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STORM ACCUMULATIONS OF BRACHIOPOD SHELLS AND SEDIMENTARY ENVIRONMENT OF THE TEREBRATULA BEDS IN THE MUSCHELKALK OF UPPER SILESIA (SOUTHERN POLAND)

(6 Figs.)

Osady burzowe i środowisko sedymentacyjne warstw terebratulowych

(6 fig.)

Abstract: This paper deals with allochthonous brachiopod accumulations in the Terebratula Beds (Middle Triassic). Some of such accumulations are thought to have been deposited by rushing storm currents carrying large amounts of suspended load. The environmental model of the Terebratula Beds, as advanced in this paper, is that of a shallow epicontinental sea with shoals and sediment ponding depressions. The unusual density and low diversity of bivalve fauna is attributed to temperature controlled environmental instability.

The aim of this paper is to discuss some selected problems concerning the sedimentation of coquina layers in the Terebratula Beds (Lower Muschelkalk). The following considerations are chiefly devoted to current--drifted brachiopod accumulations infilling extensive scour channels. The observations here presented are from exposures in a quarry at Strzelce Opolskie, in the type area of the Terebratula Beds (Upper Silesia in Southern Poland).

Stratigraphically, and in ascending order, the Terebratula Beds represent the third member of the Muschelkalk formation (see Assmann, 1944; Siedlecki, 1949). In the study area, the maximum thickness of the Terebratula Beds is 15 meters. These strata are here divided by a crinoidal "key bed" of constant thickness (1,5 m) into two parts; the upper and the lower one.

The Terebratula Beds consist of light coloured limestones intercalated with greyish marls. The limestones are essentially of three types; 1. coquina limestones composed of brachiopod shells and/or shell fragments, 2. crinoidal limestones; and, 3. aphanitic, almost unfossiliferous limestones showing wavy and crumpled bedding (for details concerning the crumpled bedding see Bogacz et all., 1968).

The Terebratula Beds owe their name to abundant brachiopods belonging to one or a few species of terebratulids (chiefly *Coenothyris vulgaris* Schloth.). The associated fossils are equally poor in species and consist of abundant crinoids and rare molluscs (chiefly pectinids and oysters).

The terebratulids tend to occur in form of coquina layers which constitute a very considerable part of the Terebratula Beds. Such layers are of two types: 1. autochthonous or semi-autochthonous accumulations and, 2. allochthonous, current-drifted accumulations.

The autochthonous accumulations are comprised of brachiopod shells with both valves together showing a wide range of growth stages of a single specimen. This is regarded as „strong de facto evidence of life assemblages". (Ager, 1967, p. 165, see also Boucot, 1953; Boucot at al., 1958, Middlemiss, 1962) [1].

The life assemblages in the Terebratula Beds have developed on current-made hard-ground surfaces or on the top of allochthonous accumulations. Only rare and scattered individuals are found within the fine-grained limestones.

In the study area (Strzelce Opolskie) the allochthonous accumulations predominate and the life assemblages are rare. However, already a few kilometers north-east of Strzelce Opolskie, in the region of Dziewkowice, the autochthonous accumulations are of common occurrence.

The allochthonous accumulations are of two types; 1. accumulations composed of moderately sorted shell detritus indicative of drifting over the sea floor for long periods and of deposition from bottom currents of long duration; and, 2. accumulations comprised of poorly sorted mixtures of brachiopod shells, shell fragments, crinoids and calcareous mud.

Our considerations are chiefly devoted to the second type of allochthonous accumulations and notably to the accumulations infilling flat scour channels located at one specific level in the upper part of the Terebratula Beds.

The channels are cut in fine-grained limestones and their general orientation is approximately north-south. In transverse vertical cross--sections, the infillings of the channels take a shape of flat-topped, lenti-

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[1] Admittedly, no statistical treatment of the size-frequency distribution of shells has been made. It is realized that only with this kind of information can the full environmental significance of brachiopod accumulations be evaluated (compare Boucot et al., 1957; Middlemiss, 1962). This question, so important for discrimination of fossil bivalve life and death assemblages, awaits further investigations.

cular bodies, several to several tens of meters in width and about 1 meter thick (Fig. 1).

