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FLYSCH FORMATION IN THE TERTIARY OF THE POLISH CARPATHIANS

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Formacja fliszowa w trzeciorzędzie Karpat polskich

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Abstract: The Tertiary of the Polish Carpathians is represented by nummulitic and flysch formations. In the latter, organisms are poorly represented and agglutinating Foraminifera predominate. The paucity of fossils in flysch sediments may be explained by unfavourable conditions in fresh and brackish water for the preservation of shells, as a rule made up of an organic substance, as fossils. For animals, the deciding life factor is food, of which there is a great deal in shallow water.

On the basis of the occurrence of Foraminifera in the Tertiary flysch of the Polish Carpathians, the areas of sedimentation of this flysch may be defined as follows. Sediments with exclusively agglutinating Foraminifera are lacustrine, reflecting fresh-water environments such as swamps, enclosed bays and river mouths, in which life conditions undergo rapid changes. Occurrences of mixed assemblages, that is, comprising agglutinating and small, calcareous Foraminifera, indicate a marine environment of the littoral and neritic zones. Occurrences of large Foraminifera which are rarely encountered in flysch, also suggest a shallow sea. On the other hand, assemblages of small, calcareous Foraminifera, together with nannoplankton, reflect the existence of pelagic marine conditions, with depths equivalent to those of the present-day bathyal zone.

INTRODUCTION

Problems in the study of flysch are presented in the abundant literature, comprising works somewhat varieated in approach. Sedimentological and stratigraphic papers predominate, particularly in more recent decades. This the flysch sediments of different ages and various localities have become known with regard to the formation of sedimentary structures and relations between particular complexes of beds. An indication of age is provided particularly by studies of the remains of micro--organisms. Also a considerable number of studies deals with the problem of the environments, in which flysch sediments were laid down.

In some papers the ecological conditions of the organic world of flysch are mentioned in various ways. There is also information about the palaeogeographic distribution of flysch fossils. To a lesser extent, atten-

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tion has been given to the palaeoclimatology of flysch. Furthermore, in addition to the main stratigraphic works, there exists in science a tendency to consider different problems, biological in character, to find out about life occurring in flysch sediments. But it is necessary to state at the outset that the problem of the occurrence of fossils in flysch is particularly complicated. Biological information is then useful and important for geologists, if the conditions in which the organisms lived are known. There is a lack of actualistic data; that is, it is not possible to compare present-day life conditions and those in which flysch organisms lived. Here assumptions are made; that is why the genesis of flysch is poorly understood and conclusions are drawn on the basis of hypothesis.

The purpose of the present account is an attempt to understand what the study of flysch organisms may reveal of the environmental conditions, in which they lived. Thus it is a biological approach to the problem of flysch genesis. The method here employed involves, first statement and then differentiation of those biological data, the nature of which can be easily distinguished, from uncertain, doubtful phenomena, requiring further study. In a previous account (F. B i e d a, 1968), of which this paper is continuation, two definitions were given: n u m m u l i t i c f o r m a t i o n and f l y s c h f o r m a t i o n. In the sediments of nummulitic formation, the organisms may be easily recognized in all respects. On the other hand, the connection between the sediments of flysch formation and their organic life and ecology is difficult to explain. It should be remembered that T e r c i e r (1947) deals with flysch and nummulitic formations separately.

The term flysch formation is controversial. It was originally used in Switzerland for a particular sedimentary facies and later became a stratigraphic term. An incorrect amplification of this term took place, an example of which is provided by the view that, for instance, the *Globigerina* Marls of the Carpathian Tertiary are proof of the occurrence of greater depths in the flysch sea; but, on the other hand, these rocks are called „nonflysch".

V a s s o e v i c h (1951) proposes another term, f l y s c h g e o g e n e-r a t i o n. Here is an approach to the problem similar to that employed in the present account, for the author also draws attention to the connection between this geogeneration and others. V a s s o e v i c h somewhat differentiates geogeneration from formation. In the present account, emphasis is placed upon organic components, that is, upon b i o g e n i c formation. Thus it is possible to speak of b i o f o r m a t i o n only. Nevertheless we use here the term formation, having a wider sense, because we speak also of the lithologies, that is of lithoformation.

In previous results, based mainly on the occurrence of agglutinating Foraminifera, a characteristic biogenic component frequently encountered in flysch, there is the view that these Foraminifera are proof of the deepwater origin of flysch. The task here is to consider habitats of present-day agglutinating Foraminifera on the basis of literature, particularly that from recent years. An attempt is then made to draw conclusions as to the life conditions of Flysch Foraminifera, and thus to the geological conditions, in which flysch sediments might originate.

Only data obtainable from the Tertiary of the Polish Carpathians will be taken into account. Although this is not a wide range of material, there exists the possibility of distinguishing sediments belonging to different formations, both of nummulitic and flysch types. Such a sub-

division should be attempted separately for sediments of the Carpathian Cretaceous. The possibility arises to use the term Gosau Formation for the Upper Cretaceous sediments, which are not of flysch type.

OCCURRENCE OF BIOCOENOSES AND BIOFACIES IN TERTIARY OF THE POLISH CARPATHIANS

Assemblages of organisms (biocoenoses) better lend themselves to the recognition of life conditions and geological conditions than do single species or even larger systematic units, such as genera or families. Interest in present-day and fossil biocoenoses increased markedly in recent time. According to H u t c h i n s o n (in: Treatise on marine ecology, 1957) it is possible to speak of a separate science, b i o c o e n o l o g y. A g e r (1963) is of the opinion that considerations of the ecology of organic assemblages give rise to a new branch of ecology, for which he proposes the name s y n e c o l o g y.

There exists therefore a necessity for the consideration, in a broad sense, of the life conditions of whole complexes or biocoenoses. But it is necessary to remember operative limitations in this field. A g e r (1963) and J. I m b r i e and N. D. N e w e l l (in: Approaches to Palaeoecology, 1964) indicate this in the following statements:

1-It is not possible to demonstrate the life processes of fossil organisms.

2-External conditions, or physico-chemical conditions of past ecosystems, can only be considered indirectly.

3-Information obtained through studies of fossils is to a marked degree obscured by changes after the death of the organisms and by changes during the diagenetic processes.

This last point may be amended with the observation that the assemblages of organisms commonly encountered in sediments do not represent primary biocoenoses, but rather thanatocoenoses or tafocoenoses; usually however, the term biocoenosis is used.

Thus the necessity is seen for precise and critical appraisal of the value of information obtained through studies of the organic world represented by fossils. Actualistic results, obtained from studies of present-day organisms, should be taken into account in studies of fossils. V a s s o e v i c h (1951) writes that palaeoecological studies of flysch fossils are at an early stage; the problems arising are complicated, difficult and awkward (1. c., p. 153). Since that time, however, science has accumulated a succession of data, shedding more light upon problems presented by the biogenic components in flysch.

By analogy with instances provided by other geological formations, better results are obtained in the research on the nummulitic and flysch formations of the Carpathian Tertiary, as a result of considerations of particular organic assemblages occurring in mass and forming biofacies. Some of these arose from biocoenoses of a single group of organisms, for example, the *Globigerina* Marls; other Biofacies are made up of more groups. In the Carpathians, there are biofacies, as yet not closely indentified to the desired degree, such as, for example, the hornstones of the Menilitic Shales.

The biocoenoses and biofacies of the Carpathian Tertiary, because of their differentiation, clearly evidence variability of environments and

geological conditions. Biocoenoses and biofacies are discussed for the nummulitic and the flysch formation respectively.

BIOCOENOSES AND BIOFACES OF THE NUMMULITIC FORMATION

Biocoenoses of the nummulitic formation may be fairly well understood, since they are better known, owing to the possibility of using actualistic data, as well as comparisons with the sediments of other areas. Some data, given by the present author in a 1968 paper, should be recalled.

The nummulitic formation occurs in two areas in the Carpathians. One area has the nummulitic formation preserved in situ, namely as the Tatra Eocene. The second area is the flysch region, with a nummulitic formation occurring in the form of exotics, or represented by sediments, up to the present day designated non-flysch.

a) B i o c o e n o s e s a n d b i o f a c i e s o f t h e T a t r a E o c e n e

One of the main biocoenoses of the Tatra Eocene is that with large Foraminifera. From this the biofacies of calcareous nummulitic rocks originated. The characteristic rock, occurring in Hemera II of the Tatra Eocene is called j a r z e c, and consists almost exclusively of shells representing a single species, *Nummulites perforatus*. There are also concentrations, in which more species of nummulites and other large Foraminifera occur.

In the lower part of the Tatra Eocene, that is in Hemerae I and II, resting on the Lower Conglomerates (unfossiliferous), the geological conditions of the whole area were uniform. This is shown by similarities in petrography and faunal composition. A greater differentiation in geological relations is seen, however, in the second or upper part of the Tatra Eocene. In Hemera III, at the boundary between the Middle and Upper Eocene, there is a higher proportion of clastic rocks, giving the Upper Conglomerates. In places, strong development of *Discocyclina* biocoenoses is seen; these organisms lived in calm waters, presumably in quiet bays. The petrographic composition of the *Discocyclina* Limestones indicates a richness in calcium carbonate, which accumulated as a result of abundant life.

Lithothamnium is important among the other organisms of the Tatra Eocene. According to the percentage composition of organisms, Foraminifera-*Lithothamnium* biocoenoses may be distinguished. There are also biocoenoses of small, calcareous Foraminifera (A l e x a n d r o w i c z, G e r o c h, 1963); which inhabited somewhat deeper water.

In Hemera IV, clastic sediments predominate. Here, in places, sediments of flysch type (exceptionally in Hemera III also) occur. Thus geological conditions show greater differentiation.

