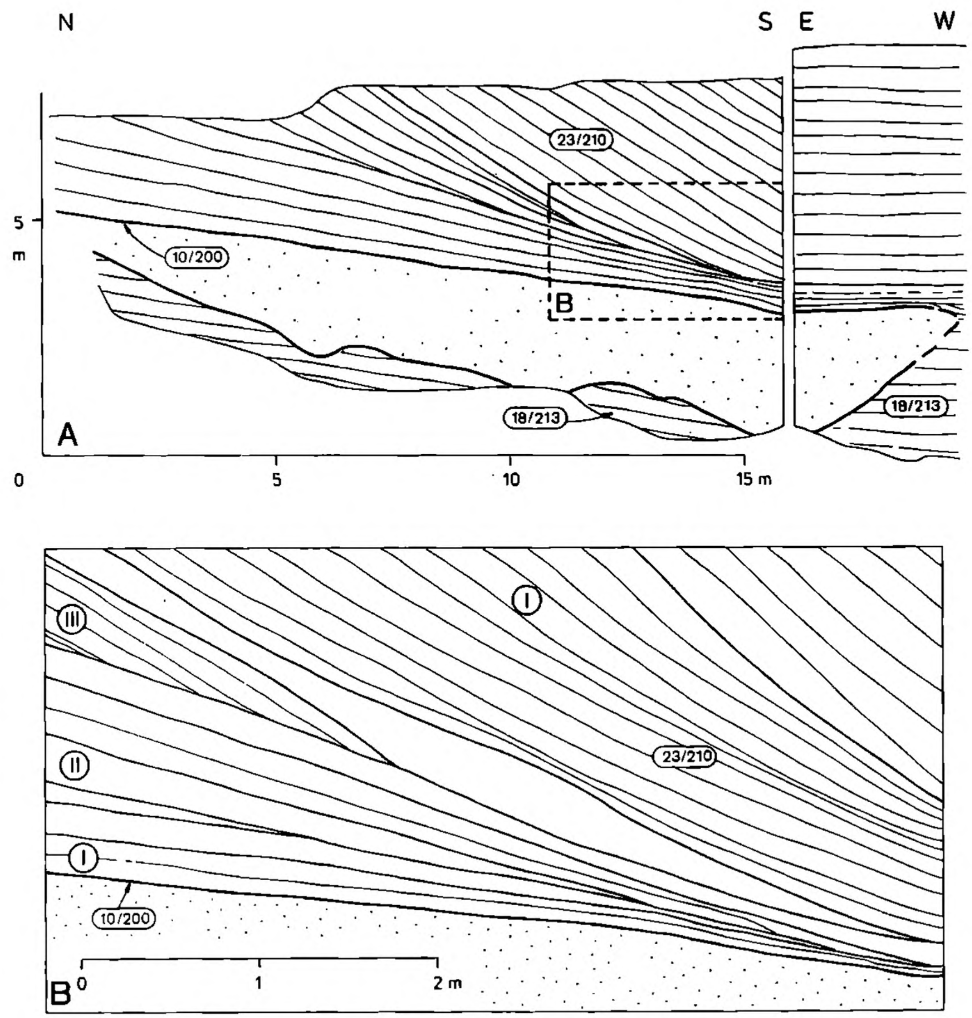

Fig. 7 A – slump lens (*dotted*) of bottomset deposits at the base of foreset deposits. Note uneven erosional contact of lens mass with underlying low-angle cross-stratified set. True dips and dip azimuths are marked. B – detail of figure A, showing lower terminations of some lamina sets at foreset/lens boundary (legend see Fig. 4A). Karolinów

AZIMUTHS AND DIPS OF CROSS-STRATA

The measurements were made in all quarries where the biocalcarenites were exposed, so that all the outcrop areas were included. In most cases the inclinations of the steepest segments of cross-strata were measured in the walls (apparent dips) together with the azimuths of the walls. The true dips and dip azimuths were then calculated. Only few readings were directly taken on the cross-stratification surfaces.

The results for foreset and bottomset deposits are presented separately, in geographical arrangement within each group.

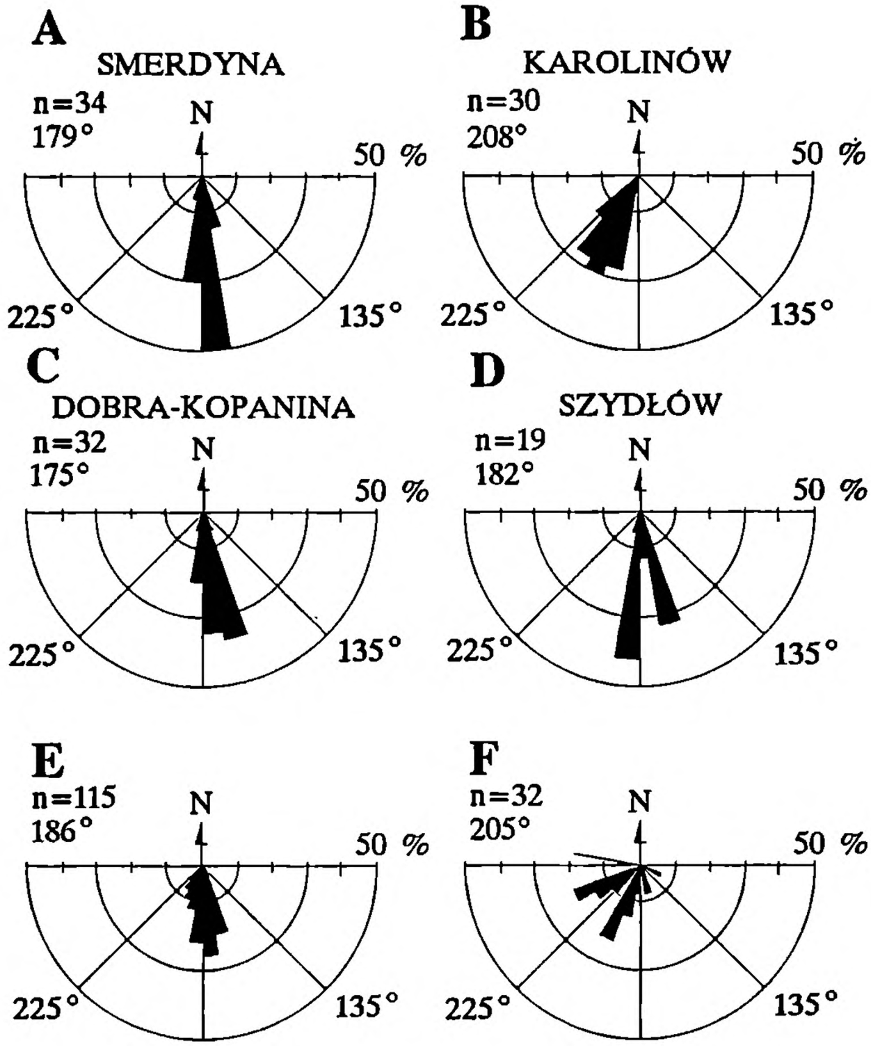

Fig. 8 True dip azimuths of cross-strata. A-D – giant-scale foreset strata in four outcrop areas, E – summary diagram for A-D, F – bottomset deposits (data mainly from Karolinów). Number of measurements (*n*) and average value of dip azimuths for every region are marked