The channels are filled with a poorly sorted mass of comminuted shell fragments and crinoids, whereby the grain size of clastics, often but not always, decreases upwards (graded bedding). Near or at the sharply

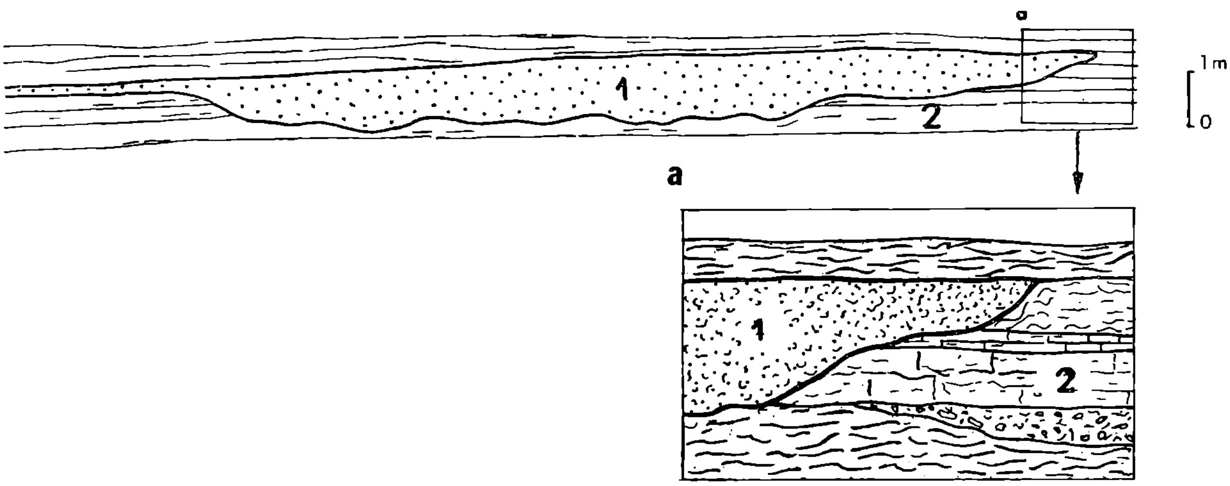

Fig. 1. Channel eroded in fine-grained limestones composed of brachiopod shells, shell debris and crinoids. a — detail of channel shown in rectangular inset (right); 1 — allochthonous shell accumulations, 2 — fine-grained limestones showing common wavy and crumpled bedding. Strzelce Opolskie

Fig. 1. Rynna wyżłobiona w mikrytowych wapieniach marglistych, wypełniona skorupami ramienionogów oraz detrytem cienkoskorupowej fauny i krynoidów. a — powiększony fragment rynny; 1 — allochtoniczne nagromadzenie okruchów organogenicznych; 2 — mikrytowe wapienie faliste i gruzłowe. Strzelce Opolskie

defined base of the channels there occur angular and rounded pebbles of fine-grained limestones measuring up to several centimeters in diameter (Fig. 2).

Significantly, the channel-fill deposits contain also abundant brachiopod shells with both valves preserved and joined. The abundance of such schells is indicative of very local derivation (B o u c o t, 1953; B o u c o t et al., 1958; M i d d l e m a s s, 1962) and is explained by the fact that the valves of pediculate, articulate brachiopods are very resistant to disarticulation and a considerable force is required to open them (M i d d l e m a s s, 1962; A g e r, 1967).

From the foregoing considerations it is clear that the channel-fill allochthonous brachiopod accumulations were deposited by violent episodic currents and that the clastic material infilling the channels is of very local derivation.

In many places, the channel deposits show conspicuous load deformations. These deformations take a shape of familiar "pseudonodules", "load folds", "drop structures" etc. Selected examples of such structures are shown in figures 3, 4, 5 and 6. The figures are largely self-explanatory and need no additional comments. The structures depicted point to predominantly vertical read-justment movements in „horizontally non-

-mobile" systems characterized by instability in density stratification (Anketell et al., 1970). This means that contemporary paleoslopes were not a prerequisite for the formation of these structures.

