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O WARUNKACH ŻYCIA W BASENACH FLISZOWYCH

Life conditions in Flysch Basins

STRESZCZENIE

Treść: Warunki życia w basenach fliszowych stały pod wpływem kształtu oraz sytuacji paleogeograficznej i paleotektonicznej basenów. Czynniki te utrudniały przewietrzanie głębszych warstw wody oraz wymianę wód powierzchniowych z sąsiednimi morzami. Dlatego ilość tlenu w głębszych wodach była niższa od normalnej, a ilość substancji odżywczych słabo uzupełniana przez dyfuzję i regenerację. Wskutek zwiększonej ilości bezwodnika węglowego nie mogła rozwijać się w głębszych wodach mikrofauna wapienna, natomiast przenoszenie dużych ilości materii roślinnej pochodzenia lądowego i koncentrowanie jej przez prądy zawiesinowe w wyższych częściach epizodycznie składanych warstw umożliwiało bujny rozkwit organizmów osadożernych.

Osady fliszowe występują we wszystkich górach fałdowych, w których mają duże rozprzestrzenienie i z reguły znaczną miąższość. Niemal zawsze są one ubogie w skamieniałości. Charakter szczątków organicznych w utworach fliszowych jest podobny do siebie, bez względu na ich sytuację stratygraficzną i geograficzną. Zazwyczaj zespół szczątków organicznych w utworach fliszowych składa się z allochtonicznych (redeponowanych) organizmów płytkowodnych, z niewielkiej ilości autochtonicznych organizmów planktonicznych (głównie otwornic i radiolarii), z ubogich zespołów bentonicznych, począwszy od karbonu reprezentowanych przez otwornice aglutynujące, obfitych śladów zwierząt osadożernych i częstych resztek roślin pochodzenia lądowego.

Istnieją wskazówki, że tylko częściowo można ubóstwo skamieniałości w osadach fliszowych przypisać rozpuszczaniu skorup podczas sedymentacji i diagenezy. W większej mierze ubóstwo resztek organicznych zdaje się odzwierciedlać ubóstwo życia organicznego w basenach fliszowych wywołane niekorzystnymi warunkami życiowymi. W wielu przypadkach skamieniałości są początkowo dość częste w osadach fliszowych, ale ilość ich zmniejsza się ku górze szybko, wskazując, że warunki, w jakich tworzył się flisz, były niekorzystne dla większości organizmów morskich.

Redeponowane resztki organiczne, pochodzące ze strefy lub osadów przybrzeżnych, wskazują na środowisko o normalnej słoności i na ogół wystarczającej ilości pokarmu w pobliżu brzegów basenu. Natomiast ubogie i do pewnego stopnia skarlałe fauny autochtoniczne wskazują bądź na zmniejszoną ilość tlenu, bądź niedostateczną ilość pożywienia w bardziej centralnie położonych częściach basenów. Cechy osadów wskazują, że tlenu było w pewnych okresach i miejscach mniej niż w innych, ale rzadko dochodziło do prawdziwie euksynicznych warunków. Ubogie bentoniczne fauny otwornicowe są szczególnie zubożałe w tych częściach serii fliszowych, w których większość osadów jest złożona prądami zawiesinowymi. Prądy te mogły wpływać na warunki życia w basenie w różny sposób. Znosiły one w głąb basenu pewne ilości materii organicznej pochodzącej ze strefy przybrzeżnej, szczególnie materii roślinnej, która do strefy przybrzeżnej dostawała się z lądu. Materia organiczna jako lżejsza koncentrowana była w górnej części prądu i składana w wierzchniej części odkładanego przez prąd osadu. Rozkład jej mógł obniżać *pH* wód przydennych i w ten sposób utrudniać rozwój organizmów wytwarzających skorupki wapienne, wskutek czego wytwarzało się środowisko bardziej stosowne dla rozwoju otwornic aglutynujących. Równocześnie zmniejszała się ilość tlenu w wodach przydennych zużywanego przy rozkładzie materii organicznej. Ponadto prądy zawiesinowe powodowały wyniszczanie fauny dennej, przykrywając od czasu do czasu dno nagle deponowanym, nieraz grubym osadem. Z drugiej strony wskutek przenoszenia dużych ilości skoncentrowanej materii organicznej na głębsze części dna prądy zawiesinowe wpływały na silny rozwój zwierząt osadożernych. Jeśli prądy te następowały po sobie szybko, w krótkich odstępach czasu, jak to przypuszczalnie odbywało się w niektórych odcinkach serii fliszowych, wskutek pokrywania dna osadem przeszkadzały regeneracji substancji odżywczych z rozkładu materii organicznej na dnie i użyźnianiu wyższych warstw wody.

Podczas gdy specjalne warunki życia na dnie basenu wpływały na szczególny charakter dennej fauny fliszowej, brak lub ubóstwo oraz zaznaczające się poniekąd skarlenie fauny nektonicznej i planktonicznej wskazuje na ubóstwo wód basenu w substancje odżywcze. Ograniczone niedużymi a ruchliwymi lądami „tektonicznymi”, a nie rozległymi kontynentami baseny fliszowe nie otrzymywały odpowiednich ilości soli odżywczych przynoszonych do mórz dużymi rzekami. Wymiana wód i dyfuzja z sąsiednimi morzami była też utrudniona na skutek istnienia barier lądowych i utrudnionych połączeń. W niektórych tylko okresach, gdy połączenia z sąsiednimi morzami poprawiały się, plankton i życie nektoniczne rozwijały się przejściowo bujniej. Warunki paleotektoniczne i sytuacja paleogeograficzna w dużej mierze zatem wpływały na warunki życia w basenach fliszowych.

Abstract:* Life conditions in flysch basins were influenced by the shape of basins and their paleogeographical and paleotectonic situation. Aeration of deep water layers was imperfect and nutrients were not sufficiently replenished by diffusion or regeneration. The increased amount of CO_2 in deeper waters eliminated calcareous microfauna, while concentration of organic matter in the upper parts of periodically deposited turbidite layers favoured development of sediment feeders.