The rocks and organisms of the Tatra Eocene show that the sea bottom was fairly strongly differentiated, both laterally and vertically. Also on the land were conditions for life, evidenced by the rich development of a land flora. The occurrence of various biocoenoses side by side and of relatively rapid changes of them, indicate similarities to biocoenoses and their variants in present-day seas. The organic world changes, subject to changes arising in the enclosing inorganic milieu. But there are also cases in which a new group of organisms develops and supercedes the

group previously living there, in absence of any physico-chemical changes. Examples of present-day phenomena of this kind are given by J. W a l t h e r (1927) from the Bay of Naples, and by W. S c h ä f e r (1966) from the North Sea.

How may jarzec-type biofacies arise? The explanation given by N a-l i v k i n (1967), that it is a shore-line bar, arising as a result of marine wave-action, seems unlikely. If this were so, why are there no shells of other organisms? The organic world of a littoral sea in a warm climate is, as a rule, represented by numerous species and groups.

There is another explanation for the formation of such concentrations of organisms belonging to one species. A given form may develop abundantly in the shallow waters of places lying further away from the shore, to which no terrigenous material is transported. Such elevations of limited extent on the bottom usually gave rise to fairly small, lenticular biofacies.

It appears probable that large Foraminifera lived somewhat below the wave base, since the delicate tests of the first stage of development could not survive in the disturbed conditions of the uppermost reaches of the water. Also the union of zoospores, corresponding to sexual reproduction, would have taken place under the more suitable conditions provided by calm waters. Furthermore, it is doubtful whether large Foraminifera, with big and delicate tests in the adult stage, as in the case of *Discocyclina* or *Operculina,* could survive a rough sea without damage.

In biocoenoses of large Foraminifera, particularly nummulites, one of the dimorphic forms (macrospheric or microspheric forms) sometimes predominates, even to the extent that other form is excluded. In flysch sequences, only the macrospheric form is found as a rule. This is explained as being the result of sorting of material among others in turbidity currents. But exclusive occurrences of microspheric forms are also known, for example, of *Nummulites laevigatus* in the Lutetian of the Paris Basin (R. A b r a r d, 1925). In the Tatra Eocene, both dimorphic forms of species are usually found, which is the normal occurrence of large Foraminifera.

b) B i o f a c i e s   o f   n u m m u l i t i c   l i m e s t o n e s   i n   t h e
    f l y s c h   r e g i o n

Assemblages of large Foraminifera, forming biofacies similar to nummulitic limestones of the Tatra Eocene, are found in nummulite--bearing exotics occurring in flysch. The composition of these biocoenoses, as well as their age and the histories of the rocks of which they form a part, have been discussed already (F. B i e d a, 1968). The most commonly occurring rock here is an almost pure limestone, consisting of large Foraminifera with admixtures of other organisms. Non-biogenic components form a fairly small percentage of the rock; as a rule, grains of this type, mainly of quartz, are not rounded.

In addition to the nummulite-bearing exotics in flysch, layers of other organic biofacies are found. These are *Lithothamnium*-Bryozoa--Foraminifera Limestones called the Koniaków (or Wola Łużańska) Limestones. These sediments of Upper Eocene age (F. B i e d a, 1962) are in some cases inclusions forming part of the normal flysch succession, while, in other instances, they are perhaps olistoliths. In addition to the main groups of organisms, listed in the name of the rock, although in

smaller proportions, are molluscs, brachiopods, ostracods, otoliths and fish-teeth. This biofacies is somewhat similar to rocks occurring in the upper part of the Tatra Eocene. It consists of sedimentary and motile benthos, as well as nekton and also plankton, as may be seen in the occurrence of rather rare *Globigerina*.

Furthermore, in Upper Eocene time, a nummulitic formation developed in the flysch region, from the Cieszyn district of Silesia in the West to Dukla in the East. Nummulite-bearing exotics from this formation are also known. J. M a ł e c k i (1963) stated that the bryozoan colonies are usually without their basal parts and had been torn away from the substratum and transported, together with other organisms, to give a taphocoenosis at the place of deposition.

Rocks known as *Lithothamnium* Sandstones (S. A l e x a n d r o w i c z et al., 1966) are similar to Koniaków Limestones. Biogenic components, constitute about half the rock. The preservation of these sediments in flysch series evidences displacement and reworking of their components, perhaps at some considerable distance from the source. This rock type occurs, not only in the Upper Eocene flysch, but also in flysch series of various ages. From considerations of structures characteristic for flysch sandstones on the one hand and abundance of biogenic components on the other, the *Lithothamnium* Sandstones may be regarded as forming a passage series between nummulitic and flysch formation (F. B i e d a, 1968).

c) O t h e r b i o f a c i e s o f t h e n u m m u l i t i c f o r m a t i o n
   i n t h e T e r t i a r y f l y s c h

Other sequences containing abundant organic remains, which are seen even in mass occurrences, also occur in the Tertiary flysch of the Carpathians. These organisms permit a definition of the ecological and biogeographical environment and the assignment of the sediments to the nummulitic formation.

The *Globigerina* Marls form one biofacies of this type. These are particularly well developed in the Upper Eocene of several flysch units. J. G r z y b o w s k i (1898) recognized this horizon as the boundary between the Hieroglyphic Beds and the Menilitic Shales, in the area between Jasło and Krosno. This area is today included in the Silesian unit (Central Carpathian Depression). The horizon is also known from the Skole, Sub-Silesian and Pre-Magura units; it probably also occurs in the Magura unit, here being also found on older sequences (A. J e d n o r o w s k a and S. W ę c ł a w i k, 1965; A. J e d n o r o w s k a, 1968. Each time conditions existed suitable for the development of *Globigerina*, the biofacies of *Globigerina* Marls was formed, giving sequences without true flysch. These, however, were fairly short periods of time, reflecting temporary widening and deepening of sea.

It is known that *Globigerina* can live in calm, shallow-water conditions. Generally, however, these are organisms of the open and relatively deep sea.

Besides the planktonic Foraminifera, such as *Globigerina*, planktonic micro-organisms with siliceous tests lived in the Carpathian Tertiary sea. From these arose rocks such as hornstones, radiolarites and diatomites. The lack of sufficient data does not permit the statement that all the rocks, commonly called radiolarites and occurring at various Tertiary horizons, owe their origin to Radiolaria alone. Z. S u j k o w s k i

(1932) proved that Radiolaria occur in Cretaceous radiolarites of the Eastern Carpathians. Hornstones in the lower part of the Menilitic Beds, however, throw a different light upon the subject. A. Gaweł (1952) and Cz. Kuźniar (1954) show that in these hornstones there are diatoms.

The indeterminate nature of the biogenic components in the hornstones of the Menilitic Beds, as well as the extreme diagenesis of the rock, give rise to uncertainty as to the formation to which they should be assigned. A similar question may also be applied to the whole of the Menilitic Beds. This matter will be discussed later.

It is also difficult to decide to which formation the diatomites belong. These rocks occur in a fairly small area in the Polish Carpathians, near Przemyśl, in the upper part of the Krosno Beds (J. Kotlarczyk, 1966). Diatoms live in all aquatic environments; their occurrence is important in that it indicates the possibility of the existence of not only marine aquatic environments in the Carpathian Tertiary.

BIOCOENOSES AND BIOFACES OF THE FLYSCH FORMATION IN THE TERTIARY OF THE POLISH CARPATHIANS

a) General remarks

The impoverished nature and monotony of organic assemblages is the main characteristic feature of the flysch formation. These assemblages are here analyzed, so that conclusions may be drawn about geological relations and particularly about the genesis of flysch on the basis of the bionomical relations of the organisms in flysch sediments.

Micro-organisms and Foraminifera in particular form the most important group of fossils in a flysch formation. According to many authors, (see for instance U. Pflauman, 1967) the most fundamental feature of flysch is the presence of biocoenoses of agglutinating Foraminifera. In addition, there are also mixed biocoenoses, comprising agglutinating and small, calcareous Foraminifera. There are also biocoenoses of large Foraminifera. Among the other micro-organisms of flysch sequences, nannoplankton is particularly important.

M. Książkiewicz (1961) recently studied the problem of life in flysch seas, with special reference to Foraminifera. Some observations of this author are very important to an explanation of the life conditions of the organisms inhabiting the flysch environment. However, some questions may be examined from another point of view; one of these is that relating to the areas in which agglutinating Foraminifera lived.

First, an appraisal is made of data, given by various authors, concerning the occurrence of agglutinating Foraminifera in shallow waters of the present-day; the life conditions of these Foraminifera is discussed. Later a review of biocoenoses of the flysch formation is given. Finally the problem of flysch genesis is considered in the light of material of a biological nature.

b) Shallow-water, agglutinating Foraminifera at the present time

Agglutinating Foraminifera live today in shallow water of various salinities and in deep water, even at considerable depths. In science, particular prominence is given to the fact that agglutinating Foraminifera

occur in the abyssal zone; flysch with these Foraminifera is therefore considered to be of deep-water origin (see, for example, H. H i l t e r-m a n, 1968). To this one-side view, which alone, of course, does not have adequate argumentary force, are added other suppositions of a sedimentological character, such as the activity of turbidity currents.

Thus the acceptance of a deep-water origin of flysch has a composite nature, deriving from various branches of knowledge. However, it is necessary to state that too little information from the science of biology is employed. Thus an attempt will be made to consider the problem of agglutinating Foraminifera, namely information on the occurrence of agglutinating Foraminifera in shallow waters, on the physico-chemical conditions of these waters and their significance for the existence of these Foraminifera.

1) One of the fundamental works for a knowledge of present-day agglutinating Foraminifera is that of H. B r a d y (1884). At the very beginning of his paper (Introduction, p. II), the author writes that, during the Challenger expedition, attention was paid mainly to both sediments and life in deep waters; only to a lesser degree is shallow water considered.