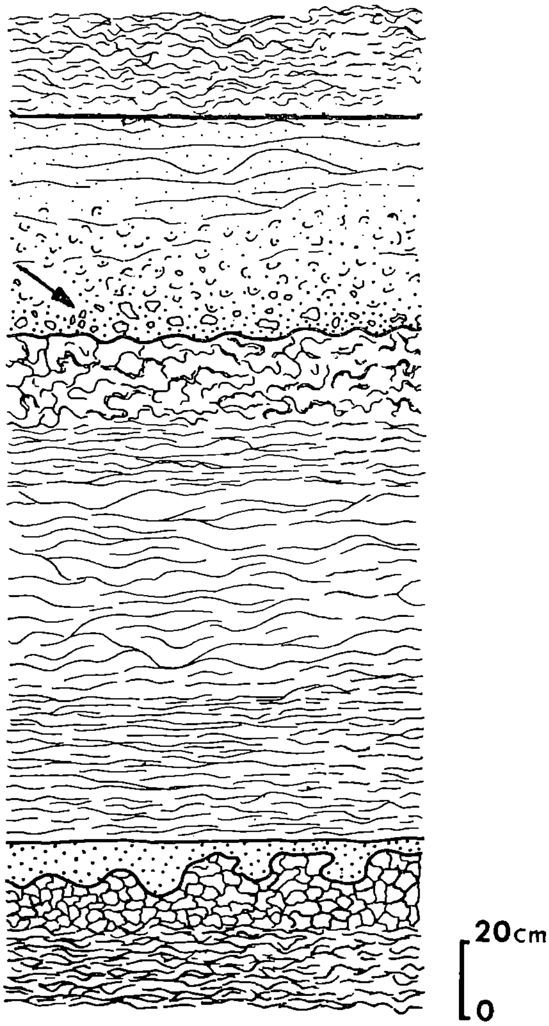

Fig. 2. Detail of section with allochthonous shell accumulation exhibiting graded bedding. Note concentration of limestone fragments (arrow) near the base of accumulation. Strzelce Opolskie

Fig. 2. Fragment przekroju z allochtonicznym nagromadzeniem fauny ukazujący uziarnienie frakcjonalne. Strzałka wskazuje nagromadzenie okruchów wapiennych w spągu ławicy. Strzelce Opolskie

The structures depicted in figures 3—5 have been repeatedly reported from various environments and are known to be associated with channel-fill deposits in fine-grained sediments (see e. g. Sorauff, 1965). They have also been described from the Muschelkalk (see e. g. Schwarz, 1970, 1971; Bialik et al., 1972). It is only the size of the deformations here described, uncommon in shallow-water marine carbonates, that calls for attention.

The drop structure shown in fig. 5 sunk down almost 2 meters below the original base of the shell layer. This indicates that, at the time of deposition of the shell debris, at least the uppermost 2 or 3 meters of fine bottom muds were still prone to partial liquefaction induced by overloading and/or mechanical impulses.

The implication of the foregoing considerations is that the fine-grained limestones underlying the channels were deposited neither in areas of very slow sedimentation and temporary emersion nor in zones of early cementation. Relatively rapid rate of deposition is amongst important prerequisites for the formation of load deformations and "crumpled" bedding [2]. The temporary emersion of carbonate sediments leads to dia-

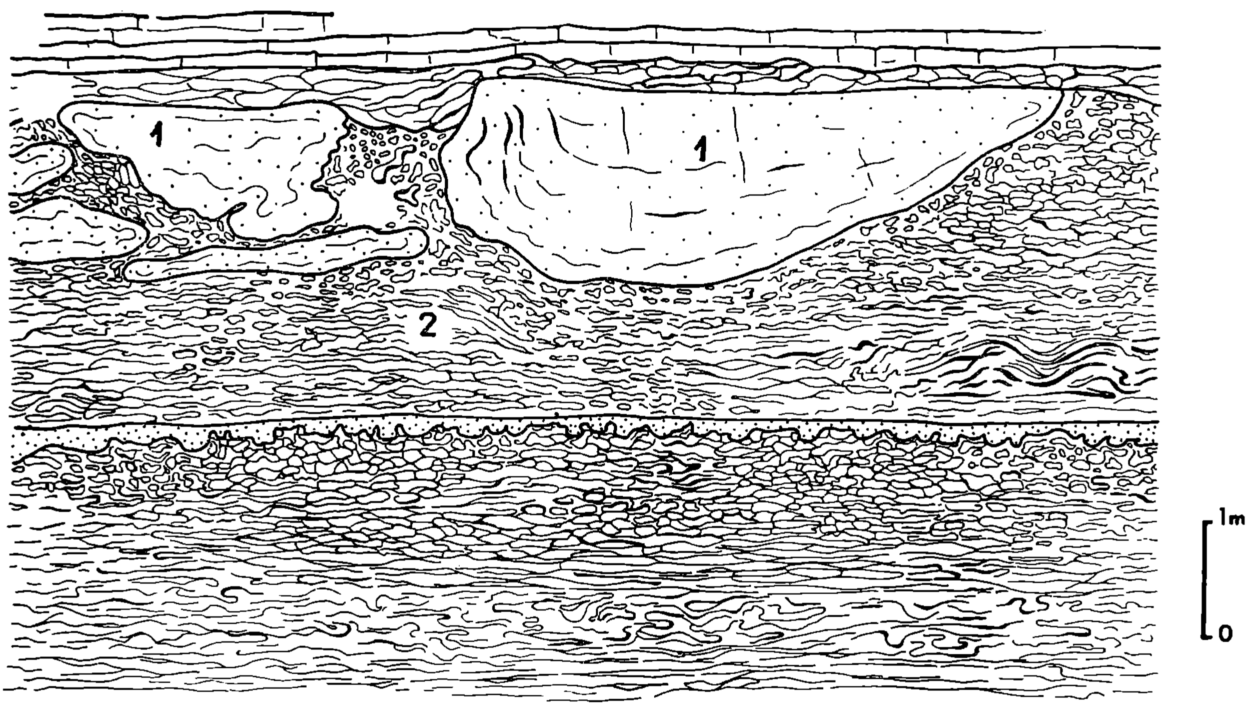

Fig. 3. Balled-up and disrupted parts of channel filled with shell debris (1). Note diapiric injection of fine-grained limestones (2) exhibiting wavy and crumpled bedding. Strzelce Opolskie