Foreset cross-strata

Azimuths of dip. The azimuths of dip of foreset strata in four main outcrop areas are shown in Fig. 8 A-D. The foreset strata dip almost invariably to south. The mean azimuth for all measurements is 186° and the individual measurements do not depart from this value by more than 35°. Noticeable is the lack of directions opposite or transverse to the general direction of dip. The mean values for each area do not depart by more than 20° from the mean for the whole area.

Dip angle. The results of measurements of maximum dips of cross-strata

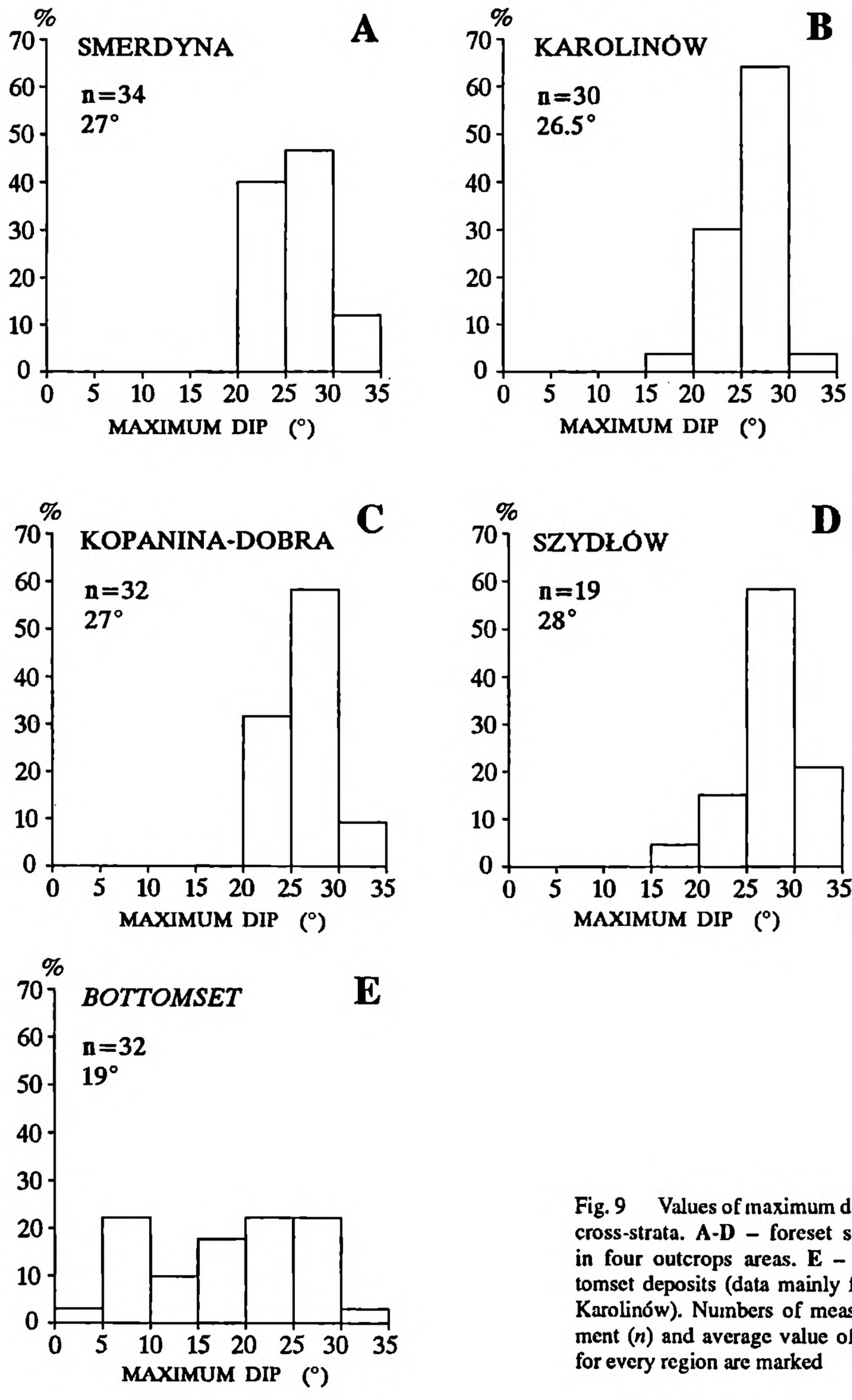

Fig. 9 Values of maximum dip of cross-strata. A-D – foreset strata in four outcrops areas. E – bottomset deposits (data mainly from Karolinów). Numbers of measurement (*n*) and average value of dip for every region are marked

are plotted in Fig. 9. Steep angles, close to the angle of repose, strongly prevail at all outcrop areas.

The measurements are not corrected for tectonic tilt which may attain 5° to the south. Hence the actual dips of cross-strata may be less by this amount.

Bottomset deposits

The azimuths of dip vary from 113° to 276°, and dip values – from 5° to 31° (Figs 8F, 9E). More than a third of all azimuth measurements are deflected to the west as compared to those in the foreset deposits. Most values of maximum dips are less than 20°.

ORIGIN OF CROSS-STRATA

The giant-scale cross-strata dipping at an angle close to the angle of repose could originate in conditions of flow detachment at the margin of a foreset slope. The aggradation of a foreset slope is due to two processes – grainfall and grain avalanching (Jopling, 1966; Hunter, 1977; Allen, 1982, vol. II, p. 141).