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* A summary of the present paper (Life conditions in flysch basins) is published in Preprints, International Oceanographic Congress, Amer. Ass. for Advancement of Science, Washington 1959, pp. 280—281.

INTRODUCTION

Flysch deposits are known to occur in all the mountains of the world. After Marcel Bertrand (1894) it may be repeated here that every folded range has its flysch, and every geosyncline passed through a stage during which flysch deposits were laid down. Flysch deposits have a vast areal extent, and usually a considerable thickness. Their sedimentary features are invariably much the same notwithstanding their age: a Paleozoic flysch displays the same features as a Tertiary flysch. Nearly always flysch deposits show extreme poverty of fossil life record. The recurrence of this feature, together with always the same or very similar sedimentary character, suggests that life conditions in flysch basins must have been influenced by a similar set of paleogeographical agencies responsible for special environmental and ecologic conditions.

It may then be said that flysch biota represent a special case of the marine environment of wide paleobiogeographical significance, and are somehow connected with the evolutional history of geosynclines.

PALEOGEOGRAPHIC AND PALEOTECTONIC SETTING

The present paper is mainly based on the observations of the Carpathian flysch, and on the more cursory observations on the flysch of the Eastern Alps and the Balkan range. The Carpathian flysch, however, constitutes the largest and longest flysch belt in Europe, and probably also one of the largest in the world; it embraces a long time span ranging from the lowest Cretaceous to the end of the Early Tertiary. It may easily be regarded as a true representative of this type of deposits.

In the Alpine mountain system of Europe flysch deposits occur in a comparatively narrow belt along the northern edge of the folds zone. They occupy a similar position in the Dinaric system. In either cases flysch sediments appear toward the end of the evolutionary cycle of the geosyncline although they often well precede the paroxysmal stage of the orogeny. In the Carpathians and the Eastern Alps the sedimentation of the flysch started at the beginning of Cretaceous time, in the Balkan already in the Tithonian, but in some other areas of the Alpine zone the flysch type of deposits appeared at a much later date.

In the Carpathians, if the folds are stretched and the overthrusts pushed back, it appears that the flysch zone, at present ca. 100 km wide, was originally about 300 km wide. The basin in which they have been deposited must have been of about that width. Probably in other parts of the Alpine zone flysch basins were narrower.

It follows then that flysch deposits have been laid down in relatively narrow but longitudinally extended basins. The flysch belt of the Alps, Carpathians and Balkan is about 2500 km long.

It results from the measurement of directional features and the facial analysis that the floor of the basin, in which the Carpathian flysch has been deposited, was pitching in one or other direction. On these data it may be visualized that the long flysch zone along the northern margin of the Alpino-Carpathian range was deposited in one linearly elongated trough divided by some transversal submarine swells into a few longitudinally interconnected basins.

There are several sedimentary features pointing out that the flysch basins could not be very shallow: astonishingly uniform character of most of flysch deposits (e. g. Upper Cretaceous „Inoceramian beds" have identical appearance in the Eastern Alps, in the Carpathians and in the Balkan, the same pertains to the Lower Cretaceous and many Eocene beds), persistence and eveness of bedding and many other features were taken into account by several writers who advocated a deeper water environment for flysch deposits (cf. Bailey, Tercier 1947). Now when the application of the turbidity current theory cleared the puzzle of the distribution of sand and gravel on the floor of deep basins, flysch deposits may safely be regarded as laid down in fairly deep waters. In the Carpathians, from the areal extent (ca. 30 km from the presumed shore, Książkiewicz 1958) of the deposits that may be attributed to the sedimentation by submarine mudflows, the depth of the basin may to some extent be estimated. In some cases, taking the inclination of the sea-floor as 1° only, and assuming that a water-logged sediment can flow on such a grade, we obtain the depth of about 1000 m. In the Carpathian basin with its maximal width of about 300 km, a greater depth would mean a considerable slope toward the axial zone of the basin and, consequently, very frequent slumping phenomena in the flysch deposits. Actually, slumping structures are not so frequent, and if frequent, limited to some narrow zones. The general character of the flysch sediments in the Carpathians also points rather to deposition on a fairly flat sea-floor. From these features it follows that on the average the depth of the Carpathian flysch basin did not exceed much 1000 m.

The presence of thick masses of detrital sediments (in the Carpathians 6000 m) implies that flysch basins must have been bordered by lands furnishing terrigenic material. It appears however, from paleogeographic data, that these lands never were very large; the foreland of the Carpathian and Balkanian flysch basins were in most times covered by epicontinental seas, and the same refers to the Alpine flysch basin, while on the other side these basins adjoined to a geosynclinal area, or again, were bordered by small lands. On the other hand, tremendous amounts of terrigenic material indicate that the neighbouring lands must have strongly been eroded. From the evidence supplied by measured current directions it results that the principal source areas were situated inside the flysch basin. Taking these facts into account one can conclude that small and narrow but steadily uplifting areas situated along the margins and inside the flysch basin supplied the basin with sediments. These „tectonic lands" were apparently drained by innumerable short but rapid streams and rivers washing down to the sea masses of terrigenic material deposited in shallow-water zones and constructing aprons fringing the tectonic lands. In overloaded detrital aprons submarine slumping led to the generation of turbidity currents, in conformity with the theory of Kuenen and Migliorini (1950).

The European flysch basins were situated to the all appearance in the warm climatic zone, probably in the subtropical belt. Under these circumstances narrow and fairly deep water bodies had always surface waters warm, and the exchange with deeper cool waters, which may operate only during cool seasons, must have been very limited. The continuous rising of marginal tectonic lands certainly impeded the exchange of water with external seas, for if any connections existed with external seas, they probably were of shallow-entrance character. On the whole true euxinic sediments occur among flysch sediments but exceptionally, although flysch sediments fairly often display features suggesting feebly reducing conditions on the sea-floor. Unlike with external seas, connections between vicinal flysch basins were possibly deep enough for a circulation of deeper water layers in most times, but never so good as to eliminate the increasing amount of products formed by decomposition of organic matter. In comparatively deep flysch basins the amount of carbon dioxide was probably larger than it could be if flysch basins were shallow water bodies.