Fig. 3. Porozrywane fragmenty osadów organodetrytycznych wypełniających rynny (1). Zwraca uwagę diapirowe wyciśnięcie faliście i gruzłowato zaburzonych wapieni mikrytowych (2). Strzelce Opolskie

genetic cementation which may effectively impede the development of syn-sedimentary load deformations. No inference, however, can be drawn with respect to the depth of sedimentation. Fine grained calcareous muds are known to accumulate in deep and shallow waters. They may even accumulate in very shallow water environments either in small depressions protected from waves and currents by shoals and barriers or on the top of the shoals where low energy conditions are ensured by damping of waves and tidial currents. There is, however, little doubt

[2] Crumpled and wavy bedding, so common in fine-grained calcarenites in the Muschelkalk is indicative of rapid deposition (compare Bogacz et al., 1968). Parenthetically, it may be added that the „crumples" which typically are streched out along bedding planes show an increased sphericity close to the deformed shell accumulations (fig. 6).

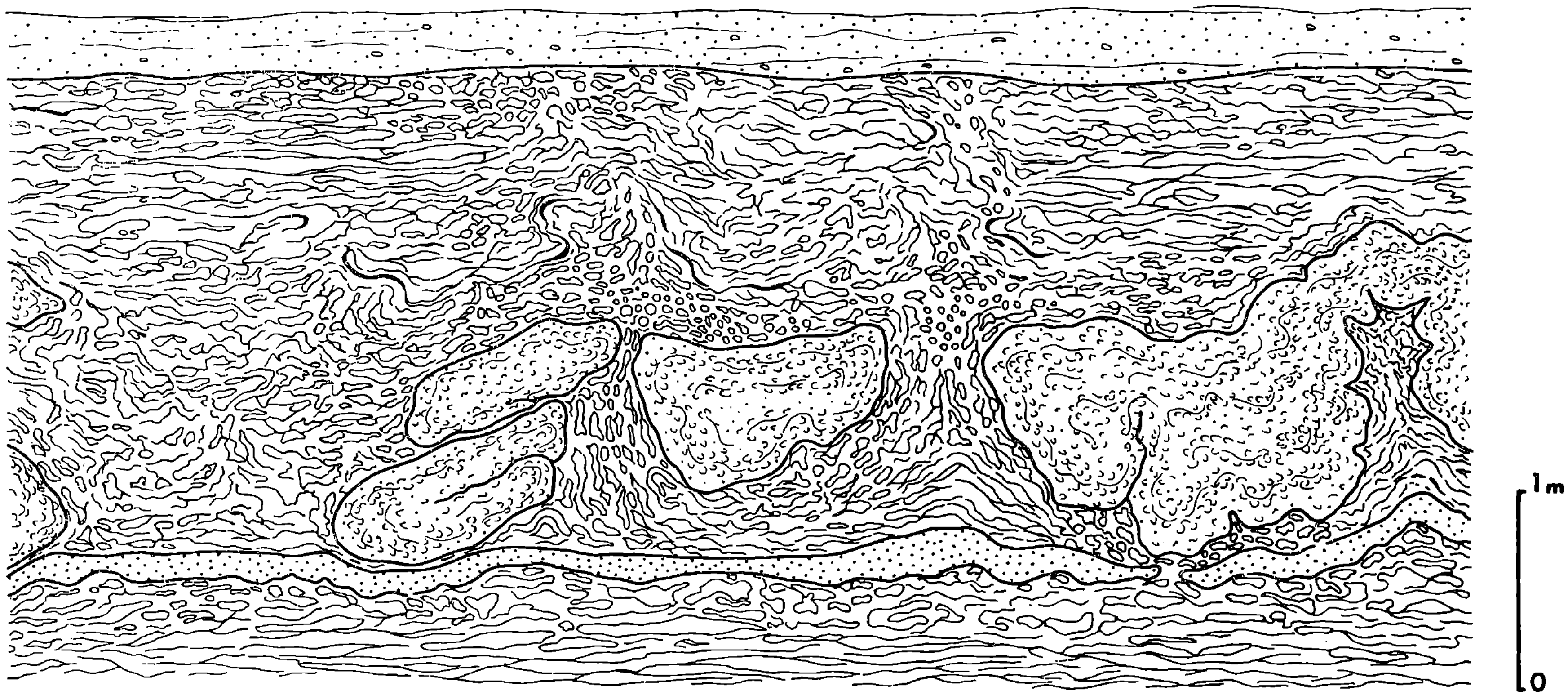

Fig. 4. Disrupted and contorted fragments of allochthonous shell bed incorporated fine-grained limestones. The fragments take a shape of irregular „pseudonodules" and ruptured load-folds devoid of preferred orientation. Some fragments sank into another allochthonous shell accumulation causing it break and bend down. Compare with Fig. 5. Strzelce Opolskie

