

FRANK SIMPSON\*

## INTERFACIAL ASSEMBLAGES<sup>1</sup> OF FORAMINIFERA IN THE CARPATHIAN FLYSCH

(Pl. XC—XCIII, 2 Figs.)

### *O międzyrytmowych zespołach otwornicowych<sup>1</sup> we fliszu karpackim*

(Tabl. XC—XCIII, 2 fig.)

**Abstract:** Aggregates of small, benthonic Foraminifera occur at the interfaces between thin, fine-grained sandstone and shale layers of successive beds in sequences of Eocene flysch belonging to the Magura Series, Polish Western Carpathians. These interfacial assemblages are frequently seen as intermittent layers of thickness equal to the diameter of a single test. For descriptive purposes, four different types of interfacial assemblage were named after the most commonly occurring genera.

Varying degrees of lateral displacement of foraminiferal tests by the currents which deposited fine sand above the interfaces may be deduced. In many cases, however, lateral displacement of tests was at a minimum and the interfacial assemblages are residua, formed when bottom muds were selectively eroded by sand-bearing currents. The burrowing activities of larger invertebrates were effective in the disruption of interfacial assemblages and in the mechanical fragmentation of tests.

#### INTRODUCTION

Nesteroff (1961, 1963) described pelitic elements of beds from deep-sea cores of Recent turbidites, divisible into two parts: a lower layer, in which the microfauna is either impoverished or absent, and an upper layer, characterized by the presence of pelagic Foraminifera and pteropods. Where the succeeding bed begins with fine-grained sand or silt, the tests may be concentrated in a band, of thickness equivalent to the diameter of a single test, occurring at the mud/sand interface. Nesteroff (1961, 1963) and Nesteroff and Heezen (1963) deduced deposition of the layer of tests from the tail of a turbidity

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<sup>1</sup> Powierzchnia międzyrytmowa odpowiada „interface” sensu Dżułyński i Simpson (1966, p. 197). Pojęcie „rytmu” wyjaśnia autor w pracy (Simpson, 1970).

Interface sensu Dżułyński and Simpson (1966, p. 197). Other terms concerning stratification, used here, are given by Simpson, 1970.

\* Address: Dr Frank Simpson, Department of Mineral Resources Sub-surface Geological Laboratory 201-E, Dewdney Ave., Regina, Saskatchewan, Canada.

current and furthermore, concluded that pelagic deposits are generally eroded away by succeeding turbidity currents (Nesteroff and Heezen, 1963). An alternative explanation was subsequently provided by Kuenen (1964), who suggested that the removal of clay from the sea-bottom by a turbidity current lacking the energy required to lift the tests gave rise to a thin concentrate of shells, forming a „pavement” at the base of the turbidite sand. Though no fossil pavements have been hitherto recorded as such in the voluminous literature pertaining to flysch and flysch-like deposits, Kuenen’s hypothesis is attractive in that it is supported by some experimental and theoretical evidence (Kuenen, 1964, p. 242).

Organic remains from the interfaces between flysch sandstones and the shales beneath them have been previously reported as assemblages occurring on the soles of sandstones. A brief survey of these occurrences is followed by a detailed account of interfacial assemblages from the Eocene of the Magura Series. The sedimentation of the flysch formations of the Magura Series, to which reference is made in this account, is considered in detail by Simpson (1969).

Książkiewicz (1960, p. 743 and Plate III, Figs. 12, 13) described, under the name „*Halimeda*”<sup>1</sup>, ramifying, chain-like arrangements of siliceous, capsulate bodies, found on sandstone soles in the Istebna Beds and in the Cretaceous and Palaeocene of other units. As pointed out by Książkiewicz (op. cit.), these chains correspond in shape to systems of negative sole structures described by Fuchs (1894). Both occurrences are probably referable to the *Aschemonella* Brady (see Neagu, 1964, p. 586). An occurrence of tubes of *Bathysiphon* M. Sars on the soles of thin sandstones belonging to the Istebna Beds was reported by Książkiewicz (1961, pp. 23—25 and Plate I, Fig. 1). Tubes up to 4 cm. in length are aligned in parallelism with the principal current direction and exhibit a preferred orientation, with their pointed ends downcurrent (see also Bieda, 1948, Plate IV, Fig. 5). Książkiewicz (1961) also described groove moulds with *Bathysiphon* at their downcurrent ends (see also Dżułyński, 1963, Plate XXVIII, Fig. 3) and linguoid ridges of the sole, downcurrent with respect to the *Bathysiphon* tubes with which they make contact. The former structures may have arisen as a result of the dragging action of the current, while the latter may be interpreted as current-formed scours, eroded either before or after the deposition of the tests (Książkiewicz, 1961). Similar occurrences of *Bathysiphon* have been recorded from the Ciężkowice Sandstone of the central Polish Carpathians by Ślaczka (1964, p. 203). Aligned tests of the *Bolivina argentea* at the base of a graded sandstone layer from the submarine Santa Barbara Basin, off southern California, are figured by Harman (1964, Fig. 6, p. 86).

Assemblages of Foraminifera have been found on the soles of flysch sandstones belonging to the Upper Senonian of the eastern Carpathians by Danysz (1966), who describes „needle-like” (probably *Hyperammina* or a related form; see also op. cit., p. 21), „worm-like” (an indeterminate, tubular form), „rosary-like” forms (*Aschemonella* or a related form). On some sandstone soles, the tests are aligned parallel to the lineation given by interfacial sedimentary structures (Danysz, 1966,

<sup>1</sup> The apostrophes are used by Książkiewicz (op. cit., p. 743).

p. 20). Species of the branching, *Dendrophryna* Vialov and *Aschemonella* Vialov, as well as straight tubes of *Aciculina* Vialov reaching up to 12 cm. in length, were described by Vialov (1966) from the soles of Upper Cretaceous flysch sandstones in the northern Carpathians. Other tubular forms were reported from the lower surfaces of Miocene sandstones in the western Ukraine by Vialov and Pishvanova (1967).

Also relevant to the present discussion are certain interfacial accumulations of graptolites, described by Jaworowski (1964, 1966) from the Silurian of eastern Pomerania. Jaworowski (1966) deduced bottom traction of graptolite rhabdosomes from considerations of short groove moulds and prod moulds evidently formed by these on the sole of a thin (6 mm.) siltstone layer and concluded that the rhabdosomes were transported by weak currents of low density (compare with Khaletskaya, 1967).

From this brief review, several general considerations emerge:

1. Occurrences of the remains of pelagic and benthonic organisms have been reported from the soles of flysch and flyschoid sandstones.

2. There is reason to believe that some of these occurrences are fairly common (see, for instance, Książkiewicz, 1960, p. 743), though the distribution of organic remains on a given sole is usually sparse.

3. Interpretative emphasis has hitherto rested upon the sandstones, on the soles of which the fossils are found. Thus erosion of the organic remains from the bottom muds, followed by redeposition at some more distal point from a sand-bearing current has been deduced (Książkiewicz, 1960, 1961; Jaworowski, 1966).

4. The microfauna of the shales immediately underlying such sandstones has not been investigated.

#### EOCENE INTERFACIAL ASSEMBLAGES OF THE MAGURA SERIES

By interfacial assemblage is meant a concentration of foraminiferal tests occurring as a layer, usually of thickness equal to the diameter of a single shell, and coincident with the erosional shale/sandstone interface, where successive beds make contact. These assemblages are only found where fine-grained sandstones rest upon shales; in instances, where either the sandstone is medium- or coarse-grained or where the shale contains a significant proportion of the coarser size fractions, interfacial assemblages of microfossils do not normally occur. For descriptive purposes, four different types of interfacial assemblages are here named after the genus usually predominant among those commonly appearing in a given assemblage:

1. *Aschemonella* assemblage,
2. *Bathysiphon* assemblage,
3. *Hyperammia* assemblage,
4. *Sphaerammina* assemblage.

It is emphasized that, by definition, such an assemblage is characteristic for a part of a given interface only and is not necessarily typical as a whole for either the sandstone or shale elements respectively of the beds in contact at that interface. Also, a genus predominating in a particular

assemblage may appear in reduced proportions in a different assemblage. An interfacial assemblage carries no age connotation.