Most sets of B-type gravelly strata and some sets of A-type strata – whose basal contacts are mainly angular or pinching out – are probably deposited by avalanching grainflows. The sets of cross-strata tangentially flattening near the bottom (mainly type A) were deposited from grainfall, probably when the height of the foreset slope diminished (Jopling, 1965; Allen, 1982, vol. II, p. 169), e.g. due to the accumulation of slumped material at the toe of the slope (Karolinów). Most strata, however, do not display features that would permit one to distinguish between the two depositional processes, and to restore the ratio of the current depth above the top of the slope to the height of the giant-scale cross-stratified sediment body. Sedimentation by grainfall was probably rhythmically interrupted by grain avalanching. A constant, high angle of the slope was maintained in this way.

The folded deformations of the giant-scale cross-strata in the biocalcarenite bodies of the southern foreland of the Góry Świętokrzyskie were interpreted as load-casts (Rutkowski, 1976) or as synsedimentary disturbances formed by sediment slumping on the slope of "accumulation platform" (Czapowski, 1984, p. 189). These "folded" structures represent plastic deformation of cross-laminae (Allen & Banks, 1972; Allen, 1982, vol. II, p. 386). They could be formed in laminae underlying the front of the foreset slope, due to slumping of a large mass of granular material along the slope, from its margin to the toe. The slumping mass cut channels in the sediment in front of the slope toe, thus forming the massive biocalcarenite lenses with flat horizontal tops and uneven, erosional soles. The continuing processes of the slope aggradation – grainfall and avalanching – obliterated the traces of the erosional surface of the slump on the slope. The successive foreset strata encroached on the top surface of the slump lenses with strong flattening near the bottom.

The convex upward termination of foreset cross-strata, without their erosional truncation, has its equivalent in Gilbert-type deltas. According to Colella (1988, p. 40), foreset laminae terminate in this way when the influence of waves is prevailing over the current strength on delta plain when the basement of the delta is subsiding.

The occurrence of fairly numerous large slumps from the foreset slope, of large erosional channels, and the occurrences of convex upward terminations of foreset strata, all may indicate tectonic mobility of the basement beneath the biocalcarenite bodies.

The presence of various bottomset deposits beneath the foreset deposits indicates that the transporting current was able to carry the finer fraction to the forefront of the foreset slope.

ORIGIN OF THE BIOCALCARENITE BODIES

The biocalcarenite bodies formed during the Middle Miocene in the nearshore zone of the northern part of the Carpathian Foredeep basin. The basement was tectonically mobile, in connection with the uplift of the Góry Świętokrzyskie.

The biocalcarenite material was derived from calcareous and marly red-algal and bryozoan sediments (Pińczów formation of Alexandrowicz *et al.*, 1981) deposited earlier in the same basin (Fig. 1). Only a small part of the material comes from pre-Tertiary rocks of the Góry Świętokrzyskie.

The giant-scale cross-stratified bodies with steep foreset slopes formed due to current detachment over the upper edge of the slope. The depositional current could be a longshore current, probably entering the basin along the southern margin of the Góry Świętokrzyskie from the northeast (the basin formed a kind of a gulf open towards the east – Rögl & Steininger, 1984, p. 185). The strongly elongate shape and the palaeoshoreline-parallel alignment of the biocalcarenite bodies may suggest that they formed as a barrier due to the action of the longshore current (as concluded by Czapowski, 1984). However, one important feature of the biocalcarenite bodies, not reported by the authors who describe barrier deposits (Allen, 1982, vol. II; Mc Cubbin, 1982; Kumar & Sanders, 1975; Johannessen & Nielsen, 1986), is the constant dipping direction of the giant-scale stratification, perpendicular to the elongation of the whole sedimentary body, and directed basinward (cf. figs. 1, 8). Moreover, lagoons should exist between the barriers and the land of the Góry Świętokrzyskie. The only one fossil example of similar giant-scale cross-bedded bodies known to the author are Cretaceous sandstones in the Góry Stołowe, Sudetes, Poland (Jerzykiewicz, 1968; Wojewoda 1986). Wojewoda (1986) concluded that the giant-scale cross-bedded terraces formed by interaction of tectonical and sedimentary processes.

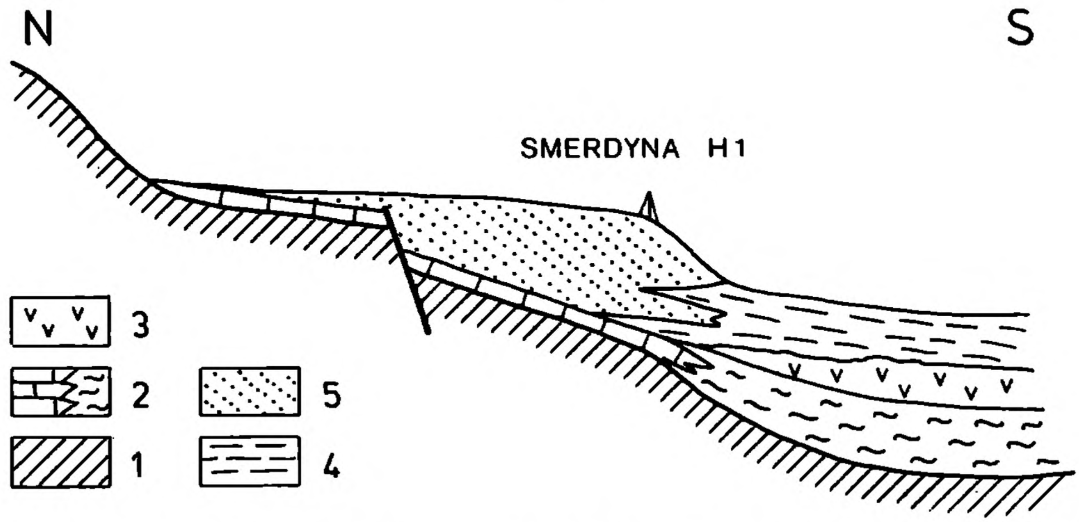

Fig. 10 Simplified cross-section of biocalcarenite body between Karolinów and Smerdyna. *Thick line* – synsedimentary fault scarp (initial slope of giant-scale foreset cross-strata). *1* – deposits older than Miocene; *2-5* – Miocene: *2* – red-algal-bryozoan limestones, marls and sands (Pińczów formation), *3* – gypsum (Krzyżanowice formation), *4* – clayey and sandy deposits of Machów formation, *5* – biocalcarenite body