In short, flysch basins formed partly land-locked water bodies with poor connections with other seas, relatively narrow, but long and interconnected, with not too restricted circulation. Their sedimentation was strongly influenced by the immediate vicinity of tectonically active zones.

GENERAL CHARACTER OF FLYSCH BIOTA

The fossil record in flysch sediments presents an association of organic components unknown from other formations. This association is common to flysch deposits of various stratigraphic and paleogeographic positions. Flysch deposits usually contain redeposited assemblages of shallow-water animals and plants; they contain often a poor benthonic fauna, and only an insignificant admixture of planktonic organisms, displaying at the same time abundant traces of the activity of mud- and sand-digesting animals. In many flysch deposits debris of land plants are abundantly present.

In several flysch sequences at the beginning fossils are not infrequent, but upward in the sequence they become fairly rapidly less and less numerous. This pertains to the Carpathian flysch, where in the Lower Cretaceous organic remnants are fairly abundant, and also partly to the Balkanian range and the Caucasus. No doubt this might be due to a certain extent to evolutionary trends of the fauna, as exemplified by the decrease in the number of ammonites toward the Middle Cretaceous, but generally it implies that once the flysch regime had commenced to develop, it became gradually but fairly quickly detrimental to the life conditions in the basin.

The fossil content of flysch deposits generally points to normal water salinity in flysch basins. In the Carpathian flysch there are few instances that the foraminifera indicating brackish waters or having a great range of tolerance to wide ranges of salinity are present (e. g. *Ammobaculites, Rotalia beccari),* but usually they occur in assemblages abounding in the forms restricted to waters of normal salinity. It might be inferred that the waters of flysch basins neither have been diluted by more considerable influx of fresh water nor had an excessive salinity.

It might be argued that the paucity of fossils in flysch deposits is due not to a primary poverty of organic life but to sedimentary or diagenetic processes which tended to eliminate organic structures by solution. According to Wassoewich (1951, p. 155) on the sea-floor calcareous tests were dissolved during the sedimentation. This would occur if the sea-water above the sea-floor was undersaturated with calcium carbonate. In this case calcareous shells might have been dissolved, or if the bottom waters were saturated with calcium carbonate, siliceous tests could be eliminated. It should, however, be noted that in many flysch deposits with a high calcium carbonate content, then presumably deposited on the bottom above which the water could easily be saturated with calcium carbonate, calcareous fossils are also absent or very rare. On the other hand there are numerous cases of argillaceous deposits containing some well preserved delicate tests of planktonic foraminifera, while thick-shelled fossils are absent. Also, on the whole, one does not observe any marked corrosion of tests. These facts seem to point out that depositional or post-depositional solution was of restricted importance and, conversely, the poor record of life in flysch deposits might be primarily a reflection of unfavourable life conditions in flysch basins.

The poverty of fossil record in flysch deposits has always been noted and every hypothesis aiming at explaining the origin of the flysch took this fact into account. It has been believed that deltaic or lagoonal conditions, dilution by plentiful inflow of fresh water, muddiness of near-shore waters, poor light in mangrove swampy forests, exposition to sun rays on tidal flats etc., were the causes of poor development and special type of organic life under the flysch regime (Zuber 1901, Abel 1926).

Now, as the sedimentary conditions, under which flysch deposits have been laid down, are better understood, an attempt might be made of examining how the sedimentary regime could influence the life conditions in flysch basins.

REDEPOSITED MACROFOSSILS

Large fossils are very infrequent in flysch deposits although there are some notable exceptions to this rule. Most of the macrofossils occur in coarse-grained beds, while fine-grained layers contain larger fossils only exceptionally. There are many indications that the organic remnants in coarse-grained beds are as a rule redeposited, and in some cases even reworked. Redeposition of flysch macrofossils was described in many instances, and sometimes it was believed that the organic shells or remains were transported from more open parts of the basin into the littoral or eulittoral zone. Götzinger and Becker (1932) thought that the nummulites of the Eocene in the Wienerwald flysch (Austria) had been transported by waves from the shallow-water zone and deposited on tidal flats. The present writer (1937) regarded an occurrence with a Lower Cretaceous ammonitic fauna as an accumulation of shells by waves or currents. It has been noted by several workers (Książkiewicz 1947, p. 152, Kuenen-Carozzi 1953, p. 367, Tercier 1947, p. 178) that many macrofossils, mainly large foraminifera, are sorted in the same way as the components of the bed in which they occur, larger tests or shells occurring together with larger grains, and smaller ones with finer grades. Redeposition of larger fossils has also been reported from the Caucasus by Wassoewich (1948, 1951). In the light of the turbidity current theory redeposition was caused by turbidity currents which either swept organisms inhabiting the slopes of submarine accumulations of the coastal zone, or the organic remains already buried were exhumed and carried away by the current. In either cases the organic remains have been laid down in deeper parts of the basin. In some instances fossils occurring in the pebble-clay type of deposits might have been redeposited by submarine mudflows. In the Carpathian flysch many occurrences of ammonites, most of the occurrences of belemnites, gastropods, pelecypods, bryozoans, sponges, corals, probably all occurrences of *Nummulites* and related large foraminifera are connected with coarse-grained or conglomeratic layers, or pebble-clays. In many instances by mapping current directions it might be proved that the fossils were transported away from the presumed shore, and not in the direction of the coast. Redeposition was probably the main, if not the only reason, that the assemblages of *Nummulites* occurring in flysch deposits as a rule contain much more abundant megaspheric than microspheric forms. More spherical tests of the former must have easier and farther been transported by turbidity currents than the flat tests of the latter. If flysch deposits with *Nummulites* and other large foraminifera were a shallow-water deposit, the reverse should be expected: sorting by waves would enrich the deposit in flat tests. This actually may be observed in truly shallow-water nummulitic limestones, in which microspheric forms are much more abundant.