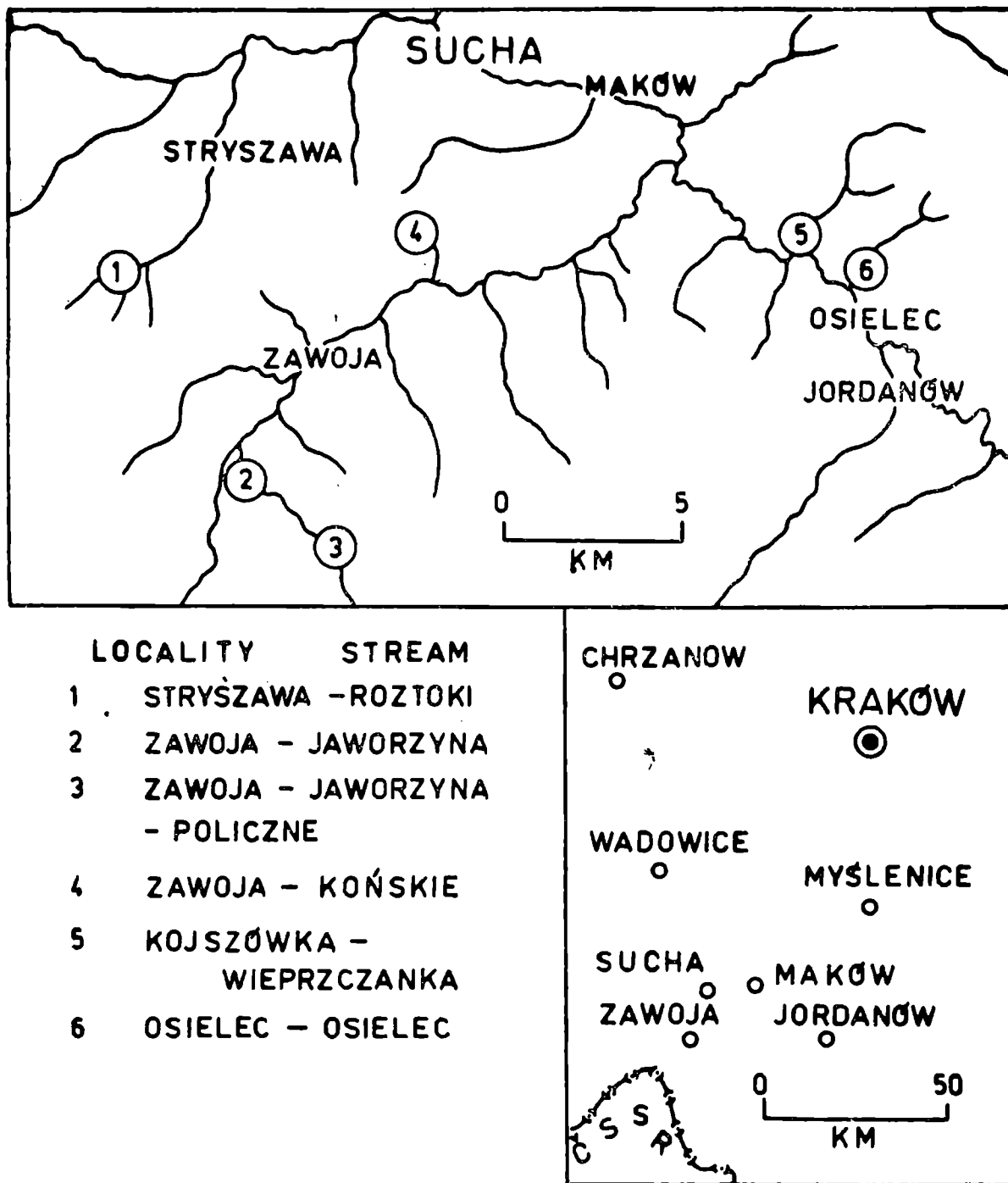


Fig. 1. Sketch map showing location of main points where interfacial assemblages found

### *Aschemonella* assemblage

This assemblage is known from a single occurrence in the Beloweza Beds, exposed in the stream Przywarówka, NW of Lipnica Wielka (locality beyond the area shown in Fig. 1). Test of *Aschemonella* Brady are irregularly distributed as fragments up to 3 cm. long, showing

random orientation in the plane of the interface. They frequently occur at the upcurrent ends of flute marks or are partially enclosed by small current crescents. The material described was not located in situ and therefore the microfaunal composition of the underlying shales is not known. The absence of a preferred orientation with respect to the lineation defined by current-formed interfacial structures suggests the possibility that the tests underwent a minimum of lateral displacement by the sand-depositing current. This interfacial assemblage (Plate XC, Fig. 1) is also known from the Inoceramian Beds and Variegated Shales of the Polish Western Carpathians (M. Książkiewicz, personal communication, 1967).

#### *Bathysiphon* assemblage

An interfacial assemblage consisting exclusively of narrow, elongate and tapering tubes, referable to the genus *Bathysiphon* M. Sars (fide Loeblich and Tappan, 1964, p. 186), is of fairly common occurrence in the Hieroglyphic Beds and in fine-grained complexes belonging to the Osielec Sandstone. The tubes are made up of fine-grained siliceous material held together by a chalcedonic cement. They may reach lengths of 7 cm., as in the uppermost Hieroglyphic Beds, exposed in the stream Wieprzczanka, near Kojuszówka; tubes of lengths up to 3 cm. are most commonly seen. Tests are generally laterally compressed and buckled, so as to give hour-glass and C-shaped cross-sections. Further evidence of the flexibility of these tests is provided by the common occurrence of tubes bent so that, in each case, an acute angle is described by two connected portions of the tube. On the other hand, *Bathysiphon* tests are frequently transected by fractures at right angles to the walls and dividing the tubes into sections up to 1—2 mm. in length (see Plate XC, Fig. 2). These sections correspond in size to fragments of *Bathysiphon* found as part of the microfauna yielded by disaggregated shales.

The microfaunal composition of this interfacial assemblage is unvarying, comprising tests of *Bathysiphon* only. The most striking variation exhibited by the assemblage is in population density, with different interfaces characterized by rare, common or abundant tests.

In relatively sparse assemblages, tests frequently show a well developed preferred orientation. The lineation so defined usually corresponds to that given by sedimentary structures at the same interface or to the direction of maximum dip for cross-laminae in the sandstone above the interface. Current-formed structures at these interfaces include grooves at the upcurrent ends of tests (Plate XC, Fig. 3) and downcurrent scours as described by Książkiewicz (1961), as well as current crescents developed at the upcurrent ends of tests (Plate XC, Fig. 4). Plate XC, Fig. 4 shows a concentric arrangement of *Bathysiphon* tests, evidently formed by the action of vertical vortices, following entrapment of the tests in a depression of the mud surface.

Tests of similar dimensions tend to occur together in these sparse assemblages and bent tests are rare or absent. Furthermore, fragments of *Bathysiphon* are extremely rare in the shales below the interface. Thus the relatively sparse *Bathysiphon* assemblages display a number of features which suggest that the tests have undergone lateral displacement by the currents from which sand was deposited. Assemblages of this type are known from the Osielec Sandstone, exposed in the stream

Roztoki, Stryszawa, and the stream Osielec, Osielec Górny, from the uppermost Hieroglyphic Beds in Roztoki, and from the Beloweza Beds of Ochlipów, Zubrzyca Górna.

Assemblages richer in individuals reflect a diminished influence of current activity upon a given population. For instance, in the upper part of the Hieroglyphic Beds exposed in Końskie, Zawoja, shale elements in the order of 3—6 cm. in thickness and containing abundant *Bathysiphon*, visible in hand specimen, are each succeeded in vertical sequence by sandstones in which *Bathysiphon* is rare or absent. At the interfaces between beds, *Bathysiphon* tubes are found in rich assemblages showing a low degree of preferred orientation. Bent tests are fairly common. Tool markings are rare and scour structures absent. Thus the Końskie assemblages are considered to be autochthonous, as are certain *Bathysiphon* assemblages in the upper part of the Hieroglyphic Beds of the stream Wieprzczanka, near Kojaszówka.

