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STORM-GENERATED SHELL BEDS IN PELAGIC ALBIAN-CENOMANIAN SEDIMENTS, PIENINY KLIPPEN BELT, CARPATHIANS

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Abstract: Shell beds in the Albian-Cenomanian of the Pieniny Klippen Belt are nearly monospecific (paucispecific) and are composed of *Aucellina* sp. bivalves. Their sedimentary features and the host deposits indicate storm origin of the shell beds. The main mechanisms involved in their sedimentation were suspension and low-energy currents. Differences between various types of shell bed reflect the differences in energy of individual storms during which shell debris was eroded, fine material washed away and transported downslope.

Key words: Albian-Cenomanian, Western Carpathians, Pieniny Klippen Belt, Niedzica Succession, shell beds, paleogeography.

Introduction

Bathypelagic sediments were laid down in the Pieniny Klippen Belt at the Albian/Cenomanian transition. The moderate depth of their deposition (possibly a few hundred metres) is indicated by the presence of benthic and epibenthic molluscs: ammonite *Hamites* and bivalves *Aucellina* and *Pycnodonte* (see Birkenmajer & Kokoszynska 1958) and also by foraminifers (Gasinski 1991; Birkenmajer & Gasinski 1992).

This paper presents a description and interpretation of the stratinomy and sedimentary features of shell beds that occur within these bathypelagic sediments, and a discussion of the influence of storms and tectonics on the origin of these shell beds.

Geological setting

The Pieniny Klippen Belt is a very complex tectonic unit nearly 600 km long and up to 20 km wide, situated between the Inner and Outer Carpathians (Fig. 1A). It is composed of strongly deformed Mesozoic and Palaeogene rocks. The Mesozoic rocks include various types of limestones, radiolarites, shales and siliciclastic turbidites, deposited in a separated (Alpine-Carpathian) branch of the Northern Tethys. Longitudinal facies zones distinguished in the Pieniny Klippen Belt are described as Klippen successions (Birkenmajer 1977, 1979, 1986) (Fig. 2).

Pelagic deposits corresponding to the Albian/Cenomanian transition occur mainly in the Kapusnica and Jaworki Formations. The Kapusnica Formation (Upper Aptian-Albian) is represented by dark-grey shales, grey-blue and green marly shales with intercalations of light-grey pelitic spotty (also cherty) limestones, rare fine-grained turbidite sandstone intercalations, and a few layers of black radiolarian shale. The lower part of the Jaworki Formation, i.e. the Brynczkowa Marl Member (Upper Albian-Lower Cenomanian) is represented by pelagic green marls, marly shales and marly limestones with siliciclastic turbidite wedges (i.e. Trawne Member, Grobka Member), and some layers of radiolarian black shale.

Seven local foraminiferal zones have been distinguished in the Upper Albian through Cenomanian sediments, on the basis of abundant and well preserved foraminifers (Gasinski 1988), corresponding to four standard ones (Birkenmajer & Jednorowska 1987). Other fossils, i.e. belemnites, ammonites and pelecypods, are very rare (see Kokoszynska & Birkenmajer 1956).

The shell beds described here for the first time occur in the Niedzica Succession and represent the late Upper Albian (Vraconian) through early Lower Cenomanian (foraminiferal paleobathymetric association B1 of Gasinski (Gasinski 1991; Birkenmajer & Gasinski 1992)).

The Albian-Cenomanian shell beds discussed are exposed in a right tributary of the Skalski Stream, about 1.5 km southeast of the Jaworki village (Fig. 1B, C). A section 7.5 m thick is seen in the steep bank of the stream (Fig. 1D, 3).

Albian - Cenomanian section near Jaworki (Figs. 1C, D, 3)

The section exposes mostly green and green-grey hard marls, spotty marly limestones and shales (cherry red-grey at some places), with subordinate intercalations of green spotty pelitic limestones and shell beds from a few to 30 cm thick. Some beds are tectonically boudinaged.