B r a d y gives bathymetric data for genera and species of Foraminifera; data on agglutinating Foraminifera are cited here as an example:

Clavulina parisiensis	12—6000 m
Gaudryina pupoides	300—4700 m
Hyperammina vagans	28—5600 m
Hyperammina elongata	150—3600 m
Bigenerina nodosaria	28—3000 m
Bigenerina digitata	70—2300 m

Haplophragium agglutinans — wide bathymetric range

Textularia, Verneuillina, Ammodiscus, Rheophax — wide bathymetric and geographic range

Rhabdammina — characteristic genus for deep waters; two to three species live outside of these waters.

Dendrophrya erecta and *D. radians* — in various littoral areas.

Of course, one might have doubts as whether the same species really do occur at such different depths; in B r a d y's paper many forms are grouped together under a single name. The fact remains that, in the shallow waters of seas, agglutinating Foraminifera are fairly abundant.

2) L. W. L e R o y (in Treatise on marine ecology, 1957) states that in the Indo-Malayan region, near the Java shore, a Foraminifera facies with *Haplophragmoides* and *Haplophragmiun* occurs in semibrackish waters.

3) According to W. R. W a l t o n (1955), in Todos Santos Bay, California, shallow water Foraminifera exhibit strong development during late spring and summer; this is related to the development of phytoplankton, which is at a maximum in August. In marsh facies, the following agglutinating Foraminifera occur:

Arenoparrella mexicana
Discorinopsis cf. *aguayoi*
Jadammina polystoma
Trochammina inflata

Among calcareous forms, only *Elphidium* sp. and *Triloculina* sp. occur.

4) E. R. Z a l e s n y (1959) states that in Santa Monica Bay, California, *Trochammina pacifica* is so abundant, in the zone between the shore and

the 75 m isobath, that it alone makes up 82% of the assemblage of Foraminifera. The author calls attention to the fact that one of the important factors of this occurrence is the abundance of food.

5) W. Polski (1959), on the basis of studies of Foraminifera assemblages in the Yellow Sea and Bay of Korea, maintains that the greatest percentage of agglutinating Foraminifera is found in shallow water. Upwards from the 85 m. isobath, the percentage of agglutinating Foraminifera reaches more than 10%, while, on the other hand, below this isobath there is a lowering of this percentage.

6) Osnowy paleontologii (1959) give the information that in environments with inadequate aereation occur *Trochammina, Haplophragmoides, Cyclammina* and *Bathysiphon.*

7) A great deal of information on the habitat of agglutinating Foraminifera is given by F.B .Phleger (1960). One fact of particular importance is that Foraminifera assemblages from swamps are composed entirely or nearly entirely of agglutinating Foraminifera. This is connected with the pH value, which because of the release of CO_2 by plants is reduced at night; the lowest state is reached in the morning and an increase takes place during the day. The low value of pH at night is not without effect on the calcareous Foraminifera and is derogatory for them. The author (p. 112) states that the pH value is generally lower in pelitic sediments than in clastic sediments. Very little is known, in Phleger's opinion, about pH conditions with changes in depth of the basin.

8) O. L. Bandy (1963) states that in swamps the following species of agglutinating and siliceous Foraminifera predominate:

       Jadammina polystoma
       Miliammina fusca
       Saccammina sp.

The tests of these forms are markedly more resistant to solution in water of changeable and lower pH.

9) O. L. Bandy (in: Approaches to Palaeoecology, 1964) states that in a shelf area, but near the shore, the following genera of agglutinating Foraminifera occur: *Trochammina, Eggerella, Textularia, Rheophax.* In places, *Rhabdammina* and related genera are the dominant representatives.

10) McGrone and Schafer (1966) write that, in the mouth of the Hudson River, far from ocean waters, there are mainly agglutinating Foraminifera, of the genera *Ammomarginulina, Miliammina, Trochammina, Proteonina* and *Ammobaculites* only, with the rare calcareous forms *Elphidium* and *Ammonia beccarii.*

11) M. Neumann (1967) deduces, from a study of ecological conditions, that agglutinating Foraminifera can live in an acid environment, in stagnant or poorly aerated waters. Essential to the existance of Foraminifera are slimy bottoms with very fine organic material for food. The fact that present-day agglutinating Foraminifera do not occur in the bathyal zone is particularly important; this point will be taken up later.

12) H. E. Kane (1967) states that in some fresh-water basins, such as in Lake Sabina, connected to the Bay of Mexico, are the genera: *Haplophragmmoides, Miliammina* and *Ammobaculites.*

One might add even more data of this type, relating to the occurrence of agglutinating Foraminifera in paralic areas, in which there are waters

varying from normally saline to brackish and fresh. It is beyond doubt that today agglutinating Foraminifera are found in waters with varying degrees of salinity and with varying life conditions generally. As life conditions worsen, the most resistant forms are agglutinating Foraminifera (M. K s i ą ż k i e w i c z, 1961). Here it may be added that rapid changes in life conditions must have derogatery effects on organisms in shallow waters also.

On the other hand, there is comparatively little information about biocoenoses, in which there are representatives of other groups of organisms besides agglutinating Foraminifera, that is, about the synecological viewpoint, in the meaning of D. V. A g e r (1963). Here data from B r a d y's paper (1884, p. 270) may be cited: he frequently encountered tests of *Rhizammina* with bryozoans and other sedentary benthonic organisms attached to their branches. The material collected by the oceanographic expedition was separated into parts for the benefit of specialists; for this reason, there are difficulties in recognizing biocoenoses.

c) E c o l o g y o f a g g l u t i n a t i n g F o r a m i n i f e r a

From information in a number of papers cited above, it may be seen that today agglutinating Foraminifera live in a variety of environmental conditions; here it may be assumed without doubt that this was the case in previous geological time. Environmental factors are the physico--chemical factors of the external milieu. A variable type of factor reflected in life is seen as the biological factor.

Factors of the external milieu with a fundamental influence on the existence of agglutinating Foraminifera are:

temperature and climate in general
depth of water
degree of salinity and occurrence of other chemical compounds
oxygen content
lithological composition of the substratum
food — nourishment factor.

The factor of temperature is connected with the depth of water. It is claimed that temperature has more significance for the existence of Foraminifera than does depth of water, as shown by the occurrence of the same species in deep water with low temperature and in cold, polar waters of shallow depth.

Above, mention was made of the question that agglutinating Foraminifera display a marked tolerance towards the various factors of the external milieu. The sole factor, towards which tolerance is not exercised, is that of nourishment.

The food of Foraminifera consists of nannoplankton and microscopic portions of larger organisms. This nourishment reaches the bottom either from the surface or is carried by continuous currents of Gulf-Stream type. Turbidity currents cannot be taken into account as agents of food supply; at the most, they fullfil an additional role, but one of no great significance. The occurrence of continuous sources of food supply provided proof that an area in which flysch sediments were formed was not a desertlike environment without life.

One biological factor of particular importance for the existence of agglutinating Foraminifera is the mode of life. Some forms are motile and benthonic, others sessile.

The latter forms are sensitive to factors of the external milieu and particularly to the nourishment factor.

d) M i c r o - o r g a n i s m s i n t h e T e r t i a r y f l y s c h o f t h e P o l i s h C a r p a t h i a n s.

1) A g g l u t i n a t i n g F o r a m i n i f e r a. This group has already been given considerable attention in the present account. At this point, an account of the state of knowledge of these forms in the Polish Carpathians is included. J. G r z y b o w s k i (1898) was the first to consider them in detail and describe their composition exactly. In G r z y b o w - s k i's 1898 paper, translated to appear in the volume commemorating the 100th anniversary of his birth, he distinguished 4 Foraminifera horizons in the Tertiary of the Silesian unit, from a complex of beds named the Ciężkowice Sandstone at the bottom to the Menilitic Shales at the top. In terms of age, this complex represents a span from Palaeocene to Upper Eocene. G r z y b o w s k i termed the third horizon that of exclusively agglutinating Foraminifera; this contains 5 zones, defined by marker forms (G r z y b o w s k i, 1898, 1969).

The occurrence of such biocoenoses is not at all limited in space, they were also confirmed in other flysch regions of the Carpathians and Alps; in 1937, M. F. G l a e s s n e r described them from the Caucasian flysch.

Knowledge of agglutinating Foraminifera in the Tertiary flysch of the Polish Carpathians is gradually increasing, as a result of studies carried out after the Second World War. Of the three main flysch units (Skole, Silesian and Magura), that with the best known forms is the Silesian unit; the fauna of this unit was elaborated by G r z y b o w s k i. The most important work dealing with these Foraminifera is that by H. J u r k i e w i c z (1959). A. J e d n o r o w s k a (1968) gave an account of aglutinating Foraminifera from the Magura unit. In some papers, Foraminifera of this type, identified by J. M o r g i e l o w a, and occurring in the Skole unit, are to be found.

Several assemblages from the Skole and Magura units, containing the agglutinating Foraminifera only, are now given; these assemblages were studied by A. J e d n o r o w s k a (Magura unit) and J. M o r g i e - l o w a (Skole unit).

An assemblage of Palaeocene age from the Skole unit (see Pl. XCIV) consists of numerous species belonging in general terms to the motile benthos. Species of *Glomospira* are characteristic; in all flysch units, these are common in the Lower Eocene. A Lower Eocene assemblage with *Glomospira* from Magura unit is given in Pl. XCV.

Another Lower Eocene assemblage from the Magura unit displays a third characteristic biocoenosis (Pl. XCVI). Here occur numerous sessile forms, or forms resting immobile on the bottom and belonging to *Rhabdammina*. The occurrence of these forms in fragments does not permit a statement of whether the Foraminifera are on place.