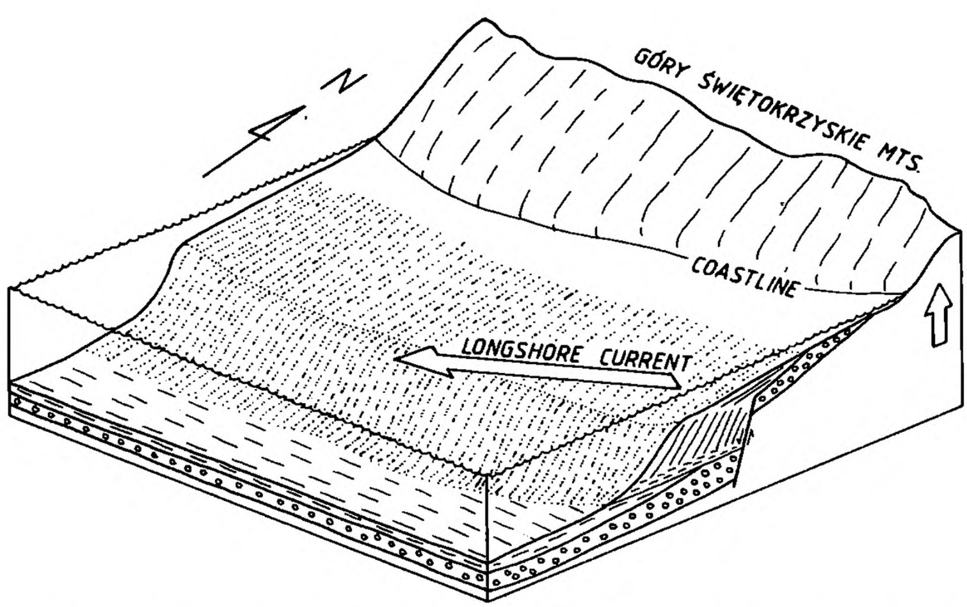

Fig. 11 Deposition of giant-scale cross-stratified biocalcarenite bodies along syndepositional fault-scarp in northern near-shore zone of Carpathian Foredeep basin in Middle Miocene. Giant-scale foreset cross-strata are dipping south in accordance with facing of fault scarp. Deposits of Pińczów formation (*circles*) and Machów formation (*dashes*) are marked beneath the biocalcarenite body

The biocalcarenite bodies of the southern margin of the Góry Świętokrzyskie formed at the boundary between the shallow and deep (tectonically lowered – borehole H-1)) zones of the basin. Therefore the initial foreset slopes could be fault scarps parallel to the shoreline. It may be suggested that a longshore current transported material shed from the abrasion zone obliquely towards the SWW over the edge of a fault scarp parallel to the axis of the Góry Świętokrzyskie (Figs 10, 11).

The material supplied by the current was accumulated on a terrace above the fault scarp as the topset deposits, and on its slope – as foreset deposits. The joint action of grainfall and grainflows resulted in the aggradation of the foreset slope perpendicularly to the initial fault scarp. The foreset cross-strata in the whole area of their occurrence acquired thus a uniform, southward dip, controlled by the fault scarp. The tectonical mobility of the basement resulted in numerous slumps, recorded by the folded slope cross-strata.

Bottomset deposits are built partly of massive sediments slumped from the slope, partly of the sediments laid down at the forefront of the advancing foreset slope. The latter are fine cross-stratified biocalcarenites with quartz sand admixture. Palaeocurrent directions are close to that of the inferred longshore current direction (SWW, see Fig. 8 F). Nevertheless a mechanism of their deposition is not clear yet. The biocalcarenites of the bottomset deposits interfinger with the clayey and sandy deposits of the deeper parts of the basin.

An important factor favouring the formation of the studied biocalcarenite bodies was the low specific weight of the organogenic calcareous grains. The low weight positively influenced on the amount of material transported by the current, on the distance of transport, the length of grain travel over the bottom after the place of the current detachment, and on the angle of repose.

ACKNOWLEDGEMENTS

I thank Dr L. Chudzikiewicz for the critical review of the manuscript, as well Drs S. Porębski and G. Haczewski for their help in the naming and interpretation of sedimentary structures typical of clastic sediments, encountered in the studied limestones.

This research was carried out within project CPBP 03. 04.

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Streszczenie

NASYPY PRZEKĄTNIE WIELKOSKALOWO WARSTWOWANE W MIOCEŃSKICH BIOKALKARENITACH POŁUDNIOWEGO OBRZEŻENIA GÓR ŚWIĘTOKRZYSKICH

Andrzej Łaptaś

W środkowomioceńskich osadach klastyczno-wapiennych południowego przedpola Gór Świętokrzyskich występują biokalkarenity zawierające warstwowania przekątne wielkoskalowe. Według wstępnej propozycji podziału litostratygraficznego (Alexandrowicz *et al.*, 1982) badane osady są częścią tzw. formacji z Chmielnika, wieku górny baden - dolny sarmat. Według ostatnich badań (Dudziak & Łaptaś, 1991) biokalkarenity powstawały w poziomach NN5 i NN6 (środkowy miocen - baden).

Biokalkarenity tworzą stosunkowo wąski (1 - 3 km) pas równoległy do stoku Gór Świętokrzyskich (Fig. 1), o łącznej rozciągłości około 25 km. Warstwowania wielkoskalowe występują w poziomo zalegających nasypach i mają dość stały, stromy kąt nachylenia lamin (Fig. 9 – średnia wartość kąta nachylenia najstromszych odcinków lamin wynosi 27°), skierowanych przeważnie ku południowi, czyli od dawnej linii brzegowej na stokach Gór Świętokrzyskich ku osi basenu mioceńskiego (Fig. 8). Miąższość pojedynczych tabularnych pakietów wielkoskalowych dochodzi do 17 m (Pl. II: 1), a ich lateralna rozciągłość sięga 2 - 3 km, przy rozpiętości wzdłuż kierunku progradacji do 1 km. Miąższość całych nasypów jest rzędu 30 m (wiercenie Smerdyna H-1, Fig. 2)

W materiale ziarnistym biokalkarenitów zdecydowanie dominują fragmenty organiczne, krasnorostowo-mszywiołowe nad klastami wapieni starszych i skał innych (Pl. IV: 1-3). Materiał ten ma bardzo niski ciężar objętościowy w porównaniu z piaskiem kwarcowym.

Nasypy biokalkarenitowe wykazują trójdzielną budowę – można w nich wyróżnić topset, foreset i bottomset (Fig. 6; Pl. III: 2).