The shell beds occur as layers and lenses varying in thickness from about 0.5 to 20 cm. They are built almost exclusively of small thin-shelled bivalves of the genus *Aucellina*. The shells are dismembered and severly crushed, many are also deformed by compaction, as is shown by broken shells whose fragments remain in place. Unbroken shells are preserved in the lower parts of some shell beds. Abundant and very well preserved mainly planktonic foraminiferal tests are present together with the bivalve shells, other fossils are represented by small pieces

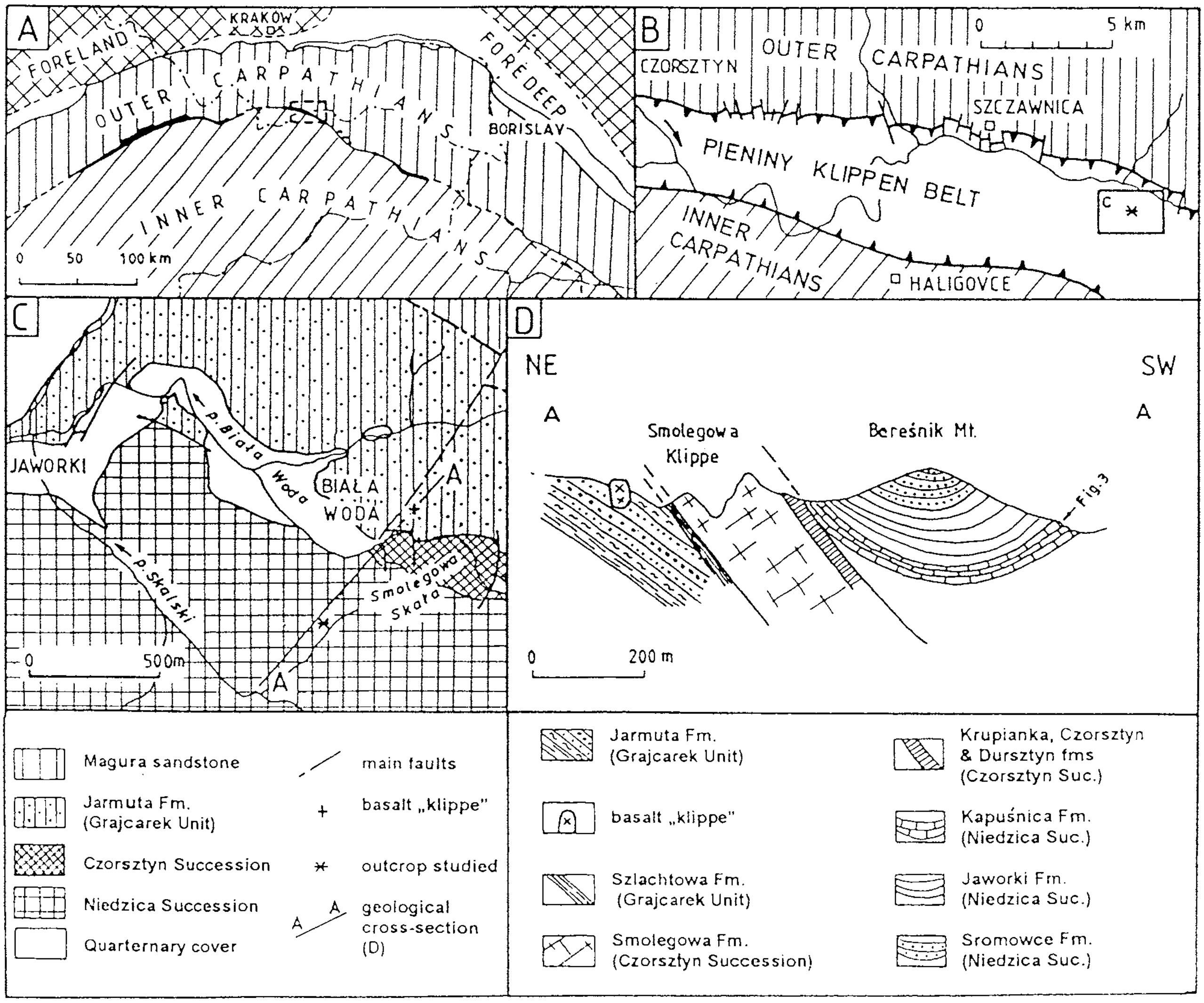


Fig. 1. Position of the investigated outcrop in the Carpathians (**A**) and in the Pieniny Klippen Belt (**B**). **C** - Geological sketch-map of the Pieniny Klippen Belt in the vicinity of Jaworki (after Birkenmajer 1979 simplified). **D** - Geological cross-section at Biała Woda village.

of indeterminable bivalve shells with spines and fragments of echinoderms. The shell beds are nearly monospecific (paucispecific sensu Kidwell et al. 1986).