Two assemblages of Middle Eocene age from the Skole unit are given. According to J. M o r g i e l o w a, the fourth assemblage, given in Pl. XCVII, comes from the lower part of the Middle Eocene; numerous forms of *Rhabdammina* confirm this view. *Cyclammina amplectens* is a known marker fossil for the Middle Eocene. The fifth assemblage, in Pl. XCVIII, comes from the upper part of the Middle Eocene, containing *Haplophragmoides walteri* and *Spiroplectammina spectabilis*.

2) A g g l u t i n a t i n g   a n d   s m a l l   c a l c a r e o u s   F o r a m i-
n i f e r a. In biocoenoses with calcareous Foraminifera, there are both
benthonic and planktonic forms; among the latter belong *Globigerina,*
Globorotalia and extremely rare *Hantkenina.* These occur in varying
proportions; in some assemblages agglutinating Foraminifera predomi-
nate, in other calcareous.

These biocoenoses are found in the Tertiary of all flysch units. The
occurrence of such mixed assemblages is particularly characteristic in
the Sub-Silesian unit (F. H u s s, 1957, 1966); in the other geological
units, assemblages of the same age consist exclusively of agglutinating
Foraminifera (H u s s, 1966). H u s s recently mentions the existence of
a fairly thin complex in the Sub-Silesian unit, in which there are agglu-
tinating Foraminifera exclusively. Mixed agglutinating-calcareous biocoe-
noses are also known from the Dukla Folds unit and the Pre-Magura
unit; for the latter, the paper by H. K o z i k o w s k i (1956), with iden-
tifications of Foraminifera by A. J e d n o r o w s k a, may be cited.

A statement of the depth is not easily made. These are undoubtedly
marine sediments; indeed calcareous Foraminifera are known from
slightly saline waters (see above), but usually these specimens are fairly
scarce. The occurrence of planktonic Foraminifera indicates the possi-
bility that here is a neritic zone under consideration, that is, a shelf
zone, and also a bathyal zone. This is particularly likely where aggluti-
nating Foraminifera are poorly represented. It may be that the occurrence
of fairly small numbers of calcareous Foraminifera, in which the forms
are fairly small in size, maybe stunted, indicate sediments of brackish,
but not necessarily littoral, waters.

3) C a l c a r e o u s   F o r a m i n i f e r a   a n d   n a n n o p l a n k t o n.
In recent years, work has begun on the Tertiary nannoplankton of the
Western Carpathians. H. B y s t r i c k á (1964) gave data on these micro-
-organisms in the Slovakian Carpathians. In Poland, A. R a d o m s k i
(1967, 1968) described a series of nannoplankton zones in the Car-
pathians. Calcareous Foraminifera accompany these plant micro-organ-
isms with calcareous skeletons, and commonly *Globigerina* is among
these.

The character of these taphocoenoses provides certain results con-
cerning the habitat of the constituent organisms; the sea was normally
saline, somewhat distant from the shore and deep. In this case, the
flysch with these assemblages is a sediment of the neritic zone and
certainly also of the bathyal zone.

4) L a r g e   F o r a m i n i f e r a. These Foraminifera generally occur
in flysch sediments as rather scarce, loosely scattered specimens. They
do not occur in pelitic rocks, except in rare instances, but are found, on
the other hand, in clastic rocks, mainly in fine-grained conglomerates
and in sandstones. This is, therefore, a type of occurrence of fossils
differing from that found in a nummulitic formation; in the latter case,
the Foraminifera are usually rock-forming organisms. In flysch, cha-
racteristic are finds of large Foraminifera in the form of thin layers,
sometimes equivalent in thickness to the diameter of a single shell.

The occurrence of large Foraminifera is important to the stratigraphy
of flysch; this point has been discussed in other papers by the present
author (F. B i e d a, 1946, 1963a, 1968). In the 1968 paper, there is the
supposition that sediments, in which large Foraminifera are poorly

represented, should be referred to sediments of flysch type. More abundant occurrences of them, as in the Pasierbiec Sandstone, form a type of sediment transitional between nummulitic and flysch formations.

5) A u t o c h t h o n o u s o r a l l o c h t h o n o u s o c c u r r e n c e s o f F o r a m i n i f e r a i n f l y s c h. To the question of whether the large Foraminifera encountered in flysch sediments were deposited in their place of habitat or were transported from another area to the place of deposition, the view of M. K s i ą ż k i e w i c z (1961), that redeposition has taken place, may be endorsed. The tests of nummulites could withstand transport over long distances, as a result of which, sorting of tests according to their size took place. Redeposition might be effected, not only by turbidity currents, but also by the action of other movements in the sea. On the other hand, large Foraminifera with thin and delicate tests, such as *Discocyclina, Asterocyclina, Spiroclypeus, Grzybowskia* and *Operculina,* presumably could only be transported over small distances without damage being inflicted.

Clastic rocks with large Foraminifera in flysch might be imagined to arise in the following way. The inorganic material came from a land area; the large Foraminifera, on the other hand, lived far from the shore, in shallow water. Later transportation took place of both types of material to the basin, where flysch was laid down. One of the features, which supports sedimentation of this type, is the occurrence of the thin layers of large Foraminifera. These components were transported by a stronger water current and deposited on the surface of the growing body of sediment.

How is the question of an autochthonous or an allochthonous origin, as applied to small Foraminifera? Adherents to the theory of a deep--water origin of flysch are of the opinion that these are fossils occurring in situ, since the deep-water sediments could suffer erosion only in exceptional cases. Recently, there appeared a paper by F. S i m p s o n (1969), in which are given assemblages of agglutinating Foraminifera, comprising mainly tubular forms, which would have a sessile mode of life. These concentrations, described by S i m p s o n as interfacial assemblages, are either in situ or almost in situ. At the present time, it is not possible to state whether this exceptional organic remains, on the lower surface of sandstone layers, took place in deep or shallow waters.

Assemblages of tubular and branching, agglutinating Foraminifera encountered in flysch (Pl. XCV, XCVI, XCVII) generally consist of specimens preserved as fragments, unlike interfacial assemblages. It is not yet clear whether the state of preservation in small fragments arose as a result of transportation, or whether diagenesis was responsible: it is also not excluded that the primitive manner of sieving rock material is at fault.

In a number of cases, Foraminifera assemblages comprising species of various ages have been found; an example of this, which may be cited here, is the common occurrence in the Tertiary of Cretaceous Foraminifera, such as *Globotruncana.* Here undoubtedly is proof of the erosion of soft sediments (clays), at some time considerably later than when they were formed. The transportation of Foraminifera from some sediments to others could also take place a short time after burial; this is extremely likely under shallow-water conditions.

e) O t h e r g r o u p s o f o r g a n i s m s i n t h e T e r t i a r y f l y s c h

Besides Foraminifera, other Protozoa and nannoplankton, fossils belonging to other organic groups are, as a rule, encountered only rarely. Particularly striking is the lack of any organic remains whatever among the biocoenoses of agglutinating Foraminifera. In the waters of very deep seas, this absence may be explained as being due to solution by sea-water; on the other hand, it is supposed that solution would not destroy other biogenic components in the bathyal zone of the seas.

It is difficult to account for the relative paucity of fossils in flysch. Up to now, there are two explanations of this phenomenon.

I) The paucity of fossils in flysch is a primary phenomenon. M. K s i ą ż k i e w i c z (1961) gave an analysis of causes of bad life conditions; such conditions would be operative in a flysch sea about 1000 m in depth.

II) Others take the view, that the absence of organic remains and above all of calcareous tests, is a secondary phenomenon. Thus, in non--calcareous sediments, which are abundant in flysch, calcareous tests would suffer solution. In flysch, the clastic sediments are particularly impoverished in fossils; in these, the circulation of dissolving solutions is, as a rule, clearly evidenced.

In the clays, shales and marls of flysch, the occurrence of fossils is irregular. Sometimes beds with a complete absence of fossils occur between those with a rich fauna. It is difficult to imagine how the circulation of solutions in pelitic sediments, in so far as they are able to pass through rock of this type, might leave effects in some beds without entering others.

III) Probably an other explanation of the paucity of fossils in flysch will be that closest to the truth. A b e l (1927) gives observations on the difficulties of preservation even of hard skeletal parts in littoral sediments. Here, there is destruction of these by other grazing organisms, such as crabs, which quickly break down the large calcareous shells of molluscs.

It is known that the organisms of fresh and brackish waters are represented to a marked degree by forms without shells or with shells liable to destruction, in which a thick horny or chitinous layer rests on a thin calcareous layer. This latter shell composition does not permit long persistance, either on the surface of sediments or buried. The absence or paucity of former organisms is thus argument that the flysch formation represents sediments of the shallow waters of a land area and of shallow seas.

Organisms of the flysch formation in the Tertiary of the Polish Carpathians include extremely rare corals and somewhat more commonly occurring bryozoans. In some places, for example in the Babica Clays (see B. K r o p a c z e k, 1917 and W. K r a c h, 1963, in press) are found faunas of molluscs. These organisms occur also in clastic rocks such as the Czarnorzecki Sandstones and the Siedliska Conglomerates. All the animal groups mentioned and *Lithothamnium,* among plants are marine organisms.

Fish constitute an animal group encountered in abundance in the flysch region. They occur however mainly in one flysch series, the Menilitic Shales. This group will be considered later.

Connected with pelitic sediments and also with clastic sediments of the Tertiary flysch are other fossils: traces of animal life preserved as biohieroglyphs. S e i l a c h e r (1967) defined these fossils as i c h n o - c o e n o s e s. These traces generally occur as moulds on the lower surfaces of sandstone layers and are, therefore, negatives. Numerous occurrences of them provided a reason for the distinction of the Hiero- glyphic Beds within the Tertiary flysch. Other traces of life occur within the rocks, in pelitic sediments; among these, fucoids, found mainly in the Cretaceous, are important.