The redeposited assemblages consist largely of shallow-water organisms, and accordingly, an epineritic, and in some instances also infraneritic provenance can be ascribed to them. This leads to the inference that in coastal belts of flysch basins there existed not unfavourable conditions for organic life, at least at some places, although the scarcity of redeposited macrofossils seems to indicate that these belts were not thickly populated.

The existence of coastal belts with fairly abundant organic life, probably only in some places and at certain times, might be traced not only by the presence of redeposited shallow-water organisms in flysch beds, but also by fairly numerous pebbles and blocks of such rocks as *Lithothamnium* limestones, reef limestones, nummulitic rocks etc., which are of the same age or slightly older that the flysch sediments in which they are imbedded. These occurrences indicate that in flysch basins there existed — apart from normal flysch sediments — also organogenic deposits, which presumably formed narrow and limited fringes along the shores of the basins. Probably these deposits could only accumulate where accumulation of terrigenic material was not too obstructive for the development of organic life. These deposits must have been very limited in extent and thickness. Since they could easily be removed by submarine denudation connected with slumping, or by subaerial erosion in the case of temporary emersion, there is no great chance of their preservation. Actually, they are unknown in the Carpathians, except redeposited or reworked pebbles. An additional reason for the absence of these deposits in the Carpathians, and probably also in the Alps, is that the flysch deposits in these ranges are stripped off from their base, and the actual shallow-water deposits, bordering the flysch basins, if preserved, might be hidden below thrust masses. But in the Balkanian range that is not so strongly folded, and where the flysch is autochthonous, there exist more favourable conditions for preservation of such deposits. In the basin of Haskovo, at the foot of the Rhodope Mts., probably near the southern coast of the Balkanian flysch sea, there exist shallow-water limestones with *Lithothamnium,* molluscs, echinoderms etc. (S. Bonchev, 1896) in the immediate contact with the flysch, while in the

Balkan range the deposits of the same age are developed as a flysch. The Haskovo deposits might be regarded as an example of true neritic sediments in flysch basins. Actually the remnants of presumably shallow-water deposits in the form of reworked or redeposited fragments occurring in the Carpathian flysch greatly resemble the limestones of Haskovo.

NEKTONIC AND PLANKTONIC LIFE

The macrofossils occurring in marls and shales of the flysch formation are certainly not redeposited unlike those that are contained in graded sandstones, conglomerates and mudflow deposits. With few exceptions the macrofossils occurring in fine-grained sediments belong to nektonic or planktonic animals, in the Carpathian flysch represented by some ammonites, belemnites, fish, and in a few instances probably by thin-shelled Inoceramii (thick-shelled Inocerami occur invariably in coarse sediments and are clearly redeposited). All these fossils can be regarded as autochthonous, i. e. those which sank to the sea-bottom below the water layer in which they lived. On the whole macrofossils of this type are very rare in flysch deposits. It is significant that many ammonites occurring in shales or marls often belong to the types regarded as adopted to a planktonic mode of life *(Baculites, Scaphites)*. It also may be noted that the representatives of the animal life within the basin, in contrast to normally grown up forms from the shallow zones in redeposited faunas, are as a rule small in dimensions. This pertains for instance to *Scaphites* of the Carpathian flysch zone, not only less frequent but also smaller than the specimens of this form in the neighbouring epicontinental sea. Also fish-teeth, not infrequently found in sieved samples, are invariably very small, although the same or closely related species are represented by normally grown up teeth, e. g. in the Upper Cretaceous vicinal non-flysch sediments. In several cases *Globigerinidae* and *Globotruncanae* are smaller in typical flysch deposits than in associated beds devoid of flysch features or in beds occurring outside the flysch zone. For instance, *Globotruncana* ex gr. *lapparenti* occurring in the non-flysch Turonian-Lower Senonian marls is markedly larger than the specimens from this group occurring in the surmounting flysch. Also *Globotruncana arca* occurring in the flysch Istebna beds of Upper Senonian age is smaller than in the coeval grey marls. The specimens in both cases are actually dwarfed as they are smaller with the same number of chambers (cf. Tasch 1953).

It may be concluded that generally life conditions must have been unsuitable in the internal portions of the basins for planktonic and nektonic life; the animals were not numerous and generally small. Occasionally some normally grown up planktonic foraminifera are found in flysch sediments. It is possible however, that they had attained their normal size in other basins and were brought into a flysch basin by surface currents from other areas. They belong then to the „expatriated" organisms according to the term used by Ekman (1953, p. 317).

There were periods, on the whole of short duration, in the history of the Carpathian flysch basin that microplankton, represented by *Foraminifera* or *Radiolaria*, or both, occasionally also by *Diatomaceae*, appeared in some strength. The same applies to fish fauna. In the first line this presumably was due to improved connections with open seas when the entrances reopened or became larger and surface currents from vicinal seas could easier penetrate into the basin. It follows from the distribution of planktonic organisms in Carpathian sediments that on the whole land-barrier approaches were prohibitive for planktonic organisms probably mainly for two reasons: dilution of sea water by influx of fresh water from the barriers, and pollution by clay particles excessively washed out into the sea by normal currents and waves from the overloaded coastal embankments. Besides, planktonic sediment, if produced in these zones, must have been greatly diluted within the large amount of terrigenous material deposited in the proximity of the shores. For these reasons truly planktonic sediments (radiolarites, Globotruncana marls, Globigerina marls) have at times been deposited only in the axial portion of the basin. On the other hand there exist sedimentary zones with abundant planktonic Foraminifera apparently situated in the proximity of the presumed coasts, however only in the case when those did not furnish much detrital material, being probably tectonically inactive, and a small influx, if any, of terrigenic material did not dilute the foraminiferal deposit; in this case the great accumulation of planktonic Foraminifera might have been due to a drift by surface currents into embayments of the coastal zone.