Belemnites and single shells of the bivalve *Aucellina* sp. are very rare in the accompanying marls and marly limestones which show the presence of abundant trace fossils. They are represented mainly by *Chondrites* (Pl. II: Fig. 3) and by *Zoophycos* (Pl. II: Fig. 4) and *Planolites* -like burrows (Pl. II: Fig. 3) in marls and pelitic limestones. The trace fossils usually do not occur within the shell beds. Some pelitic limestone layers are silicified and form cherts or thin (0.1-0.5 cm) intercalations within the limestones. A bed of radiolarian black shales occurs in the lower part of the section, presumably representing an anoxic events.

Sedimentary features of the described deposits are indicative of deep water pelagic deposition. Soft-substratum conditions are suggested by body fossils (*Aucellina* shells) and trace fossils (deposit-feeders dominating), the latter indicative of low energy of the bottom water. The foraminiferal assemblages are characteristic of middle slope (Gasinski 1991; Birkenmajer & Gasinski 1992). The appearance of the shell beds indicates high energy events.

Description of shelly accumulations

The shelly accumulations are from a few milimetres to 20 cm thick. All have sharp, usually non-erosive bases, without prod marks or any other erosional structures on their soles. Some of the beds just above the base include clasts of green pelitic limestone, armoured with shell fragments (Pl. I: Figs. 1, 2). The fabric of most shell beds is bioclast-supported, in some cases grading upwards to a mud-supported fabric (Pl. I: Fig. 5).

The degree of shell crushing and shell orientation is variable. A concordant (sensu - Kidwell et al. 1986: Fig. 2A) orientation of shells dominates, without concave-up or concave-down positions prevailing. Oblique orientation is rare and occurs mainly near the bed base. Some shell beds are graded; the basal skeletal lag is overlain by mud-supported limestone with dispersed shell fragments, followed by marl without macrofauna (Pl. I: Fig. 5).

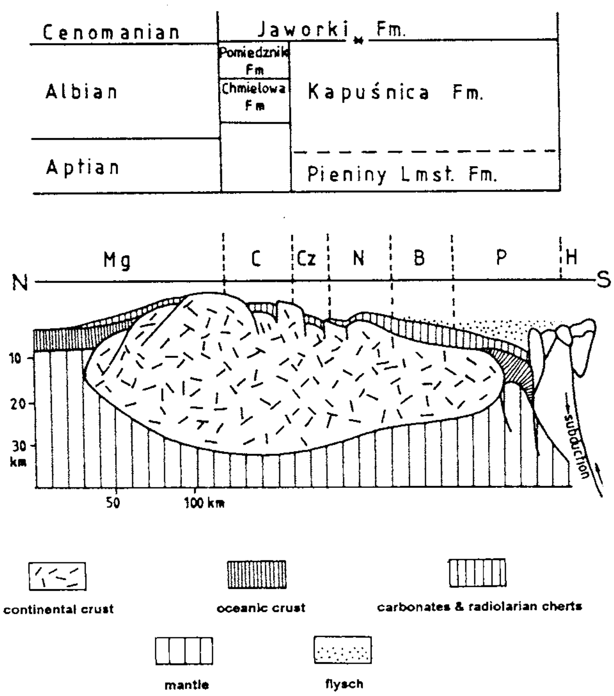


Fig. 2. Palinspastic reconstruction of the sedimentary basin of the Pieniny Klippen Belt during the Albian/Cenomanian, and mid-Cretaceous lithostratigraphical units (after Birkenmajer 1977, 1986; Gasinski 1988) with stratigraphical position of investigated shell beds (asterisk). **Mg** - Magura Basin, Outer Carpathians. Successions of the Pieniny Klippen Belt: **C** - Czorsztyn; **Cz** - Czertezik; **N** - Niedzica; **B** - Branisko; **P** - Pieniny; **H** - Haligovce.