Fig. 4. Porozrywane fragmenty allochtonicznej ławicy muszlowcowej w obrębie powyginanych wapieni mikrytowych. Fragmenty te przybrały kształty nieregularnych „pseudonodul" i rozłamują struktury faliste pozbawiając je uprzywilejowanej orientacji. Niektóre fragmenty allochtonicznych ławic muszlowcowych utonęły jedne w drugich powodując ich wzajemne załamywanie się i wychylanie. Strzelce Opolskie

that the aphanitic limestones underlying the channel deposits were laid down under low energy conditions and that the sedimentation was permitted to build up an appreciable amount of fine-grained layers before it was interrupted by current erosion and deposition of the shell debris.

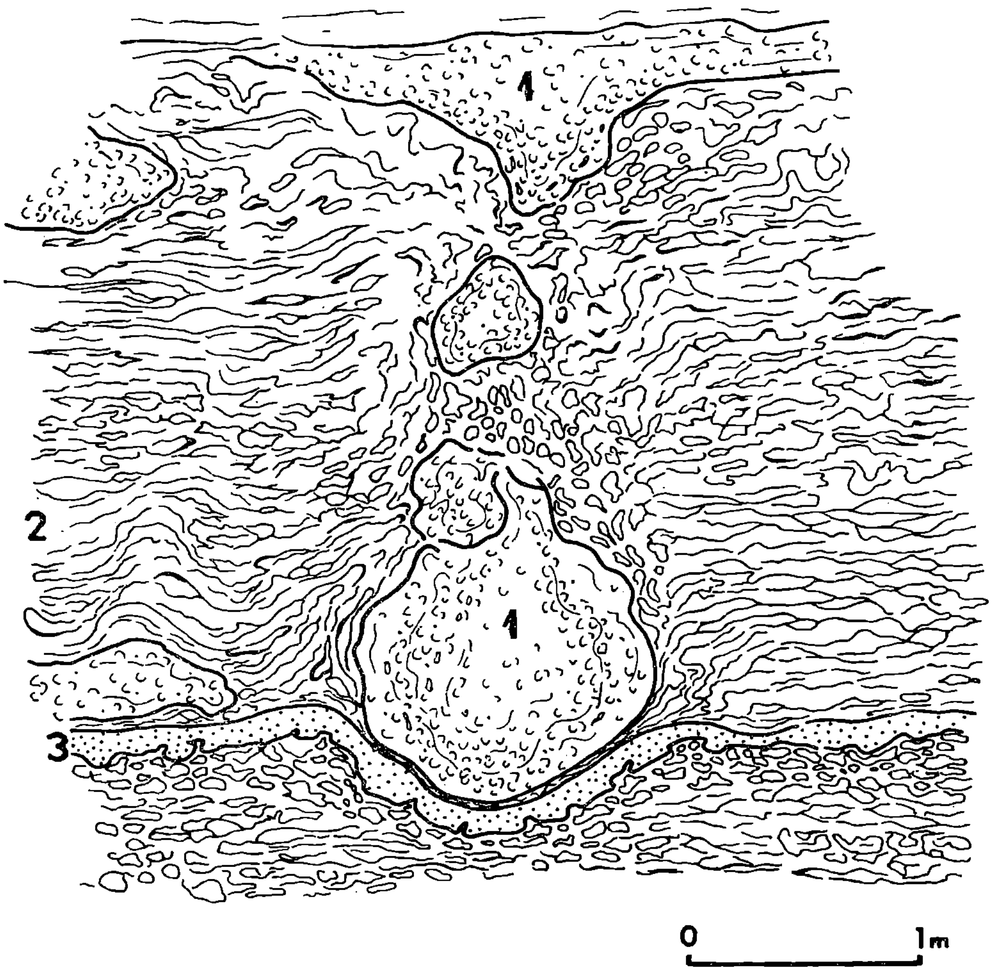

Fig. 5. Large „drop" of shell material (1) in fine-grained marly limestones (2) showing wavy and crumpled bedding. The „drop" sank into soft allochthonous shell layer (3) in coming to rest, dragging the layer downward. The dropstructure points to dominantly verticall readjustment movement in horizontally non-mobile system with reversed density gradient. Strzelce Opolskie