### *Hyperammina* assemblage

Assemblages in which the predominant form is *Hyperammina* Brady are found throughout the Hieroglyphic Beds. They are seen as transitions between an impoverished fauna, comprising mainly scarce tests of *Hyperammina*, and a rich assemblage, consisting of numerous, closely packed tests of *Hyperammina* with subordinate amounts of other benthonic forms.

In the relatively sparse assemblages, tests of *Hyperammina*, up to 4 mm. in length, are frequently oriented in parallelism with the current-direction given by flute-lineation and rare current crescents (Plate XC, Figs. 5, 6). Sometimes low, elongate scours are located at the downcurrent ends of tests. The tests are often bent into gentle sigmoid curves (Plate XC, Fig. 6). The minimum extent of current influence upon the assemblage is thus seen as rotation of tests into positions of stability and widespread entrainment of bottom mud.

These current effects are further developed in the richer *Hyperammina* assemblages. An extreme example is provided by an interfacial assemblage from near the top of the Hieroglyphic Beds in Wieprzczanka, between Wieprzec and Kojaszówka. Here *Hyperammina* predominates in an assemblage comprising both tubular and many-chambered forms. The former are represented by *Hyperammina*, *Psammosiphonella* Avnimelech (see Pflaumann 1964, pp. 49—54), *Rhizammina* Brady and fragments of *Bathysiphon*; the latter by *Sphaerammina*, *Trochaminoides* Cushman, *Haplophragmoides* Cushman, *Recurvoides* Earland, *Lituotuba* Rhumbler, *Glomospira* Rzehak, and *Aschemonella* Brady.

Though the population density of the assemblage and its composition tend to vary within the interface, tests are closely spaced throughout. Tubular forms and scarce fish-teeth (Plate XC, Figs. 5, 6; Plate XCI, Figs. 1, 2) are oriented parallel to the current direction given by the maximum dip of sandstone cross-laminae above the interface (Plate XCI, Fig. 3) and by the trend of groove moulds on the sandstone sole (Plate XCI, Figs. 1, 2). *Hyperammina* occurs as bent, sometimes bilobed tubes, found in a fragmented condition. The fragile, terminal swelling of the tube, or proloculus, is sometimes present and usually indicates the up-current direction. Numerous, sand-filled grooves, exhibiting a preferred

orientation in agreement with that of the elongate tests and bilobed like *Hyperammia*, are of common occurrence. These were presumably formed as a result of bottom traction of *Hyperammia* tests. *Psammosiphonella* occurs as straight, undeformed tubes, while *Rhizammina* is seen as Y-shaped, branching forms. *Bathysiphon* is present as scarce tubes up to 5 cm. in length and more commonly as small, laterally folded fragments found characteristically at the downcurrent ends of paired groove-sets (Plate XC, Fig. 5; Plate XCI, Fig. 1). The many-chambered forms, taken as a single sub-population, show poor sorting and the proportions of the genera present vary over relatively short distances on the interface. The presence of small, fragile tests of *Aschemonella* which show no preferred orientation, suggests this form suffered a minimum of lateral displacement.

The closely packed foraminiferal tests and associated tool markings do not occur where either of two types of interfacial structure are found:

1. organic trails of *Palaeophycus* type, formed after the deposition of the sand layer,
2. flat-bottomed, multiple groove-moulds, up to 2 cm. in width and 0.5 cm. in depth.

These structures mark unfossiliferous, relatively smooth areas of the sandstone sole (Plate XCI, Fig. 2). In the case of *Palaeophycus*, rejection of tests by a sediment-eating burrower is indicated. The comparatively smooth surfaces of groove-moulds evidence a much lower density of Foraminifera at only short vertical distances below the layer of tests presently preserved at the interface. Within the sandy infilling of a groove, but at the level of the interface on either side of the groove-mould, tests of *Bathysiphon* are frequently localized. Above the interface, for a distance of 4—6 cm., organic remains are scarce (< 1%). At this level, however, the amount of organic material in the sandstone sharply increases (6%) in the form of tests seen at the interface, among which *Bathysiphon* is conspicuous.

The faunal composition of the shale underlying the interface is as follows: *Sphaerammina*, *Trochamminoides*, *Recurvoides*, *Psammosiphonella*, fragments of *Bathysiphon* and indeterminate tubular forms (probably *Hyperammia*). The most striking feature here is the extremely low proportion of *Hyperammia*, which may be explained in one of three ways:

1. the tests of *Hyperammia* were mostly destroyed during preparation of the shale;
2. *Hyperammia* was allochthonous;
3. *Hyperammia* was autochthonous, but was confined to the uppermost, eroded part of the mud.

The first possibility is considered to be unlikely, since samples from other beds treated in a similar manner yielded varying proportions of *Hyperammia*. The presence of the fragile proloculus on tests in the interfacial assemblage is taken to indicate a minimum of lateral displacement. Thus the third possibility is held as being most likely (see also Nyholm, 1957, Fig. 1, p. 76, for the modes of life of some tubular, small Foraminifera).

#### *Sphaerammina* assemblage

Interfacial assemblages characterized by the predominance of *Sphaerammina* Cushman are fairly common in the Hieroglyphic Beds.

Other forms often present as minor constituents in this assemblage are *Trochamminoides*, *Haplophragmoides*, *Hyperammina* and *Psammosiphonella*. Near the top of the Hieroglyphic Beds exposed in the stream Jaworzyna, Zawoja-Policzne, interfaces with the *Sphaerammina* assemblage are of common occurrence in complexes of beds where fine-grained sandstones, 1—6 cm. thick, are succeeded by shales of similar thickness. The sandstones are usually made up entirely ripple-drift cross-laminae and interfaces are relatively even. The assemblage is also frequently found in similar complexes belonging to the Hieroglyphic Beds, seen in Końskie, Zawoja-Gołynia.

Differences are seen from one interface to another in population density, in associated current-formed, interfacial structures and in degree of disruption due to burrowing activity. On the basis of these three variables, four arbitrary subtypes of assemblage may be distinguished. These subtypes may occur separately or to varying degrees mixed.

1. *Sphaerammina* and other many-chambered forms are randomly distributed within the interface (Plate XCI, Fig. 4). Sorting of many-chambered tests is poor. The only evidence of current action upon the assemblage comes from the preferred orientation of scarce tubular forms. This is the most common variant of the assemblage, occurring widely in Jaworzyna and Końskie.

2. There is relative uniformity of distribution of Foraminifera within the interface, but lateral displacement by the sand-bearing current is evidenced by short, sand-filled grooves, each with a test at its down-current end (Plate XCI, Figs. 5, 6). The grooves are up to 2 mm. in length and the maximum width corresponds to that of the adjacent test. Throughout the Policzne section of Hieroglyphic Beds in Jaworzyna, grooves of similar dimensions are found on the soles of fine-grained sandstones, but without the tools responsible for their formation. Clearly these structures evidence bottom traction of many-chambered Foraminifera. Plate XCI, Fig. 5 and 6 show *Sphaerammina* tests at the down-current ends of short grooves on the sole of a 7 cm. layer of convoluted sandstone from Policzne. The faunal composition of the shale below the interface is: abundant *Sphaerammina*, with *Trochamminoides*, ? *Haplophragmoides* and ? *Hyperammina*.

Therefore in this case, although some lateral movement of the tests is clearly indicated by interfacial structures, the assemblage is considered to be essentially autochthonous. It was concentrated primarily in response to a vertical component of displacement, attendant upon the selective erosion of bottom muds by the sand-bearing current.

3. *Sphaerammina* and other many-chambered forms are sometimes concentrated by current action in depressions of the mud surface and by the activities of burrowing organisms in postdepositional trails. In the Hieroglyphic Beds at Policzne, for example, closely packed concentrations of tests occur as infillings of prod moulds, and in the Końskie section, *Sphaerammina* is concentrated in flute moulds (Plate XCII, Fig. 1). Tests of many-chambered forms are sometimes found as accumulations in current-excavated trails of predepositional origin (compare with Książkiewicz, 1960, p. 739). These trails are usually of *Subphyllochora* and *Spirophycus* types (see Plate XCII, Fig. 2—4), showing localized fluting and with cross-laminated infillings.