On the contrary, bivalve shells in pelitic limestones are unbroken and chaotically arranged. Some skeletal accumulations are very thin, even one shell-thick, bioclastic-lag layers (Pl. I: Fig. 4; Pl. II: Fig. 2). They are separated from one another by thin pelitic limestones with very abundant foraminifers (Pl. II: Fig. 2). Sequences comprising clasts and shell lags at the base, followed by graded skeletal debris, overlain in turn by parallel laminated limestone, and passing upwards to silty marls with *Chondrites*-like bioturbations, occur sporadically (Pl. I: Fig. 5). No modification due to bioturbation of the primary position of skeletal debris in shell beds was observed. The clasts present in the shell beds consist of green to grey-green pelitic limestone with sporadic very thin-shelled fragments of bivalves.

Four types of shell beds may be distinguished (see Figs. 3 and 4): (1) densely packed, homogeneous shell beds, in some cases with clasts, sharply delimited from marl or pelitic limestone beds (Pl. I: Figs. 1, 2); (2) graded shell beds with clasts at the base (Pl. I: Figs. 3, 4); (3) sequences starting from small clasts and shell lag at the base, through graded, laminated to bioturbated at the top (Pl. I: Figs. 5-7); (4) thin shell accumulations in silty marls and limestones (Pl. II: Figs. 1, 2).

Origin of skeletal accumulations

The dominant sedimentary features of the Albian-Cenomanian pelagic marls and limestones, their foraminifers and the macrofauna, all indicate low energy of their depositional environment. In contrast, the skeletal accumulations represent high-energy events. Wide occurrence of shell beds in different carbonate or mixed clastic/carbonate shallow-marine sediments, both ancient (e.g. Kreisa & Bambach 1982; Aigner 1985; Fürsich & Oschmann 1986; Eyles & Lagoe 1989; Johnson 1989) and modern (e.g. Gagan et al. 1988; Davies et al. 1989) is well known. Most of the shell beds formed above the storm wave-base, and skeletal accumulations formed below it are rare (Kidwell et al. 1986: Fig. 5). Pelagic bivalve turbidites occurring widely in the Alpine-Mediterranean region are an exception (e.g. Bernoulli & Jenkyns 1974).

Skeletal accumulations described from the Albian-Cenomanian of the Pieniny Klippen Belt are typical minor simple shell beds (sensu Kidwell 1982) with respect to both the contiguous facies and internal complexity. They have simple taphonomic history and reflect single, short-term accumulations due to high energy events, namely storm-generated shelly turbidity currents in a deep-water basin (Aigner 1982; Kidwell et al. 1986).

The described shell beds are distinguished from storm accumulations *sensu stricto* by the lack of an erosive base, the presence of discontinuous grading, preferred convex-up orientation, some sedimentary structures (e.g. amalgamation, hummocky cross-stratification etc.) and by the density or the type of trace fossils present (cf. Fürsich & Oschmann 1986). The

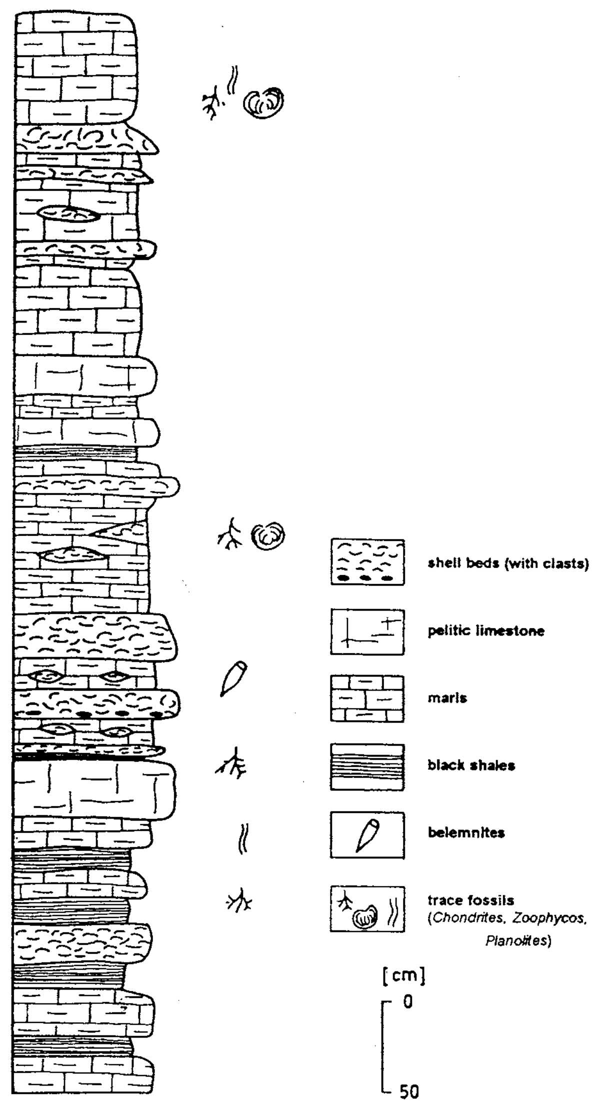


Fig. 3. *Aucellina* shell beds-bearing exposure of the Kapusnica Formation attributary of the Skalski Stream.

