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MARIAN KSIĄŻKIEWICZ

Bathymetry of the Carpathian Flysch Basin

ABSTRACT: The environment in which the Carpathian flysch was deposited is here discussed. The views ascribing its origin to paralic, littoral or neritic environments are rejected on the basis of the sedimentary features and faunal evidence. Arguments are presented in favor of deposition from decelerating currents. This type of deposition is indicated by the sorting of mineral grains and fossils, an approximately positive correlation between the thickness and coarseness of beds and dimensions of erosional structures (flutes) on their soles, and a succession of structures in flysch sequences. Proximal, intermediate and distal deposition regions are characterized in each member of the succession. From the sedimentary features the conclusion is drawn that the Carpathian flysch was deposited at depths greater than the neritic zone. It is shown that the microfauna contains 50 species of Foraminifera which in present-day seas live in waters with normal salinity. Most of these species display a marked preference for bathyal and abyssal depths. Several Foraminifera, closely related to modern deep-water species, also occur in the Carpathian flysch. The presence of calcareous Foraminifera in nearly all stratigraphic members excludes a deposition below the calcium carbonate compensation depth. Consequently, bathyal (mostly upper bathyal) depths are assigned to the Carpathian flysch basin, and changes in depths during the long deposition (uppermost Jurassic through Lower Miocene) are estimated tentatively. It has been found that the number of branched and patterned trace fossils is larger in the beds, to which greater depths are assigned on the basis of sedimentological and microfaunal evidence.

INTRODUCTION

The Carpathian flysch has for a long time been believed to be deposited in a shallow-water basin. This view was based mainly on the presence of sandstones and conglomerates. Sujkowski (1937), who started modern sedimentological investigations of the flysch, considered the flysch sandstones as deposited at depths greater than those in the North Sea. The origin of graded beds, frequently very coarse and thick, commonly occurring in the Carpathian flysch, was, however, considered difficult to explain under shallow-water conditions (Książkiewicz 1948, p. 139). Therefore, when Kuenen & Migliorini (1950) presented the turbidity current hypothesis, several Carpathian geologists accepted this idea (Vašiček 1952; Książkiewicz 1954). Under its influence it has been assumed that the Carpathian basin must have been fairly deep. In the present writer's opinion (Książkiewicz 1958), the depth of the basin varied with time and place, but the flysch was deposited mostly in the bathyal zone. The beds containing arenaceous Foraminifera with the Buliminidae and Lagenidae were assigned to the upper bathyal zone, while those with numerous Radiolaria were supposed to be deposited in the lower bathyal zone [1]. It was also presumed that some parts of the flysch could have been deposited in the neritic zone. Taking into account the reconstructed width of the basin (about 300 km), moderate development of slumping and sliding and a fairly flat floor of the basin, it has been estimated that the average depth of the Carpathian flysch basin did not exceed much 1000 m (Książkiewicz 1961). A similar reasoning is followed by Wieseneder (1967), who assigns to the western extension of the Carpathian basin in the Eastern Alps a deposition depth of a few hundred meters. Considering the distribution of the arenaceous Foraminifera in present-day seas, Koszarski & Żytko (1966) believed that during the Early Cretaceous the basin was relatively shallow, while in the Late Cretaceous and Early Tertiary its bottom attained abyssal depths and in the Oligocene gradually became shallower. More recently, in the Rumanian part of the Carpathians, Dimian (1973) assumed a depth greater than 1000 m in the Cretaceous and a gradual shallowing of the basin in the Paleogene.

The hypothesis of a deep-water origin of the Carpathian flysch was questioned by several authors. According to Hanzlikova & Roth (1963), the Cretaceous flysch in the area of Czechoslovakia was deposited in the neritic zone. Watycha (1963) considers the flysch as a tidal-flat or a very shallow-water marine deposit. According to Nalivkin (1963, 1967), the Oligocene Krosno Beds represent a fluvial sediment, while the Menilite Beds and the Podhale Flysch are lagoonal deposits. He compared the conditions of some flysch deposits with those of the Coal Measures. A similar view was expressed by Draghinda (1963). According to Bieda (1969), the members of the Carpathian flysch which contain exclusively agglutinated Foraminifera were deposited in lacustrine environments such as salt swamps, enclosed bays and river mouths. Only the members with mixed assemblages of agglutinated and calcareous Foraminifera were regarded by Bieda as deposited in the littoral or neritic zone. Bieda applied his view to the Tertiary part of the Carpathian flysch, but an identical reasoning may be applied to the Cretaceous flysch.

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[1] The following division is employed in this paper: upper bathyal zone (200 to 600 m), middle bathyal zone (600 to 2500 m), lower bathyal zone (2500 to 3500 m) of water depth.

Since elsewhere, several authors have presented views opposing the hypothesis of the deep-water origin of the flysch and turbidity currents, it seems advisable to reexamine the problem on the basis of diverse facts and observations which have been collected since the writer's previous publications (Książkiewicz 1958, 1961).

GENERAL CHARACTER OF SEDIMENTS

The main part of the sediments occurring in the outer Carpathians is represented by the flysch, which consists of alternating more coarse-grained layers (conglomerates, sandstones, siltstones and, locally, limestones and marls) here called "element *I*" and fine-grained ones (clay, argillite) called "element *II*". Elements *I* and *II* form a "sequence". It is believed that element *I* was deposited by a current, while element *II*, in its lower part, might also have been produced by this same current (Crowell 1955; Radomski 1960) except for its upper part which is a pelagic deposit. There may be instances of the whole element *II* being current-deposited, or on the other hand, it may be entirely pelagic. In addition to the flysch, there occur more or less thick complexes of argillites and marls, often intermingled with the flysch. In all probability, they are mostly of pelagic origin. The third component is formed of clays and silts mixed with sand and gravel. These deposits are believed to be produced by submarine mudflows.

As presented before (Książkiewicz 1954; Dżułyński & Walton 1965), bedding is variable. The internal structure of element *I* displays graded bedding, gradational laminated bedding, parallel lamination and small-scale current lamination. These types seldom occur singly, their combinations being more frequent. The "composite bedding" (Książkiewicz 1954) consisting of graded, horizontally laminated and current-laminated portions is the most common type. Referring to Bouma's (1962) classification, we may say that complete combination *ABCDE* is only rarely represented in the Carpathian flysch; in particular, in the Carpathians *D* is hardly recognizable, as it is in other regions (Walker 1965, 1967). Beds with divisions *ABE, ABCE* and *BCE* seem to be predominant. In category *BCE*, gradational laminated bedding (Książkiewicz 1954, Fig. 3a) is fairly common. It has also been found in the Ordovician flysch of Wales by Kelling & Woodlands (1969), who called it "laminar bedding" (see also Marković 1963, Fig. 5).

The lateral extent of element *I* is on the whole difficult to ascertain. Under the Carpathian conditions, where outcrops are mostly small and widely scattered, one may only very rarely trace a bed over long distances. The present writer has never succeeded in tracing or correlating a bed for more than a few kilometers. In the Eocene, a calcarenite could be identified on the strength of its fossil and mineral composition over a distance of 4 km and a bed-by-bed correlation permitted the identification of some beds over only 3 km. However, the rarity of instances of pinching-out of element *I* suggests a rather considerable extent of these beds. This approach was also adopted by McBride (1969). It should be stressed that wedging-out is more common in some members than in others. It has also been reported by Halicki (1961) that the beds are more extensive along than across the transport direction. At any rate, there are no instances of beds correlated over as great distances as those reported by Grossheim (1963) from the Caucasian and by Hesse (1965) from the Bavarian flysch.

The vertical succession of structures in element *I* is of fundamental significance for the origin of flysch beds. It implies that element *I* must have been deposited by one current which initially had high velocity, at least some part of its load kept in suspension and deposited it gradually with decreasing velocity (Glaessner 1958; Walker 1965; Walton 1967). Element *I* (and in some instances part or the whole of element *II*) is thus a result of a single depositional event. The deposition certainly occurred in stagnant water, without interference of waves or other currents. This leads to the inference that the flysch was deposited below wave base. The most satisfactory explanation of this type of sedimentation is given by the turbidity current hypothesis.

The concept of both the deep-water origin of the flysch and of its deposition by turbidity currents were questioned by several authors. According to Mangin (1962a, 1964b), Draghinda (1963), Arkhipov (1965) and Van der Lingen (1969), flysch sandstones owe their origin to multiple events and a slow, prolonged sedimentation. Mangin (1962a, 1964a) believed the lamination in flysch sandstones was caused by climatic factors. Each lamina he supposed to be formed by a separate flow, reflecting a seasonal change; the flysch lamination was comparable to the lamination of varves, limestones and marls. There is little doubt that lamination may be caused by various factors, and not necessarily by currents only, but the flysch lamination, as shown by its position in the sequence and a common, usually most intimate association with the ripple-current lamination, is clearly connected with the stage of a decelerating current.

According to Bieda (1969, p. 504), Arkhipov's (1965) paper "contains fully documented arguments" disproving the turbidity current hypothesis. Arkhipov states, that the "primitive simplicity" of this theory prevents it from being applied to flysch sedimentation. In particular, he uses the presence of the pensymmetrical and discontinuous graded bedding, described by the present author (Książkiewicz 1954, Figs 2d,e, 5e) as an argument for a lengthy deposition of each flysch sandstone (element *I*). It is possible that under some conditions a bed with pensymmetrical bedding was deposited by two currents: the basal fine-grained part by one current and the rest by another which came soon after the former had deposited its load (Crowell & al. 1966). Usually, however, the basal portion passes gradually into the coarser part (Pl. 1, Fig. 1). The origin of the pensymmetrical bedding may be explained in the following way: The current brings its load from a coastal fringe of detrital sediments, or from a delta. In either case, there should be some spatial segregation in the source material: coarser grains nearer the coast or the river mouth and a finer material — seawards. If a slump is formed and a turbidity current generated, the frontal part of the current carries more finer material than its tail. This probably happens in all turbidity currents, but if the current travels for a long distance, the coarser material comes eventually to the head of the current and drops first. If the load is deposited near the place where the slump was formed, finer grades may be deposited first (Fig. 1).

A more sophisticated interpretation may be put forward following Walker's (1965) explanation of the origin of reversed grading. In the

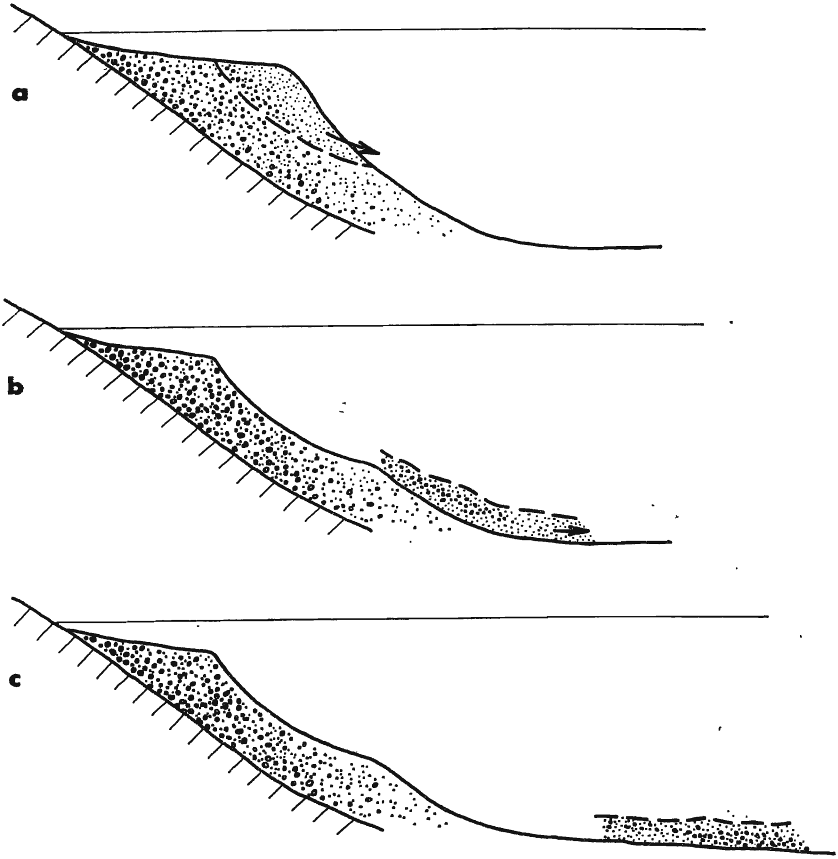


Fig. 1. Origin of pensymmetrical bedding

a — Slump originates from the coastal fringe

b — If deposition takes place in this stage, pensymmetrical bedding is formed

c — If deposition takes place farther away, normal graded bedding is formed turbidity current, larger grains tend to work their way towards the zone of the least shear strain, that is towards the free surface of the flow, while smaller grains tend to drift towards the zone of the greatest strain (bottomwards). The pensymmetrical bedding is likely to represent an incomplete stage of this process which terminates in the formation of reversed grading. In either case, the pensymmetrical bedding may serve as an indicator of proximal deposition.

Discontinuous bedding (Książkiewicz 1954, Fig. 5e; or interrupted bedding in Walton 1956) may at most be due to deposition resulting from two currents. More probably, however, the lower part can be formed by coarser and heavier grains dropping from the current that has still sufficient velocity to carry away grains of intermediate size. With further deceleration finer grains are deposited. The break in bedding is frequently only local and laterally there occurs some intermingling or transition between the two parts of the bed (Fig. 2) or a rapid passage into the laminated portion, as in Walton's (1956, Fig. 1c) delayed bedding. The discontinuity of grain size may also be due to the scarcity of the missing grain size in the source area (Kuenen 1967).

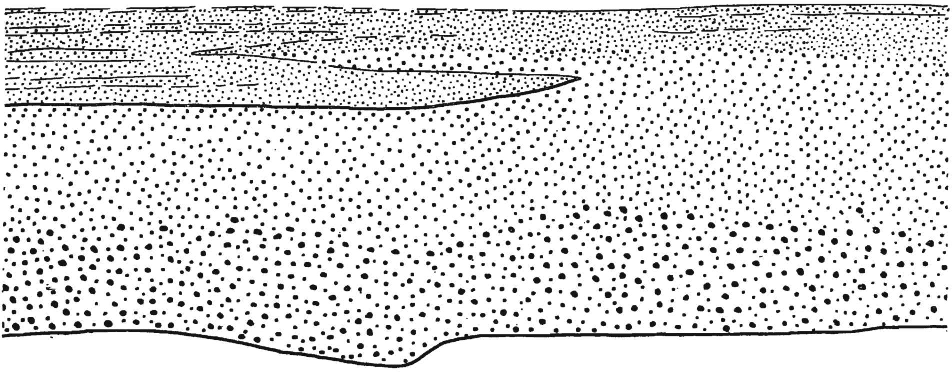


Fig. 2. Discontinuous bedding (left side) passing into a normal sequence of bedding (right side): graded layers pass into fine-grained laminated division
Upper Godula Beds (Lower Senonian), Malinka near Wisła; nat. size

The presence of ungraded beds, alternating with graded elements cannot be considered an argument against the deposition in deeper waters. Such layers may be produced by a grain-flow (Stauffer 1967; Simpson 1970, p. 270) or, more probably, by high density currents which did not travel far and in which brief suspension of the grains kept sorting to a minimum (Allen 1960).