Fig. 5. Duża „kropla" osadów muszlowcowych (1) w faliście i gruzłowato zaburzonych wapieniach mikrytowych (2). „Kropla" utonęła w marglistym wapieniu mikrytowym i zatrzymała się w nie stwardniałej ławicy allochtonicznego muszlowca (3), powodując jego wygięcie ku dołowi. Obecność struktur kroplowych wskazuje na przewagę pionowych ruchów przemieszczających w ośrodku horyzontalnie stabilnym, wywołanych niestatecznym uwarstwieniem gęstościowym. Strzelce Opolskie

What statement can we make on the origin of currents that resulted in the formation of channel-fill shell beds? Let us speculate on some possible origins.

There has been a tendency on the part of some authors to interpret somewhat similar channel deposits in shallow water carbonate rocks as ebb gullies. Can this interpretation be applied to the Terebratula Beds? We think not. The Terebratula Beds in the study area represent offshore deposits of the Muschelkalk sea. As already noted these deposits are devoid of any features diagnostic of periodic subaerial exposure. In

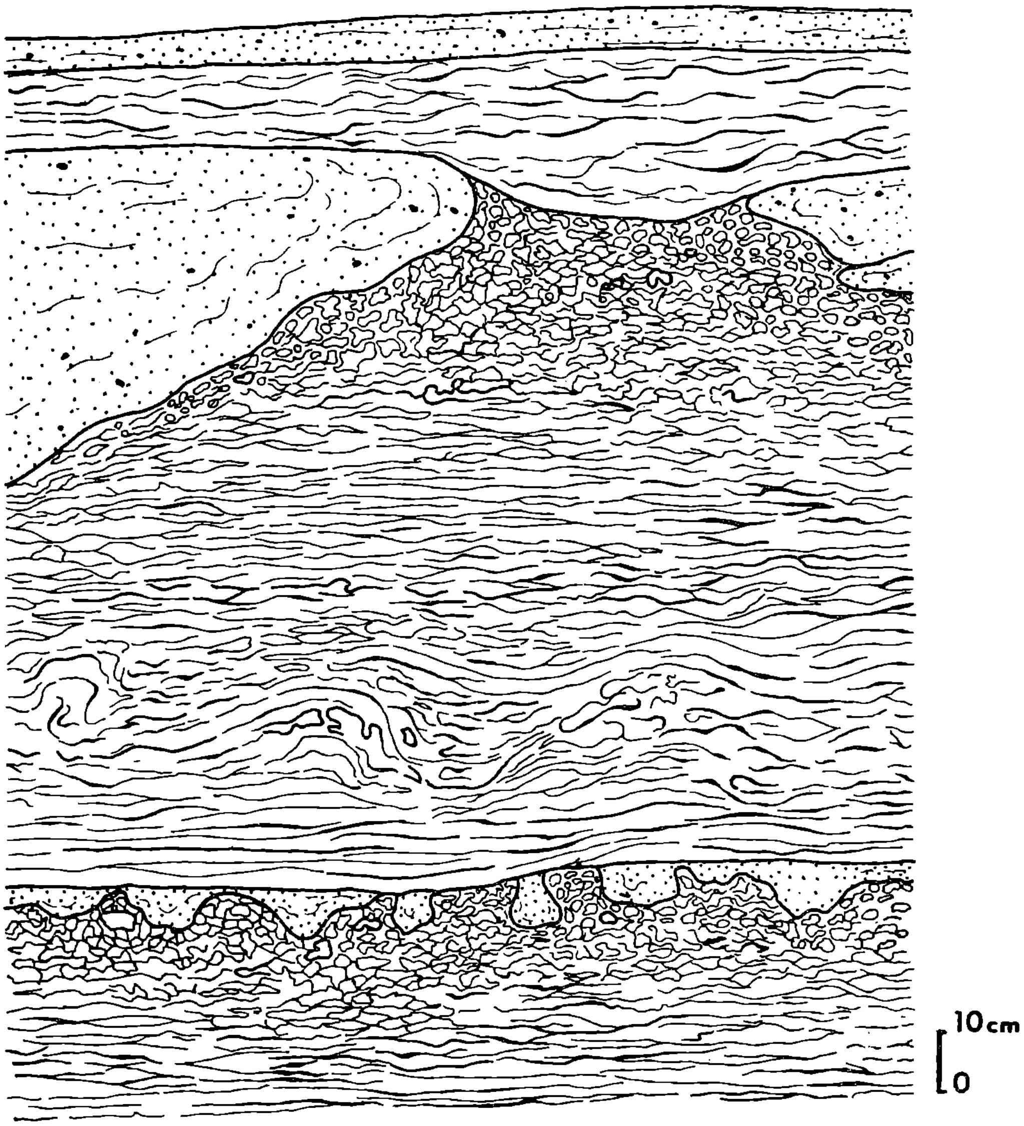

Fig. 6. Increased sphericity of „crumples" near and between load-deformed channels. Detail of channel-fill in uper left is end of deformed channel shown in Fig. 3, upper right. Strzelce Opolskie