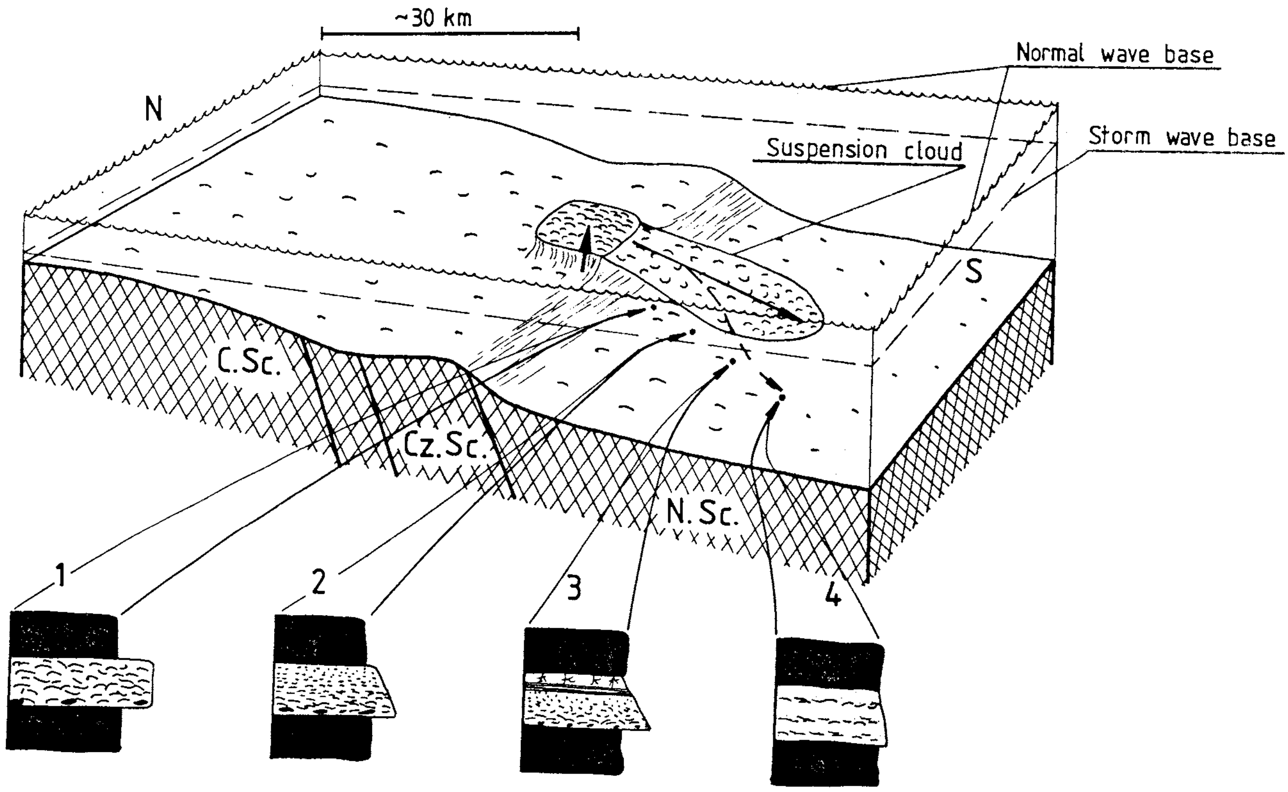


Fig. 4. A generalised model for the origin of the four types (1-4) of storm-generated shell beds. C.Sc. - Czorsztyn Succession; Cz.Sc. - Czertezik Succession; N.Sc. - Niedzica Succession. Type of shell beds: 1 - densely packed, homogenous shell beds, in some cases with clasts, sharply delimited from marl or pelitic limestone beds; 2 - graded shell beds with clasts at base; 3 - sequences starting from small clasts and shell lag at base, through graded, laminated to bioturbated at top; 4 - thin shell accumulations in silty marls and limestones.

trace fossils represented by *Chondrites*, *Zoophycos* and *Planolites*-like burrows, are indicative of fodinichnia-dominated associations which are typical for basins with aerobic or dysaerobic bottom water and anaerobic or anoxic interstitial water (Ekdale & Mason 1988).