Biohieroglyphs as a rule consist of autochtonous fossils; only in exceptional cases, redeposited specimens are found (S e i l a c h e r, 1964) and these are without great significance. The fact that these are un- doubtedly primary fossils is of particular significance in the under- standing of the geological history of flysch.

Life traces are to-day found at various depths in seas and other waters. The problem of the existence of the organisms leaving the traces must be considered in the light of an abundance of life, bottom-dwelling and swimming, which provided food for the animals. Traces are formed on the sea-shore by snails with shells (A b e l, 1927). The majority of traces was formed by worms, organisms without skeletal parts.

It is accepted (K s i ą ż k i e w i c z, 1961; S e i l a c h e r, 1964, 1967) that the biohieroglyphs are formed by deep-sea animals, since trails similar to those in flysch have been found in present-day oceans. However, the necessity of an abundance of life, as a food supply for the trace-forming organisms, suggests shallow waters, since in these there is more food material than in deep waters. Where an origin of flysch in fairly shallow waters might be accepted, the reason for the absence of other fossils, even in local occurrences, is not clear. However, this lack of other organisms has already been explained above.

It is necessary to add that, in some flysch sediments outside the Carpathians, footprints of birds have been described (M a n g i n, 1964), traces which undoubtedly are of shallow-water origin. It is worthwhile to quote a paper of V i a l o v (1966) about various traces (Zooichnia), formed on the bottom of various bodiest of shallow water.

THE PROBLEM OF SEQUENCES TRANSITIONAL BETWEEN THE NUMMULITIC AND FLYSCH FORMATIONS

The acceptance of the existence of two different geological formations in a single area automatically rises the question, whether there are series transitional between these formations and what are their characteristics. It is necessary to state right away that it will only be possible to think definitively in terms of passage series, when the genesis of the flysch formation is understood and its composition defined. In these consider- ations, as emphasizes at the very beginning of this account, reference is made to bioformations; an attempt is made to examine the passage series from a biological point of view.

The problem of passage series has already been considered (F. B i e - d a, 1968) in a discussion of the boundary between the Tatra Eocene and the Podhale Flysch. Here also it was indicated that, taking into account biogenic components, rocks such as the Pasierbiec Sandstone and *Lithothamnium* Sandstones may be included in the passage series.

In the Tertiary of the Polish Carpathians, series are encountered, which, both lithologically and from the point of view of organic composition, differ both from sediments of the nummulitic formation and from those of the flysch formation. The Menilitic Beds are of this type. Above there has already been mention of the different lithological character of such rocks complexes as hornstones, which are undoubtedly of organic origin. The occurrence of diatoms, organisms known from waters of all types, gives rise to doubts, as to the marine origin of these rocks. Furthermore, their organic origin renders problematical the inclusion of the cherts in the flysch formation.

In the Menilitic Shales, rich taphocoenoses of fish occur. In general terms, these are similar and have been considered up to now from the point of view of their stratigraphic utility. But a significant thing is that stratigraphic results, based on these nectonic organisms, the only nekton in fact in the Carpathian Tertiary, were at variance with results given by other, benthonic organisms.

The fish of the Menilitic Shales may include fresh-water components, as stated in a number of papers. Recently, the studies of A. J e r z m a ń-s k a and J. K o t l a r c z y k (1968) and A. J e r z m a ń s k a (1968) show that in some taphocoenoses of fish, there are forms with light organs, indicating marine, deep-water conditions. The study by A. J e r z m a ń-s k a and J. K o t l a r c z y k (1968) of fishes from the Menilitic Shales at Jamna Dolna are of great importance. The authors described the occurrence in this exposure of two different fish assemblages; in the lower part of the shales a deep water fauna occurs, in the upper part, a shallow water fauna. In another paper by A. J e r z m a ń s k a (1968) information is given about the occurrence of a third, upper assemblage, again belonging to deep-water. Thus the existence of changes in depth of the basin during deposition of the Menilitic Shales is evidenced by biological indices. Therefore one single complex of beds in the Carpathian Tertiary was deposited in different bathymetric conditions: first bathypelagic sediments and fauna, then littoral and again bathypelagic. Certain authors (N a l i v k i n, 1967) deduce a possibility of transportation of deep-water fishes to shallow-water this would occur after the death of the organisms. However, the studies by A. J e r z m a ń s k a and J. K o t l a r c z y k, cited above, show that the fishes fall to the bottom in their life environment.

Besides fishes, other fossils have been described in the Menilitic Shales. In addition to the diatoms making up the hornstones, which might represent organisms of fresh or brackish water, all other groups of fossils from the Menilitic Shales are of marine origin. Thus here are both small and large Foraminifera, sponge spicules, bryozoans and molluscs. The organisms of the Menilitic Beds are therefore differentiated, but in general terms marine; it is necessary to draw attention to the similarity between these organisms and those of the nummulitic formation.

The lithologies represented in the Menilitic Beds also exhibit differences by comparison with other rocks of the Carpathian Tertiary. Of major importance is the high proportion of bituminous material. This is a primary deposit strictly bound up with the rock, in contrast to larger deposits of fluid and gas bitumens. In the works of different authors are notes and more extensive studies of the sedimentology of

the Menilitic Beds. D ż u ł y ń s k i et al. (1959) assign these beds to the fluxoturbidite type of rocks. D ż u ł y ń s k i and S m i t h (1964) distinguished the Kliwa Sandstone from other flysch sandstones as comprising rocks of non-flysch character.

An account of the more important characteristics of the Menilitic Beds, even one as short as that given above, shows that these Beds are different both from those of the nummulitic formation and those of the flysch formation. A closer definition of their sedimentary character as well as biogenic components remains to be done.

THE SALT MARSH LACUSTRINE ENVIRONMENT IN FLYSCH

Now the problem of the origin of flysch will be treated, using the information given above about life encountered in the Tertiary sediments of the Polish Carpathians, as well as results of recent studies on different aqueous environments.

In bounding areas, lying between the open sea and dry land, there are various aqueous basins, in which both sediments and organic assemblages display differentiation. Among these are swamps and bogs, the waters of which part of the time are changed, but otherwise remain standing. The occurrence of agglutinating Foraminifera in such areas has been confirmed. The situation regarding life and changes of environment is seen to be similar in instances provided by lagoons, enclosed bays and river deltas, in which particularly large differences in salinity are exhibited. Marine bays are also environments of variable characteristics.

In these different environments of a variable nature, not only changes in salinity, but also other physico-chemical changes such as pH and oxygen and CO_2 content, are important; diurnal oscillations in these values have a particularly important influence on the lives of organisms. Organic life in such boundary areas of land and sea must also display changes. As is known, marine organisms are generally intolerant of dilution of the saline water; also the marine environment is unsuitable for fresh-water animals. The variability and mixing of various aqueous environments in the area of flysch sedimentation must have had some effect on the organic life there. P h l e g e r (1960, p. 176) presumes that, in Middle Tertiary time, swamps covered greater areas in some places than at the present day.

Furthermore, the sedimentation of the flysch formation in the Tertiary area of the Polish Carpathians may be explained in the following way. Agglutinating Foraminifera display great tolerance to changes in life conditions. There exists a variability in the faunal composition of flysch, in which biocoenoses consisting exclusively of agglutinating Foraminifera are replaced by mixed assemblages, with agglutinating and small, calcareous Foraminifera. There are biocoenoses of small, calcareous Foraminifera and nannoplankton. Thus the occurrence of these organisms permits the localization of the type of area, in which flysch was formed. Sediments with exclusively agglutinating Foraminifera belong to shallow waters, both fresh and brackish, though it is not possible to exclude shallow waters of normal salinity. A more considerable admixture of small, calcareous Foraminifera indicates a marine environment, which would be the neritic zone (shelf). On the other hand, sediments with a predominance of small, calcareous Foraminifera (with

small proportions of agglutinating forms), as well as sediments containing small, calcareous Foraminifera and nannoplankton, indicate a greater distance from the shore, with pelagic sedimentation; the water depth would correspond more or less to that of the present-day bathyal zone.

These different environments were subject to change, as shown by fluctuations in faunal composition, for example, fossiliferous flysch beds lying on or under unfossiliferous beds; also the compositions of bio-coenoses may change. It is an obvious fact that the sea-bottom, on which flysch sediments accumulated, was particularly mobile. It is considerably easier to accept changes in life conditions in shallow waters than in deep ones.

Now that a statement of the links between Foraminifera and flysch has been given, an attempt will be made to give a brief review of previous hypotheses dealing with the conditions of the formation of flysch sediments. There are two basic hypotheses: one holds that flysch comprises deep-water marine sediments; the other that it is of shallow water marine origin.

On the subject of depth of the marine environment and conditions of deposition relating to the distinctive sediments in flysch, a few of the most important papers out of the prolific literature may be cited: U h l i g (1911), Z u b e r (1918), A b e l (1927), T e r c i e r (1947), V a s s o e-v i c h (1951), K s i ą ż k i e w i c z (1954, 1961), S u j k o w s k i (1957), D ż u ł y ń s k i and S m i t h (1964); mention has already been made of other papers, and others will be noted.

None of the previous hypotheses on the origin of flysch is alone adequate to solve this problem, since they are usually biassed studies or biassed opinions. Using an example from mathematics, it is possible to say that flysch presents an equation composed of many unknowns.