Fig. 6. Wzrost kulistości gruzłów w pobliżu i pomiędzy zdeformowanymi osadami rynnowymi. Widoczny po lewej stronie fragment osadów rynnowych jest prawym skrajem rynny przedstawionej na fig. 3. Strzelce Opolskie

addition there are no features indicative of alternating ebb and flow directions and no evidence of lateral migration of channels. Therefore the channels under consideration cannot be regarded as fossil drainage trenches carrying off the water from tidial flats during the ebb of the tide.

Theoretically, one can explain the channel deposits in the beds discussed in terms of turbidity current sediments. Indeed, these deposits show many features which are commonly encountered in turbidites, e. g. graded bedding, sharply defined bottom surfaces. Yet this explanation, too, offers difficulties and it is difficult to make a certain case for it. Perhaps the main argument against such explanation is the shallow water environment of the Terebratula Beds combined with the obvious absence of any significant slopes which could generate gravity mass movements involving large masses of bottom sediments and capable of intensive erosion. In addition, the very local derivation of clastics and shells excludes remote sources and long transportation. There is also a good reason to suppose that the channel deposits here discussed are areally of very limited extent.

Of present day processes, only storm currents or tsunamis may be taken into account in explaining the origin of channel deposits under consideration. Although the tsunamis cannot be discarded, it is the first alternative that seems to provide the most simple explanation. Such explanation is not entirely new.

Until recently, the problem of storm deposits in ancient rocks has rarely been mentioned in literature, although the scarcity of references to such deposits appears to be one of recognition rather than one of existence (B a l l, 1971). Storm deposits and the fossil antidunes associated with them have been reported from Cambrian quartzites in the Holly Cross Mts. in Poland (D ż u ł y ń s k i and Ż a k, 1960). The second author (K u b i c z, 1971) has previously drawn attention to storms as to possible causative factors responsible for the formation of some "slump-like" deposits in the Muschelkalk of Silesia. Brief reference to storm deposits in the Muschelkalk of Bulgaria is also found in the paper by C h a t a l o v (1972). However, only few publications deal at length with storm deposits preserved in fossil record. Pertinent to the purpose of the present article are the publications by: B a l l, 1971; H o b d a y and R e a d i n g, 1972; B r e n n e r and D a v i e s, 1973 and by A g e r, 1974. The above indicated publications are concerned with sedimentological effects of storms and several observations given in these papers are consistent with the character of deposits here described. Parenthetically, it may be noted that storm deposits have been indicated as "tempestites" by Gilbert K e l l i n g (see A g e r, 1974) in analogy with "turbidites".

The role of strong storms and hurricanes in redistributing present day sediments is considered to be very important (see e. g. P e r k i n s and E n o s, 1968) and the hurricanes themselves are "commonplace events in term of geologic time" (B a l l et al., 1967).

The present day hurricane and typhoon deposits are chiefly known from beaches and tidial zones where violent storm generated currents are seen to scour deep trenches and fill them with gravels, shell debris and coarse clastics (e. g. McKee, 1959; Ball et al., 1967; Perkins and Enos, 1968; Shideler, 1973). Heavy storms are also known to stir the bottom sediments at depth of several tens of meters, and it seems reasonable to assume that in somewhat shallower waters they can also generate sediment laden bottom curents strong enough to scour the trenches and fill them with clastics.

The storm current hypothesis cannot be regarded as proved from evidence provided by the exposures, but it may be regarded as a tentative explanation. Such explanation imposes further depth limitations upon the sedimentary environment of the Terebratula Beds inasmuch as storm currents are presumably not very effective at depth greater than 10—20 meters. Whether or not the sedimentary environment of the Terebratula Beds in the study area Strzelce Opolskie was that shallow may be matter for discussion (sedimentological and paleoecological evidence is liable to be in interpreted in either way). However, to explain the channels at Strzelce Opolskie in terms of storm currents it is not necessary to assume that these channels were scoured in waters shallower than 10 m. One can assume that at the time of deposition of the Terebratula Beds the see floor showed a slight relief with very shallow shoals and somewhat deeper sediment ponding depressions. The notion of slight depth differences from a few meters to a few tens of meters is not at variance with field evidence and matches the situation that exists in recent areas of limestones sedimentation. It agrees also with a number of environmental models suggested for similar depositional basins elsewhere (e. g. Hallam, 1971, 1972). One can further assume that the shoals were inhabited or build up by autochthonous and semi-autochthonous brachiopod accumulations. Such shoals, when swept by rushing storm waves might have acted as chief sources of shell debris for graded channels deposits. The gentle slopes of the shoals, although not large enough to generate gravity mass-movements, might have been among the factors controlling the spread of storm induced suspension currents by carrying them to somewhat deeper areas (gravity assisted storm currents). The section at Strzelce Opolskie may represent one of such areas.