It seems that surface currents, so influential on the development and dispersal of organisms, were particularly of great importance in restricted and partly land-locked basins. Probably, if they penetrated into the basin, they could change the temperature of the basin, bring more nutrients, and in many other ways change life conditions. They also could have some influence on the distribution and dispersal of organisms. In open seas they rather tend to spread organisms wide and large, but in narrow, channel--like seas their action might have been in some cases restrictive. Two instances of their presumed action of this type in the Carpathian flysch basin can be given. Some Turonian and Lower Senonian non-flysch deposits within the flysch sequence contain abundantly Globotruncana of the *lapparenti* group, while *Globotr. marginata* occurs but in few instances; in the foreland deposits of the same age *Globotr. marginata* occurs together with *lapparenti* (Alexandrowicz, 1956). This might be explained in the following way: although during that time there existed some direct connections between the Carpathian basin and the foreland sea through which benthonic forms could penetrate into the Carpathian basin from the foreland sea (e. g. Inocerami, some Foraminifera), and the exchange of bottom dwellers was not impeded, surface currents were so directed that they carried *Globotr. lapparenti* into the foreland sea but prevented penetration of *Globotr. marginata* into the Carpathian basin.

Also the distribution of Nummulites and other related large Foraminifera is suggestive of the influence of surface currents. Nummulites are more numerous in the southern portion of the basin, populating probably in fair abundance shallow bottoms in this part, and occur only rarely near the northern shore. There is no reason to assume that the separating deeper parts of the troughs could not be crossed by free swimming young forms. If a surface current, however, was flowing along the axis of the basin, free swimming youngsters must have been drifted away by the current and could not reach the northern coastal zone. Another cause may, however, also be kept in mind in this case. Along the northern coastal belt, situated in the lee side of western winds, an upwelling of deeper water might be expected. This upwelling could bring up to the surface cooler waters, as it does to-day along the California coast (cf. Ladd, 1957, p. 37), and thus create unfavourable conditions for stenothermic forms to which Nummulites in all probability belonged.

Unfavourable bottom conditions could be another cause of the poor development of nummulitic fauna near the northern coast.

BENTHONIC FORAMINIFERA

While the Carpathian flysch shales and marls contain macrofossils only exceptionally, foraminiferal faunas occur in them fairly frequently, although varying in number of species and individuals from one stratigraphic member to another. Flysch foraminiferal assemblages have been known for long time since the works of Grzybowski and Rzehak. A characteristic feature is that they are in their typical form exclusively or nearly exclusively composed of arenaceous forms. Assemblages of arenaceous foraminifera are known to occur in flysches of Cretaceous and Tertiary age. They are also reported from the Carboniferous flysch of the Ouachita (USA) by Cline (1960). These foraminiferal assemblages consist of a small number of species and individuals. They occur in shales, while underlying turbidites are devoid of small foraminifera or contain quite different assemblages of small foraminifera, as it has been found in the Carpathians (Książkiewicz 1952), in the Caucasus (Grossheim and Borisienko 1953) etc. There is every reason to believe that the foraminifera occurring in turbidites are redeposited. Very often only the topmost part of the covering clays contains foraminifera, while silts or clays covering directly the turbidite contain practically no microfauna.

A typical flysch assemblage is poor, monotonous, consisting of arenaceous forms, while the admixture of calcareous, both planktonic and benthonic foraminifera is generally negligible or none. This fauna is also characterized by small dimensions of tests, which often are also deformed, twisted and asymmetrical. There are, however, in the flysch sequence also beds with less marked flysch features, as thick series of shales or even marls with few if any turbidite intercalations. Usually in these beds richer and more diversified assemblages appear.

In the Carpathian flysch the following interrelations between the microfauna and the sediment can be observed.

1. Lithofacies composed of alternating sandstones and shales, i. e. a typical flysch deposit, contains poor arenaceous assemblages, while calcareous benthonic and planktonic forms are very scarce or absent.
2. Argillaceous lithofacies contains richer assemblages. If the colour of sediments is red, the microfauna is even fairly abundant and better grown up; conversely, in dark and particularly in black shales it is very poor, and in extreme cases absent, whilst in greenish or greyish beds its abundance is intermediate.
3. Marly non-turbidite lithofacies contains a fairly abundant microfauna consisting of both arenaceous and calcareous forms, often but not always with a strong admixture of calcareous plankton.
4. Calcareous non-turbidite lithofacies, only exceptionally occurring in flysch deposits (calcareous turbidites are much more frequent) contains only calcareous, both benthonic and planktonic foraminifers.

It may be seen that the more the flysch character of deposits is pronounced, the poorer is the microfauna. It appears then that extreme flysch conditions have a detrimental influence on the development of microfauna.

It also may be noted that the more limy is the sediment, the more abundant are calcareous forms. This is in agreement with the idea of Le Calvez (1956, p. 595) that the water saturation with calcium carbonate is influential on the development of calcareous foraminifera. If in the sediment the amount of calcium carbonate is small or nil, which indicates that presumably the saturation in $CaCO_3$ in the waters above the sediment was negligible, calcareous forms are absent or very few. At the same time arenaceous forms are more profilic, possibly for two reasons: the lack of competitive calcareous forms, and plentiful suitable building material for their tests brought in by turbidity currents which sorted the transported material and accumulated the finest grades in the uppermost layer of a turbidite deposit. Although arenaceous species seem to be not too particular about the constructional material, as it is suggested by the experiments of Slama (1954), on the floor built of a turbidite deposit they certainly had a good choice of particles of various physical and chemical nature to be used in construction of their tests.