Topset nasypów (często usunięty przez późniejszą erozję) – poziomo warstwowane pakiety biokalkarenitowe miąższości do 5 m – ma albo erozyjny, równy spąg (Karolinów, Dobra), albo jego laminy mogą przechodzić w sposób ciągły, wypukły w laminy foresetu (Smerdyna – Fig. 3; Pl. III: 1).

Foreset stanowią wspomniane pakiety wielkoskalowe, warstwowane przekątnie stromo, o stałym nachyleniu lamin ku S. Miąższość foresetu waha się od 5 do ok. 20 m. Pakiety są zbudowane przez dwa typy lamin: laminy typu A (miąższości 20 - 40 cm, o przebiegu planarnym, równoległym, ciągłości do kilkudziesięciu metrów wzdłuż nachylenia i do 100 m lateralnie, o ziarnie wielkości od średniego do bardzo grubego piasku) i laminy typu B, miąższości 2 - 10 cm, o podobnej kontynuacji wzdłuż nachylenia, ale tylko kilkumetrowej ciągłości lateralnej, o ziarnie grubszym – od bardzo drobnego do średniego żwiru (do 2 cm średnicy) (Pl. I: 1; II: 2). Ziarna piasku kwarcowego występują jako drobna domieszka w materiale lamin obydwu typów. Ziarna te są dobrze obtoczone, mają wielkość od 0,1 do 0,3 mm, niezależnie od frakcji biokalkarenitu w którym występują. Sedymentacja tych pakietów mogła się odbywać w warunkach odrywania się prądu na krawędzi stoku czołowego nasypów (Jopling, 1966; Hunter, 1977; Allen, 1982 vol. II str. 141). Prawdopodobnie sedymentacja z opadu ziarn (np. lamin typu A tangencjalnie spłaszczających się przy spągu) była rytmicznie przerywana spływami ziarnowymi (tworzącymi m.in. klinowato zakończone zestawy lamin typu A oraz żwirkowate laminy typu B o kątowym kontakcie ze spągiem) (Figs: 4, 7). W ten sposób utrzymywał się stały, stromy kąt nachylenia lamin stoku.

Bottomset nasypów to słabo rozpoznane w odsłonięciach osady masywnych ławic biokalkarenitowych i soczewek osuwiskowych (o ziarnie różnorodnej wielkości), oraz pakiety różnokierunkowe (o ziarnie drobniejszym od żwirowego, zawierające niekiedy znaczniejszą domieszkę drobnego piasku kwarcowego) (Figs: 4, 6, 7). Są to prawdopodobnie osady zbudowane z materiału wynoszonego przez prąd poza nasyp. Osady bottomsetu mają zapewne powyżej 15 m miąższości.

Źródłem materiału ziarnistego biokalkarenitów były wapienie i margle krasnorostowo-mszywiołowo-otwornicowe ("wapienie pińczowskie" lub inaczej "wapienie litotamniowe"), tzw. formacji z Pińczowa – wieku wczesnobadeńskiego (Alexandrowicz *et al.*, 1982), niszczone w strefie brzeżnej zbiornika w trakcie tektonicznego wypiętrzania Gór Świętokrzyskich w środkowym miocenie. Wapienie te występujące pod osadami całego nasypu, mają wyraźnie obniżoną pozycję (około 60 m), w stosunku do pozycji analogicznych utworów występujących na powierzchni na północ od nasypu, pomiędzy nasypem a podnóżem Gór Świętokrzyskich.

Nasypy powstawały w środowisku przybrzeżnym, na granicy strefy płytszej i strefy głębszej basenu (obniżonej tektonicznie) i progradowały na osady ilasto-piaszczyste tam powstające. Obniżanie dna Zapadliska przebiegało prawdopodobnie w sposób tarasowy; zrzut tektoniczny bardziej wewnętrznej części wybrzeża spowodował utworzenie podmorskiej skarpy, równoległej do wybrzeży Gór Świętokrzyskich, o stromym stoku nachylonym ku osi basenu (Figs: 10, 11).

Prąd przybrzeżny ze wschodu spowodował powstawanie nasypów o kształcie i kierunkach warstwowań narzuconych przez warunki tektoniczne. Materiał niesiony przez prąd gromadził się na tarasie tektonicznej skarpy (tworząc topset nasypów), oraz na jej stoku. Współdziałanie procesów opadu ziarnowego i spływów ziarnowych powodowało przyrastanie stoku czołowego nasypu równolegle do inicjalnej skarpy tektonicznej, a skośnie do kierunku prądu. Laminy foresetu nasypów na całym obszarze południowego przedpola Gór Świętokrzyskich uzyskiwały w ten sposób jednakowy, stały kierunek zapadania na południe, wymuszony przez stok tektonicznej skarpy.

Powstanie nasypów biokalkarenitowych z wielkoskalowymi warstwowaniami przekątnymi mogło być ponadto znacznie ułatwione dzięki znacznej lekkości materiału ziarnowego biokalkarenitów (w porównaniu do ziarna kwarcowego).

EXPLANATION OF PLATES

Plate I

General views of quarry walls at Smerdyna.

1 — Giant-scale cross-stratification (middle part of foreset). Visible fragment of exposure is 8 m high and 20 m long.

2 — Convex-up bending of cross-strata at topset/foreset boundary. Mean height of exposure face is 4 m. Handle of geologic hammer (encircled) is 35 cm long.

Plate II

1 — Frontal view of giant-scale cross-stratification – cross-strata are dipping toward the observer. Maximum height of exposure is 18 m. Smerdyna.

2 — Detail of giant-scale cross-stratification on fresh rock surface. A-type strata (sandy fraction) and B-type (gravelly fraction) are marked. Visible length of measuring tape is 35 cm. Smerdyna.

Plate III

1 — Horizontally stratified topset deposits (upper part of exposure) lying on evenly truncated giant-scale foreset cross-strata. Height of exposure is 5 m. Karolinów.

2 — Fragment of exposure from Figure 7. Height of exposure corner in the background is ca 7 m. Karolinów.