There is a feature which strongly supports the view that element *I* is not a product of multiple events. The present writer noted (Książkiewicz 1954, p. 418) that (with some exceptions) the thicker the sandstone bed, the larger are the flute casts on its sole. In the Carpathians this observation has been confirmed by Simpson (1970, p. 269) who finds in the Eocene flysch "a rough positive correlation" between the thickness of element *I* and dimensions of flute- and groove casts. Simpson's observations pertain to the Hieroglyphic Beds, in which bedding abounding in the horizontal and ripple lamination prevails. Also a positive correlation between a maximum grain-size and the dimensions of flute- and groove casts was found by Simpson. Similar observations come from other flysch areas. In the Apennine flysch Sestini & Curcio (1965) found a fairly positive statistical correlation between the dimensions of flute casts and bed thickness. In the Chilean flysch Scott (1966, p. 80) sees a "general, but far-from-perfect, correlation between the amplitude of flute casts and bed thickness". According to Hubert (1966, p. 689, 691), in the Prealpine flysch "the thicker, coarser-grained sandstones have larger flutes". Similar observations were reported by Tanaka (1970). Pett & Walker (1971) obtained somewhat different results, but at any rate they found that in graded beds flutes were of larger absolute width, although not deeper than in beds starting with divisions *B* or *C*. Simpson (1970) also finds that simple beds display a positive correlation between the number of divisions *A*—*E* and bed thickness.

The obvious implication of these facts is that the erosion of the sea--floor, as marked by flutes, depends on the volume, velocity and load of the entire current, and that the element *I* was deposited by one current only.

CRITICAL REVIEW ON THE DEPOSITIONAL ENVIRONMENTS OF FLYSCH

CONTINENTAL ENVIRONMENT

According to Nalivkin (1967), the Oligocene Krosno Beds represent fluvial sediments deposited by "continental turbidity currents". Apparently he has in mind sediment-laden rivers. Graded bedding, locally observed in continental deposits, may be formed by sheet-floods, heavily laden with a suspended sediment (*cf.* Cummins 1958). According to Kuenen (1968), the main force causing the flow of the river is provided by a surface slope of the water, while density differences in the river may play an additional role. There is no question that the Krosno Beds are a marine formation; this is indicated by marine molluscan and fish faunas, marine, small and large Foraminifera (*Nummulites* and others) and by the absence of any features indicative of subaerial conditions.

The hypothesis of the deposition of the Carpathian flysch in a lacustrine fresh--water environment (Bieda 1969) is also untenable. Graded bedding was reported from formations supposed to be deposited in lakes, as is the case of the English Keuper (Klein 1962), or the Miocene lacustrine beds of the Apennines (Sestini 1970), but in these instances the graded bedding is associated with beds which display features indicative of a deposition above the wave base.

PARALIC SWAMPS AND LAGOONS

Sedimentation of the flysch sequence in such environments was postulated by Bieda (1969). However, there is no resemblance of sedimentary features of the flysch to those of marine saline marshes. According to Bouma (1963, see also Reineck 1972), the stratification in saline swamps is marked by a wavy, parallel lamination, by a lenticular lamination with distinct contacts between laminae (in the flysch these contacts are diffuse) and by a very high content of plant fragments and roots. Tidal channels and salt peats also occur frequently (Sanders & Ellis 1961). Today, extensive paralic marshes develop in areas of rapid alluviation, such as large deltas. These could have been formed if the Carpathian basin was bordered by large continents, but there are many arguments against (Dżułyński & al. 1959). Also the geometry of the Carpathian flysch argues against the concept of salt-marsh environments: the belt of swamps would have to have been at least 300 km wide. The same applies to the suggestion of lagoonal origin. Mangin (1963) sees a similarity in "*millimétriques*" alternations of finegrained sands and peaty ("*tourbeux*") clays in a lagoon to flysch sediments. No "peaty" laminae occur in the Carpathian flysch.

TIDAL FLATS

This assumption is untenable not only on account of geometry (more than 300 km wide tidal flat?), but also because of a quite different stratification of tidal flat deposits, very well known from the work of many authors (e.g. Van Straaten 1959; Reineck & Singh 1967; Reineck 1972). Such features as flaser lamination, megaripple bedding, herring-bone bedding, numerous small-scale erosion features, and intense bioturbation do not occur in the Carpathian flysch.

LITTORAL ZONE

A number of authors believe that the flysch is a littoral deposit. According to Rech Frollo (1964), graded beds form from materials suspended by waves or landward currents in small bays ("*criques*") of the Algerian and Catalonian coasts during storms. She realizes that the flysch could not be deposited in such small water bodies and believes that it has been laid down on some continental platforms ("*platiers*") around islands, but fails to explain how the hydrodynamic conditions of small bays may be applied to larger water bodies. Her explanation by "*rupture d'équilibre*" (Rech Frollo 1962a) is meaningless. The absence of scours on upper surfaces of flysch sandstones argues against the deposition in the agitated littoral waters. Also, the internal structures of sand accumulating in the coastal zone are quite different from those of flysch sandstones, as seen on the photographs presented by Reineck (1970).

The wave-generated longshore currents may carry sand and possibly form grading and fluting, although in principle they are tractional currents which mostly should form large-scale cross-stratification. Since they are due to wave-refraction, the longshore currents are restricted to a very narrow surf zone (Inman & Bagnold 1963). If the coastal zone is very shallow and wide, these currents may be active in a wider area but, making every allowance, incomparably much smaller than the width of the areas occupied by any of the Carpathian flysch members, which as a rule exceed several dozens of kilometers.

NERITIC ZONE

The sedimentation conditions in the neritic zone of present-day seas are still imperfectly known, but several features have been recognized which are absent in the flysch. The main currents active in this zone are induced by waves, winds, and tides. Tidal currents are still noticeable at a depth of about 150 m. According to Stride (1963), sand ribbons arranged concordantly with the direction of tidal currents, sand ridges and sand waves to 20 m high occur on the shelf around the southern half of Great Britain. The direction of transport is variable over short distances. Echo-sounding has revealed lenticular masses of sand several meters thick. The rate of sand transport is slow: one mile in three months near the coast and much less farther away. The conditions on the Atlantic shelf off North America are similar, with linear sand waves, shifting shoals and sand bodies (Uchupi 1968), implying a highly irregular bedding. On the Guiana shelf (Nota 1958), sand appears concentrated in pockets, nests and lenses, seldom mixed homogenously with clay. Photographs of core sections from the middle shelf off the Orinoco River reveal a bedding entirely different from that of flysch sediments. Neither the observations from a tideless shelf (Reineck & Singh 1971) present any similarity of the sedimentary features to those of the flysch.

Martinsson (1965) envisaged the idea that in the very shallow shelf sea steady winds, such as trade winds, may induce currents that "feel" the bottom and stir the sediment and deposit it as graded sediment with flute casts. Probably, only fine-grained sediments may be affected by this process. The Carpathian flysch is on the whole too coarse and its beds too thick and therefore it is hardly possible to apply such a concept to its origin. In this process, some unstirred portions of the original sediment should have been left, as it is hardly possible that all sediment lying on the floor has been disturbed. No beds representing such sediments are known from the Carpathians. It is likely that the Carpathian basin was situated in the trade wind zone of the northern hemisphere. If the currents were induced by trade winds, they should flow predominantly in one direction. However, in the three troughs of the Carpathian flysch basin the directions of paleocurrents are different: in the northern (Main) trough predominantly east- and south-eastward, in the median (Magura) trough on the whole westward and in the southern (Podhale) trough once again eastward (Radomski 1958; Książkiewicz 1958, 1962).

According to Reineck & Singh (1971b), graded bedding may be formed in the neritic zone by storm-induced waves. During storms sand is eroded on the coast and transported as a suspension by the retreating waters to the open sea. There the material suspended drops down and forms graded and laminated sand beds in calm, deeper layers of water. In this case sand is not transported by currents that touch the bottom and no erosional structures such as flute- and drag casts can be formed.

Grading in shallow water may, according to Dżułyński & Walton (1963), be produced when on entering a water reservoir, sediment-laden flows from steep mountain slopes spread and produce "turbidite" layers. This mechanism can be hardly applied to the origin of the Carpathian flysch, in which the presence of calcareous cement in sandstones of most units, and the frequent occurrence of glauconite and shallow-water organisms in element *I* indicate provenance from a neritic environment.

Clearly then, shelf sedimentation is entirely different from that of the flysch. Particularly, in the neritic zone there are no conditions under which regular alternation of coarser and finer-grained beds could be formed (Kuenen 1964). Such an alternation has never been found in shelf deposits. On the contrary, alternating beds with very many features typical of the flysch (sharp soles, grading and grading combined with lamination) have been recognized in many deep-water basins: to mention only a few instances, basins off the Californian coast (Gorsline & Emery 1959; Von Rad 1968), the Caribbean Sea (Nesteroff 1961), the Adriatic Sea (Van Straaten 1964), the Tyrrhenian Sea (Ryan & al. 1965, the Puerto Rico Trench (Conolly & Ewing 1967), and the Tasman Sea (Conolly 1969) etc.

Since glauconite forms in relatively shallow waters, the presence of this mineral which frequently occurs in many members of the Carpathian flysch, is used by several authors (Zeil 1960; Reichelt 1960; Rech Frollo 1963; Hanzlikova & Roth 1963) as an argument for the shallow-water origin of the flysch. It should be recalled, however, that the grains of glauconite in the Carpathian sandstones are often graded and in the laminated parts of element *I* they frequently occur more abundantly in certain laminae (Książkiewicz 1954, p. 408, 443—444; and Pl. 1, Fig. 2 of the present paper). The last-named feature, also reported by Kotlarczyk (1961) is known from the Caucasian flysch (Grossheim 1963). These facts indicate that the glauconite grains have in many cases been transported together with sand. They are rarely rounded, which is in conformity with Rech Frollo's (1963) observations and may suggest a transportation not by traction currents but in suspension. The grains with diffuse contours may be post-depositional, of early diagenetic origin. It is worth mentioning that, according to Cloud (1955), in the tropical belt glauconite forms below 50 m, mostly below 230 m. If the Carpathian basin was situated in the tropical or subtropical belt (*cf.* discussion below), some of the glauconite grains could derive even from the upper bathyal zone.

Some flysch workers admit that glauconite in flysch sediments may be redeposited, e.g. Hubert (1967, Fig. 19) presumes that in the Prealpine flysch glauconite was transported from the "shelf" to the deeper basin.

The presence of graded bedding is not by itself indicative of the depth of water and it is beyond any doubt that it might be formed occasionally and locally in the neritic zone (Nesteroff 1965), but to a small extent and subordinated to other types of bedding. The problem is whether a succession of persistently graded beds like that of the Carpathian flysch, could be formed under marine shallow-water conditions. It appears that no currents operating in the neritic zone could do it. Therefore, one must resort to the turbidity current hypothesis. These currents may be generated only on a slope, where overloading or a shock evokes slumping. The volume of the deposited bed must be proportional to the volume of slumped material. If the slope is low, there is little chance that the volume of slumped material is big and the deposited bed will be of limited extent. In shallow water, then, only graded beds of small extent may be expected, and lensing and wedging-out should be common. The fairly great extent of element *I* in the Carpathian flysch indicates rather high slopes in the basin. The building-up of a fairly high slope in the neritic zone can be hardly expected, as waves and currents tend to distribute the material more or less evenly on the floor.

The Carpathian flysch, 6000 m thick, deposited continuously in the Cretaceous and Paleogene, does not display any significant lacunas (or breaks) in its succession. Shallowing up to the wave base is marked, as it will be seen, only in a few cases of purely local importance and limited extent. If the Carpathian flysch were deposited in the neritic zone, say 100 to 200 m deep, the subsidence would have to have been always commensurate with the sedimentation. This, indeed, would be a singular case.

SEDIMENTARY FEATURES INDICATIVE OF THE DEEP-WATER SEDIMENTATION

In the Carpathian flysch, there are some features which suggest that this flysch, or at least several of its members, was deposited at depths exceeding those of the neritic zone.

One of them is a peculiar type of sequences, called here briefly the sand-marl sequence, which consists of the following divisions: sandstone (often with conglomerate at the base) — marl (or limestone) — argillite. There is a transition between the sandstone (which is well graded, has calcareous cement, and diplays horizontal lamination near the top) and the marl (cf. Fig. 5). The boundary between the marl and the overlying shale is more or less distinct. The sandstone may contain shallow-water organisms (*Lithothamnium, Nummulites,* etc.); the marls contain only a few microfossils (calcareous Foraminifera, sponge spicules, radiolarians); while the argillite usually contains abundant microfauna distinctly different from that occurring in the marl. The gradation of the sandstone into the marl implies that the calcareous material was transported together with the sand by the same current and its deposition on top of the sand is due to longer suspension. The explanation of the origin of these sequences is as follows: the sand-laden current descending from a shallow-water zone traversed a belt of calcareous mud, mixed its sand with the mud, and farther down from the suspension first sand and later marl were deposited. The belt of calcareous ooze must have existed in all probability a good distance from the coast, most probably in the outer neritic or upper bathyal zone. The deposition of the sand-marl sequences must have taken place on the floor lying deeper than the calcareous belt. Similar sequences occur in the Bavarian flysch (Reichalt 1960), in the Westalpine "*flysch à Helminthoides*" (Lanteaume 1962) and in the Biscayan flysch (Richter 1965). According to Nesteroff (1963), the limestones in the Westalpine flysch do not represent a pelagic deposit, but are the terminal part of the sequences deposited from turbidity currents. He noted that similar sequences are being formed on abyssal plains when pelagic calcareous ooze is reworked by a turbidity current and redeposited in the sequence sand-calcareous mudstone-clay (Nesteroff & al. 1966).

Certain conclusions as to the depth of the basin may be drawn from the presence and composition of olistostromal deposits. They occur in nearly all members. According to Bukowy (1956) and Crowell (1957), these are submarine mudflow deposits formed when gravel and sand during more strong movements of the sea are deposited on muds farther offshore. The excessive overburden causes slumping and mixing. Slumping requires a considerable slope and consequently a substantial depth may be inferred, while absence of winnowing and sorting indicates a deposition in calm water.

In some cases these olistostroms give further depth indications. In the Czarna Wisełka (Black Vistula) Valley, the Senonian Istebna Beds contain a mudflow deposit about 30 m thick, which, in addition to blocks and pebbles of pre-flysch rocks, contains blocks of dark-bluish marls full of globotruncanids (the writer's unpublished observations). Evidently, the descending mudflow on its way tore away lumps of foraminiferal ooze. This could be deposited in the outer neritic or upper bathyal zone and the inference is that the mudflow traversed this zone and deposited its load below the depth at which the foraminiferal ooze was being laid down. Similar conclusions may be drawn from the case, described by Geroch & Kotlarczyk (1963) from the Paleocene Babica Clays, where a pebble-mudstone contains a block of marls with numerous Globigerina and Globorotalia. The Senonian Frydek Marls largely consist of structureless marls with gravel and numerous globotruncanids (Książkiewicz 1962) and are to a considerable extent olistostromal in origin. According to Dżułyński & Kotlarczyk (1965), the Eooligocene Popiele Beds, are a product of large-scale gravity mass movements; they also contain blocks of marls. It follows that during some periods the flysch basin was fringed by zones of calcareous mud deposition and from these zones slumps and mudflows transported the material to deeper parts of the basin. Since it seems most likely that the calcareous sediments with planktonic Foraminifera were deposited in the outer neritic zone, where they are often laid down at present (Bandy & Arnal 1957), the conclusion can be drawn that the olistostromal deposits have been laid down at least at depths greater than those in the outer neritic zone. This gives a picture comparable with some of present-day deep-sea basins, in which graded beds are accumulated on the deep floor, while foraminiferal oozes are formed on the slopes as is the case in the Puerto Rico Trench (Conolly & Ewing 1967), or in the Gulf of Mexico (Burk & al. 1969; Kuenen 1970).