Although it is possible that only these two above discussed factors can account for the presence of exclusively arenaceous assemblages, it should be mentioned that other factors have been taken into account in order to explain the existence of such associations. According to older views, represented by Galloway and Noth, in modern times supported by Montanaro-Gallitelli (1943) and Emiliani (1954), arenaceous assemblages are indicative of cool, deep waters (cf. also Glaessner 1948). This view is in agreement with the modern views on the sedimentation of flysch deposits, although it should be kept in mind that purely arenaceous assemblages occur in present oceans only at depths where calcareous forms are already dissolved. There is, however, no reason to suppose that flysch basins attained abyssal depths, say about — 4000 m or more; presumably they were much shallower. Another explanation, put forward by Stainforth (1952) is that neither depth nor temperature, but water turbidity is a major factor controlling the existence of arenaceous assemblages. According to him turbidity impedes photosynthesis which is to be vital for the existence of lime-secreting organisms. However, in all probability light is only indirectly needed for secretion of calcareous tests, as it facilitates the growth of plants which by removing CO_2 cause that the water approaches saturation limit of calcium carbonate. It is possible that in shallow water turbidity may eliminate calcareous forms by hindering photosynthesis and thus keeping large content of CO_2 in water, but this factor can not be operative in deeper waters. Probably the sea-floor in lithofacies (1) and (2) was lying too deep for the waters above it could be turbid; clay particles in the water-layer near the surface could be kept in suspension by waves and currents for long time, but when they fell low into quiet water layers they must have been deposited quickly on the sea-floor.

While low saturation in $CaCO_3$ and abundance of constructional material were the two factors promoting the development of arenaceous forms, there also were active some limiting factors that caused that the foraminiferal flysch assemblages were on the whole poor and the individuals dwarfed. According to Said (1951) a low oxygen content may cause both the impoverishment and dwarfing of a protozoan fauna. Actually in the deposits that presumably have been deposited in a better oxygenated environment (red shales and marls) the microfauna is richer and better developed, which no doubt suggests the influence of oxygen content. Often side by side there occur deposits of the lithofacies (1), (2) and (3) passing laterally one into another, and there is no reason to believe that they were deposited in different troughs or on a sea-floor of appreciably different depth. This leads to a suggestion that there might have been operative some factors of more local character causing better or poorer development of foraminifera in different facial environments. As the poorest assemblages occur in beds of extreme flysch character (lithofacies 1) with numerous turbidite layers, it might be supposed that the deposition of turbidites could be influential. Very often the uppermost layer of a turbidite is enriched in plant detritus. Vegetable matter, at first carried down by rivers and deposited in the coastal zone, was subsequently involved in the transport by turbidity currents and redeposited on the deeper parts of the sea-floor. Sorting during the transport by turbidity currents was the cause that plant debris and generally light organic matter have been concentrated in the topmost part of the turbidite. The organic matter when undergoing decomposition, produced a certain amount of CO_2. In the decomposition both the oxygen contained in deeper water and the oxygen brought down by turbidity currents (cf. Dżułynski and Ślączka 1958) were used. The function of CO_2 was twofold: it decreased pH and lowered the saturation of bottom waters in calcium carbonate, creating in this way an environment unsuitable for lime secreting bottom dwellers; in the second place the formation of CO_2 depleted the amount of free oxygen available for benthonic life[1].

We come thus to the conclusion that the amount of oxygen in flysch basins was not necessarily very low, but where turbidites were deposited at comparatively short intervals, their deposition could indirectly create conditions lowering the amount of oxygen.

It should also be envisaged that turbidity currents, causing periodical destruction of all or nearly all bottom dwellers, could act as an important limiting agent for the development of the bottom fauna. The destructive action of turbidity currents has already been discussed (Erickson, Ewing, Heezen 1952, Natland 1957). According to Natland young forms of foraminifera are carried upward by the current and subsequently settled on the new surface, thus immediately recolonizing the bottom. Some observations from the Carpathian flysch seem to point out that the destruction must have been total in several instances, as the argillaceous layers above the turbidites are often devoid of foraminifers, and also, that in some cases the populations vary from one to another layer in the sequence, e. g. in the Hieroglyphic beds one layer is dominated by *Haplophragmoides walteri*, while the next layer by *Cystammina subgaleata*. This tends to point out that a new population immigrated into the area, apparently from a region situated farther away from the region invaded by the turbidity current. This may be the reason why on the

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[1] The presence of slightly reducing conditions between the deposition of turbidite layers is also indicated by the fact that red shales only exceptionally occur between the turbidites although a turbidite series may pass laterally into beds containing abundant red intercalations.

whole benthonic foraminifers are better developed beyond the reach of turbidity currents (i. e. in the shaly facies).

Still another circumstance unfavourable for the development of the benthonic faunas in a flysch basin might be kept in mind. The bottom constituted by the pasty mass laid down by a turbidity current probably was not a suitable ground for bottom foraminifera in contrast to the floor formed by slow steady fall of minute particles. This would be compared with the explanation offered by Crickmay, Ladd und Hofmeister (1941) why on certain bottoms near reefs bottom foraminifers are absent (cf. also Cloud and Barnes 1957).

As we said, in sediments deposited under better oxygen conditions, the assemblages are more diversified, and individuals better grown up, but still these assemblages can not be considered as normal in respect to their composition and growth. There must have been also some other factors hampering the development of microfauna on the bottom of flysch basins. The following factors should be taken into consideration apart from the oxygen content: temperature and food. According to Pokorny (1951) the water of the Carpathian flysch basin was at depth warmer than the water of the present ocean, and this factor suppressed the growth of arenaceous foraminifera, usually larger in colder environments. However, also calcareous species in flysch deposits are sometimes of smaller dimensions, and if a pelagic foraminiferal deposit with profilic planktonic species is superseded in the sequence by a flysch deposit, the planktonic forms in the flysch are smaller than in the underlying foraminiferal marls. It may here also be recollected that the fish fauna is also dwarfed in most units of the Carpathian flysch succession. Therefore, the other factor, food, seems to be of greater influence. The influence of insufficient food supply on the growth of foraminifera was stressed by Myers (1943), Lalicker (1948) and more recently by Boltovsky (1954). According to the last named writer the foraminiferal assemblages of an undernourished fauna are poorer in number of species and individuals, and inclined to asymmetry. Therefore one can say that not so much the low oxygen content and increased temperature, as the limited food supply created unfavourable conditions for benthonic life.