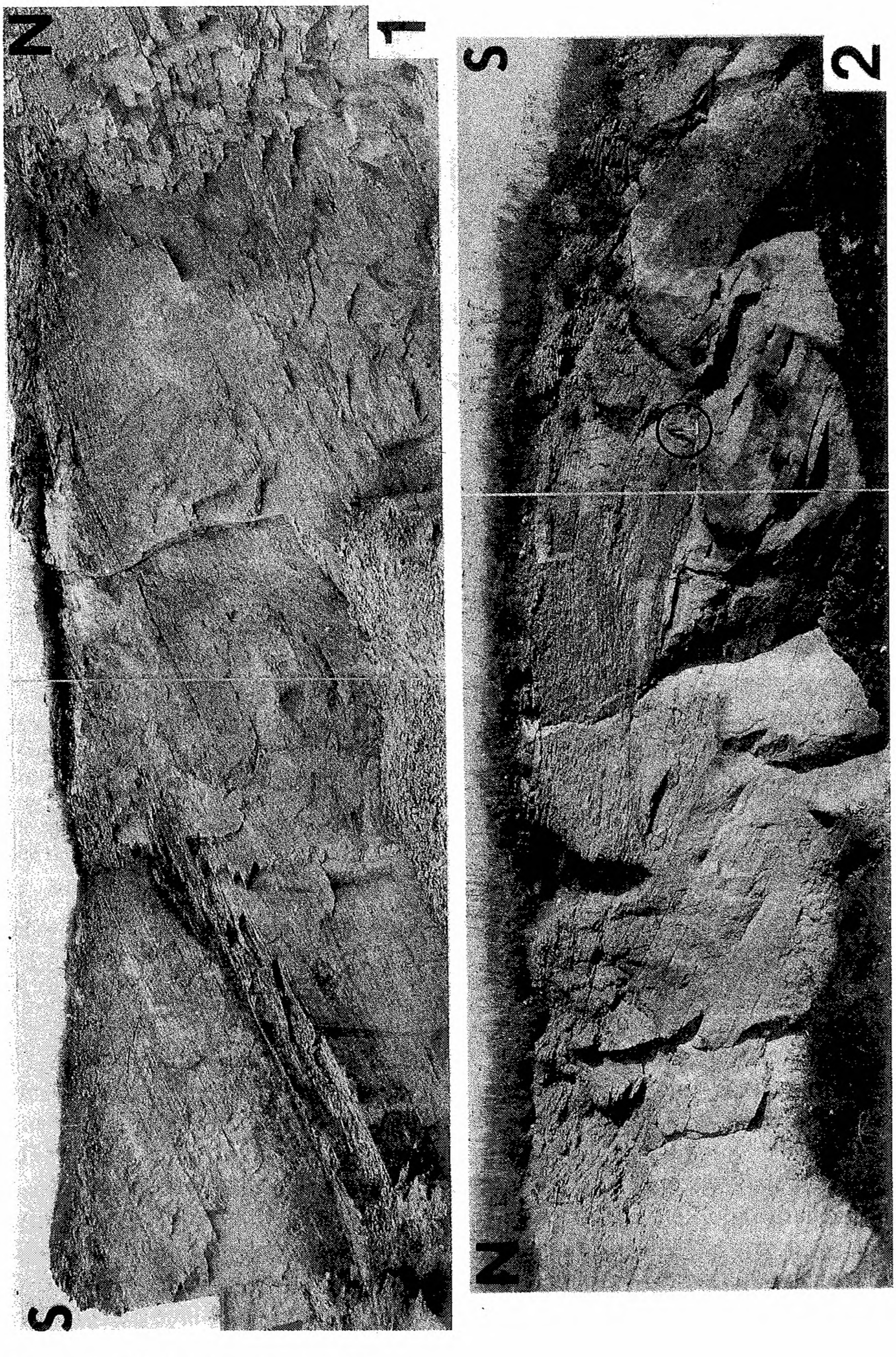
Plate IV

1 — Red-algal-bryozoan biocalcarenite from A-type strata of foreset, Smerdyna. Dark patches - intergranular porosity. Top upwards, negative print of thin section, x 4.5.

2 — Red-algal biocalcarenite with foraminifers, from A-type foreset strata, Karolinów. Top upwards, negative print of thin section, x 4.5.

3 — Red-algal - shell biocalcirudite with foraminifers from slumped lens, Smerdyna. Top upwards, negative print of thin section, x 4.5.