While, as presented above, in some members there are indications of deposition at depths below the neritic zone, there also occur features which suggest that in some, on the whole exceptional instances, the water depth was not very great. In a few members, one or two elements *I* occasionally exhibit large-scale cross-stratification (the lowest part of the Albian Lgota Beds and the Eocene Magura Sandstone in some places), and in one member (the Eocene Ciężkowice Sandstone) large-scale cross-bedding is developed to some extent. It was believed that this type of bedding could be produced by watery slides, depositing fluxoturbidites (Dżułyński & al. 1959), but there is ample evidence that such flows may produce unsorted or imperfectly graded beds (Stauffer 1967) while large-scale cross-bedding indicates a fully turbulent traction current (Walker 1967). If such is the case, one has to presume that the layers with large-scale cross-bedding were deposited at or near the wave base and, if they occur together with graded beds, the latter were deposited, to be sure, at somewhat greater depths, but the depth difference could not be very great. It is possible that single occurrences of large-scale cross-bedding were caused by occasional, more violent behavior of the sea and momentary lowering of the wave base. Instances of large-scale cross-stratification are also reported from other flysch areas (Mutti & al. 1968). One case the author saw (with J. E. Sanders) in the Ordovician flysch of the northern Appalachians.

The facies variation along the current direction, as described by Radomski (1961) in the Swiss flysch, may permit the estimation, with some plausibility, of the distance from the source and, consequently, differences in the depth of deposition. Following Parea (1965, see also Walker 1967; Kelling & Woodlands 1969), one may determine proximal, intermediate and distal regions of deposition on the basis of sedimentary features. On the basis of the observations in the Carpathian flysch, the following characteristics may be presented.

The proximal region will be characterized by poor grading or its absence, by frequent lensing and pinching, by the presence of olistostromes, fluxoturbidites, channelling, multiple (= amalgamated *sensu* Walker 1967) bedding, thick elements *I*, thin elements *II*, abundance of conglomerates, few mechanical and organic sole marks and occasional large-scale cross-stratification.

The intermediate region is characterized by parallel-sided elements *I*, a nearly equal proportion in thickness of element *I* and *II*, a well-developed composite bedding (*ABCE*, also *ABE*, *BCE*), a smaller degree of coarseness and thickness of element *I*, numerous flute casts, hardly any pinching, and a greater number of organic trails. Sand-marl sequences may also occur here.

The distal region is marked by generally thin elements *I* displaying mainly *BCE* and often *CE* sequences, a larger thickness of element *II*, fewer mechanical sole marks and an abundance of trace fossils. Thick argillaceous packets are here developed and pinching out may be more frequent than in the intermediate region.

The differences in depth between these regions are not necessarily very large, since turbidity currents can flow over a floor with a slope 1 : 1000 (Kuenen 1967).

It should, however, be stressed that changes in character of beds occurring transversally to current direction are also noted and a series of the nature of the intermediate region may pass laterally into a facies with the characteristics of a distal region. The Hieroglyphic Beds (Middle Eocene) of the Magura unit may serve here as an example: they display features of the intermediate region, but they pass at a right angle to the current direction in beds with features of a distal region. There are also units with features of a proximal region that do not pass in coeval beds with features indicating a far-off deposition (Istebna Beds). They were deposited in the proximal region only.

The downcurrent variation is difficult to account for on the assumption of a shallow sea. It may be explained much more easily by assuming a basin of some depth.

Another argument in favor of the deep-water origin of the Carpathian flysch is provided by the dispersal pattern of paleocurrents (Książkiewicz 1962). A unimodal pattern predominates in most members (Godula-, Inoceramian-, Ropianka-, Beloveza-, Hieroglyphic-, Magura Beds). In some units the pattern is bimodal (Krosno Beds, according to Dżułyński & Ślączka 1959; Podhale Flysch, according to Marschalko & Radomski 1960), in the instances when the basin was filled from two or more sources. In certain members, a uni- or bimodal pattern is combined with a fan-shaped paleocurrents arrangement (Krosno Beds, Pasierbiec

Sandstone). According to Klein (1967), the patterns of this type characterize a deposition in relatively deep water bodies, while multi-directional dispersal patterns are typical of coastal environments (the intertidal zone has a complex quadrimodal pattern) and in shallow seas tidal, wind-driven currents and storms would also create variable transport directions.

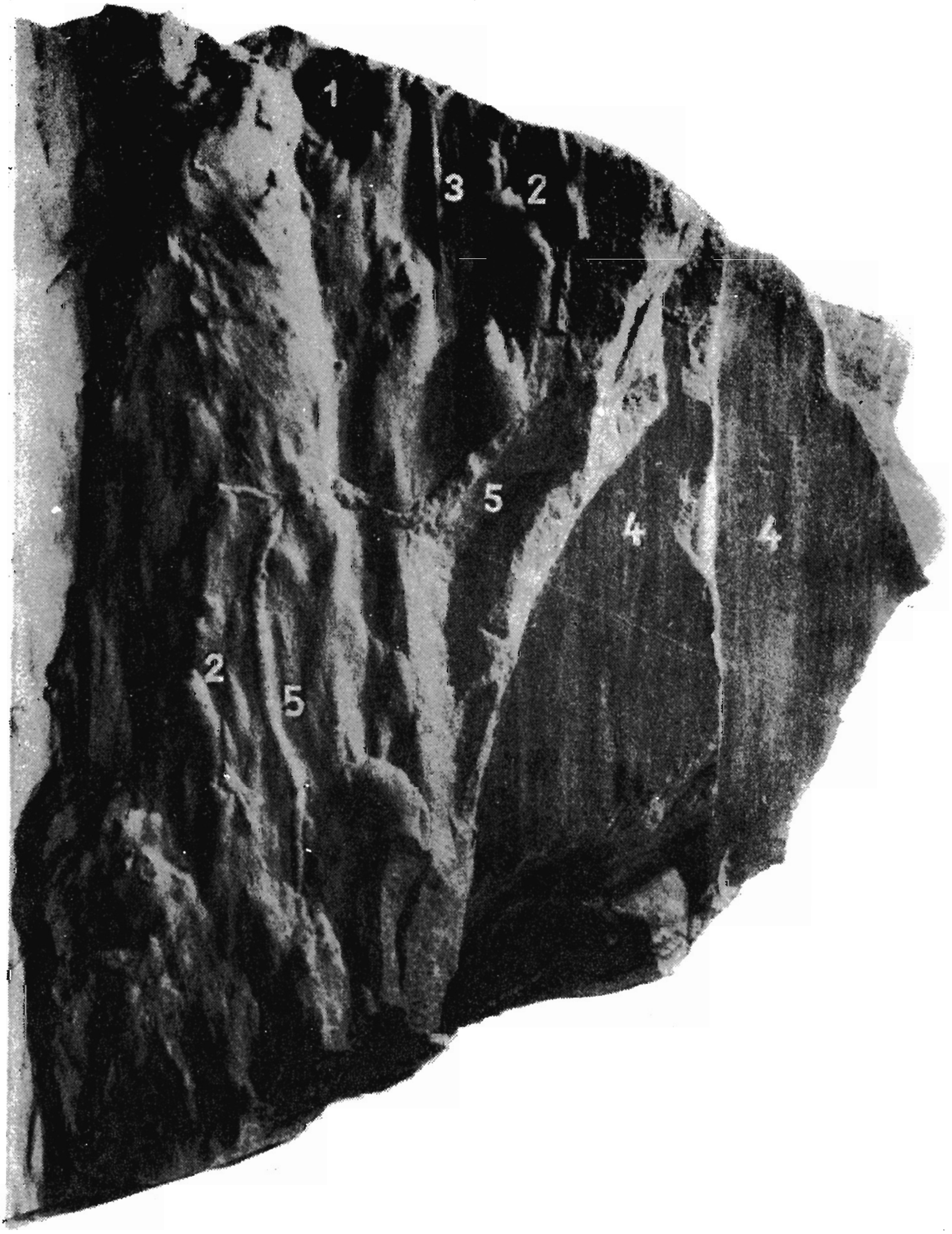
An important proof for a deep-water deposition of variegated shales, so common in many members of the Carpathian flysch (Cenomanian — Middle Eocene), has been provided by Wieser (1969), who identified clinoptilolite in the Lower Eocene (also in the Cenomanian — Turonian, personal communication). This zeolitic mineral forms on deep-sea floors under halmeic conditions of eupelagic slow sedimentation.

Noteworthy also are the newest trends in flysch sedimentology. After the discovery of deep-oceanic bottom currents, some authors believed that flysch beds were formed by materials supplied laterally by slumps and sandflows and reworked by ocean bottom currents (Scott 1966; Klein 1966; Hubert 1967). Some others presumed that they were deposited by turbidity currents, but the tops of the sandy layers were more or less reworked by bottom currents (Craig & Walton 1962; Hsu 1964; Kelling 1964; Walton 1967). The latter hypothesis was based on the divergence observed between the direction of sole marks and that of ripple-current lamination.

The hypothesis of the depositon by bottom currents does not imply the shallow-water origin of the flysch. On the contrary, if justified, it rather strengthens the idea of its deep-water deposition, since geostrophic currents operate at considerable depths below the foot of the continental slope (Heezen, Hollister & Ruddiman 1966). This hypothesis evokes many doubts stressed by several authors, the actual force of bottom currents (Kuenen 1967) and the problem of their waning (Van der Lingen 1969) being its weak points. To these doubts a few others may be added in respect to the Carpathian flysch.

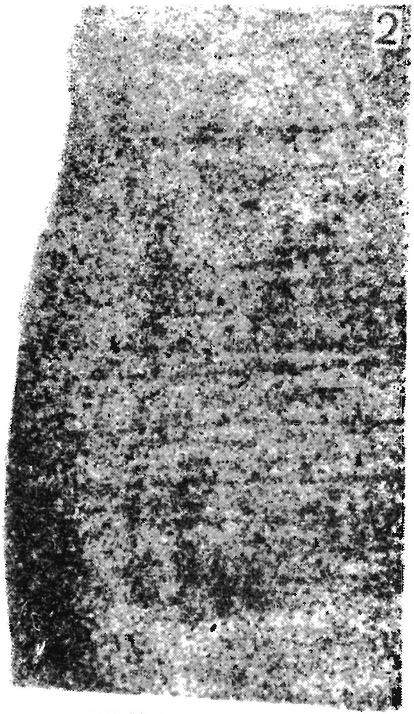
Graded beds in the Carpathians are often very thick and coarse. The thickness of element *I* is often 0.5 m, not uncommonly 1.0 m, grains being often larger than 1 mm. It is doubtful whether the currents with reported velocity (max. about 40 cm/sec) could carry such coarse material in suspension.

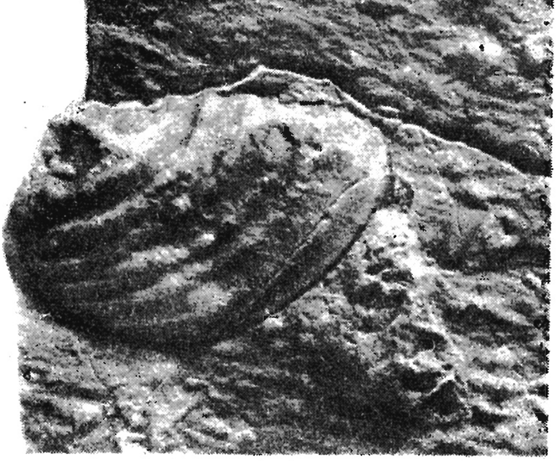
No significant differences between the direction of flutes and current bedding were noted. The differences observed are generally small, and larger occur only exceptionally (Dżułyński 1963, p. 69, 117; Książkiewicz 1962). The parting lineation is often perfectly parallel to sole marks (Pl. 2). The differences observed may be explained in a number of ways: as related to crescentic-shaped ripple crests (Basset & Walton 1960), lateral spreading, or crossing current lobes (Enos 1969). In his experiments Middleton (1970) finds that the head of the turbidity current is lobate and the motion in it deviates from a mean direction of the flow.



Lower surface of a sandstone layer (17 cm thick) and its parting surfaces; Magura Sandstone (Upper Eocene), Bystra near Jordanów; × 0.3

1 apex of large flute, 2 flute casts, 3 drag mark, 4 parting lineation, 5 post-depositional burrows





1 — Pensymmetrical bedding; Inoceramian Beds (Senonian), Kosina near Rzeszów.

2 — Horizontally laminated sandstone with dark laminae composed mainly of small glauconite grains (these are larger in light, coarser laminae); Magura Sandstone (Upper Eocene), Żegocina.

3 — Graded biogenic limestone with angular quartz grains concentrated in the lowest part; intercalation in the Hieroglyphic Beds (Upper Eocene), Skawinki near Wadowice.

4 — *Inoceramus* valve on the sole, convex side down; Ropianka Beds (Senonian), Limanowa.

All figures in natural size

The abyssal thermo-haline circulation is caused by considerable differences in salinity and temperature in present-day oceans. It is not proved that these differences were so great in the Cretaceous and Tertiary times. It may also be doubtful whether this type of circulation existed at all and if so, whether it had sufficient force in the partially enclosed basin not connected directly with polar seas.

MACROFOSSILS

It is here recalled only that the macrofossils occurring in element *I* are size-graded (Książkiewicz 1948, p. 148, 152, and 1954, p. 404, 443) and usually concentrated in the basal part of this element. This indicates that the organic remains (ammonites, belemnites, bryozoans, large Foraminifera, lithothamnia etc.) have been displaced from their habitat and transported. Thus, the presence of large Foraminifera (*Nummulites* etc.) in flysch conglomerates and sandstones does not necessarily indicate a shallow-water sea as stated by Bieda (1969), nor may the *Nummulite*-bearing layer at Skawinki (which was considered by Bieda 1962 as an autochthonous bed of his "Nummulitic formation") be an indigenous bed. It is well graded (*Nummulites* and other organic debris are sorted according to their size, Pl. 1, Fig. 3) and displays some imbrication and lineation. Also Nalivkin's (1967) view that the Middle Eocene Pasierbiec Sandstone is a surf deposit is groundless. The sandstones of this member are often conspicuously graded and the tests of *Nummulites* and other large Foraminifera are sorted in the same way as mineral grains. As shown by flutes, the gravel and sand were transported for a distance of at least 10 km and their thickness and coarseness decrease in the direction of current. In the flysch beds the delicate surface ornamentation of *Nummulites* and *Discocyclina* is, as a rule, perfectly preserved, suggesting that the tests were transported in suspension and not by traction currents. It is hardly imaginable that in the surf zone they could remain undamaged.

There is another feature that seems to counter the assumption that the remains of shallow-water organisms in the flysch actually imply shallow-water conditions. The Upper Cretaceous sandstones contain fairly abundant disarticulated valves of Inoceramus ("Inoceramian Beds"). The valves occur as a rule on the very sole or near it, invariably with their convex sides downward (Pl. 1, Fig. 4). This feature was noted long ago by Fuchs (1895, p. 380). More recently Crowell & al. (1966) also noted such a position of lamellibranch valves in sandstones, the origin of which they assign to turbidity currents. Separate valves of lamellibranchs can easily be turned over convex side up by traction currents as seen in the littoral zone. According to Middleton (1967a), the convex-down orientation suggests that the valves have been deposited rapidly from suspension and indicates the absence of longer movement by traction. Middleton experimentally obtained a high frequency of convex-down position of shells in artificial turbidity currents.

The same interpretation may be applied to the halved shell of an ammonite found in a thick sandstone layer of the Upper Cretaceous Godula Beds and used by Hanzlikova & Roth (1963) as an argument for a lengthy deposition of this layer under shallow-water conditions. It is possible, however, that the shell lying in the littoral zone had been truncated by waves or corroded in deeper waters and later the halved shell was transported by a turbidity current and deposited convex side down.