Differentiation of the investigated shell beds (types 1-4) is considered to reflect the variable energy of storms (Fig. 4). The beds of types 1 and 2 correspond to relatively weaker storms; they most probably originated from suspension with very small influence of bottom currents. There is no evidence of current erosion either in the character of the layer base or in its internal structure. The clasts at the base are allochthonous, like the skeletal debris. In this respect the beds of type 1 and 2 are similar to the lower parts of allodapic limestones (Meischner 1964), but in our case there is a distinct difference in the lack of shallow-water macro- and micro-fauna.

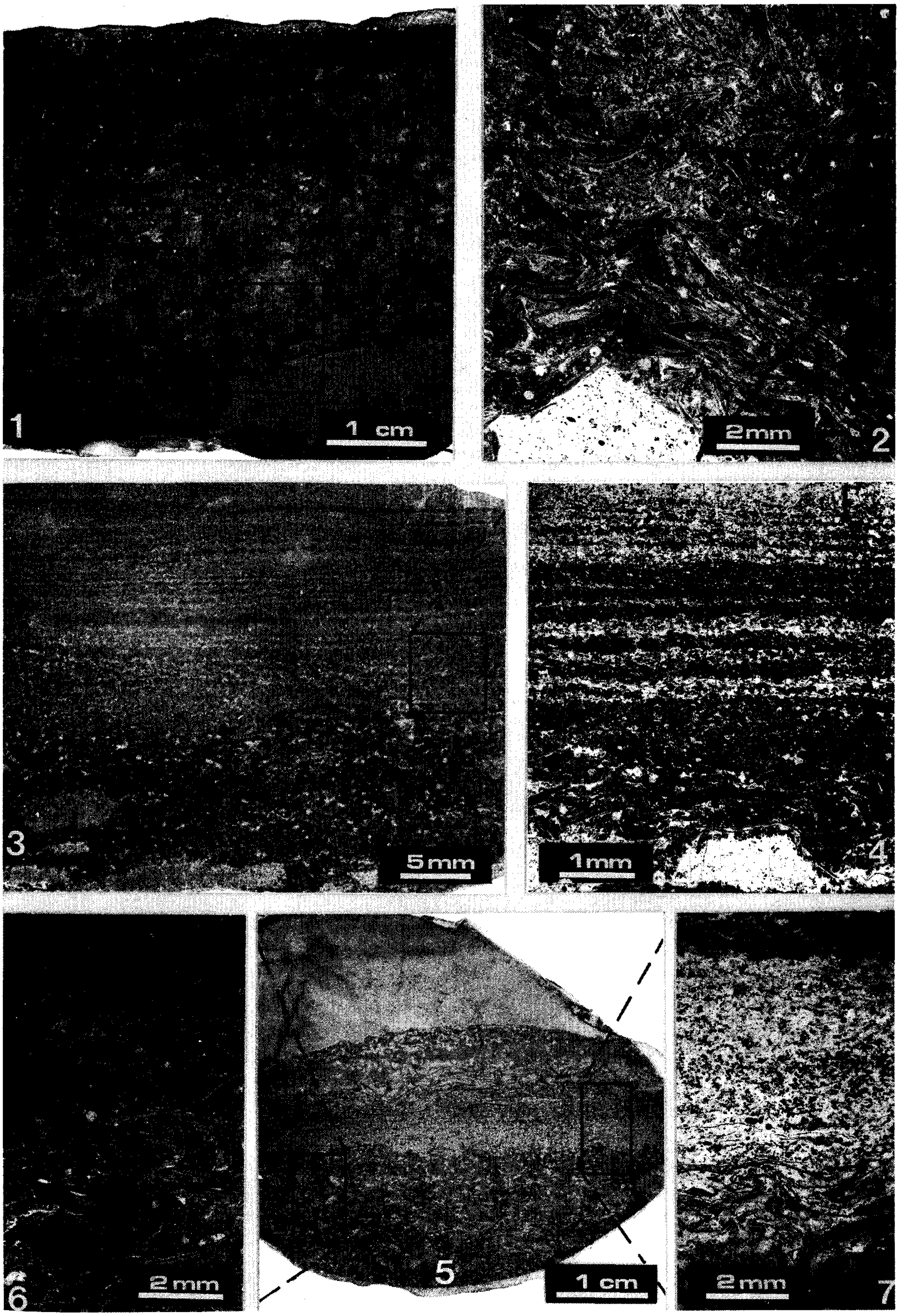
The beds of types 3 and 4 originated from both, suspension and bottom currents. Single, very thin light shell fragments might have been transported easily even by weak currents, resulting in thin shell beds within marls and pelitic limestones (type 4) - so-called "transported assemblages" of Johnson (1960 his model III). These sedimentary events are the most completely recorded in type 3 accumulations. The lower part of the sequence, with clasts near the base and gradation higher up, was laid down from suspension, while the upper part, with parallel lamination, by a bottom current. The bioturbated top reflects quiet water conditions with a low sedimentation rate. Types 3 and 4 are related to stronger storms than types 1 and 2. Type 3 is transitional between 2 and 4 as it includes some features of both.