Summarizing the above discussion it may be said that the character of typical flysch assemblages of benthonic foraminifera was probably controlled by a number of factors, both negative and positive: low saturation of deeper waters in calcium carbonate prohibitive for carbonate secreting organisms, plentiful constructional material for arenaceous forms, depletion of the already moderate oxygen content by the decomposition of organic matter brought into deeper parts of flysch basins by turbidity currents, periodical destruction of benthonic populations by turbidity currents and insufficient amount of food in the basin.

SEDIMENT-EATING BOTTOM DWELLERS

Apart from the redeposited macrofauna and the benthonic arenaceous microfauna the third faunistic element is very characteristic for flysch deposits, although preserved only in the form of numerous tracks and trails of burrowing or bottom creeping, mud- or sand-eating animals. A part of them may be related to gastropods, crustaceans etc., the majority, however, was in all probability represented by worms, mainly annelids. It is known that worms may thrive in poorly oxygenated waters and populate fairly deep bottoms (down to 400 m according to Richter 1928, p. 229). This feature of the flysch life has been known for long time and usually is referred to a littoral environment, as in the intertidal zone similar tracks are observable. The main condition for developing of this type of life is the presence of plentiful organic matter in sediments, usually abundant in littoral and sublittoral zones. Normally little of this matter reaches a deeper floor, but under flysch regime turbidity currents transferred large amounts of organic (mainly plant-) detritus and colloidal organic matter into deeper parts of the basins. Sorting during the transport tended to accumulate this light matter near the top of each turbidite layer. Several forms evidently specialized in grazing in the uppermost layers of turbidites (*Zoophycos, Spirophyton, Palaeobullia*), several were burrowing across sandy layers, others at the interface between clay and covering sand as supposed by Götzinger-Becker (1932) and Seilacher (1954), but there is plentiful evidence that many crept on the uncovered sea-floor, as furrows ploughed by their creeping on soft mud are often filled by coarser grain than elsewhere, acting clearly as traps for transported sand along the bottom. Tubic forms of burrowing worms are more plentiful in beds with coarse-grained layers, while in shales and marls fucoidal types develop. The most beautiful forms appear in the complexes where sandy layers are thin and alternating with light-coloured shales. In the Carpathian flysch in such beds *Palaeodictyon* (Lower Cretaceous — Oligocene), *Cosmoraphe* (Albian-Eocene), *Subphyllochorda* and *Palaeobullia* (Albian-Eocene), *Beloraphe* (Cretaceous-Eocene) etc. occur plentifully. They are, however, in spite of the same facies, much more numerous in the southern trough of the basin (cf. Książkiewicz 1958), that was narrower than the main trough. Possibly, the proximity of the shores was the influential factor, for the basin could be better supplied with organic matter from the near-by shallow-water zones. Scarcity or absence of these forms in units with more thick-bedded layers seems to point out that many populations were exterminated by thicker turbidity deposits, although no doubt, some could easily live inside thick layers and could avoid destruction. Some Eocene thick-bedded sandstones of the Carpathians, particularly the Tarcau sandstone of the Roumanian Carpathians, occurring in beds 2—3 m thick may be still full of burrows (cf. also macigno, Ten Haaf 1959).

From the abundance of various types and their adaptation to different sediments it may be inferred that most of the sediment-eating animals relied in their sustenance on food brought in from the near-shore zones by turbidity currents together with mineral sediment, and only a small fraction lived on organic matter fallen on the sea-floor from the upper water layers.

THE CAUSE OF UNFAVOURABLE LIFE CONDITIONS

From the data presented above it may be inferred that flysch basins offered generally poor conditions for life. These conditions were not uniform, neither in space nor in time. In neritic zones organic life might have been flourishing, although on the whole impeded by great influx of terrigenic materials. On the slopes of coastal detrital aprons spongians and other benthonic organisms could exist in certain periods; during the periods when flysch regime was relaxed and smaller inflow of clastics fed the basin, an improvement of life conditions may be noted. In this way the life conditions varied from time to time, and from place to place, but at the same time they were all the time different from the conditions in the vicinal marine basins.

These abnormal life conditions must have in some way been connected with the tectonic and paleogeographic conditions, for these controlled the shape of the basins, their sedimentation and their relation to neighbouring seas.

As the redeposited organisms have been brought into the sediment from coastal regions, the inference should be made that in some places, probably in those not too exposed to the great inflow of terrigenous material, presumably in small quiet bays away from stream-mouths, an organic life could flourish. Such places could not be very abundant as the occurrences of redeposited organisms are not very numerous in flysch deposits. Poor benthonic faunas indicate that deeper sea-floors received but very little dead organic matter from nektonic and planktonic zones. The absence or extreme scarcity of remains of nektonic and planktonic organisms in flysch deposits points out that, except short periods, these types of life were practically absent or extremely feebly developed in flysch basins. The sea-floor received periodically, but usually at long intervals, comminuted organic, mainly vegetable matter, brought by turbidity currents, but this could only be of use for sediment-eating animals, and of little avail for other organisms. It appears that the open and deeper parts of flysch basins have been sterile and could sustain no life of any significance. To all appearance, the lack of food was the main factor influencing the poverty of life in flysch basins.

Sterility of a sea basin may have a number of causes. The chief cause is the lack of nutrients inhibiting the development of vegetable plankton, on which in turn animal plankton feeds. The absence or poor development of planktonic life hinders the development of nektonic life, and, to a great extent, impedes also the production of life on the sea-floor.