Likewise, tests may be concentrated in trails, post-depositional with



respect to the sandstone above the interface. Plate XCII, Fig. 5 and 6, for example, show tests of *Sphaerammina* concentrated in a trail of *Palaephyucus* type, while in Plate XCIII, Fig. 1 and 2, tests occur abundantly in the systems of sand-filled tubes belonging to an irregular *Paleodictyon* network (sensu Seilacher, 1962, Fig. 1, p. 230). In the latter example, the sandy tubes with *Sphaerammina* are also found in the uppermost part of the shale below the interface.

In all cases considered above, tests seen at the interface exhibit poor sorting, adult forms occurring with juvenile stages. The elongate shape of the tubular forms effectively excludes them from both the current-formed and organically generated types of assemblage.

4. Closely packed aggregates of many-chambered Foraminifera, forming a discontinuous basal layer of thickness equal to the diameter of a single test, are seen on the soles of some fine-grained sandstones exposed in Końskie (Plate XCIII, Fig. 3, 4). Similar aggregates, differing in that the tests are not so closely spaced, are also found on the upper surfaces of the underlying shales. Presumably this splitting of an interfacial assemblage is a result of unevenness in the distribution of cement, due to irregularities in the packing of tests. These aggregates comprise tests of *Sphaerammina* and extremely scarce tubular forms, usually represented by *Hyperammina*. The many-chambered tests are poorly sorted. In the shale sampled for a vertical distance of 1 cm. below such an interface, the faunal composition was: abundant *Sphaerammina*, with *Trochamminoides* and indeterminate tubular forms. Thus a strong predominance of *Sphaerammina* is a feature common to both the interfacial assemblage and the uppermost part of the shale below the interface. Rare, branching tests of *Rhizammina*, reaching up to 3 cm. in length (Fig. 2 and Plate XCIII, Fig. 5), have been discovered in the same interfaces as the sheet-like aggregates of *Sphaerammina*. These delicate forms, well preserved and showing no signs of deformation, cannot have suffered displacement, either vertical or lateral.

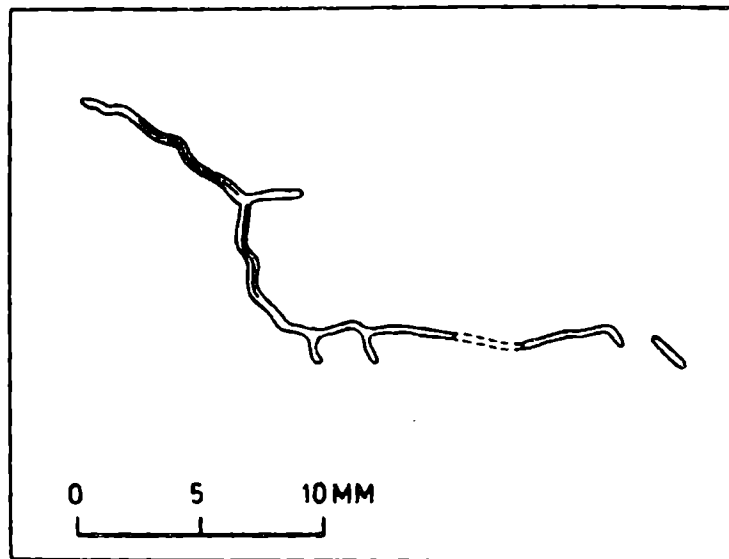


Fig. 2. Delicate, branching test of *Rhizammina* sp. on sandstone sole. Hieroglyphic Beds, Middle Eocene. Stream Końskie, Zawoja—Gołynia. The same specimen is shown in Pl. XCIII, Fig. 5

Any one of the above subtypes may be found at a given interface, either separately or mixed to varying degrees with one or more of the other three. The only exception here is that sheet-like aggregates of tests (subtype 4), though frequently associated with randomly scattered, isolated tests (subtype 1) and often transected by post-depositional burrows packed with many-chambered forms (subtype 3), are nowhere found together with current-formed sedimentary structures (see subtype 2).

#### ORIGIN OF INTERFACIAL ASSEMBLAGES

Four different origins are conceivable for the interfacial assemblages of microfossils described:

1. The layer of foraminiferal tests was laid down during the final depositional phase of the current, which formed the bed immediately below the interface. Any pelagic deposits later formed were eroded away by the next suspension current, without disruption of the layer. This approach, analogous to the view expressed by Nesteroff (1961, 1963) and Nesteroff and Heezen (1963), is not acceptable here because of the extremely poor sorting of tests making up a given interfacial assemblage. For example, coarse silt and all sand grades are frequently represented by tests of *Sphaerammina* in assemblages where this form is common. As pointed out by Rusnak (1957, pp. 387—389), differences in effective density and shape of current-borne organic remains of similar sizes give rise to differences in hydraulic behaviour (see also Rusnak and Nesteroff, 1964, pp. 489—493). However, where tests confined to a particular genus, abundant in a given interfacial assemblage, display poor size sorting, it is unlikely that they were transported any great distance prior to deposition.

2. The tests were eroded from bottom muds and carried by a sand-bearing current, to be deposited and concentrated as the coarse-grained fraction (compare with Phleger, 1960, p. 98) at a more distal point. Certainly evidence of tests having acted as tools during bottom traction and the concentrates of tests, found as infillings of various types of interfacial structure, indicate that lateral displacement took place. However, the strikingly poor sorting of tests, the good preservation of delicate tubular forms, such as *Hyperammina* and particularly *Rhizammina*, and good qualitative correspondence between the interfacial fauna and that of the underlying shale suggest that, in many cases, lateral movement was at a minimum. Clearly the degree of displacement of tests will vary from one interface to another, according to the consistency of the bottom sediment and the flow characteristics of the sand-depositing current.

3. In many cases, the microfossils were concentrated primarily by vertical movements of tests, consequent upon the winnowing away of clay from the bottom muds (see Kuennen, 1964) by a sand-bearing current. A minimum of lateral displacement, in the form of rotation of tubular forms into preferred orientation and perhaps limited rolling of many-chambered forms, to give closely packed aggregates, took place. This explanation satisfies the arguments against points 1 and 2 above, and is considered to be the one most generally acceptable.

4. A final possibility is that tests from the underlying shales were concentrated at the interface by the activity of burrowing organisms.

Though aggregates of indisputable organic origin are known, these are exclusively in the form of tubes, and it is difficult to envisage how a continuous layer of particles might be generated by organic means alone. On the other hand, the widespread disruptive effects of burrowing upon interfacial assemblages should be borne in mind. Describing the Foraminifera of the slope province in the Santa Barbara Basin, off California, H a r m a n (1964, p. 86) wrote:

„Broken tests, sporadic frequency distributions of species, abnormally low foraminiferal numbers and large percentages of fecal pellets may indicate that the larger burrowing organisms destroy some of the foraminiferal tests”.

This passage suggests that H a r m a n had in mind mechanical effects of burrowing. The displacement and fragmentation of tests by burrowers is well demonstrated by certain interfacial assemblages, preserved on sandstone soles exhibiting abundant trails, postdepositional with respect to the sandstone. Displacement of tests is well illustrated by the example already discussed, in which *Sphaerammina* is concentrated into the tubes of an irregular *Paleodictyon* network (Plate XCIII, Fig. 1 and 2). Some soles, characterized by numerous postdepositional trails of *Scolicia* type, display both displacement and fragmentation of tests belonging to the *Sphaerammina* assemblage. Where *Scolicia* is seen as high, positive reliefs, tests are usually absent from the surfaces of the trails, while occurring in fair abundance on the „unburrowed” parts of the sole. However, where the trails are low in relief, tests of *Sphaerammina* and *Rhizammina* may occur at the interface. In these cases, the latter is seen as broken networks of branching tubes (Plate XCIII, Fig. 6). Thus it is likely that burrowing action frequently led to the fragmentation of branching, tubular Foraminifera by mechanical means. On the other hand, chemical effects appear to have been slight or absent, even where ingestion of tests can be inferred.

#### CONCLUDING REMARKS

1. Aggregates of small, benthonic Foraminifera occur at the interfaces between thin, fine-grained sandstone and shale layers of successive beds in sequences of Eocene flysch belonging to the Magura Series, Polish Western Carpathians. The sandstone layers above such interfaces are usually made up of cross-laminae of ripple-drift type.