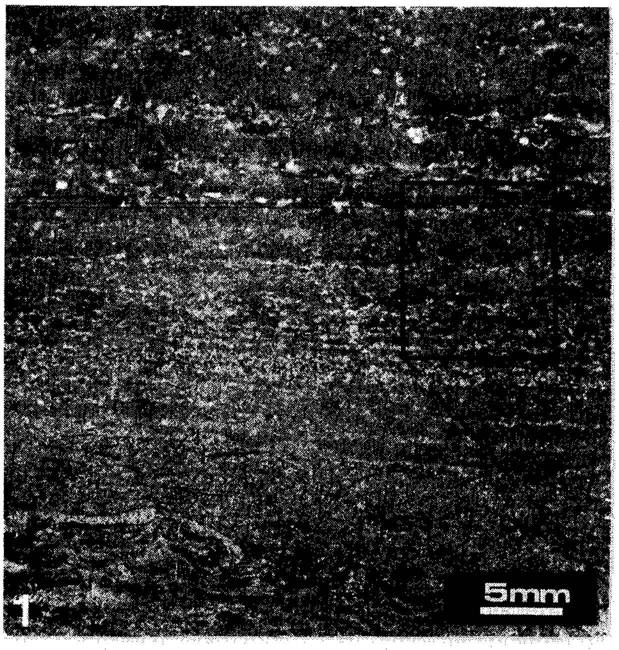
The shell beds dominated by bivalve *Aucellina* sp. and planktonic foraminifers reflect the paleoecological conditions in their primary environments in the Pieniny Klippen Belt Basin. The basin was filled with soft marly mud colonised by epibenthic bivalves. The monospecific nature of the shell beds is probably a consequence of the primary structure of the community inhabiting a soft sea floor before the storm events, rather than a secondary modification, as there is no evidence of destructive postdepositional (diagenetic) processes such as dissolution, disintegration etc. There are no taxonomical differences in shell assemblages of different types of beds. Bio- and lithoclasts which occur in the shell beds were eroded from a shallower area where the lithology of the bottom sediment was very similar to that of the present host sediment. The great difference in the abundance of fauna is due to the depth difference (see below, Fig. 4).

A generalised model for the origin of all the four types of storm-generated shell beds is the following:

Plate I: Different types of *Aucellina* shell beds in pelagic Albian-Cenomanian sediments, Kapusnica Formation of the Niedzica Succession, Pieniny Klippen Belt. Right tributary of Skalski Stream in vicinity of Jaworki village. **Fig. 1** - Homogeneous *Aucellina* shell beds with clast of pelitic limestone near the base; shell bed of type 1 (see the text to detailed explanation). Polished section. **Fig. 2** - Densely packed of strong crushed of *Aucellina* shells; enlarged area indicated in Fig. 1. Thin section, negative. **Fig. 3** - Graded shell beds with clasts at base; shell bed of type 2. Polished section. **Fig. 4** - Enlarged area - see Fig. 3. Thin section, negative. **Fig. 5** - Shell bed with very well visible sequence with small clasts and shell lag at base, through graded, laminated to bioturbated at top; shell bed of type 3. Polished section. **Figs. 6, 7** - Enlarged areas indicated in Fig. 5. Thin sections, negatives. Photo - M. Doktor.