The view accepting a deep-water origin of flysch at the present time has adherents among geologists, holding turbidity currents to constitute a geological factor. Authors, who have recently considered the genesis of the Carpathian and other flysch from this point of view, include K s i ą ż k i e w i c z (1954), S u j k o w s k i (1957), D ż u ł y ń s k i and S m i t h (1964) and M a r s c h a l k o (1968). In K s i ą ż k i e w i c z' s paper is a review of previous discussions on both the deep and shallow--water origins of flysch. Among the opponents of the hypothesis, which connects flysch with turbidity currents, the views of M a n g i n (1964) are worthy of note; M a n g i n states that the viewpoint of adherents to such a solution is too dogmatic. An important paper by A r k h i p o v (1965) contains fully documented arguments disproving the hypothesis as to the significance of turbidity currents in the formation of flysch deposits.

The view that flysch consists of the sediments of a geosyncline is treated in a far too onesided manner. Thus these geological phenomenon are treated as large depressions in the earth's crust and hence the view that flysch is a deep-water deposit.

It is, however, sufficient to consider the immense complex of Upper Carboniferous beds, undoubtedly shallow-water sediments, to draw attention to the possibility that the geological formations with considerable thickness of sediments exist in different labile parts of the earth's crust. K s i ą ż k i e w i c z (1961) indicates the impossibility of the existence of large depths during the deposition of flysch; in the opinion of this author, flysch originated at depths not greatly exceeding 1000 m.

Above it was mentioned that certain authors are of the opinion that the agglutinating Foraminifera occurring in flysch constitute proof of its deep-water origin. In fact, the information given above about the occurrence of these Foraminifera in shallow waters also does not alone suffice as proof of a shallow-water origin. However, the argument put from a biological point of view shows that a deep-water origin may be questioned and supports the possibility that the agglutinating Foraminifera of flysch come from shallow waters.

Consideration of other biological arguments for the existence of deep waters in the Carpathian Tertiary showed that either there are non-flysch formations, such as the *Globigerina* Marls, or sediments as yet undefined from a genetic point of view, for example, the Menilitic Beds, with bathypelagic fishes or hornstones, the biogenic components of which are not yet recognized to the desired degree.

Many authors have already supported a shallow-water origin of flysch. This opinion is, however, mainly based on lithological characteristics and particularly on the considerable role of clastic rocks in flysch; there are also data of a biological nature. Noteworthy among the relevant papers is that of U h l i g (1911), who was of the opinion that the Carpathian flysch is, in general terms, the sediments of a shallow sea and that only in certain places deeper trenches might have existed. On the one hand, that author had in mind the occurrence of the *Globigerina* Marls and, on the other, results based on studies carried out at that time by R. N o t h (1912) in Vienna. On the basis of analyses of faunas of agglutinating Foraminifera from the Hieroglyphic Beds, from the localities Barwinek (Polish Carpathians) and Komarnók (Komarnic, Slovakian Carpathians), he calculated that these beds were formed at depths of around 1000 m. N o t h's data are based on out-of-date sources and he did not take into account at all, the occurrence of these Foraminifera in shallow-waters.

At the time of U h l i g's, a comprehensive study of Alpine Nummulitic by J. B o u s s a c (1911) appeared. This author also dealt with flysch sediments and stated that the Alpine flysch does not consist of sediments from deep-water, not even from the bathyal zone.

Here it is necessary to return to the data given by M. N e u m a n n (1967), namely that according to previous works, agglutinating Foraminifera occur in three out of the four existing marine zones. They are found in the littoral zone, in the neritic shelf zone and in the abyssal zone; however they are absent from the bathyal zone. It appears that the assignment of flysch to sediments of the bathyal zone has few adherents.

For some phenomena in flysch, it is possible to apply the delta hypothesis of R. Z u b e r (1918). A number of flysch series have the character of deltaic fans; material came from the land. It is difficult, however to accept that all the flysch sediments originated in a large delta, while moreover, there is no proof that during Tertiary time, there were great rivers flowing from large continents in the Carpathian area.

O. A b e l (1927) put forward the hypothesis that flysch is a sediment of the type, which today is seen in the growing shore zone with the formation of mangrove plants. In A b e l's information is a series of accurate data, for example, as to the destruction of hard skeletal parts in this belt of water; also important is the statement of a shallow-water origin for some organic traces. A b e l's hypothesis employs the fundamental matter, namely as to the amount of plant material in sediments

of this type; it appears that here the argument supports shallow water with an abundant flora — crude petroleum originates from plant remains.

The conviction expressed by a number of the authors mentioned above (U h l i g, Z u b e r, A b e l), generally prevails; that flysch originated in regions of warm and even hot climate. Recently M a n g i n (1962) also drew attention to climatic phenomena indicated in flysch sediments. The warm climate of the environment is in a sense proof of shallow water.

There are also views that some flysch sediments were formed on land. An example is provided by N a l i v k i n (1967); according to him, the Krosno Beds in the Carpathians are terrigenous sediments, which were only temporarily covered by a sea. This supposition is based on the absence of fossils in the marl layers, in which calcareous Foraminifera are extremely rare.

The problem of sediments with a high percentage of calcium carbonate, formed in water, may also be explained differently. M. W i l l i a m s and E. S. B a g h o r n (in: Organic Geochemistry, 1963) give the results of studies on diurnal fluctuations in pH in the shallow waters of Massachusetts Bay. During the hours in which there is intense sunlight, there is a definite increase in pH to 8,52; in the night, because of plant respiration, there is a reduction of this value to 7.82. An analogical phenomenon is seen in the waters of the Bay of Florida, with a variation from pH 8.9, in maximum sunlight, to pH 8.0 at night. At pH 8.2, the water is saturated in calcium carbonate; with an increase in pH to 8.9, there is a precipitation of $CaCO_3$, to the extent of 35 mg per litre of water. With strong evaporation, this is decreased to 10 mg. per litre. Thus we have here proof that life takes part in the process of calcium carbonate precipitation in coastal waters.

P h l e g e r (1960) states that in the warm bottom waters of the Atlantic Ocean is an excess of $CaCO_3$, which is greater by 40 % than the normal proportion of this compound. Certainly precipitation of $CaCO_3$ takes place. The data given above, including that dealing with difficulties of preservation of hard, organic remains in shallow waters, explain the formation of the poorly fossiliferous Krosno Beds; they are however the deposits of an aqueous and not continental environment.

The definition of flysch characteristics and conditions of its formation, given by J. T e r c i e r (1947), included four points:

1) Flysch comprises sediments, which are generally detrital or terrigenous and to a minimal degree, of organic origin.

2) It is a formation of great thickness and, as a rule, the lithological complexes do not display differences.

3) They are marine sediments, partly from the neritic zone, partly from the bathyal zone.

4) They are formed in mobile basins, in which there are cordilleras without connections.

This statement of the characteristic features of flysch may be accepted, with changes to point 3: flysch consists of salt-marsh lacustrine sediments, in a sea extending to the bathyal zone.

Recently L. C o n t e s c u (1964) dealt with the problem of formation of flysch. According to his views, flysch is a tectoformation, since he erects various categories of flysch, originating in different parts of a geosyncline. This aspect of the problem of flysch genesis should be taken into account in the final synthesis.

In a previous paper (F. B i e d a, 1968), it was stated that the area of the Carpathian Tertiary, in which the nummulitic formation was deposited, was occupied by a sea with archipelagoes. After a consideration of the conditions of origin of the flysch formation, it is possible to include in entirety the morphological differentiated area, in part land with various aqueous basins and in part marine, so that both formations could arise, depending, among other things, on the configuration provided by cordilleras and the various depths of the sea bottom.

CONCLUSIONS

In the last section, an attempt was made to give a different explanation of a shallow-water and partially deep-water (bathyal) origin of flysch. On the basis of recent studies of life in various bodies of water, from fresh to salt water, as well as work on life in the Tertiary flysch of the Polish Carpathians, a concept of flysch genesis generally is advanced. The main purpose of the present account was to draw attention to and emphasize the importance of biological considerations in studies of flysch, to a wider extent than in previous accounts.

Previous informations about organisms in flysch sediments, and above all about agglutinating Foraminifera, are not adequate. Present methods of micropalaeontological study were employed with only stratigraphy in mind; besides this purpose of primary importance, other aspects of biological problems, concerning the organisms in flysch, were treated incidentally. The new method of studying nannoplankton permits a hope for benefit from results other than those obtained through traditional micropalaeontology.

The assumption put forward above, that flysch is a sediment of various aqueous environments, encounters oriticism. One of the arguments for a deep-water origin of flysch and its connection with turbidity currents is the constant nature of some features characteristic for flysch. As indicated above, this has been explained by A r k h i p o v (1965). The present author, for his part, adds once more that neither a constant organic content in flysch nor constant ecological conditions are hardly feasable.

So far as the genesis of flysch is concerned, it is to be hoped that new results will arise out of the involvement of various branches of knowledge and out of collective studies. Thus for example, further studies of the distribution and ecology of present-day organisms, as well as biochemical and geochemical studies, should be rewarding. A new approach to palaeontological material is essential; particularly necessary are papers on the relations between flysch fossils and the rocks in which they occur.

<p style="text-align:center">*</p>
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commented on some problems considered in the present account. To these people, I am very much obliged.

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STRESZCZENIE

We fliszu trzeciorzędowym Karpat polskich występują dwie różne formacje, jedna — numulityczna została opisana w innej pracy (F. B i e d a, 1968), druga — to formacja fliszowa. W niniejszej pracy są przedstawione różnice w zawartości składników organicznego pochodzenia, a przede wszystkim wykształcenie biocenoz tak formacji numulitycznej, jak i formacji fliszowej.

Na podstawie różnic składników biogenicznych można wyjaśnić powstanie trzeciorzędowych osadów fliszowych Karpat. Najczęściej spotykanymi tu skamieniałościami są otwornice; w niektórych kompleksach występują wyłącznie otwornice aglutynujące, na co pierwszy zwrócił uwagę J. G r z y b o w s k i (1898). Występowanie tych pierwotniaków stanowi zdaniem szeregu autorów cechę charakterystyczną fliszu; ostatnio podkreśla to U. P f l a u m a n n (1967).