A marine basin receives, as it is known, its nutrient content from three sources: from the land by rivers, from neighbouring marine basins by water exchange and diffusion, and from the regeneration of dead organic matter decomposing on the sea-floor and producing nutrient salts, which through upwelling fertilize the upper water layers. The proportion of these sources varies according to the relation of the basin to the vicinal land areas, depends also on the facility of water exchange with neighbouring basin and s. o. The basin neighbouring with a large and well drained continental area receives a good supply of nitrates and phosphates necessary for the sustenance of autotrophic life. Poor supply from the land area may be made up by diffusion or exchange of waters with neighbouring basins, provided the connections between the basins are sufficiently free. Regeneration operates in fertilizing if there is good mixing of waters in the basin, and, primarily, if there is sufficient amount of dead organic matter on the sea-floor.

From the available paleogeographic evidence we know that the Carpathian flysch geosyncline had never been bordered by lands of any large extent. The same might be said of other contemporary flysch basins in Europe (for Caucasus, cf. paleogeographic maps in Strachow 1948). It also was more or less strictly separated from the seas existing in its vicinity by narrow and steadily uplifting barriers, These could not supply much dissolved mineral salts to the basin, as there was no room for large rivers, and the streams flowing down the barriers although probably numerous, were too short and also probably too swift to dissolve on their way to the sea any considerable amount of mineral and organic compounds. Thus this source of nutrients was deficient, and what was furnished to the basin in this way, it was immediately utilized by autotrophic organisms as soon as it became available in the neritic zone, and little could reach the more distant parts of the basin. Even in the period of fairly abundant fish faunas in the Carpathian sea (Eocene-Oligocene boundary) according to Pauca (1934) rich life existed only near the shore. At the same time streams flowing down the slopes of cordilleras and other tectonic lands carried a considerable amount of comminuted but generally undecomposed plant detritus. This mixed with abundant detrital material, was of use only when redeposited and concentrated by sorting in turbidity currents.

The steady uplift of marginal zones inhibited free connections with the external seas, even if they existed in close vicinity. There are several indications that the entrances existed, but they were narrow, shallow and intermittent. This partial land-locking tended at times to create euxinic conditions, but only once in its history the Carpathian geosyncline reached the stage that truly can be determined as euxinic. The same might be referred to the Caucasus geosyncline. The presence of some connections with external seas is indicated by faunal mixing and migration, but these connections were too imperfect for any considerable influx of water rich in phosphorus compounds and nitrates, especially as the entrances were probably shallow, and only mixing with the uppermost water layers could have place; these layers are, as a rule, depleted in nutrients. No important amount of nutrients could then be introduced by water exchange and diffusion.

The third source of nutrients, i. e. by regeneration, plays in present seas important role in fertilizing sea water. It is of course only of importance in these cases, when the floor receives sufficient amount of dead organic matter. This condition probably in flysch basins was not fulfilled for generally the amount of organic life was small. Quick deposition of fine-grained sediments, and, to a certain extent, also the periodical covering of the sea-floor by deposits laid down by turbidity currents, were also the factors, if not impeding, at any rate not favourable for decomposition of organic matter and the production of nutrient salts. Turbidity currents, on the whole, occurred in the Carpathian basin at long intervals, amounting probably to a few dozens of years between two flows, and therefore could not impede the decomposition by burial with sediment, as the decomposition on the sea-floor takes probably little time, but if they were too frequent, they could to a certain extent play an additional role. In the Carpathian flysch there exist a few sequences deposited apparently in a very short time (e. g. Magura sandstone 2000 m thick laid down only in a fraction of Eocene times, similarly the Upper Eocene Podhale flysch, the Pieniny Lower Senonian flysch, partly the Krosno beds) and just these beds are devoid even of microfauna, being the poorest in organic content of all flysch members.

There existed periods, on the whole apparently very brief, in the history of the Carpathian geosyncline in which the factors causing its sterility did not operate at all or only partly: connections with neighbouring seas improved, or vicinal lands became larger, land-locking was absent or relaxed. In such periods, possibly with a certain lag, life conditions improved, and if the period of amelioration lasted long time enough, more plentiful life began to flourish in the basin. However, only one instance of flysch deposits rich in fauna is known to the present writer. In Bulgaria E. Bonchev (1955) described a Tithonian flysch with an abundant fauna of ammonites, consisting mainly of species regarded as characteristic for open and deep basins, and therefore Bonchev defined these deposits as a „deep-water flysch". I visited typical outcrops of these beds in the company of the Bulgarian writer, and must say that this Tithonian flysch exhibits all features of a typical flysch deposit. It seems that this case may be referred to the paleogeographic picture: the Tithonian flysch of the Balkans passes northward into calcareous platform facies; this means that the flysch sea of the Balkans was freely connected with the epicontinental sea of northern Bulgaria (cf. Bonchev 1955, p. 156, Fig. 69). It seems that this free and direct connection made possible water exchange and better fertilizing of the flysch basin. Similar conditions lasted in the Balkan until the end of the Hauterivian.

FINAL REMARKS

The flysch biotope, so often developed in the history of geosynclines, has specific features differing markedly from other marine biotopes. The flysch biotopes have been controlled by tectonic conditions. Tectonic unrest of the geosynclinal floor, rising of geosynclinal margins and cordilleras, accumulation of thick detrital deposits on the slopes of these elements and the distribution of sediment by turbidity currents, partial locking of the troughs not by large land masses but by narrow barriers, caused special conditions for organic life. No comparable conditions are known from other environments, although some features may well be found in other marine basins owing to the convergence of some influential factors.

Long, interconnected flysch basins, stretching along the trend of geosynclines, often persistently lasting during the history of geosynclines, with unfavourable life conditions, were not suitable channels for faunal migrations, and in this respect they could act as paleobiogeographic barriers.

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