4 — Rims of cement on red-algal grains; note crystals of "dogtooth" cement growing into intergranular pores. A-type foreset strata, Smerdyna. Thin section, crossed nicols, x 200.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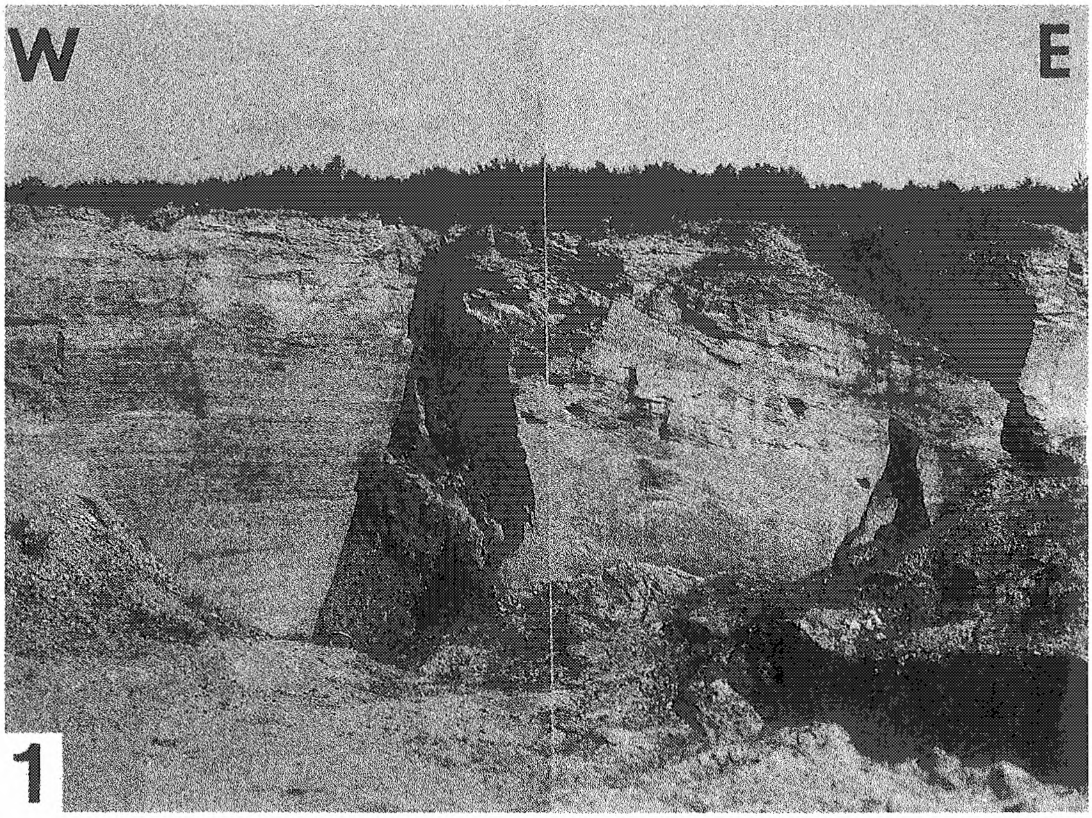
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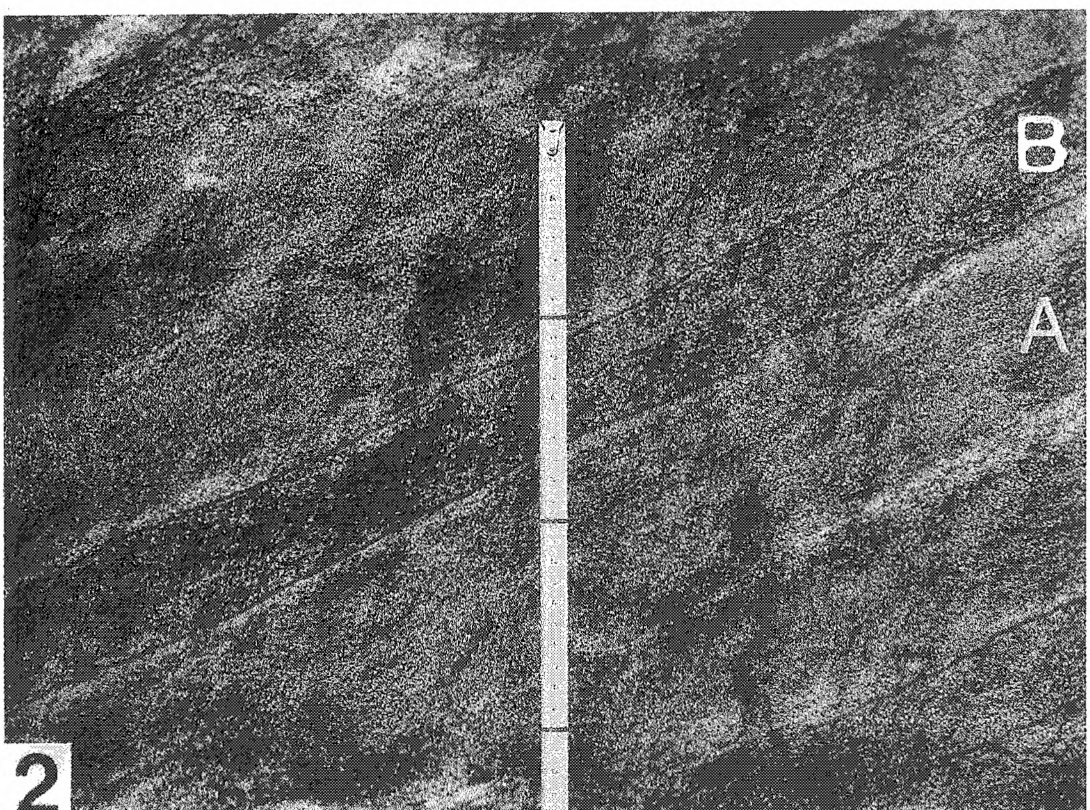