We fliszu trzeciorzędowym Karpat polskich można wyróżnić cztery odmienne zespoły mikroorganizmów:

1 rodzaj zespołów stanowią otwornice wyłącznie aglutynujące, kilka przykładów podano na tablicach,

2 rodzaj to zespoły mieszane złożone z otwornic aglutynujących i małych otwornic wapiennych,

3 rodzaj to zespoły złożone z małych otwornic wapiennych przeważnie planktonicznych i z nannoplanktonu,

4 rodzaj to zespoły dużych otwornic.

Otwornice aglutynujące występują dzisiaj w wodach płytkich słodkich lub o niewielkim procencie soli, a więc w zbiornikach wód przejściowych i sięgają w morzach do zewnętrznego brzegu szelfowego, tj. do głębokości około 200 m; w strefie batialnej albo nie występują (M. N e u m a n n, 1967), albo są nader rzadkie; są licznie reprezentowane w strefie abisal-

nej. Występowanie otwornic aglutynujących w różnych głębokościach i o różnym zasoleniu wód dowodzi ich dużej tolerancji co do warunków życiowych, tolerancji znacznie większej niż u innych organizmów zwierzęcych. Ten fakt oraz inne jeszcze przesłanki nasuwają przypuszczenie, że obszarem życiowym otwornic aglutynujących fliszowych były wody płytkie, morskie i innych zbiorników, w których zachodziły zmiany zasolenia.

Zespoły otwornic (i innych mikroorganizmów) wymienione powyżej pod liczbami 2, 3 i 4 przedstawiają zespoły organizmów morskich. Zespoły złożone z otwornic aglutynujących i małych wapiennych, tj. zespoły nr 2 żyły w strefie litoralnej i w strefie nerytycznej (P h l e g e r, 1960). Zespoły składające się z otwornic wapiennych, przeważnie planktonicznych i z nannoplanktonu, wskazują na środowiska pelagiczne o większej głębokości odpowiadającej mniej więcej dzisiejszej strefie batialnej.

Zespoły z dużymi otwornicami (zespoły nr 4) występują w osadach klastycznych powstających w płytkim morzu.

Zespoły otwornic, szczególnie małych tak aglutynujących, jak i wapiennych są nieregularnie rozmieszczone w osadach fliszowych; warstwy z otwornicami są przegradzane warstwami nie zawierającymi ich. To zjawisko można lepiej wyjaśnić przyjmując zmiany środowisk życiowych, a które to zmiany zachodzą szybciej w wodach płytkich niż głębokich. Tak więc przy zmianach warunków fizykochemicznych (np. zmniejszenie zasolenia wody) zespoły morskie złożone w części z otwornic wapiennych ginęły, natomiast mogły tutaj żyć zespoły otwornic wyłącznie aglutynujących.

Obok biocenoz otwornicowych i niekiedy już to razem z nimi, już to osobno występują biocenozy złożone z innych organizmów, jak mszywioły, niekiedy mięczaki, są także małżoraczki. Dość pospolite są biocenozy litotamniowe. Ważną grupą skamieniałości trzeciorzędu fliszowego są ślady życia zwierząt, które S e i l a c h e r (1967) określił jako ichnocenozy. Te dość różne ślady dowodzą bogactwa życia; były to przeważnie nie oskorupione zwierzęta (robaki). Te organizmy potrzebowały znacznej ilości substancji organicznej, a ona w wodach płytkich jest szczególnie obfita ze względu na rozwój świata roślinnego.

Brak lub ubóstwo skamieniałości w skałach fliszowych można tłumaczyć płytkowodnym środowiskiem życiowym. Zwierzęta zamieszkujące wody brakiczne i słodkie są albo nieoskorupione, albo mają skorupy zbudowane z substancji organicznej (chityna) całkowicie lub w części; w tym ostatnim przypadku warstwa organiczna bywa nieraz grubsza od warstwy wapiennej. Takie skorupy stosunkowo szybko ulegają rozpadowi, jeszcze przed ich pogrzebaniem. A b e l (1927) zwraca uwagę na fakt, że w płytkich morzach nawet grube skorupy wapienne są szybko niszczone przez żerujące zwierzęta (kraby).

Formację fliszową Karpat w czasie trzeciorzędu można przedstawić jako utwory środowisk lakustro-salicznych, w morzu flisz sięga do strefy batialnej.

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Kraków, wrzesień 1968

EXPLANATION OF PLATES

Plate XCIV

Assemblage of agglutinating Foraminifera of the Polish Carpathians. Paleocene. Variegated shales of the Skole unit. Bore-Hole Cisowa

1 — *Nodellum velascoense* (C u s h m a n)
2 — *Rhabdammina cylindrica* G l a e s s n e r
3 — *Dendrophrya excelsa* G r z y b o w s k i
4 — *Saccammina placenta* (G r z y b o w s k i)
5 — *Ammodiscus siliceus* (T e r q u e m)
6 — *Glomospira gordialis* (J o n e s et P a r k e r)
7 — *Glomospira gordialis diffundens* C u s h m a n et R e n z
8 — *Ammolagena clavata* (J o n e s et P a r k e r)
9 — *Kalamopsis grzybowskii* (D y l ą ż a n k a)
10 — *Hormosina excelsa* (D y l ą ż a n k a)
11 — *Hormosina ovulum* (G r z y b o w s k i)
12 — *Rzehakina fissistomata* (G r z y b o w s k i)
13 — *Haplophragmoides kirki* W i e c k e n d
14 — *Haplophragmoides suborbicularis* (G r z y b o w s k i)
15 — *Trochamminoides coronatus* (B r a d y)
16 — *Cystammina pauciloculata* (B r a d y)

Coll. J. M o r g i e l o w a. X20

Plate XCV

Assemblage of aglutinating Foraminifera of the Polish Carpathians. Lower Eocene. Variegated shales of the Magura unit. Rabka.

1 — *Glomospira charoides* (J o n e s et P a r k e r)
2 — *Glomospira gordialis* (J o n e s et P a r k e r)
3 — *Glomospira grzybowskii* J u r k i e w i c z
4 — *Trochamminoides coronatus* (B r a d y)
5 — *Saccammina complanata* (F r a n k e)
6 — *Saccammina placenta* (G r z y b o w s k i)
7 — *Thalmanammina subturbinata* (G r z y b o w s k i)
8 — *Dendrophrya excelsa* G r z y b o w s k i
9 — *Rhabdammina linearis* B r a d y

Coll. A. J e d n o r o w s k a. X20

Plate XCVI

Assemblage of aglutinating Foraminifera of the Polish Carpathians. Lower Eocene. Variegated shales of the Magura unit. Sól (district Żywiec).

1 — *Dendrophrya robusta* G r z y b o w s k i
2 — *Dendrophrya excelsa* G r z y b o w s k i
3 — *Rhabdammina linearis* B r a d y
4 — *Trochamminoides coronatus* (B r a d y)

Coll. A. J e d n o r o w s k a. X20

Plate XCVII

Assemblage of aglutinating Foraminifera of the Polish Carpathians. Middle Eocene, lower part. Hieroglyphic Beds of the Skole unit. Nahurczany

1 — *Rhabdammina discreta* B r a d y

2 — *Rhabdammina cylindrica* Glaessner
3 — *Ammodiscus umbonatus* Grzybowski
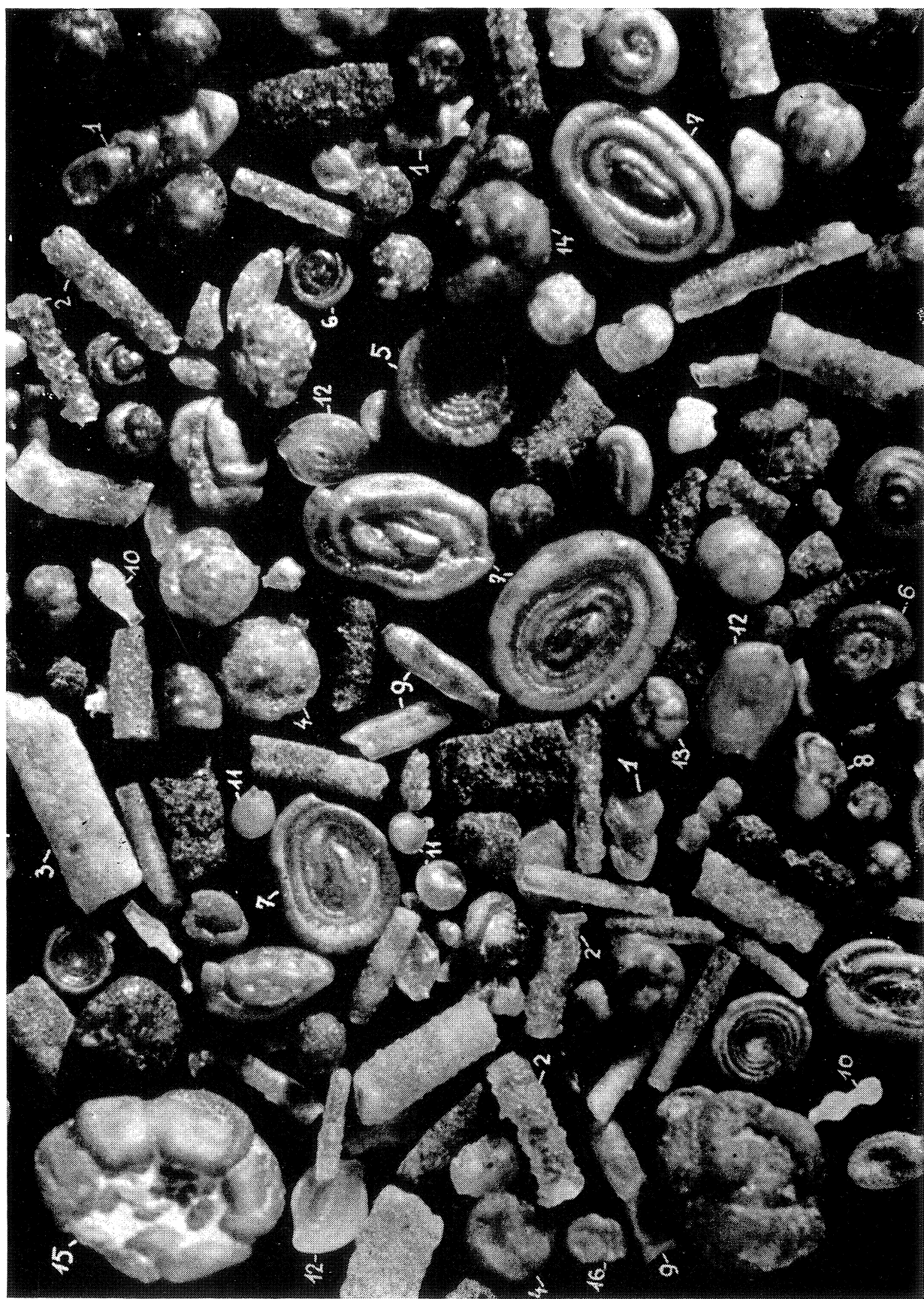4 — *Cyclammina amplectens* Grzybowski