PLATE I

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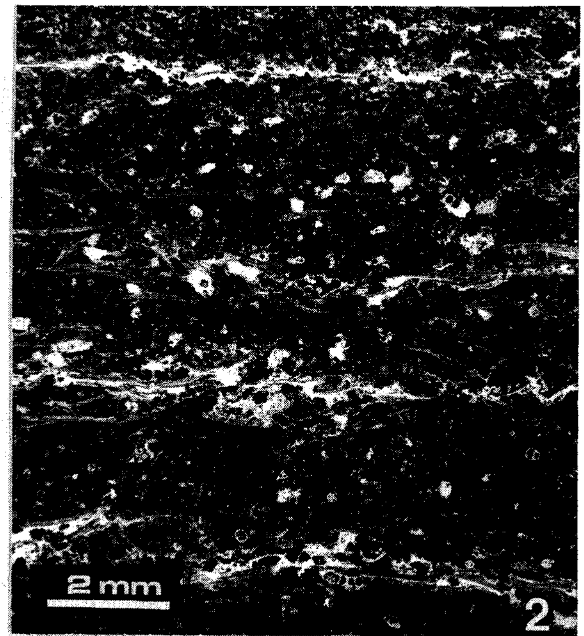
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Ch
P
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4
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Plate II: Figs. 1, 2 - Shell accumulations in silty marls and limestones formed very thin, even one shell-thick, bioclastic-lag layers with very rich hedbergellid foraminifers; shell bed of type 4. Polished (Fig. 1) and thin (Fig. 2; negative) sections. **Figs. 3, 4** - Trace fossils from typical, green and grey-green marls and marly limestones of Kapusnica Formation of Niedzica Succession in investigated outcrop: *Chondrites* (Fig. 3 - Ch), *Planolites*-like (Fig. 3 - P) and *Zoophycos* (Fig. 4). Polished sections. Photo - M. Doktor.

A - The soft substratum (pelagic mud) was colonised by highly monospecific bivalve assemblages (*Aucellina* sp.) below the fair-weather wave base but above the storm one.

B - During a storm, the storm-wave action resulted in erosion of soft mud with shell debris and formation of a suspension cloud. Fine sediment was winnowed away and the bivalves debris was concentrated, crushed and transported downslope. Initially all lithoclasts, and most of the bioclasts, fell down from the suspension depositing shell beds of types 1 and 2, while single shell fragments were being transported farther off and eventually deposited as shell beds of types 3 and 4. The occurrence of all the four types in the same outcrop is due to the different energy levels of individual storms.

C - Overlying sparsely fossiliferous marls and pelitic limestones with common *Chondrites*, *Zoophycos* and *Planolites*-like burrows indicate anaerobic or anoxic conditions of sedimentation in a quiet-water environment (cf. Ekdale 1985).

Shell beds deposited in this way are identical to the so-called pelagic bivalve turbidites known from the Lower and Middle Jurassic of the central area of the Tethys (Bernoulli 1967: Figs. 8 and 9; Bernoulli & Jenkyns 1974: Fig. 8; Monaco et al. 1994).

Paleoenvironmental implications

The occurrence of the shell beds in the Albian-Cenomanian sediments of the Niedzica Succession of the Pieniny Klippen Belt is probably a record of recurrent storm events.

The paleogeographical distribution of the ancient storm deposits suggest that severe storms occurred in the Tethyan realm in Albian-Cenomanian time (so-called hurricane path of Barron 1989). If several occurrences of condensed Albian deposits along the northern continental margin of the Tethys (Delamette 1988) are really of storm origin (Gebhard 1985) it is very probable that such storms affected also the basin of the Pieniny Klippen Belt. The uplift of the isolated block may have led to the formation of a local bottom elevation where population of epibenthic bivalves could flourish (Fig. 4). The scarcity of similar fauna in the Albian-Cenomanian sediments of the Czorsztyn Succession indicates that the area which was the source of bioclastic material for the shell beds was situated shallower than the Czorsztyn Ridge. It reached above the storm wave base during severe storms, supplying the shelly turbidity currents.

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