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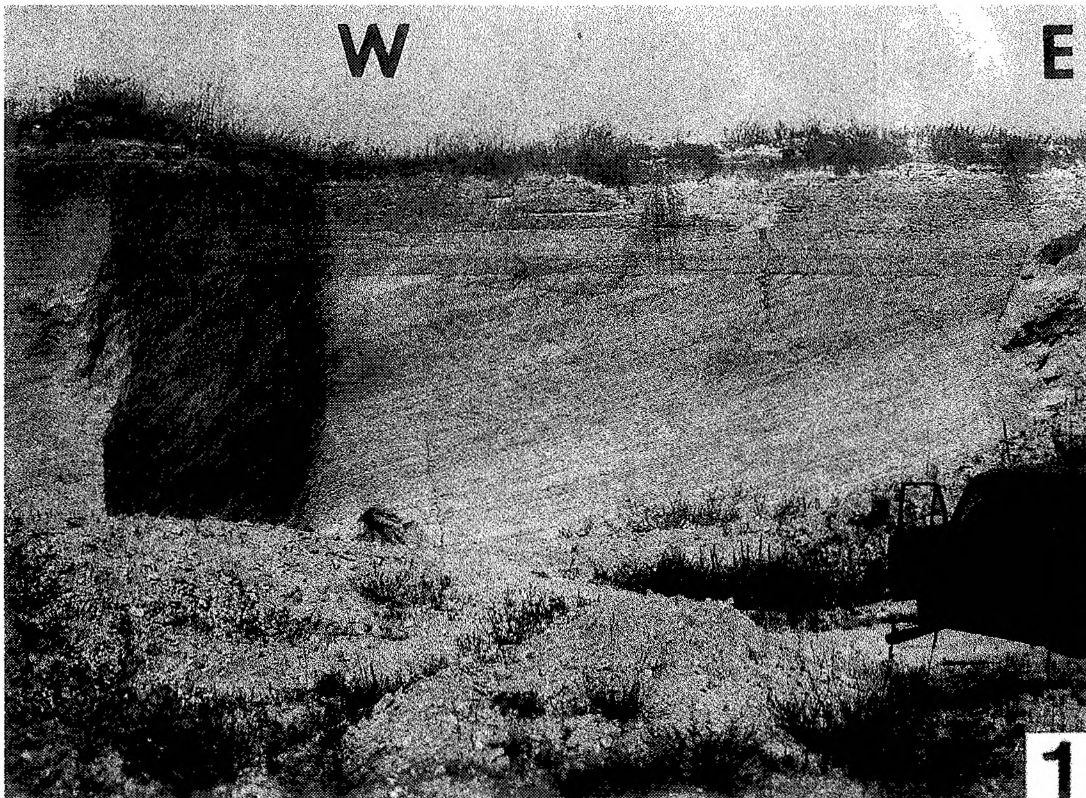
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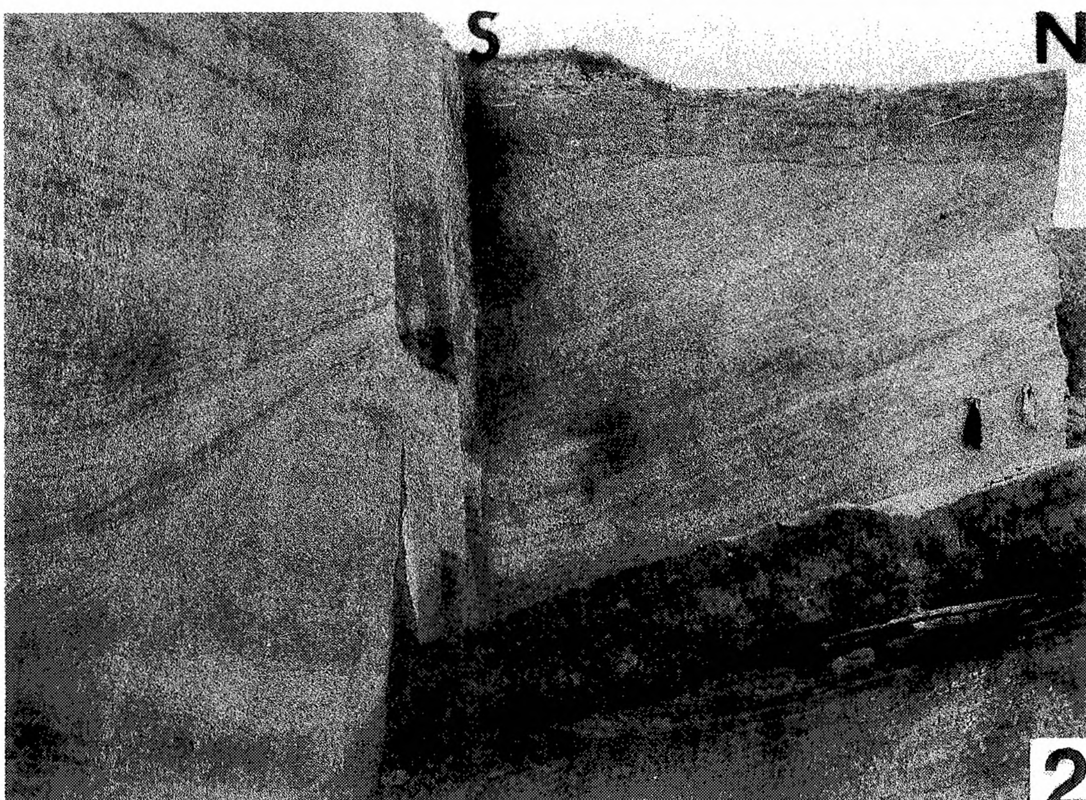
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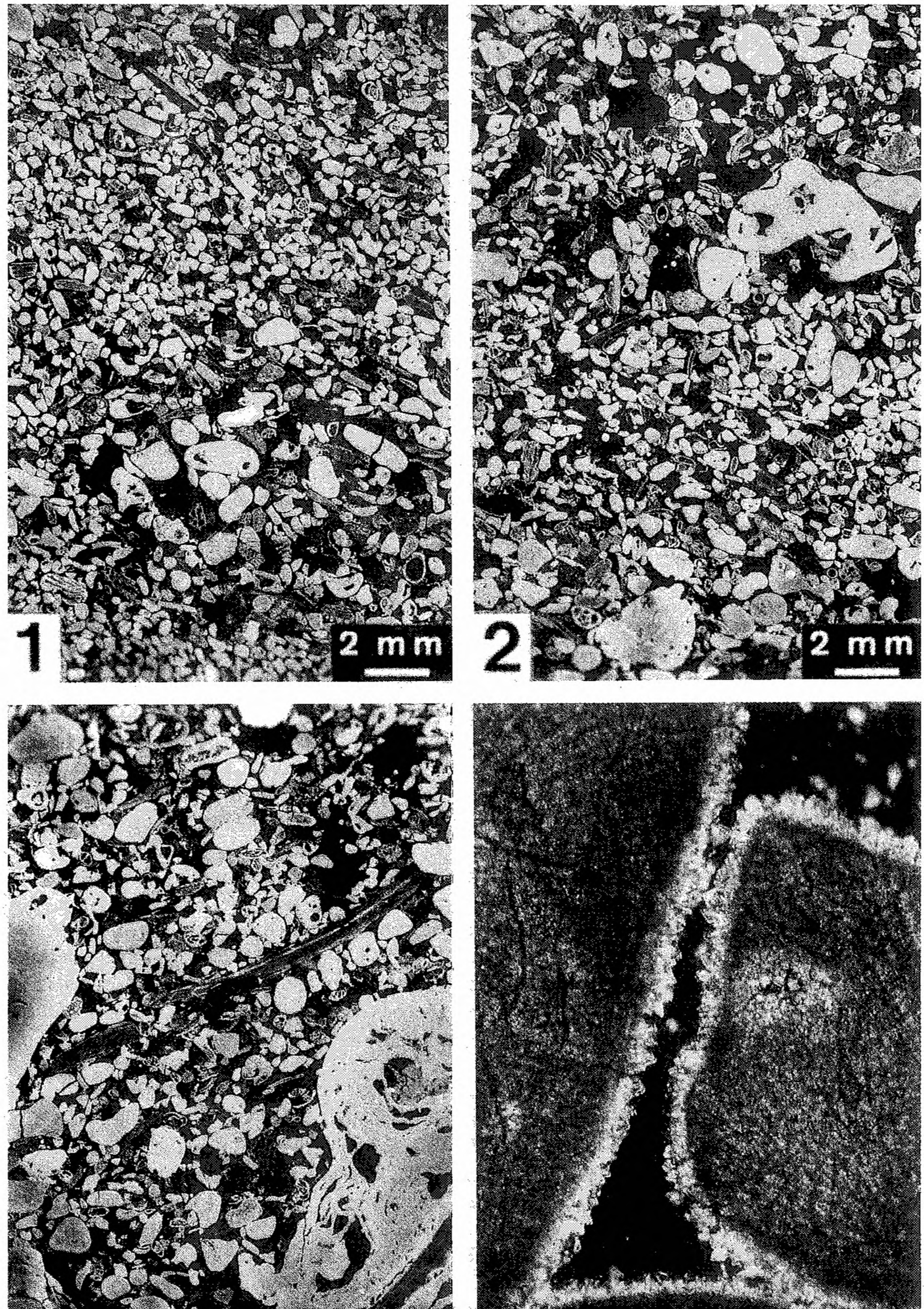
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