Displacement by currents or waves may occur either landwards (by violent storms), or by longshore currents, or seawards in the direction of deeper water. The first possibility, suggested by certain authors (Rech Frollo 1962b) is at variance with good grading and regular bedding of layers with organic remains. These features would be difficult to explain, if the layers were deposited by sudden inflows into paralic swamps, lagoons or river mouths. The other possibility also does not seem probable: longshore currents are tractional and cross-bedding, rather than grading, may be expected. Furthermore, the difference in organic content of current-transported material and the autochthonous shales would be inexplicable. Several features strongly suggest seaward displacement of organic remains. In many instances the beds with organic remains thin--out downcurrent and eventually disappear within shaly complexes (as is the case with the Eocene Ciężkowice Sandstone in the Magura unit), or within marls (Pasierbiec Sandstone). The transport towards deeper water is demonstrated by a mixing of faunas of different habitats in the case of olistostromal deposits. The Paleocene molluscan fauna lived, according to Krach (1969), in the sublititoral and neritic zones, but has been mechanically mixed and transported by currents and slumps into deeper water. Similarly, Jucha & Krach (1962) have shown that the molluscs of the Eooligocene Menilite Beds are partly littoral and partly neritic (100 to 200 m); they were mixed by mass movement and transported into deeper water.

The transport of shallow-water organisms from the coastal zone into deeper waters was ascertained in many other flysch regions as e.g. in the Appalachians (McBride 1962), in the Cyprus flysch (Weiler 1965) and in the Prealpine flysch (Hubert 1967).

In the argillaceous interbeds, there occur but rarely large fossils, in the Cretaceous beds mainly ammonites and, in some cases, thin-shelled *Inoceramus* and, as shown below, a microfauna different from that occurring in elements *I*. The difference in organic content between layers introduced by currents (element *I*) and indigenous shales (Książkiewicz 1954) is difficult to explain on the assumption that the two types of sediments were deposited in the same shallow-water environment. The significance of this difference has recently been emphasized by Weidmann (1967) and Simpson (1970, p. 270).

Limestones with *Lithothamnium* occur in some places as olistoliths (Książkiewicz 1962) and *Lithothamnium* debris are not uncommon in olistostroms and in graded layers. There is only one occurrence of *Lithothamnium* limestone known to the writer, that can be considered as formed by the growth of algae in situ, that is, a 12 cm thick layer in shales of the Upper Eocene Magura Beds at Kluczowa (Jasło area). The situation of this occurrence close to the northern border of the Magura Beds shows that the limestone was deposited in the marginal zone of the trough in which the Magura Beds were laid down. This does not prejudge the character of the environment in which the rest of this member was formed. The shales with this limestone probably could not form too close to the coast, but in the outer neritic zone about 100 to 150 m deep and the contemporaneous flysch could be deposited somewhat deeper in the trough.

MICROFOSSILS

FORAMINIFERAL ASSEMBLAGES

As is well known, the foraminiferal assemblages in the Carpathian flysch, like those in many other flysch regions, consist predominantly (and, in many cases exclusively) of agglutinate species. At present, assemblages of exclusively agglutinate Foraminifera occur in two types of environments: in paralic marshes and at abyssal depths. This is the point that Bieda (1969) used to argue that the Carpathian Tertiary flysch beds with exclusively agglutinate species were deposited in fresh-water and brackish environments including saline swamps. To strengthen his view, Bieda states that "present-day agglutinated Foraminifera do not occur in the bathyal zone" (p. 495, 505). He bases this assertion on the Neumann's statement (1967, p. 24) that in the bathyal zone there are almost exclusively planktonic Foraminifera. As a matter of fact, Neumann refers to the paper of Carozzi (1949), who maintains that in the "fairly deep zone" the microfauna consists of pelagic and benthonic elements with a tendency to diminish the importance of the latter with depth. Neither Carozzi, nor Neumann mention the presence or absence of agglutinate Foraminifera in the bathyal zone. There are several reports on the occurrence of agglutinate species in the bathyal zone. Akers (1954) states that *Cyclammina cancellata* Brady, together with other species of this genus and other arenaceous forms (*Ammodiscus incertus, Rhabdammina abyssorum, Haplophragmoides scitulus*), are most abundant in cool waters below continental shelf depths. Lowman (1949) found at bathyal depths

(180 to 1800 m) of the Mexican Gulf species belonging to *Cyclammina, Haplophragmoides, Trochammina* and *Glomospira*. Saidova (1961) showed that the agglutinate species have maxima of abundance at depths of 200 to 300, 1500 and 4000 m in the Bering Sea; at depths of 500 and 2000 m in the Okhotsk Sea; and at depths of about 500, 3000 and 5000 m, in the north-western part of the Pacific Ocean. Similarly, in the Antarctic waters the agglutinate Foraminifera display frequency maxima at depths of about 500, 1500 and 3000 m (Saidova 1961b). In the Peru-Chile Trench (Bandy & Rodolfo 1964), at a depth of 878 m, *Ammodiscus tenuis, Ammolagena clavata, Reophax scorpiurus, Rhabdammina abyssorum, R. linearis* are dominant species; and at a depth of 1000 m, 50% of specimens belong to agglutinate species which below that depth become predominant with representatives of *Cyclammina, Reophax, Alveophragmium* and others. Pujos-Lamy (1973) reports on several agglutinate forms from the mesobathyal zone (1500 to 2500 m) in the Biscaya Bay. These data are sufficent to demonstrate that the agglutinate species may exist in the bathyal zone.

The foraminiferal assemblages of marginal marshes and brackish waters are fairly well known (Hedberg 1934; Lowman 1949; Phleger & Walton 1950; Bandy 1956, 1963b; Bandy & Arnal 1960; Phleger 1955, 1960; Saunders 1957, 1958; Parker & Athearn 1960; Cooper 1961; Hiltermann 1966). In fact, these assemblages very often consist of agglutinate species only. According to Phleger (1960) and Murray (1973), *Miliammina, Arenoparella, Trochammina, Ammoastuta, Discorinopsis, Jadammina, Palmerinella* are characteristic of salt marshes. Except for *Trochammina*, none of these genera is represented in the Carpathian flysch. In marine marshes, however, species may also occur which belong to genera actually represented in the Carpathian flysch: *Saccammina, Reophax, Ammodiscus, Ammobaculites, Haplophragmoides,* associated as a rule with the species belonging to the genera listed above as the most characteristic of this environment. No modern species of these genera is present in the assemblages of the Carpathian flysch. Conversely, none of the modern species that occur in the Carpathian flysch is known from saline marshes, while at least fifty species living in present-day open seas under the conditions of normal salinity are represented in the Carpathian assemblages.

The foraminiferal assemblages in estuarine environments do not differ much from those of salt-marshes (Kane 1967; Murray 1973), but often include euryhaline calcareous forms, such as *Streblus beccarii*, several species of *Elphidium* etc. The species diversity is low but, as the river water is a source of abundant food, the estuarine populations are unusually large (Phleger 1960) off the mouth of some rivers. Neither in this respect, nor in their composition do the flysch assemblages correspond to estuarine assemblages.

The mangrove environment is also marked by the dominance of agglutinate Foraminifera with an addition of some calcareous species in its seaward part (Saunders 1958; Phleger 1960). Pflaumann (1967) has already stressed the difference between flysch and mangrove associations.

Some agglutinate species (belonging to *Ammobaculites, Trochammina, Miliammina, Textularia*) may be present in the lagoonal environment (Phleger 1960; Ayala-Castanares & Segura 1968). No corresponding assemblages are known from the indigenous deposits of the Carpathian flysch. Assemblages typical of salt-marshes, estuaries and lagoons, and also those of the shelf environment (Murray 1973) occur in deltas.

The difference between the assemblages of paralic marine environments (salt-marshes, estuaries and lagoons) and the flysch assemblages has already been pointed by Pokorny (1959) and more recently by Brouwer (1965) and Hiltermann (1966, 1972). Accordig to Bandy & Arnal (1960), agglutinate Foraminifera with simple interiors may abound in shallow near-shore waters, while forms with labyrinthic interiors are more characteristic of bathyal depths (e.g. *Cyclammina*, well represented in the Carpathian Eocene).

Agglutinate Foraminifera also occur abundantly in intertidal pools (Murray 1971). This is a marine environment that differs from paralic ("marginal") environments in intermittent changes in salinity due to evaporation or dilution by rainfalls. The agglutinated species belong to *Trochammina, Gaudryina, Eggerella* and *Textularia*, usually accompanied by numerous Foraminifera with hyaline tests, which may frequently be predominant (Cooper 1961). Where arenaceous types predominate, this is due almost entirely to the presence of the one species of *Trochammina*. The presence of its representatives is considered by Hanzlikova & Roth (1963) as indicative of brackish water in some Carpathian flysch members. No Recent species of *Trochammina*, known from brackish waters, occurs, however, in the Carpathian flysch and several species of this genus are recorded in purely marine and even deep-water environments, e.g. *Trochammina globulosa* Cushman found in the Peru-Chile Trench at depths of 870—4600 m.

As indicated above, the autochthonous shales of the Carpathian flysch contain several species, both agglutinate and calcareous, which still live in present-day seas. Recent Foraminifera identical with fossil ones are used by many authors as guides to past depositional environments, because they assume that fossil isomorphs and homeomorphs had environmental adaptations similar to the corresponding modern species, especially groups of species (Bandy 1956; Bandy & Arnal 1960; Bandy & Kolpack 1963). The known distribution of Recent marine species that exist in fossil assemblages is considered as the most reliable source of information on the ecology of fossil foraminiferal faunas (Cushman & Henbest

1940) and may be used to determine the bathymetry of ancient basins. This approach is followed in the present paper. In particular, it is applicable to the flysch of Paleogene age, which contains many species still living in present-day seas, while the species present in the Cretaceous beds are with few exceptions extinct. At any rate, this procedure is more reliable than use made of families for paleoecological interpretation, a method whose application is strongly discouraged by Phleger (1960). The determination of depth is to a certain extent facilitated by the fact that several species with considerable depth range have a markedly higher frequency at certain depths.

The knowledge of depth distribution of Recent Foraminifera is far from perfect although, according to Phleger (1960), information on it seems to be more reliable and abundant than for any other group of animals.

The effect of temperature on depth distribution of Foraminifera is debatable. Phleger (1960, p. 103) regards this factor as over-emphasized. According to Bandy & Rodolfo (1964), many Recent Foraminifera have about the same upper depth limits in various seas (isobathyal species). They do not display any good correlation between temperature and upper depth limits. A depth effect, due to the pressure gradient, seems to be more important than temperature (Bandy & Chierici 1966). On the other hand, several agglutinate species live at shallower depths in cold seas than in the seas of warmer zones. According to Gevirtz and his associates (1971), the shelf temperature seems to be a dominant factor controlling the distribution of the benthonic Foraminifera. The Carpathian basin was in all probability situated for the most time in a warm zone (Książkiewicz 1954; Koszarski & Żytko 1966) as indicated by the presence in many members (Tithonian, Berriasian, Hauterivian, Lower Aptian, Lower Eocene), of displaced reef corals, large foraminiferids (often quite abundant in many units of the Paleogene), and remnants of tropical Eocene flora derived from the neighbouring lands. It seems, therefore, that conclusions should primarily be drawn from a comparison of the depth distribution of the Foraminifera in modern seas of the tropical and subtropical belts, such as the Gulf of Mexico, the Caribbean Sea, the Gulf of California, the Peru-Chile Trench, the waters off the Californian coast, etc. The inferences based on the data from the Mediterranean Sea seem to be less reliable, as that sea, nearly completely land-locked, has an abnormal temperature distribution, with relatively warm waters even at a depth of 4000 m. There are no indications that the Carpathian sea was at any time in a similar situation. It has also been suggested that several species, both agglutinate and calcareous, which in other seas are known to be cold- resp. deep-water species, occur in the Mediterranean Sea at shallow depths as relics of the Ice Age (Hofker 1932; Moncharmont Zei 1956).

DEPTH DISTRIBUTION OF AGGLUTINATE SPECIES IN RECENT SEAS

Several of the agglutinate foraminifers that occur in the Carpathian flysch, but which persist till Recent times, are eurybathic and eurythermal but, at the same time, markedly prefer deep waters. Many other seem to be confined to depths generally greater than the neritic zone (these are marked with asterisks in the following discussion). The data summarized below (*cf.* also Table 1) come from the Peru-Chile Trench (Bandy & Rodolfo 1964), the Gulf of Mexico (Phleger 1951; Bandy 1956), the Gulf of California (Bandy 1951) and the Mediterranean Sea (Blanc--Vernet 1969; Moncharmont Zei 1962, 1964, 1968). In several cases, other references are also given.

Proteonina (= _Reophax_ aut.) _difflugiformis_ (Brady). — In the Gulf of Mexico from very small depths down to about 3000 m; in the oceans down to 6000 m; in the Mediterranean Sea, at all depths below 15 m.

Glomospira charoides (J. & P.). — Occasionally reported from inner neritic zone (near Mexico) and even in the estuary of the Dee River in Wales (Walther 1894), but elsewhere chiefly at depths greater than 200 m; in the Mediterranean and Red Sea, at depths of 160—3100 m, with the upper limit in the Mediterranean at about 100 m (Brady & Chierici 1966); in the Gulf of Mexico below 200 m, especially characteristic of depths below 400 m; in the north-west Pacific, at infrabathyal and abyssal depths (Saidova 1961a).

Glomospira gordialis (J. & P.). — In the Mediterranean Sea at neritic and bathyal depths; in the Gulf of California at depths of 18 to 410 m; in the Gulf of Mexico — 320 to 1000 m (McLean 1971); off California — 100 to 200 m (Bandy & Chierici 1966); in the oceans — at bathyal and abyssal depths.

Trochammina globigeriniformis (J. & P.). — In the neritic zone off Monaco and on the North American Atlantic shelf (Gevirtz & al. 1971); in some shallow Japanese bays, off Southern California — 720 to 1170 m; elsewhere at great depths to 7000 m. By Hiltermann (1972a) regarded as an essentially deep-water species.

Hyperammina subnodosa Brady and _H. elongata_ Brady. — Shallow coastal waters, but both extend to abyssal depths. _H. subnodosiformis_ Grzyb. is known from depths 30 to 2000 m in cold seas (Grün & al. 1964).

Recurvoides turbinatus (Brady). — Comparatively shallow waters, 50 and 120 m on the Japanese shelf (Troitskaya 1973), and deeper than 60 m in the Gulf of Maine (Phleger 1960). In many instances at bathyal depths (e.g. Peru-Chile Trench).

Ammodiscus incertus (d'Orb.). — Shallow waters in the seas of north-west Europe, in the Mediterranean Sea at neritic and bathyal depths; in the Gulf of Mexico and Caribbean Sea, very common at depths of about 900 to 1600 m (Cushman 1918); in the north-west Pacific 140 to 1270 m (Saidova 1961a). For the closely related _A. siliceous_ (Terq.) there are few data; neritic on the American shelf (Murray 1969).

Haplophragmoides canariensis (d'Orb.). — In the European and North-American waters, at shallow depths; in brackish water off the Rhone mouth, but also known from bathyal and abyssal depths (Brady 1884).

Ammobaculites agglutinans (d'Orb.). — Eurybathic, but comparatively rare in shallow waters. Reported by Brady (1884) from great depths; characteristic of depths about 1500 m in Antarctic waters (Saidova 1961b); in the Peru-Chile Trench, recorded at depths of 1863 to 5300 m.

*_Saccorhiza ramosa_ (Brady). — Depth 100 to 6000 m. In the Gulf of Naples, as elsewhere in the Mediterranean Sea, below 200 m (Hofker 1932).