2. Interfacial assemblages of small Foraminifera are frequently seen as intermittent layers, varying considerably in the packing density of the tests and of thickness equal to the diameter of a single test. Concentrations of foraminiferal tests are also found in the depressions of the interface provided by trace fossils of various types and by current-formed sedimentary structures, particularly flute moulds.

3. For descriptive purposes, different types of interfacial assemblage were named after the most commonly occurring genera. Forms predominant at a given interface are frequently found making up reduced proportions of another assemblage.

4. Lateral displacement of tests by current action is clearly evidenced where the Foraminifera of an interfacial assemblage are found at the downcurrent ends of minute groove moulds. Rotation in response to current flow above the present interface is indicated where the long

axes of tubular tests are oriented parallel to the direction of maximum dip of sandstone cross-laminae above the interface.

5. That lateral displacement of the tests making up interfacial assemblages was at a minimum in some cases is suggested by:

a) poor sorting of the tests representing a particular genus in a given interfacial assemblage;

b) the lack of preferred orientation of long axes in assemblages where elongate, tubular forms predominate;

c) the presence of undamaged, fragile forms, such as tests of *Hyperammia* with the proloculus and also delicate networks of *Rhizammina*;

d) instances in which the predominant genera of an interfacial assemblage predominate also in the shale below the interface. Such interfacial assemblages are thought to arise largely as a result of movement of tests vertically downwards, consequent upon erosion of the enclosing mud by a sand-bearing current.

6. Those interfacial assemblages, arising primarily by vertical displacement of tests, may be considered as being essentially in situ. They evidence time intervals between episodes of sand deposition, during which colonization of the mud bottom by small, benthonic Foraminifera took place. This was presumably effected under conditions of either non-deposition or pelagic deposition and in absence of strong currents.

7. It is likely that the calcareous tests of pelagic Foraminifera, with effective densities lower than those of the siliceous benthonic forms described, were preferentially eroded from the bottom, together with pelitic grains, usually to be deposited as part of a fine-grained sandstone layer. It is suggested that the test material of any calcareous forms concentrated at the interfaces was dissolved and redistributed throughout the sediment during diagenesis. The plane of lithological discontinuity, provided by the interface, would facilitate this process.

8. There is evidence that the burrowing activities of larger invertebrates were effective in the disruption of interfacial assemblages and in the fragmentation of tests.

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Department of Geology,  
Jagiellonian University,  
Kraków, Oleandry Str. 2a

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## STRESZCZENIE

We fliszowych utworach eoceńskich serii magurskiej polskich Karpat zachodnich występują nagromadzenia małych, bentonicznych otwornic, które usytuowane są na międzyrytmowych powierzchniach cienkich ławic drobnoziarnistych piaskowców i łupków (fig. 1, 2; tabl. XC—XCIII). W ławicach piaskowców, które występują ponad takimi powierzchniami międzyrytmowymi, zazwyczaj spotyka się tylko struktury złożone ze wspinających się riplemarków (tabl. XCI, fig. 3; tabl. XCIII, fig. 4). Miąższość skupień równa się średnicy skorupki pojedynczej otwornicy. Nagromadzenia skorupki otwornic obserwuje się także w zagłębieniach międzyrytmowych powierzchni, które mają charakter różnego rodzaju hieroglifów organicznych (tabl. XCII, fig. 2—6; tabl. XCIII, fig. 1, 2) lub erozyjnych struktur prądowych, a szczególnie jamek wirowych (tabl. XC, fig. 4; tabl. XCII, fig. 1). Przy opisach poszczególnych, wyróżniających się typów omawianych skupień autor posługuje się nazwami rodzajowymi dominujących w nich otwornic. Formy dominujące w danym typie skupień mogą jednak występować podrzędnie w innych typach.

Wyróżniono następujące typy skupień otwornic:

1. Zespół z *Aschemonella*,
2. Zespół z *Bathysiphon*,
3. Zespół z *Hyperammina*,
4. Zespół ze *Sphaerammina*.

W niektórych przypadkach występowanie skupień otwornic w odprądowych partiach śladów wleczenia (tabl. XC, fig. 3; tabl. XCI, fig. 1, 5, 6) wskazuje na lateralne przemieszczenia skorupki przez prąd. Również ułożenie najdłuższych osi rurkowatych skorupki równoległe do kierunku maksymalnego upadu warstewek skośnych osadów spoczywających powyżej świadczy także o działalności prądu (patrz tabl. XC, fig. 5, 6). Natomiast o tym, że lateralne przemieszczenia skorupki otwornic musiały być na ogół minimalne, dowodzi: a) złe wysortowanie skorupki danego rodzaju w danym skupieniu międzyrytmowym (tabl. XCIII, fig. 3), b) brak orientacji najdłuższych osi skorupki w skupieniach złożonych z podłużnych, rurkowatych form (tabl. XC, fig. 2), c) obecność nie uszkodzonych, kruchych form, jak np. skorupki *Hyperammina* z zachowaną pierwszą komorą, lub delikatnych skorupki *Rhizammina* (fig. 2; tabl. XCIII, fig. 5), d) przypadki, w których rodzaje przeważające w międzyrytmowym zespole dominują także w łupku poniżej powierzchni międzyrytmowej. Takie międzyrytmowe zespoły utworzone są przeważnie w wyniku wymywania przez prąd i mają charakter residuum. Powstały one w rezultacie działalności tego samego prądu, który deponował

następnie wyżejległe osady piaszczyste. Owe międzyrytmowe zespoły występują zatem niemal in situ. Zespoły te świadczą o istnieniu przerw między epizodami depozycji piasku, w czasie których zachodziła kolonizacja dna przez małe, bentoniczne otwornice. Przypuszczalnie miało to miejsce w warunkach albo braku depozycji dennej albo depozycji pelagicznej, a także przy nieobecności silnych prądów.

Jest prawdopodobne, iż skorupki wapiennych, pelagicznych otwornic, które mają mniejszy ciężar właściwy aniżeli krzemionkowe skorupki omawianych otwornic, zostały wybiórczo wyerodowane z dna wraz z materiałem pelitycznym. Niezależnie od tego wapienne skorupki otwornic, o ile zachowały się na powierzchniach międzyrytmowych, mogły później zostać stosunkowo łatwo rozpuszczone podczas procesów diagenety.

W badanych osadach można stwierdzić, że wskutek działalności większych zwierząt bezkręgowych skupienia otwornic były deformowane, a skorupki ulegały przy tym połamaniu (tabl. XCIII, fig. 6).

#### EXPLANATION OF PLATES

All photographs, with only two exceptions mentioned in explanation, show lower surfaces of sandstones. Scale in millimetres. Arrow indicates direction of current from which sand deposited.

#### Plate XC

- Fig. 1. Branching tests of *Aschemonella* Brady. *Aschemonella* assemblage. Specimen found by Prof. Dr. M. Książkiewicz. Variegated Shales, Palaeocene. Gubernasówka, Lipnica Mała
- Fig. 2. Tests of *Bathysiphon* M. Sars showing lack of preferred orientation. *Bathysiphon* assemblage. Hieroglyphic Beds, Middle Eocene. Stream Końskie, Zawoja—Gołynia
- Fig. 3. Test of *Bathysiphon* at downcurrent end of groove mould. *Bathysiphon* assemblage. Hieroglyphic Beds, Middle Eocene. Stream Roztoki, Stryszawa
- Fig. 4. In centre and on right-hand side infilling of current-formed scour with concentrically arranged tests of *Bathysiphon*. On left-hand side, current crescent formed around *Bathysiphon* test. *Bathysiphon* assemblage. Hieroglyphic Beds, Middle Eocene. Stream Wieprzczanka, Wieprzec
- Fig. 5. Tests of *Hyperammia* Brady showing preferred orientation and smaller proportions of many-chambered forms. Larger-scale, double ridges are groove moulds with fragments of *Bathysiphon* tests at the downcurrent ends. *Hyperammia* assemblage. Hieroglyphic Beds, Middle Eocene. Stream Wieprzczanka, Wieprzec
- Fig. 6. Detail from surface shown in Fig. 5. Right of centre is oriented fish tooth