The environmental model here presented accounts also for the abnormal density and low diversity of benthonic fauna and our considerations should not end without a brief reference to this question.

The perplexing problem of abnormal density and low diversity of benthonic animals has been variously interpreted in literature. The key to this question is provided by the concept of adaptive response of animals to environmental stability versus instability (see e. g. Sanders, 1968; Bretzky and Lorenz, 1971). The main postulate of this concept is that the diversity of benthonic species decreases, and the population density increases with the "decreasing physical stability or predictability of the environment in terms of fluctuating temperature and salinity"

(H a l l a m, 1972, p. 405). Bottom dwellers in unstable environments are subject to "high stress" and respond to it by an increased fecundity. Consequently, as stated by H a l l a m (1972, p. 405 and 407) "faunas in the unstable environments... are restricted to eurytopic organismus of comparatively low diversity" and such organisms "are likely to occur in large and perhaps strongly fluctuating numbers from season to season".

With the bottom configuration as previously discussed the most likely cause of environmental instability in the "Terebratula sea" was the temperature fluctuation. It seems reasonable to suppose that the shoals which provided the main habitat for brachiopod colonies and which were covered by a thin layer of water were particularly exposed to temperature fluctuation culminating in abnormal rises of temperature during hot and windless seasons. Such abnormal rises in temperature resulted in decrease in oxygen content, and mass mortality to which the bottom dwellers responded by an increased fecundity.

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STRESZCZENIE [1]

W warstwach terebratulowych dolnego wapienia muszlowego w Strzelcach Opolskich i okolicy występują allochtoniczne i autochtoniczne ławice muszlowców. Ławice takie zbudowane są głównie ze skorupek ramienionogów, należących do rodzaju Terebratula.

Wśród ławic allochtonicznych występują 1. ławice z częściowo wysortowanym materiałem organodetrytycznym, powstałe pod wpływem działania długotrwałych prądów dennych oraz 2. ławice źle wysortowane, powstałe w wyniku jednorazowego, gwałtownego aktu sedymentacyjnego. Te ostatnie zawierają pokruszone i nie pokruszone skorupy ramienionogów, krynoidy i drobnoziarnisty osad wapienny i marglisty. Tego rodzaju osady wypełniają najczęściej płaskie rynny (fig. 1 i 6) wcięte w drobnoziarniste osady wapienne. W spągu rynien występują często większe, niekiedy obtoczone fragmenty wapieni (fig. 2), wydarte niewątpliwie z podłoża. Skorupy terebratul w omawianych muszlowcach są bez wątpienia redeponowane z niedalekiej odległości. Należy zauważyć, że w pobliżu Strzelc Opolskich w miejscowości Dziewkowice znajdują się, obok redeponowanych ławice muszlowca „in situ".

Źle wysortowane ławice muszlowe wykazują często duże i liczne zaburzenia, niekiedy w postaci kroplowych pogrązów, wywołanych tonięciem materiału klastycznego w miękkie, nie skonsolidowane podłoże (fig. 4 i 5). Ławice związane z jednorazowym gwałtownym aktem depozycyjnym są zdaniem autorów osadami burzowymi.

Środowiskiem sedymentacyjnym warstw terebratulowych było płytkie morze z mieliznami. Mielizny te były najprawdopodobniej siedliskiem ramienionogów i źródłem materiału klastycznego, który wynoszony prądami burzowymi osadzał się w zagłębieniach otaczających mielizny.

Masowe pojawianie się osobników należących do jednego lub kilku gatunków ramienionogów autorowie wiążą ze znaną w paleoekologii zasadą przystosowawczej reakcji organizmów do trudnych i zmieniających się w sposób losowy warunków życiowych (adaptive response of animals to environmental stability versus instability). Tego rodzaju warunki stwarzało zdaniem autorów prawdopodobnie nadmierne nagrzewanie się i spadek zawartości tlenu w wodzie w okresach gorącej i bezwietrznej pogody.

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[1] Obszerniejszy tekst polski przedstawiono w artykule: Dżułyński S., Kubicz A. (1974), Wykształcenie warstw terebratulowych oraz duże formy erozyjno-depozycyjne i towarzyszące im deformacje. *Przew. 46 Zjazdu PTG — Opole*, pp. 166—170, Inst. Geol., Warszawa.