*_Psammosphaera fusca_ Schulze. — With few exceptions, at bathyal depths (Grün & al. 1964); in the Mediterranean Sea, mostly 370 to 2400 m.

*_Reophax pilulifer_ Brady. — At isolated points at shallow depths (off the Peru coast 46 m). In the Mediterranean Sea below 200 m; in the Gulf of California 250 to 330 m; in the north-east Pacific 620 m (Saidova 1964); in the Peru-Chile Trench below 1600 m; elsewhere in the oceans at depths of 1500 to 2400 m and deeper.

Reophax nodulosa Brady. — In shallow waters of the Puzzuoli Bay; elsewhere in the Mediterranean Sea at bathyal; in the oceans down to abyssal depths.

*_Reophax guttifer_ Brady. — In the Mediterranean Sea at bathyal depths; in the Gulf of Naples at 200 m (Moncharmont Zei 1956); in the oceans at bathyal and abyssal depths (Brady 1884).

*_Rhizammina indivisa_ Brady (= _Rhabdammina abyssorum_ var. _irregularis_ Grzyb.). — Known from bathyal depths (Grün & al. 1964).

Rhizammina algaeformis Brady. — Except for an uncertain occurrence in a bay off Monaco, occurs at depths from 380 to 5800 m; in the Peru-Chile Trench, at a depth of about 1800 m.

Table 1

Depth distribution of Recent species of agglutinate and calcareous Foraminifera present in the Carpathian flysch

Bathymetric zone: / Species:	estuarine	neritic	upper bathyal	middle bathyal	lower bathyal	abyssal
Proteonina difflugiformis		—	—	—	—	—
Glomospira charoides	- -	- -	—	—	—	—
Glomospira gordialis		- -	—	—	—	—
Trochammina globigeriniformis		- -	—	—	—	—
Hyperammina subnodosa		—	—	—	—	—
Hyperammina elongata		—	—	—	—	—
Hyperammina subnodosiformis		- -	—	—	—	—
Recurvoides turbinatus		—	—	—	—	—
Ammodiscus incertus		—	—	—	— - -	
Ammodiscus siliceous		- -	- - ?			
Haplophragmoides canariensis	- -	—	—	—	—	—
Haplophragmoides scitulus		- -	- -	—	— - - ?	
Spiroplectammina biformis		—	—	—	—	—
Spiroplectammina carinata				- -	—	—
Ammobaculites agglutinans		- -	- -	- - —	—	—
Saccorhiza ramosa		—	—	—	—	—
Psammosphaera fusca		- -	- - —	—	- - ?	
Reophax pilulifer		- -	—	—	- -	
Reophax nodulosa		- -	—	—	—	- -
Reophax guttifer		- -	—	—	—	- -
Rhizammina indivisa			—	—	- - ?	
Rhizammina algaeformis		- -	- -	—	—	—
Rhabdammina abyssorum			- - —	—	—	—
Rhabdammina linearis		- -	- -	—	—	—
Bathysiphon filiformis			- -	- - —	— ?	
Cribrostomoides subglobosus		- -	—	—	—	
Cystammina pauciloculata			—	—	—	—
Trochamminoides conglobatus			- -	—	— ?	
Trochamminoides proteus		-	—	—	—	
Trochamminoides coronatus				—	—	—
Lituotuba lituiformis			—	—	— ?	
Eggerella propinqua		- -	- - —	—	—	—
Ammolagena clavata		- -	—	—	—	
Pleotina apicularis		—	—	—	—	—
Saccammina sphaerica		- -	- -	—	—	—
Cassidulina laevigata		- -	—	—		
Chilostomella ovoidea		- -	—	—		
Gyroidina soldanii		—	—	—	—	
Bulimina aculeata		- -	—	—		
Bulimina ovata		- -	—	—		
Uvigerina mediterranea		- -	- -	— - -		
Robulus calcar			—	—	— ?	
Robulus cultratus		- -	—	- -		
Eponides umbonatus		- -	—	- -	- -	
Pullenia bulloides		- -	—	—	—	
Sphaeroidina bulloides		- -	—	- -	- -	
Melonis pompilioides			- -	—	—	

*_Rhabdammina abyssorum_ Sars. — A world-wide, deep-water species. In polar seas, at about 200 m; in the Greenland Sea, 225 and 820 m (Shredina 1947); farther south, frequent at depths of 400 to 5000 m; in the Mediterranean Sea 300 to 4200 m; in the Peru-Chile Trench, at depths of 878 to about 6000 m., with a maximum frequency (34 per cent of the benthonic population) at a depth of about 3000 m. Selected by Brouwer (1965) as typical of deep-sea assemblages. A similar bathymetric range characterizes _R. linearis_ Brady: in the Mediterranean Sea, 100 m to great depths; in the West Indies seas, 600 to 800 m; in the oceans, down to abyssal depths; in the Peru-Chile Trench, at depths of 818 to 3541 m. _R. distans_ (Brady) seems to have a similar distribution.

*_Bathysiphon filiformis_ Sars. — Reported from considerable depths. In the Mediterranean Sea off Provence 370 to 2400 m, but in the Gulf of Naples at 200 m (Hofker 1932). According to Avnimelech (1953), the usual depth of _Bathysiphon_ is below 1000 m in temperate and warm seas, while in colder waters it lives at smaller depths.

*_Cribrostomoides subglobosus_ (Sars). — Commonly 100 to 3000 m. In the Mediterranean Sea below 200 m, in the Peru-Chile Trench below 1860 m.

*_Haplophragmoides_ (= _Alveophragmium_ = _Cribrostomoides_ aut.) _scitulus_ (Brady). — In the Mediterranean Sea, below 250 m; off the west coast of North America, at about 400 m (Cushman 1927); in the Peru-Chile Trench, at about 1800 m.

*_Cystammina pauciloculata_ (Brady). — Frequent below 250 m; in the Mediterranean Sea, 200 to about 3000 m; marked preference for deep waters. In the Pacific, lower bathyal and abyssal (Saidova 1961a); in the Peru-Chile Trench, about 1800 to 6000 m.

Trochamminoides. — According to Bandy & Rodolfo (1964) this is a deep water genus. *_Trochamminoides conglobatus_ (Brady) reported from bathyal depths: in the West Indies seas, at 820 m. According to data collected by Pflaumann (1967), *_T. proteus_ (Karrer) has its upper limit at 175 m; in the Peru-Chile Trench, commonly bathyal, below 2500 m. *_T. coronatus_ (Brady) (= _Haplophragmoides_ acc. to Cushman) is known only from depths greater than 700 m (Pflaumann 1967). Some species reported from the Carpathian flysch, like _T. contortus_ Grzyb., _T. subcoronatus_ Grzyb., are closely related, if not identical.

Lituotuba (= _Trochamminoides_ aut.) _lituiformis_ (Brady). — Reported mainly from bathyal depths; in the Mediterranean Sea recorded by Moncharmont Zei (1956) at 200 m in the Gulf of Naples.

*_Eggerella propinqua_ (Brady). — Depths 180 to 5300 m, mostly in deep waters, in the Mediterranean Sea at 246 m. Widely distributed in fairly deep waters of the Atlantic Ocean (Cushman 1941).

*_Ammolagena clavata_ (J. & P.). — Mainly bathyal, in the oceans 180 to 3600 m; in the Mediterranean Sea 160 to 1300 m, in the Peru-Chile Trench at various depths between 823 and 3500 m.

*_Plectina_ (= _Karreriella_ aut.) _apicularis_ (Cushm.). — In the Gulf of Mexico below 1000 m; elsewhere, below 120 m; often at abyssal depths (Saidova 1961a).

Spiroplectammina carinata (d'Orb.). — Few data; at great depths in the Pacific Ocean.

Spiroplectammina biformis (J. & P.). — From very shallow to abyssal depths; in the Gulf of Mexico below 700 m.

*_Saccammina sphaerica_ Brady. — In the Mediterranean seas, at depths below 370 m; but in the Gulf of Puzzuoli, at 100 m; in the Peru-Chile Trench, below 1800 m.

Gaudryina filiformis Berthelin was noted by Geroch (1966) as a Recent species occurring in the Lower Cretaceous. Actually, the Recent species, determined as _G. filiformis_ by Brady 1884, belongs to _Dorothia exilis_ Cushm. (see Barker 1960).

OTHER DEPTH INDICATIONS BASED ON THE AGGLUTINATE FORAMINIFERA

The Carpathian flysch contains several extinct species that may be regarded as homeomorphs or closely related to the living species. To these forms belong the species of _Cyclammina_, common in the Eocene, such as _C. amplectens_ Grzyb. and _C. rotundidorsata_ (Hantken). The Recent _C. cancellata_ Brady, known since the Oligocene, may occur sparingly at shallow depths, but is mainly a deep-water form (Akers 1954). In the Gulf of Mexico, it occurs at 400 to 1000 m (McLean 1971); in the Caribbean Sea, at 798 to 2690 m; in the Peru-Chile Trench below 500 m (Theyer 1971) and it is frequent at 1171 m; off the South California coast below 500 m (Bandy 1963a); in the Mediterranean Sea, at 200 to 1000 m. Voloshinova & Leonenko (1973) also find this species to be characteristic of infra-shelf depths. This species is very rare at great depths (although Saidova 1961a reports it down to a depth of 7660 m), and absent from very deep waters of the Arctic seas; therefore, Bandy & Kolpack (1963) regard it as suggestive of middle bathyal depths[2].

Extinct *Spiroplectammina spectabilis* (Grzyb.) on the basis of its relationship to Recent cold- or deep-water forms is considered by Hiltermann (1972b) as indicative of deep waters.

The Carpathian assemblages include in several cases agglutinate types with calcareous cement (*Gaudryina, Dorothia, Bigenerina, Pernerina*). Their presence argues for an environment above *CCD* (calcium carbonate compensation depths), but not necessarily for neritic depths, as Hanzlikova & Roth (1963) presume. Several species of *Gaudryina* in present-day seas live not only in the neritic but also in the bathyal zone: *G. aequa* is reported down to a depth of about 1500 m (Bandy 1961) in the Gulf of California; *G. atlantica* occurs in the same basin in the outer shelf and upper bathyal zone; *G. arenaria* down to 540 m in the Santa Monica Bay (Zalesny 1959). *Bigenerina* species are reported from the outer shelf and the bathyal zone (Murray 1973). On the whole, the presence of these genera suggests depths less than 1000 m.

DEPTHS DISTRIBUTION OF CALCAREOUS SPECIES IN RECENT SEAS

The Carpathian assemblages not uncommonly contain an admixture of calcareous species, and in some sections (the Oligocene Krosno Beds) these types are predominant. A number of species living at present occur among them. Unquestionably shallow-water species have been found in several instances but they invariably occur in allochthonous components, such as sandstones (Książkiewicz 1954), siltstones, or olistostromal deposits.

The calcareous Foraminifera that occur in the Carpathian flysch in authochthonous shales and marls fall into two groups: those with a wide depth tolerance in Recent seas and those with a marked preference for deep-water environments.

The first group comprises: *Bulimina pupoides* d'Orb., *B. elongata* d'Orb., *Pullenia sphaeroides* d'Orb., *Dentalina communis* d'Orb., *Eponides schreibersi* d'Orb., *Margulina glabra* d'Orb., *Gypsina globulus* Reuss, *Lagena globosa* Montagu, *L. sulcata* Walker & Jacob, *Cibicides* (= *Cibicidoides* aut.) *pseudoungerianus* Cushm., *Epistomina elegans* d'Orb. and a few others.

The second group includes (see also Table 1):

Cassidulina laevigata d'Orb. — Its usual depth range is 300 to 1000 m (Phleger 1960). In the Gulf of Mexico, particularly common between 500 and 1900 m, but in some cases also reported from the outer shelf, as in the Gulf of Paria, at 150 to 250 m (Nota 1958); in the Gulf of California, from the shelf and the bathyal zone down to 2400 m; in the Todos Santos Bay, in abundance below 600—700 m (Phleger 1960). In the Atlantic, the shallowest record is at 100 m and the deepest at 2800 m. In the Mediterranean Sea, at neritic and bathyal depths.

Chilostomella ovoidea Reuss. — In European waters, at depths of about 200 to 400 m; in the Gulf of California, from outer shelf down to about 1500 m; in the Todos Santos Bay

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[2] Hedberg (1934) reports *Cyclammina* sp. from the brackish Lake of Macaraibo, but he presumes that it is reworked from Tertiary sediments. Rech Frollo (1962a) mentions that Dolfus found *"vases à Cyclammina"* at shallow depths near the Canary Islands, but the present writer was unable to find this statement in Dolfus' papers.

(Phleger 1960), 100 to 1200 m, with a maximum abundance at 650 to 750 m; according to Resig (1958), restricted to the greatest depths (c. 300 to 350 m) of the Santa Cruz Basin; off California, recorded at 150 to 600 m (Ingle 1967) and below 600 m (Zalesny 1959); in the Caribbean Sea, at 298 to 1600 m (Cushman 1941).

Species of *Chilostomella* seem to be characteristic of the upper and middle bathyal zone. The closely related *C. oolina* Schwager (determined sometimes as *C. ovoidea*) occurs in the Gulf of Naples at depths 200 to 300 m (Hofker 1932); in the Gulf of Mexico characteristic of depths greater than 200 m, most common at 350 to 1000 m; in the Gulf of Biscaya below 290 m (Pujos-Lamy 1973).

Gyroidina (= *Gyroidinoides*) *soldanii* d'Orb. — According to Gevirtz & al. (1971), typical of upper bathyal depths on the American Atlantic slope. In the Gulf of Mexico, characteristic of depths greater than 200 m, most common down to 1850 m; in the Gulf of California, in the lower bathyal zone; in the Peru-Chile Trench, at various depths between 878 and 3257 m; common at depths 1100 to about 3500 m off Southern California coast (Crouch 1952); in the Gulf of Biscaya, below 230 m (Caralp & al. 1970); in the Mediterranean, at 180 m and deeper.

Bulimina aculeata d'Orb. — In the Gulf of Mexico, common particularly between 500 and 1900 m, and rare in shallower waters (McLean 1971). Its upper limit in the Mediterranean Sea is given by Bandy & Chierici (1966) as 200 to 350 m. In the Gulf of Biscaya below 160 m (Caralp & al. 1970); in the China Sea, at depths of 650 to 1500 m (Polski 1969).

Bulimina ovata d'Orb. — Reported mainly from depths of 400 to 1500 m. Cushman (1927) records many occurrences in deep waters, the shallowest at 124 m, off the west coast of America.

Uvigerina mediterranea Hofker. — In the Mediterranean Sea, at depths of 200 to 1000 m, with maximum frequency between 400 and 1000 m; rare in the neritic zone.

Robulus (= *Lenticulina*) *calcar* (Lin.). — Occurs in the tropical Pacific in "deep water material" (Cushman 1933); in the Gulf of Mexico, at depths of 120 to 750 m (McLean 1971). Bathyal in the Mediterranean Sea.

Robulus (= *Lenticulina*) *cultratus* Montf. — Sparingly at depths less than 200 m. Seems to be most frequent in the upper bathyal zone in the Mediterranean Sea.

Eponides umbonatus Reuss. — In the Gulf of Mexico, largely confined to depths greater than 80 m, and (according to McLean 1971) rare below 500 m; in the Gulf of Biscaya, at depths of 850 to 3200 m (Caralp & al. 1970); in the Pacific Ocean, 1500 to 3000 m (Saidova 1961a). Natland (1957) regards this species as one of rather certain indicators of a deep-water environment.

Pullenia bulloides d'Orb. — In the Gulf of Mexico, between 150 and 3000 m, mostly at depths of 1000 to 3000 m; similar depths off Southern California (Crouch 1952); infrabathyal in the Gulf of California; in the Atlantic Ocean, also at considerable depths (Cushman 1927); in the Mediterranean Sea, mainly bathyal; in the Gulf of Biscaya, 850 to 3200 m (Caralp & al. 1970).