#### Plate XCI

- Fig. 1. Groove mould with fragment of *Bathysiphon* test at downcurrent end. *Hyperammia* assemblage. Hieroglyphic Beds, Middle Eocene. Stream Wieprzczanka, Wieprzec
- Fig. 2. In centre, groove mould with relatively smooth surface and without foraminiferal tests; on either side, numerous tests of Foraminifera cover sole. Crossing, postdepositional burrows without tests. Top, left-hand side: oriented test of *Bathysiphon*. *Hyperammia* assemblage. Hieroglyphic Beds, Middle Stream Wieprzczanka, Wieprzec
- Fig. 3. Positive print of X-ray photograph, showing part of vertical cross-section through layer of fine grained sandstone. Lower surface with interfacial

assemblage. In section are seen climbing ripples with erosion of upcurrent sides. Hieroglyphic Beds, Middle Eocene. Stream Wieprzczanka, Wieprzec

- Fig. 4. Disorderly arrangement of tests of *Sphaerammina* Cushman. *Sphaerammina* assemblage. Hieroglyphic Beds, Middle Eocene. Stream Jaworzyna, Zawoja—Policzne
- Fig. 5. Tests of *Sphaerammina* at downcurrent ends of minute groove moulds. *Sphaerammina* assemblage. Hieroglyphic Beds, Middle Eocene. Stream Jaworzyna, Zawoja—Policzne
- Fig. 6. Tests of *Sphaerammina* at downcurrent ends of minute groove moulds. Other data as in Fig. 5

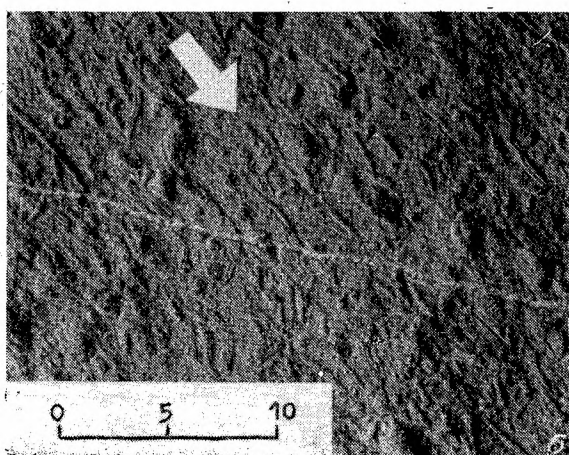
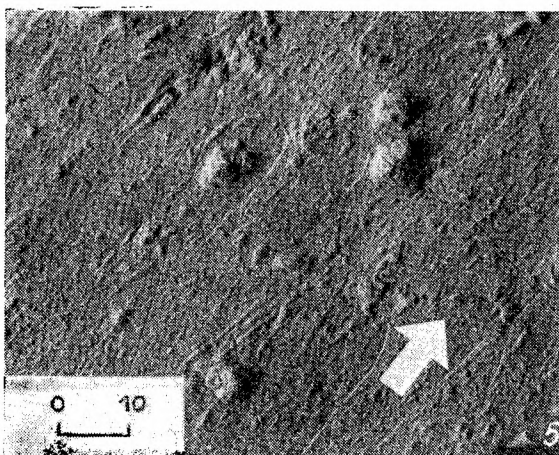
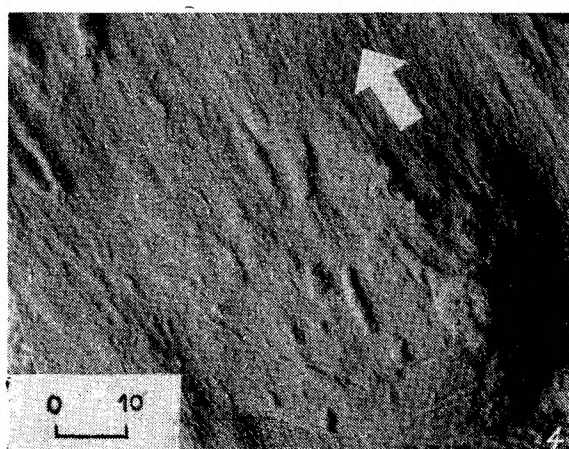
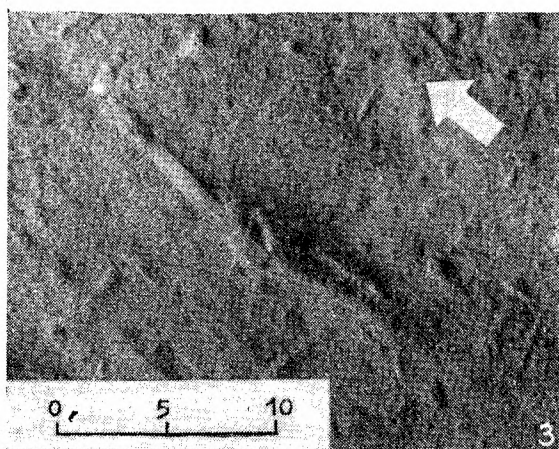
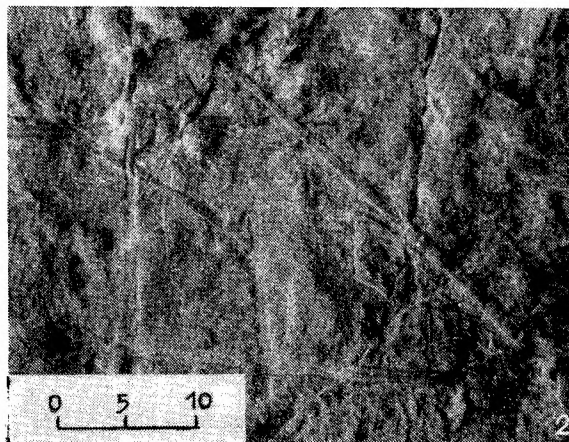
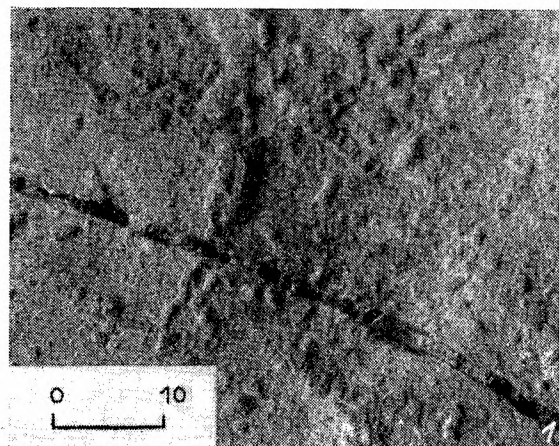
Plate XCII

- Fig. 1. Erosional depression of interface containing tightly packed tests of *Sphaerammina*. *Sphaerammina* assemblage. Hieroglyphic Beds, Middle Eocene. Stream Jaworzyna, Zawoja—Policzne
- Fig. 2. Predepositional burrow of *Scolicia* type eroded by current and filled with tests of *Sphaerammina*. *Sphaerammina* assemblage. Hieroglyphic Beds, Middle Eocene. Stream Jaworzyna, Zawoja village
- Fig. 3. Predepositional burrow of *Spirophycus* type, partially eroded by current and filled with tests of *Sphaerammina*. *Sphaerammina* assemblage. Specimen found by Prof. Dr. M. Książkiewicz. Hieroglyphic Beds, Middle Eocene. Stream Końskie, Zawoja—Gołynia
- Fig. 4. Predepositional burrow of *Spirophycus* type filled with tests of *Sphaerammina*. Other data as in Fig. 3
- Fig. 5. Postdepositional burrow of *Palaeophycus* type filled with tests of *Sphaerammina*. *Sphaerammina* assemblage. Hieroglyphic Beds, Middle Eocene. Stream Jaworzyna, Zawoja—Policzne
- Fig. 6. Postdepositional burrow of *Palaeophycus* type filled with tests of *Sphaerammina*. Latter show marked differences in maximum diameter of test. Other data as in Fig. 5