Coll. J. Morgielowa. ×20

Plate XCVIII

Assemblage of aglutinating Foraminifera of the Polish Carpathians. Middle Eocene, upper part. Hieroglyphic Beds of the Skole unit. Nahurczany

1 — *Haplophragmoides walteri* (Grzybowski)
2 — *Cyclammina amplectens* Grzybowski
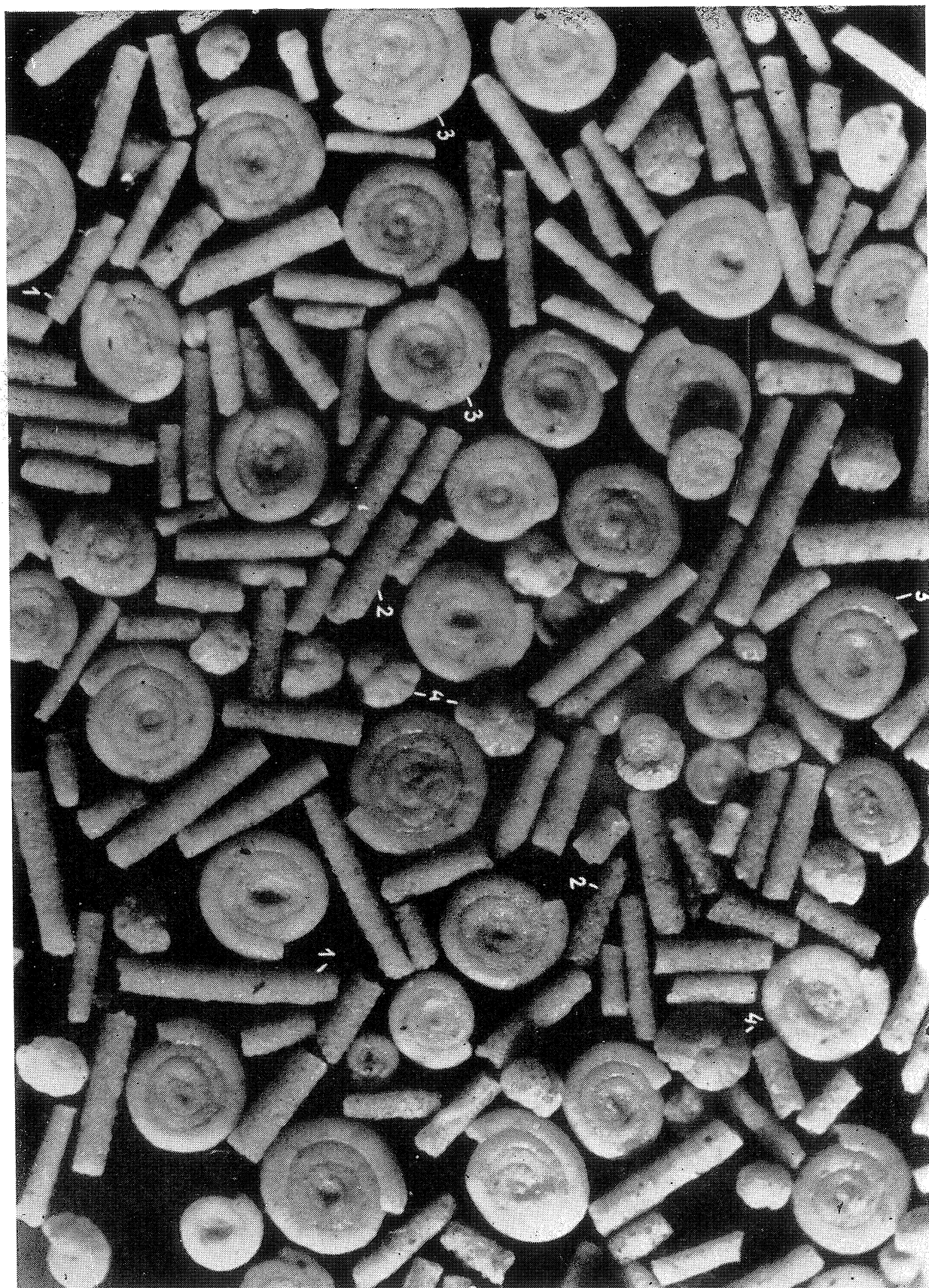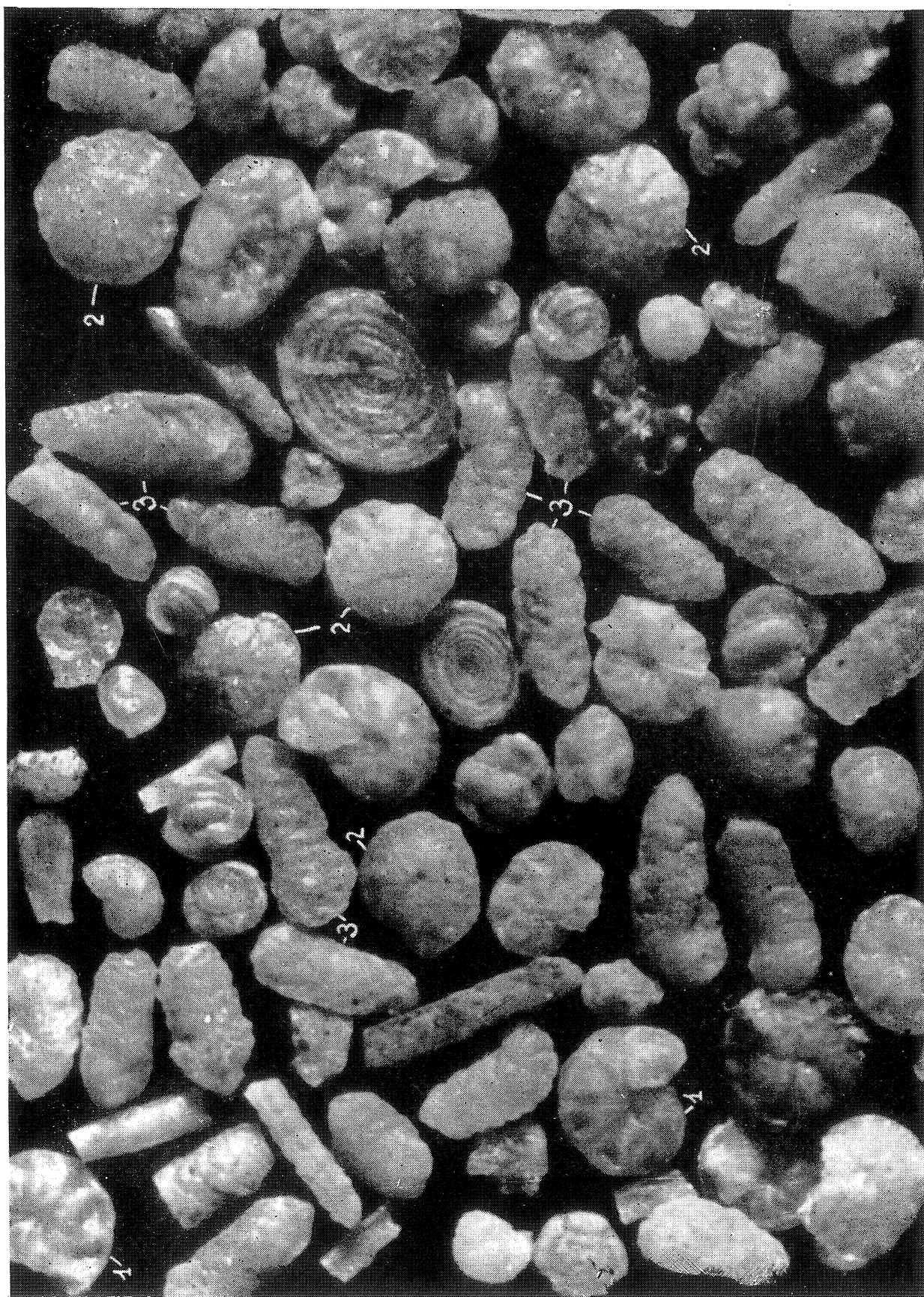3 — *Spiroplectammina spectabilis* (Grzybowski)

Coll. J. Morgielowa. ×20

F. Bieda

F. Bieda