Sphaeroidina bulloides d'Orb. — In the Mediterranean Sea, below 180 m; in the Gulf of Biscaya, 160 to 3200 m; in the Gulf of Mexico, 100 to 3000 m, but mainly 200 to 750 m. In the Atlantic Ocean, as recorded by Cushman (1927), below 1000 m.

Melonis (= *Nonion*) *pompilioides* (Fichtel & Moll.). — According to Cushman (1933), "essentially a deep-water species". This probably refers to the typical form, as a similar type occurs at shallow depths. In the Mediterranean Sea, upper bathyal; in the Gulf of Biscaya, lower bathyal (Pujos-Lamy 1973); off the California coast, its upper limit is 1300 m (Bandy & Chierici 1968); in the Gulf of California, typical of the lower bathyal zone, as in the Peru-Chile Trench.

Globorotalia. — According to Emiliani (1954), different pelagic species occupy different habitats with respect to temperature and water density. He reports that the depth of maximum population density is greater for *Globorotalia* (three species in the Gulf of Mexico, depths 130, 140 and 220 m) than for *Globigerina* (one species) and *Globigerinoides* (three species, at depths of 0 to 45 m). One may, then, presume that the beds with *Globorotalia* have been deposited at depths at least greater than 100 m.

SIGNIFICANCE OF RADIOLARIA FOR DEPTH DETERMINATION

In several members of the Carpathian flysch, radiolarians are abundant, occurring as a rule in association that consist of only agglutinate Foraminifera, a fact dismissed lightly by the followers of paralic or lagoonal origin of the flysch. In some units (Albian — Cenomanian, and a few horizons in the Eocene) even radiolarites are developed. The occurrence of radiolarites within flysch deposits is not uncommon (McBride 1962; Danner 1970). Since Radiolaria live throughout a deep column of water, even at infrabathyal depths, sediments of a deep-sea floor are likely to contain more Radiolaria than sediments deposited at shallower depths. According to Bandy (1964), Radiolaria are more abundant than Foraminifera at depths greater than about 1500 m off the Pacific coast of North America, and at a depth of about 1300 m off the west coast of Central America. In the Peru-Chile Trench, they attain a maximum abundance between 1000 and 4000 m (Bandy & Rodolfo 1964) and in the sediments of the middle bathyal zone they may be many times as abundant as the Foraminifera. Polski (1959) finds that Radiolaria occur abundantly off the North Asiatic coast at depths greater than 2000 m. Wezel (1970) uses the Radiolaria/Foraminifera ratio for depth determination, and assigns a deposition depth of 1200 to 2000 m to the Numidian Flysch (ratio $>$ 1).

CHARACTER OF FORAMINIFERAL ASSEMBLAGES

The general character of fossil asemblages may also be used for depth determination. As is well known, species diversity increases with depth and the distance from the shore, to a certain depth. Farther down, in the lower bathyal zone, the number of species decreases (Bandy & Arnal 1960). The saline marshes contain assemblages with fairly small numbers of genera and species: usually three to eight genera and five to eight species (Phleger 1960). In the brackish water and salt-marsh environments, the assemblages often consist of a few species represented by many individuals (Hiltermann 1966). In estuaries and lagoons, the species diversity is also low (Murray 1973). With few exceptions, the flysch assemblages consist of a considerable number of species, while the number of individuals is relatively small. The following may serve as examples:

Krosno Beds, Oligocene: 95 species (Gucik & Morgiel 1960),
Menilite Beds, Eooligocene: 99 species (Liszka 1957),
Magura Beds, Oligocene — Upper Eocene: 37 species (Jednorowska 1968),
Variegated Shales, Lower Eocene: 77 species (Jednorowska 1968),
Lower Istebna Beds, Senonian: 70 species (Jurkiewicz 1961a),
Ropianka Beds, Senonian: 80 species (Jednorowska 1968),
Lgota Beds, Albian: 28 species (Geroch 1966).

These are species diversities certainly much lower than normal for neritic zones, but much higher than for marginal zones.

One characteristic feature of the Carpathian flysch foraminiferids, known since Grzybowski's time, is that they are smaller in size than the corresponding modern forms. This may be caused by undernourishment or other unfavourable life conditions. Bandy (1963) has, however, found that several species become larger with increasing depths and decreasing temperature. The inference would be that the Carpathian flysch has not been deposited at very great depths.

A singular problem is posed by the presence of assemblages composed of exclusively agglutinate species. This is used by Brouwer (1965) and Koszarski & Żytko (1966) as an indication of flysch deposition below *CCD*, at abyssal depths. It should, however, be emphasized that in nearly all members of the Carpathian flysch, calcareous, benthonic and/or planktonic species are being found occasionally. Significantly, planktonic Foraminifera occur more often than the benthonic types, although their tests are more easily dissolved in deep waters than the tests of benthonic calcareous species[3] (Cità 1971). The paucity or absence of calcareous species may result from several factors, as previously discussed at length (Książkiewicz 1961). It may be assumed that in deeper, enclosed parts of the basin, poor circulation and low $CaCO_3$ concentration, caused by the decomposition of organic matter brought in by turbidity currents, were preventive factors for the development of calcareous tests. Hiltermann (1966, 1973) suggests that the low oxygen content, together with low temperature, favor the development of the agglutinated Foraminifera. The solution of tests may also be taken into account, but, as stressed before (1961), no corrosion is observed on the calcareous tests. This has also been noted in other flysch regions by Prey (*in* Gohrbrandt & al. 1960) and Pflaumann (1967). It is also possible that the occurrences of planktonic species were more numerous, but, as suggested by Simpson (1969), their tests were more easily removed by currents due to lower densities than those of agglutinate species. Grün and his associates (1964) have shown in the Austrian flysch that the colonization of the sea-floor by agglutinate Foraminifera was gradual, as indicated by the number of species increasing towards the top in a shaly bed. This agrees with the present author's observations in the Carpathians (*in* Dżułyński, Książkiewicz & Kuenen 1959, p. 1100) that the richest assemblages occur in the uppermost part of shaly interbeds. For this reason, the possibility may be envisaged that, after the colonization by agglutinate Foraminifera, the next step would be the appearance of calcareous benthonic species as more fastidious with regard to life conditions. Either the arrival of another turbidity current did not leave time for the development of calcareous species, or, if they actually had appeared, the current washed them down. Pflaumann's (1967) explanation that turbid water ("*Wassertrübung*"), hindering the light, eliminated calcareous forms can hardly be accepted since the "*Trübung*" is caused by waves in a very restricted littoral zone, and this cannot be envisaged for the Carpathian basin at least 300 km wide. The turbidity may also be produced by the inflow of a muddy river water into the sea. In the case of a large river a sheet of

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[3] The latter may occur down to 8240 m (Lukina 1967).

turbid water may spread far from the river mouth. This is hardly applicable to the Carpathian basin which, as already pointed out, was not bordered by extensive continents with large rivers (Dżułyński & al. 1959).

DISPLACED MICROFAUNAS

At the very beginning of modern studies of the Carpathian flysch it was noted that the sandstones (element *I*) contain small Foraminifera different from those in the interbedded shales (Książkiewicz 1954). Similar facts are reported from many other flysch successions: the Magellanes flysch (Zeil 1958), the Bavarian flysch (Zeil 1960; Pflaumann 1967), the Appenin flysch (Dieci & al. 1969) etc.

The displacement of foraminiferids has frequently been found in deep-water sands of present-day seas (Natland 1957; Ingle 1967). In the Adriatic Sea, a rich displaced microfauna is reported by Brouwer (1967) from a graded layer found at a water depth of 1198 m. The Foraminifera occur in the coarser part, where they are sorted and different from those occurring in the underlying autochthonous clay. According to Bandy (1964), deep-water sands are typified by a high percentage of shallow-water forms, possibly by a greater abundance of plankton species and a reduced number of species. Very similar features have been found in the Carpathian flysch.

The displacement can be brought about in two ways: by currents or mudflows. The graded siltstones in the Oligocene Krosno Beds, described by Morgiel & Sikora (1963) may be given as an example of the former possibility, in addition to that described before (1954, p. 433 and 448). They contain both the foraminiferids typical of shallow-water zone (*Miliolidae, Streblus beccarii, Amphistegina, Reussella spinulosa* etc.) and those characteristic of a deeper zone (*Gyroidina soldanii, Chilostomellidae, Cassidulina*). The current evidently took the material from different bathymetric zones. The mudflow deposit described by Geroch & al. (1972) from the Albian Lgota Beds may serve as an example of the latter possibility. Radiolarians and agglutinate species, the same as in the autochthonous shales, have been found in addition to calcareous species, most probably derived from a shallow-water environment.

CONCLUSIONS ON FORAMINIFERS

The presence of several Foraminifera living in contemporary seas at considerable depths strongly supports the view that the Carpathian flysch has been deposited in a marine basin of normal salinity and substantial depth. The inferences based on present-day depth distribution of species may be invalidated if the fossil species were actually not strictly conspecific with present-day forms, as surmised in some cases. Another objection may be based on the view that some species could have changed their habitat and that in Cretaceous or Tertiary times the deep-water species of present-day seas lived in shallow seas. However, no indications support this view.

The microfaunal composition of the Carpathian flysch invalidates the idea of its deposition in paralic environments. It suggests, on the contrary, the upper and middle bathyal depths, in some cases maybe also infrabathyal depths. There are no indications that any substantial part of the Carpathian flysch has been deposited below *CCD*.

TRACE FOSSILS

Trace fossils occur abundantly in the Carpathian flysch. In a previous paper (Książkiewicz 1970) 40 ichnogenera with some 70 ichnospecies were determined, but since that time this number has at least been doubled.

The application of ichnological studies to the problems of paleobathymetry was initiated by Seilacher (1954) who contrasted molasse and flysch assemblages of trace fossils. Subsequently, he showed that protective burrows and resting tracks characterize shallow-water environments, whereas horizontal feeding burrows prevail in deeper-water environments. The burrows of the latter type occur abundantly in the Carpathian flysch, while the former are absent or very rare.

No sub-aerial tracks have been found in the Polish Carpathian flysch. The present writer's collection consists of about 3000 specimens from all Carpathian flysch members, and there are no traces that can be regarded as bird tracks. This is emphasized here in connection with Rech Frollo's assertion (*in* Mangin 1962a, p. 36, discussion) that, together with the writer, she saw bird tracks in the Carpathian flysch. Deplorably, this untrue statement, despite Kuenen's denial (1964, p. 26, see also Dżułyński & Smith 1964, footnote on p. 250), has been repeated by Van der Lingen (1969, p. 29). Much importance is attached by Bieda (1969, p. 501) to Mangin's (1962b, 1964b) discovery of bird tracks in the Pirenean "flysch". However, Bieda overlooked the fact that de Raaf (1964) had shown that these deposits belong to a molasse. This has been confirmed by Feuillé (1970).

The environments of salt swamps is not suggested by rich assemblages in the Carpathians. Burrowing fauna is absent from, or poorly developed in the saline swamps (Bouma 1963).

The depth determination by means of ichnofauna still poses many doubts, but it seems that due to abundance and diversity of both microfauna and ichnofauna and great lateral and vertical variation of sediments certain concepts based on trace fossils may be tested in the Carpathians.

The distribution of trace fossils is influenced by many factors, and evaluation of their relative importance is extremely difficult. There is still controversy over the extent to which water-depth affects the type and distribution of trace-producing animals. In addition to depth, sediment type and amount of food may play a considerable role, but both these factors are more or less connected with depth. The possibility of the preservation of traces may also affect their distribution.

The flysch ichnofauna is of a specialized type. Most trace fossils are interfacial burrows on the soles or upper surfaces of sandy beds, a few of them are endichnial trails traversing the sandstones, and several are casts of burrows or trails made by animals grazing in clay or on its surface. The shales in the flysch are not at all, or only to a small extent, affected by bioturbation (Dżułyński & Smith 1964, p. 251). This seems to be in contrast to the conditions on shelves where the muddy bottom frequenly shows intense bioturbation (Allen 1964; Conolly 1969).

Several authors emphasize that abundant ichnofauna implies abundant food supply and, as the amount of food decreases with increasing depth, the rich ichnofaunas of the flysch are to be another proof of its shallow-water origin (Bieda 1969). However, since Fuchs's (1894) finds, burrows of benthonic organisms are repeatedly found in deep-sea cores or their trails and tracks photographed on the deep floor (Bourne & Heezen 1965). Griggs and his associates (1969) have shown that the introduction of sediment by turbidity currents actually increases the amount of organic material and, consequently, causes an abundance of fauna in a deep-water environment (see also Dimitrijević 1967).

The trace fossils of the Carpathian flysch may be divided into a few groups differing in morphological appearance [4]. This is not a phylogenetic classification, but to a great extent a functional classification based on the behavior of the sediment-processing animals. Such a classification may give a clue to the nature of environment.

GROUP 1

Sand-filled, cylindrical, mostly endichnial burrows, traversing sandy layers in various directions, also vertically. They occur in thick and relatively coarse layers.

This type of burrow is suggestive of high-energy, shallow water conditions. Similar types have, however, been found by Kern & Warme (1974) in beds deposited probably in a bathyal environment. These authors stress that the paleoenvironmental interpretation should not be based on individual ichnospecies. This group is very rare in the Carpathians.

GROUP 2

Sand-filled, cylindrical, horizontal, interfacial, hypichnial or epichnial and less frequently endichnial burrows, mostly not branching, more or less straight. Here belong sculptureless (*Sabularia* = sandy *Granularia, Arthrophycus,* forms similar to

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[4] Circular and elliptical forms are omitted (very rare).

Ophiomorpha) and sculptured types (*Halymenidium, Fucusopsis, Gyrochorte, Rhabdoglyphus,* etc.). This group may represent horizontal, branching or winding traces, which according to Seilacher (1967), characterize intermediate depth zones.

GROUP 3

Spreite burrows, helicoidal (*Zoophycos*) or planar (*Hydrancylus*). The ichnogenus *Zoophycos* is usually regarded as a shallow-water form, although Seilacher (1967) reports a horizontal *Zoophycos "Spreite"* from a depth of 3800 m. Crimes (1973) notes this form in beds of a rather proximal character and Chamberlain (1971) places it at depths between the sublittoral and bathyal zones.

GROUP 4

Rosetted trails, hypichnial casts or full burrows, or epichnial hollows, occurring often gregariously. They may be divided roughly into two subgroups: regular (*Lorenzinia, Bassaenia*) and irregular (*Glockeria, Sublorenzinia, Gyrophyllites*). These two subgroups may have different depth significance. Rosetted trails (of rather irregular type) are noted by Crimes (1973) in proximal deposits.

GROUP 5

Horizontal, hypichnial and epichnial full burrows or casts, also irregularly winding tracks with a more or less pronounced tendency to meander (*Subphyllochorda, Scolicia,* partly *Taphrhelminthopsis*). The meaning of these burrows is variously interpreted. Chamberlain (1971) regards *Scolicia* as characteristic of a shallow--water zone, while Crimes (1973) reports it both from proximal and more distal zones.

GROUP 6

More or less horizontal, densely branching, mainly endichnial (*Chondrites, Taenidium, Bostricophyton*) and hypichnial (*Lophoctenium, Strobilorhaphe*). *Chondrites* prefers calcareous sediments and its distribution is to a considerable extent influenced by lithology. Chamberlain (1971) regards abundance of *Chondrites* as indicative of bathyal depths (upper slope).