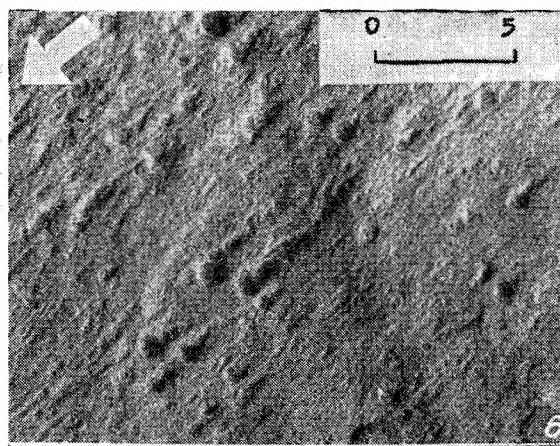
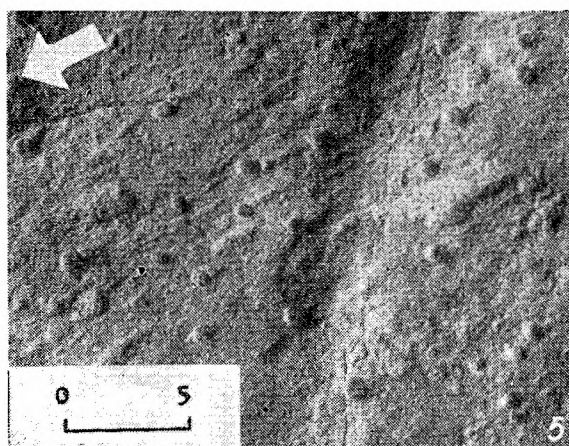
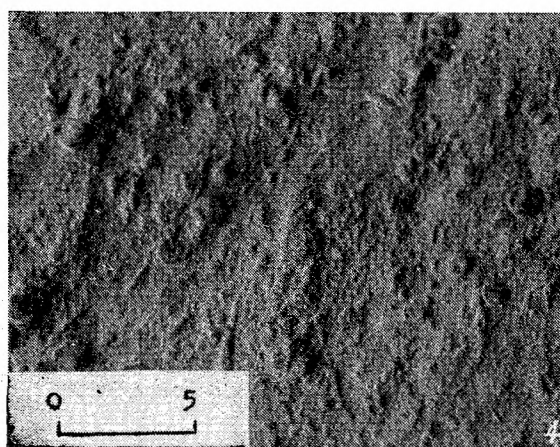
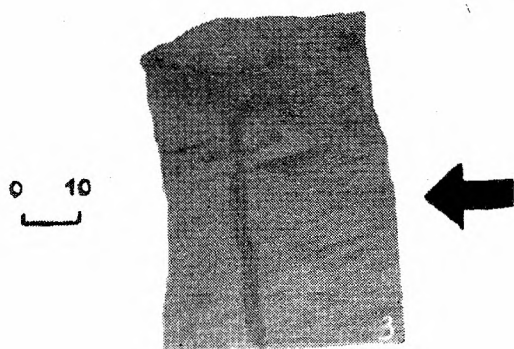
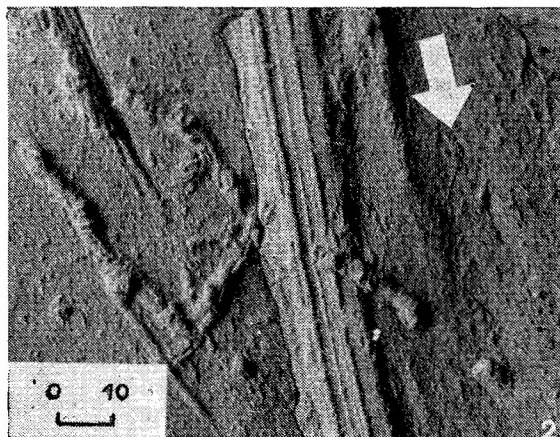
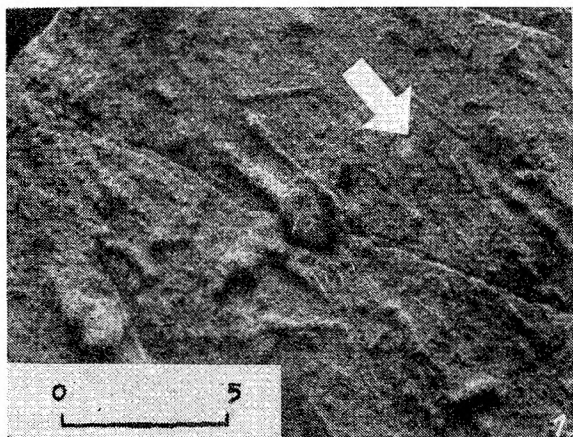
Plate XCIII

- Fig. 1. Network of postdepositional, „irregular *Paleodictyon*”. Foraminifera occur both on the flat sandstone sole and in tubes making up the network. *Sphaerammina* assemblage. Hieroglyphic Beds, Middle Eocene. Stream Jaworzyna, Zawoja village
- Fig. 2. Part of „irregular *Paleodictyon*” network containing test of *Sphaerammina*. *Sphaerammina* assemblage. Hieroglyphic Beds, Middle Eocene. Stream Jaworzyna, Zawoja village
- Fig. 3. Discontinuous layer of *Sphaerammina* tests with rare tubular forms, probably *Hyperammmina*. *Sphaerammina* assemblage. Hieroglyphic Beds, Middle Eocene. Stream Końskie, Zawoja—Gołynia
- Fig. 4. Positive print of X-ray photograph; part of vertical cross-section through layer, the sole of which is shown in Fig. 3. Lower surface with *Sphaerammina* assemblage. In section ripple-drift and trough cross-laminae. Hieroglyphic Beds, Middle Eocene. Stream Końskie, Zawoja—Gołynia
- Fig. 5. Delicate, branching test of *Rhizammina* sp. *Sphaerammina* assemblage. Hieroglyphic Beds, Middle Eocene. Stream Końskie, Zawoja—Gołynia. Compare with Fig. 2, p. 479.
- Fig. 6. Foraminiferal tests (probably *Rhizammina*) fragmented as the result of burrowing action of larger invertebrates which gave rise to postdepositional trails of *Scolicia* type. *Sphaerammina* assemblage. Hieroglyphic Beds, Middle Eocene, Stream Jaworzyna, Zawoja—Policzne