GROUP 7

Horizontally meandering hypichnial (*Cosmorhaphe, Helminthoida, Helminthopsis*) and rarely epichnial (some types of the *Helminthoida*) traces. To this group networks are assigned as most of them are produced by some sort of meandering (*Protopaleodictyon, Paleodictyon, Urohelminthoida, Megagrapton*) and also spiral forms (*Spirorhaphe, Spirophycus*), although they probably should be grouped separately. Generally, this group may be called "patterned" traces. This group is best developed in thin-bedded sandstones. According to Seilacher (1967), the patterned traces characterize deep-water environments. Actually, Crimes (1973) has demonstrated that the number of meandering species increases in the distal regions of the North Spanish flysch. Chamberlain (1971) infers bathyal depths for assemblages containing patterned types.

Groups *1* to *7* are listed according to an increasing intricacy of the grazing system. Animals producing simple traces followed more or less straight path and evidently found enough food on it. Traces of groups *3* and *4* were left by more sedentary animals which more closely processed the sediment. Group *5* tends to utilize sediment more efficiently, as shown by winding and loose meandering. In group *6* by burrowing in densely branching tunnels the animals could more efficiently rework the sediment. Group *7* includes trace of animals which, by a very intricate pattern of burrowing, left very little sediment unprocessed. Thus, the increasing intricacy of the traces denotes an increasing efficency in sediment grazing.

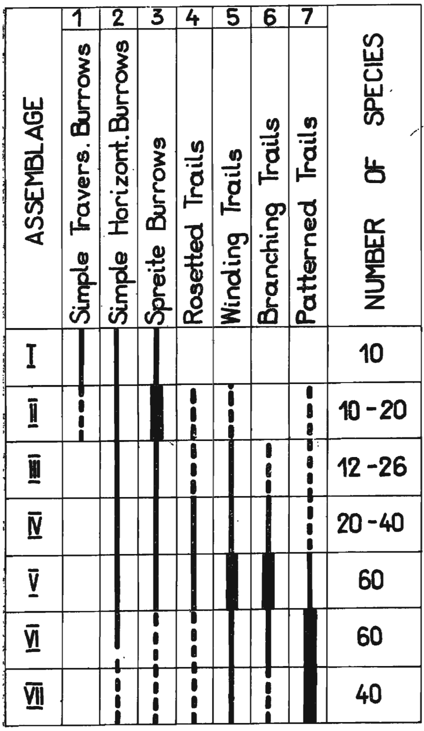

Fig. 3. Trace fossils assemblages of the Carpathian flysch

At greater depths, sediments contain less organic matter and the sediment-ingesting animals have to process it more efficiently. This reasoning justifies the idea that the traces with more complicated patterns represent the work of animals adapted to deep-water conditions, poor in food.

Except for group *1* all others occur practically in all members of the Carpathian flysch, but in various proportions. Due to this fact, seven main assemblages of different composition are distinguishable (Fig. 3).

Group *2* occurs in all assemblages. This would mean that the Carpathian flysch has not been deposited at very great depths. This conclusion seems to be supported by the presence of *Zoophycos* in nearly all associations. Group *6* with *Chondrites* clearly occupies an intermediate position, as it is nearly absent in beds containing few or no patterned forms (assemblages *I—III*) and is very scarce in assemblages with numerous patterned forms (assemblages *VI* and *VII*), while it is most abundant in assemblages with small or moderate number of patterned traces. This seems to confirm Chamberlain's (1971) view on the intermediate position of *Chondrites*. Group *4* (rosetted trails) has a somewhat ambiguous significance. It occurs either in association with few patterned traces or, conversely, in the assemblage where the latter are abundant. But in the first case the rosetted traces are mainly irregular, in the second — regular. At all events one may safely presume that assemblages *I—II* indicate the shallowest, assemblages *III—V* intermediate, and assemblages *VI—VII* the greatest water depths.

Another approach to the problem of depth determination by means of the distribution of trace fossils may be based on the principle that the species diversity is higher on the continental slope than on the shelf in present-day seas (Sanders & Hessler 1969) and that species diversity increases with depth down to a certain limit (about 2000 m; Vinogradova 1962). Care must, however, be taken, since one sediment-grazing animal may produce traces of more than one type; but if doubtful cases are eliminated, it is possible to compare the numbers of species in different assemblages. The greatest number of ichnospecies occur in the members of the flysch succession which are characterized by assemblages *V* and *VI*. It is presumed that these assemblages developed at bathyal depths, above a depth of 2000 m. Assemblage *VII* with numerous patterned types, but with smaller number of ichnospecies, may indicate a greater depth. Assemblages *III* and *IV*, with smaller number of species and smaller number of patterned traces, would represent depths between 200 and 1000 m. Assemblage *II* would indicate depths of about 200 m, and assemblage *I*, a near-shore zone.

Although these estimates may appear at first to be exercises in fancy guesswork, they are confirmed to a certain extent by results of an analysis of the composition of microfossil assemblages. As shown below, the beds, characterized by foraminiferal assemblages of the deeper bathyal zone, contain a more diversified ichnofauna, with numerous branched and patterned forms. The beds containing fewer deep-water species of the Foraminifera and, at the same time, a number of species characteristic of the upper bathyal zone, display assemblages of trace fossils which are poorer in patterned forms and of lower diversity.

In present-day seas, the population density of the infauna, like that of the epifauna, decreases with depth. It is hardly possible to draw any conclusions concerning ichnofauna, based on the number of individuals, since one organism may produce many traces and the abundance of one trace fossil on or in a bed does not mean many producers. One may only recall Kuenen's (1968) view that a very good preservation of burrows suggests a rather low intensity of life.

CHANGES IN DEPTH

It may be anticipated that the Carpathian basin existing from the Jurassic up to the Lower Miocene was not of the same depth everywhere and all the time (*cf.* Fig. 4). Changes in depth may be estimated tentatively and approximately. Sedimentary features and faunal evidence are used for this purpose. Unless otherwise indicated, the microfaunal data are taken from the papers by Bieda, Geroch, Koszarski, Książkiewicz & Żytko (1963) and by Geroch, Jednorowska, Książkiewicz & Liszkowa (1967). Ichnofaunal data are based on the writer's paper (Książkiewicz 1970) and on some new unpublished materials.

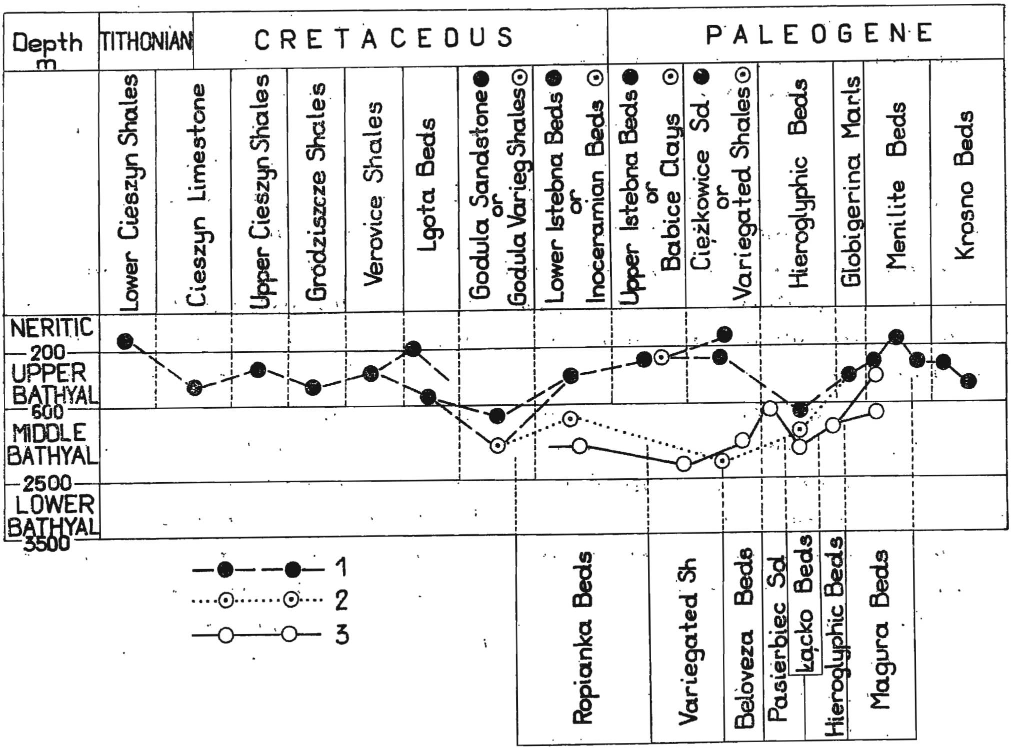

Fig. 4. Depth changes during the evolution of the Carpathian flysch basin
1 depths in the Main Trough, *2* depths for certain facies in the Main Trough, *3* depth in the Magura Trough

The Carpathian succession begins with the *Lower Cieszyn Shales (Tithonian)*. This is a marly deposit with no flysch features except for few intercalations of graded beds. Lenses of pelletal limestones indicate a local deposition near the wave base. The microfauna (several species of *Trocholina* and *Paalzowella*) argues for shallow-water. Simple burrows are not uncommon and *Zoophycos* is also present. Middle neritic depths with some shoals are inferred.

CIESZYN LIMESTONE (UPPER TITHONIAN — BERRIASIAN)

All features typical of flysch are present (Książkiewicz 1954). Grading is conspicuous, even in the thin-bedded elements *I*. A few layers of amalgamated bedding, armoured mud-balls, olistostroms with blocks of reefal and oolitic limestones, frequent wedging-out of elements *I*, and flutes not very common indicate a proximal deposition, although many beds display features of a more distal deposition. The microfauna in shales is different from that in limestones. Calcareous species (*Trocholina*, *Miliolidae*) predominate in the former and agglutinate types (*Glomospira*, *Ammodiscus*, *Rhizammina indivisa*; Geroch 1966) in the latter. The ichnofauna consists of twenty species with simple burrows, rare *Zoophycos*, fairly numerous irregular rosetted forms, abundant *Chondrites* and not very common patterned forms (assemblage *IV*). Upper bathyal zone.

UPPER CIESZYN SHALES (VALANGINIAN)

Thin-bedded flysch with black shales. Horizontal and small-scale current lamination predominant, grading rare, flutes uncommon, imply a rather distal region of deposition, but also a proximal deposition by currents with small volume of sediment may be presumed. Agglutinate and calcareous (*Lenticulina*, *Dentalina*, in the Mediterranean Sea, both genera represented mostly in the bathyal zone; Blanc-Vernet 1969) Foraminifera and some radiolarians. In the marginal zone of this unit there also occur purely calcareous assemblages (*Trocholina*, *Epistomina*), possibly marking a more shallow zone. The presence of not very uncommon ammonites, both in shales, and on the sole of sandstones, indicates an open sea. Probably due to a poor oxygenation of bottom waters the ichnofauna is poor and with low diversity (eight species). Assemblage rather *II* than *III*, with simple burrows, some rosetted trails, and very rare patterned forms. Uppermost bathyal zone seems to be most probable.

GRODZISZCZE SHALES (HAUTERIVIAN)

Thin-bedded, often with thick interbeds of marly shales. Wedging-out and not quite parallel-sided sandstones frequent, horizontal lamination predominant, grading fairly common, flutes rare, olistostromal and slumped deposits common. This may be a proximal deposit, but laid down in fairly deep water where mostly ooze accumulated. The microfauna quite rich, consisting of both calcareous (*Lenticulina*) and arenaceous Foraminifera (*Rhizammina indivisa*, as well as a few species of *Marssonella* (= *Dorothia*), *Trochammina*, *Thalmannammina*). Trace fossils (16 species) fairly abundant, simple burrows, *Gyrochorte*, *Belorhaphe*, *Paleodictyon*, meandering forms and *Chondrites* are not uncommon (assemblage *III*, locally approaching *IV*). A deeper part of the upper bathyal zone may be inferred.

VEROVICE SHALES (BARREMIAN — LOWER APTIAN)

Pelagic deposits, locally passing into flysch facies. A very well-known ammonitic fauna indicates an open sea. Agglutinate Foraminifera predominant (*Gaudryina*, *Bigenerina*, *Rhizammina indivisa*, *Haplophragmoides nonioninoides*, the last-named species known from supposedly shelf sediments of the foreland; Hanzlikova & Roth 1963); *Hormosina ovulum* appears here for the first time in abundance. This species in higher stratigraphic members is associated with forms characteristic of deeper water habitat. Radiolaria fairly common. The ichnofauna is poor, as there are few sandy interbeds, and the shales are black; simple burrows and *Gyrochorte* are present. In the marginal northern zone there are olistostroms with some calcareous Foraminifera. At least the outer neritic zone and more probably the upper bathyal depths should be envisaged for the bulk of this member.

GRODZISZCZE SANDSTONE (HAUTERIVIAN, MAINLY BARREMIAN — LOWER APTIAN)

This is a marginal facies of the Verovice Shales. Conglomerates, rough grading and few shaly interbeds indicate a proximal deposition. The graded sandstones contain displaced ammonites, the debris of which are also graded. The ammonites belong mostly to *Douvilleiceras* and *Ancyloceras,* forms provided with strong ribs and nodes and probably living in a shallow, agitated water. This suggest that the sandstones were deposited at greater depths than the habitat of these ammonites. Numerous fragments of colonial corals with perfectly preserved structures (Morycowa 1959), occurring in conglomerates, indicate a transport in suspension rather, than by traction currents.

LGOTA BEDS (ALBIAN)

In the lower part, thick-bedded sandstones are frequently developed with some lensing and imperfect or no grading, possibly deposited proximally by sandflows or very dense turbidity currents. In one or two places (Kalwaria in the western part of the mountains), a single bed exhibits large-scale cross-bedding which suggests deposition by a traction current in a very shallow water. This implies that in some places sedimentation brought the sea-floor near the wave base. Elsewhere, the Lgota Beds are developed as thin-bedded flysch, with fairly good grading, gradational and ordinary horizontal lamination. Small-scale current bedding is rather rare, flutes infrequent. In some sections, shales prevail over sandstones. An intermediate to distal deposition may be inferred. Parts with isolated lenses with single-current bedding (Unrug 1959) may be interpreted after Walker (1966) as deposited in lateral zones of turbidity currents. The indigenous microfauna contains agglutinate species. Calcareous species occur in sandstones, siltstones and mudflows only (Geroch & al. 1972). Redeposited planktonic Foraminifera (*Hedbergella*) could be displaced from outer neritic or uppermost bathyal zones. Radiolaria are numerous, which would indicate considerable depths, but the presence of the representatives of *Bigenerina* and *Gaudryina* (Huss 1957; Geroch 1966) argues for a deposition above 1000 m. Trace fossils (twelve species) belonging to assemblage *III* include simple burrows, *Scolicia, Subphyllochorda, Taphrhelminthopsis,* whereas *Chondrites* and meandering forms are rare. All this would suggest depths not greater than the upper bathyal zone. The Mikuszowice Cherts, occurring in the top part of the Lgota Beds do not differ much in micro- and ichnofauna. Like the coeval Gaize Beds, they contain layers with numerous sponge spicules; grading and lamination indicate redeposition. According to Alexandrowicz (1973), sponge meadows probably grew at depths of 150 to 250 m. The beds with spongiolites and gaizes (spiculites) must have been deposited below these depths.