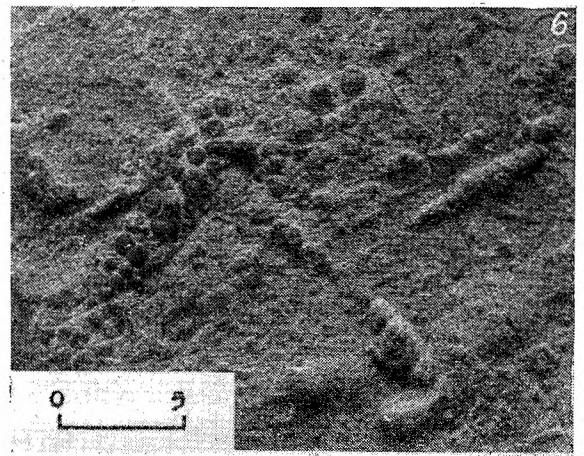
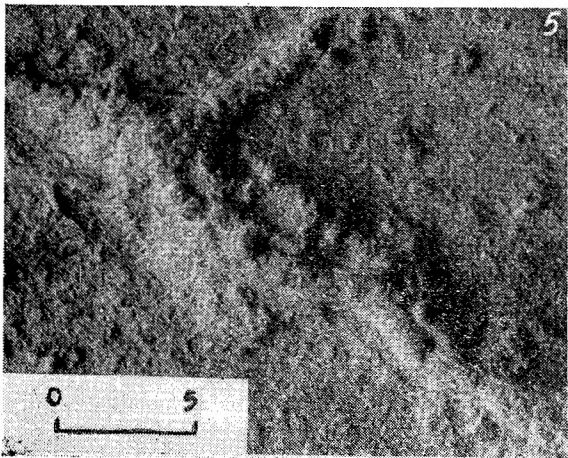
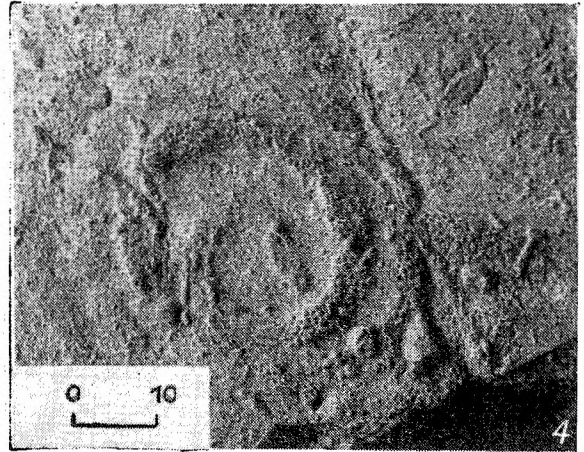
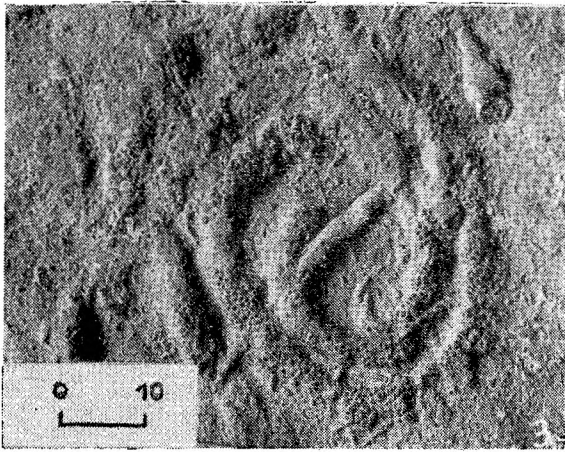
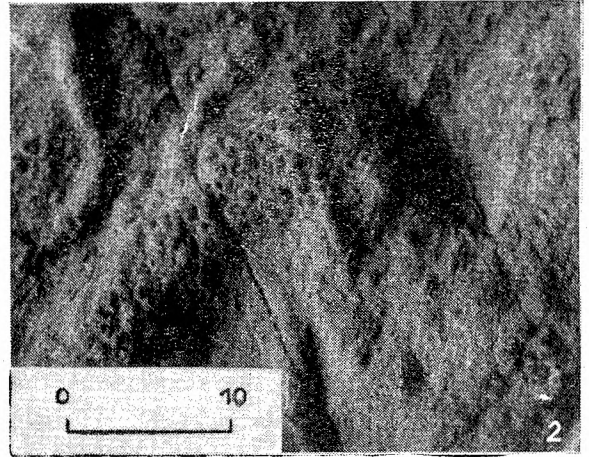
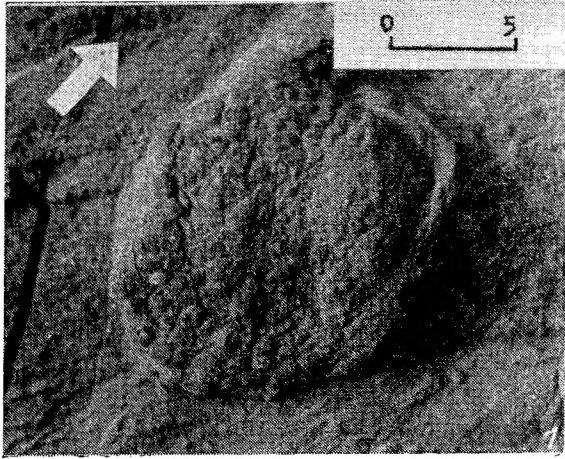




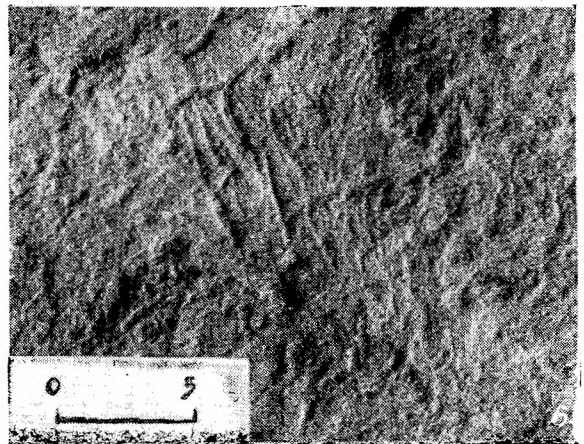
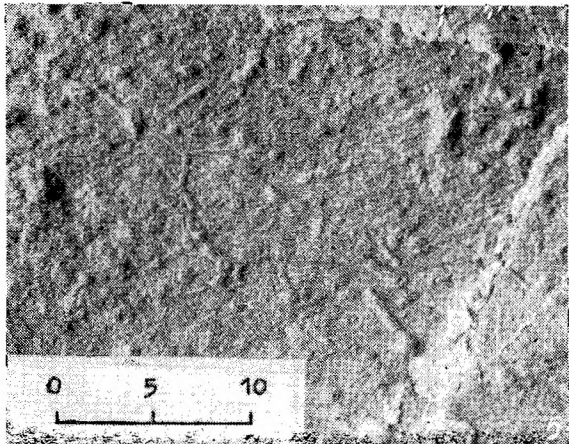
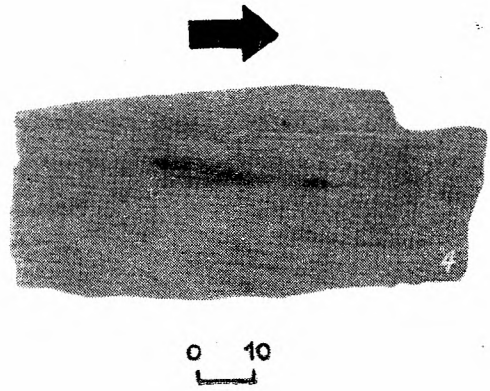
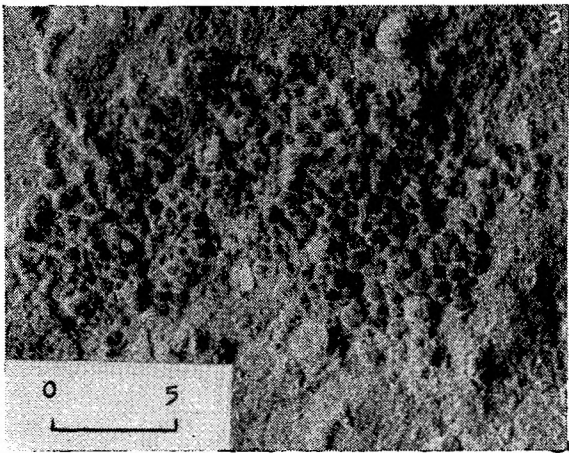
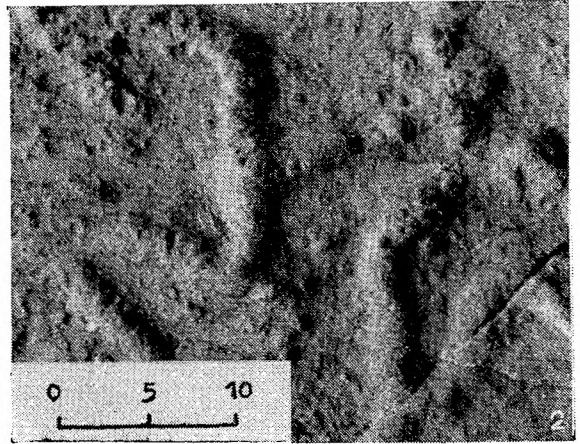
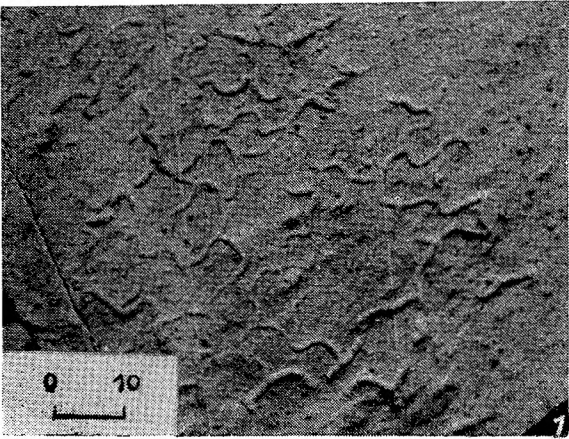
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