GODULA BEDS (CENOMANIAN — LOWER SENONIAN)

Fairly good grading, horizontal and small-scale current lamination and abundant flutes suggest intermediate deposition, except for the lowest part in the west, which displays proximal features. The not very numerous benthonic Foraminifera are all agglutinated forms. Occasional occurrences of planktonic species (globotruncanids) indicate a deposition above *CCD*. Trace fossils (twenty six species) are represented mostly by simple horizontal burrows, frequent *Zoophycos*, irregular rosetted trails, frequent *Scolicia* and *Taphrhelminthopsis*, rare *Helminthoida* and *Paleodictyon* (assemblage *III*). A higher species diversity, as compared with the lower members is probably due mainly to better oxygenated bottom waters (lighter colors of indigenous shales) and to a greater depth. A moderate depth in the bathyal zone, slightly exceeding that of the deposition of the preceding members is suggested.

GODULA VARIEGATED SHALES (CENOMANIAN — LOWER SENONIAN)

They partly or totally replace the Godula Beds towards the east. Red argillites appear here for the first time, probably deposited at depths where the amount of organic matter was not sufficient to reduce the oxydized material brought in from the land. Radiolarites occur in the lowest part, but contain marly interbeds with calcareous Foraminifera. This implies a deposition above *CCD*, unless the marls were introduced by some bottom currents from a zone situated above *CCD*. According to Cita's (1970a) observations, beds deposited by turbidity currents may still contain calcareous species even at depths at which calcareous forms are as a rule dissolved (see also Conolly 1969). This is due to a rapid deposition. Except for some delicate and to all appearance not a current lamination, there are, however, no features suggesting a deposition of these marls by currents. Variegated (red and green) argillites also contain marly interbeds with planktonic Foraminifera (*Praeglobotruncana, Rotalipora, Hedbergella*), but the argillites contain only agglutinate species in addition to radiolarians abundant in the lower part of the member. The representatives of *Trochamminoides* appear here, and *T. proteus* is reported from the overlying red marls probably of Turonian age (Huss 1966). The abundance of Radiolaria is indicative of a depth in excess of 1500 m, but marly intercalations and the presence of calcareous plankton indicate, at any rate, a deposition above *CCD*. The intermingling of the Godula Beds with the flysch indicates that the Variegated Beds could not be deposited at much greater depths than the flysch. Some 1500 to 2000 m seem to be a reasonable estimate.

In the Late Cretaceous, the hitherto single basin was divided into two troughs, the northern, Main Trough, and the southern, Magura Trough. This caused a considerable differentiation in facies and the Upper Cretaceous beds were developed in four principal facies units. From the north to the south these are:

INOCERAMIAN BEDS (TURONIAN — SENONIAN)

Its lower part is developed as the Siliceous Marls resting on the Godula Variegated Shales. The Siliceous Marls represent to a great extent a carbonate flysch consisting of alternating hard calcareous marls and soft marly shales, with sharp soles of element *I*, some grading, horizontal and small-scale current lamination and rare flute casts. Calcareous marls contain sponge spicules and some planktonic Foraminifera, while the shales, abounding in planktonic species (*Globotruncana, Gumbelina*), contain some calcareous benthonic (*Stensioina*) and very few agglutinate forms. The predominance of planktonic species suggests the upper bathyal zone, into which also calcareous material was brought by currents from the outer neritic zone. In the ichnofauna, *Chondrites* is predominant, *Hydrancylus* frequent, meandering forms rare, species diversity low (twelve species) and assemblage approaching *V*. It is likely that some parts of the Siliceous Marls, with no obvious flysch features, represent the original slope calcareous ooze.

The Inoceramian Beds proper vary in sedimentary features, but their main body is characterized by good grading, all kinds of lamination and abundance of flutes. They could have been deposited not very near the source, except for some thick-bedded, imperfectly graded sandstones. Occasional sandstone-marl-shale sequences indicate that sand was transported across a calcareous ooze zone. Agglutinate Foraminifera predominate; calcareous species, both benthonic and planktonic, are also not uncommon (Jednorowska 1957; Jurkiewicz 1960). Several modern species appear here for the first time: *Rhabdammina abyssorum*, *R. linearis*, *Reophax pilulifer*, *Ammolagena clavata*, *Trochamminoides coronatus*, *Cystammina pauciloculata*, *Bathysiphon filiformis*, *Trochammina globigeriniformis* and *Gyroidina soldanii*. The presence of *Dorothia*, *Gaudryina* and *Pernerina* and occasional occurrence of *Eponides* suggest a deposition above 1000 m. In the ichnofauna, simple burrows are abundant and *Zoophycos* fairly frequent, as well as *Scolicia* and *Taphrhelminthopsis*; on the other hand, *Chondrites* abounds in marls, but patterned forms are relatively rare (assemblages *III* and *IV*). Species diversity high (40).

Northwards, i.e. in the direction of the presumed coast of the basin, the Inoceramian Beds pass into the Węgierka Marls. The sedimentary features of the latter are not of flysch type: no grading, small-scale current bedding, occasional intrastratal washouts and frequent intraformational conglomerates (Książkiewicz 1954). Apparently, the autochthonous inoceramids and other lamellibranchs, both benthonic and planktonic calcareous Foraminifera suggest a neritic, most probably outer neritic zone and a slow sedimentation, locally interrupted by feeble bottom currents. The transition and intermingling of these marls with the flysch Inoceramian Beds would suggest that the latter could not be deposited much deeper than the zone, in which calcareous oozes accumulated. Depths, oscillating between 200 and 1000 m, seem probable.

VARIEGATED WĘGLÓWKA MARLS (TURONIAN — SENONIAN)

This sediment, deposited in the axial zone of the Main Trough, is a non-flysch, pelagic sediment, as shown by its microfauna, in which globotruncanids play an important role. Calcareous benthonic Foraminifera are the main component, with *Reusella szajnochae* (Grzyb.) as one of the most characteristic species. Modern *Reussella* live mainly in neritic and bathyal zones (e.g. Gulf of California; Bandy 1961), but *R. szajnochae* is reported from an Atlantic core at a depth of about 5000 m (Cità 1970b) in an area which in the Upper Cretaceous was in all likehood situated at considerable depths. Significantly, this species is absent from coeval marls of the Carpathian foreland, and also lacking in the marls of the outer Carpathian klippen. In either case, these are neritic sediments. The presence of *Lenticulina*, *Robulus*, *Bolivina* and *Stensioina* in the Węglówka Marls suggests outer neritic or upper bathyal depths, but several species of *Trochamminoides* are also present (Geroch & Gradziński 1955; Liszkowa 1959). Huss (1957, 1966) reports *Cystammina pauciloculata*, *Reophax pilulifer*, *R. guttifer*, *Trochamminoides proteus*, *Trochammina globigeriniformis*, *Saccammina sphaerica*, while Grzybowski (1896) also mentions *Psammosphaera fusca* and *Rhizammina indivisa*. This would mean that the Węglówka Marls were deposited well below the neritic zone. The partly coeval Frydek Marls consist of the following two types of deposits: marls with predominant planktonic Foraminifera, often with the *Chilostomellidae* (including *Chilostomella ovoidea*), and marls which, in addition to planktonic species, contain shallow-water species of the *Orbitoides* group. As these marls frequently contain "exotic" (= pre-flysch) blocks and show evidence of slumping, it may be presumed that they represent a mixture of pelagic, most likely upper bathyal, deposits and slumped calcareous ooze from the neritic zone (Książkiewicz 1962). At any rate, the Frydek Marls were deposited at a shallower depth than the Węglówka Marls.

LOWER ISTEBNA BEDS (SENONIAN)

Coarse, thick-bedded sandstones and conglomerates are the main component. Imperfect grading, amalgamated beds, lenticularity, and channelling are common features (Unrug 1963), while flute casts are very uncommon. Whether these beds should be treated as sandy flow deposits (fluxoturbidites; Dżułyński & al. 1959) or as proximal turbidites (Walker 1967) is of no importance to bathymetry, but there is little doubt that they were laid down near their source. The presence of extensive olistostroms indicates a considerable slope and not very small depth. Agglutinate species, including *Trochamminoides* and *Bathysiphon*, occur mostly. The micro-fauna, very poor in the west (Geroch 1960), is much more abundant in the east where, according to Jurkiewicz (1961), it includes *Rhabdammina abyssorum, Saccorhiza ramosa, Reophax guttifer, R. nodulosa, Ammologena clavata, Lituotuba lituiformis, Trochamminoides coronatus, Cystammina pauciloculata.* The presence of agglutinate species with a calcareous cement may indicate depths not exceeding 1000 m and *Reussella szajnochae, Eponides, Bulimina* and globotruncanids are also indicative of a deposition well above *CCD.* Blocks of foraminiferal marls in olistostroms suggest depths which are at any rate below the neritic, or even upper bathyal zone. The ichnofauna is poor (twelve species), including simple endichnial burrows, few winding traces, rosetted forms (*Gyrophyllites* seems to be particularly frequent) and very rare patterned types (assemblages *II* and *III*). In the east, where marly interbeds are developed, *Chondrites* also occur (assemblage *IV*). Upper bathyal depths may be inferred, probably greater in the east than in the west.

ROPIANKA BEDS (= INOCERAMIAN BEDS IN THE MAGURA TROUGH)

The lithology is very much the same as in the Inoceramian Beds of the Main Trough, except for the marly beds which are somewhat less developed. The micro-fauna mostly consists of agglutinate Foraminifera with *Trochammina globigeriniformis, Rhabdammina abyssorum, Bathysiphon filiformis, Cribrostomoides subglobusos, Spiroplectammina spectabilis, Cystammina pauciloculata, Eggerella propinqua, Lituotuba lituiformis, Trochamminoides coronatus, T. proteus, Reophax pilulifer, Ammolagena clavata, Psammosphaera fusca* (Grzybowski 1901; Bieda, Jednorowska & Książkiewicz 1967; Jednorowska 1968; Blaicher *in* Sikora 1970). The number of species displaying preference for deep waters is here greater than in the Inoceramian Beds. Calcareous species are rare, but both benthonic and planktonic species are present. The ichnofauna, displaying a high diversity (more than 60 ichnospecies), corresponds with assemblages *V* and *VI*, whose diversity increases in the downcurrent direction (eastward). Meandering and netlike types are frequent, along with numerous winding forms and *Chondrites, Taenidium* etc, whereas *Zoophycos* seems to be more abundant in the upper section of the Ropianka Beds and also in the more western region. All this indicates that the Ropianka Beds were deposited at greater depths than the Inoceramian Beds, but the considerable number of ichnospecies seems to preclude depths greater than 2000 m. A deposition in the middle part of the mesobathyal zone may be a sound estimate.

Situated south of the Ropianka Beds, the Sromowce Beds were deposited in the zone of the Pieniny Klippen. Their sedimentary features are not unlike those of the Ropianka Beds, except for olistostroms which are more frequent. The Sromowce Beds rest on the pelagic *Glabotruncana*-bearing green and red marls of Cenomanian — Lower Coniacian age. The very poor agglutinate microfauna does not give any depth indications, while trace fossils are fairly abundant with networks and meandering forms and may be assigned to assemblages *IV* or *V*. Species diversity moderate (about twenty five ichnospecies). An upper bathyal or upper mesobathyal depth is suggested.

During Paleocene times, in the northern belt of the Main Trough the Babica Clays, in its axial zone argillaceous and marly, non-flysch sediments, in the southern part of the trough the Upper Istebna Beds were deposited. In the Magura Trough dark shales at first, later the Variegated Beds (red and green) were formed.

BABICA CLAYS (PALEOCENE)

These are mainly olistostromal deposits (Bukowy 1956) in which forms of shallow-water provenance are mixed with those indicating deeper waters. This is shown by macrofauna (Krach 1969) and foraminiferal assemblages (Morgiel 1959) which contain *Rhabdammina linearis, Reophax pilulifer, Ammolagena clavata, Spiroplectamina carinata, Cribrostomoides subglobosus, Cystammina pauciloculata, Pullenia bulloides* and *Gyroidina soldanii.* Upper bathyal depths may be presumed. The coeval Pokucie Beds contain detrital limestones with *Lithothamnium* and calcareous foraminiferids. The limestones are graded and current bedded (Gucik 1961; Kotlarczyk 1961). Several agglutinate species with *Trochamminoides, Cystammina pauciloculata* etc. occur in the interbedded shales. The ichnofauna of these beds, probably deposited at depths similar to those of the Babica Clays, is very little known.

Red and green marls and argillites were deposited in the axial zone of the Main Trough. Typical assemblages with *Rhabdammina* sp. div., *Cystammina pauciloculata, Ammobaculites agglutinans, Trochamminoides proteus* are found by Huss (1957, 1966). These beds were very likely deposited at greater depths than the subjacent Węglówka Marls, but still above *CCD.* The overlying red argillites belong to the Lower Eocene and contain (Huss 1966) *Trochamminoides proteus, T. coronatus, Lituotuba lituiformis, Rhabdammina* sp. div., *Bathysiphon, Psammosphaera fusca, Saccammina sphaerica* and, in the east, numerous radiolarians, occurring in beds with clinoptilolite (Wieser 1969). These argillites may in all likehood represent a deep-water sediment deposited at or near *CCD* level. In the western part of the axial zone, *Eponides umbonatus* and several planktonic species were, however, found, in coeval beds (Geroch & Gradziński 1955). This would imply that the axial zone of the trough was deeper in the east than in the west, an assumption corroborated by predominant current directions in the Main Trough.

UPPER ISTEBNA BEDS (PALEOCENE)

These beds, on the whole similar to the lower division, are, however, more conglomeratic and contain numerous pebble-clay interbeds, often with large blocks of exotic, pre-flysch rocks. Very coarse, but graded conglomerates frequently occur in channels. Fluxoturbidites play here a much greater role than in the Lower Istebna Beds. The microfauna consists exclusively of agglutinate species, with some addition of Radiolaria. Richer assemblages were found in the east (Jurkiewicz 1961a, b) than in the west (Geroch 1960). The species of *Trochamminoides,* as well as *Lituotuba lituiformis, Rhabdammina abyssorum, R. linearis, Saccorhiza ramosa, Cystammina pauciloculata, Reophax nodulosa, Plectina apicularis* are known from these beds. The very poor (twelve ichnospecies) ichnofauna may be assigned to assemblage *III* having few patterned forms. The scarcity of trace fossils may be due to lithology (coarse-grained elements *I,* dark shales). Upper bathyal depths may be inferred.

In the Magura Trough, the Ropianka Beds pass through a complex of dark shales with sandstones into the Variegated Shales (Paleocene — Lower Eocene, locally also Middle Eocene). These are red and green argillites with few intercalations of thin-bedded, graded and laminated sandstones. Shales are locally marly and there are some marly interbeds. The abundant microfauna includes *Rhabdammina linearis, Trochamminoides proteus, T. coronatus, Lituotuba lituiformis, Cribrostomoides subglobosus, Ammolagena clavata, Reophax pilulifer, Trochammina globigeriniformis* (Bieda, Jednorowska & Książkiewicz 1967; Blaicher in Sikora 1970). Noteworthy are local accumulations of Radiolaria (Kostecka & Węcławik 1967) and numerous occurrences of manganese nodules (the writer's observations). Though sandy and silty intercalations are not very common, the ichnofauna is rich and of high diversity (about forty ichnospecies). Meandering forms (*Cosmorhaphe, Helminthoida*), *Paleodictyon* and other networks are quite common, *Subphyllochorda* abundant, *Lorenzinia* present, *Chondrites* rare, *Hydrancylus* occasionally met with, while *Zoophycos* seems to be absent. This is assemblage *VII*, most abundant in patterned traces. As compared with the underlying Ropianka Beds the lower species diversity seems to suggest greater depths, perhaps below 2000 m. This is in conformity with the microfaunal data, and the depth of deposition may be estimated as lower mesobathyal, or even infrabathyal, but generally above *CCD* level.

CIĘŻKOWICE SANDSTONE (LOWER EOCENE)

In the Main Trough this member rests on the Upper Istebna Beds, and in the Magura Trough it replaces laterally the Variegated Shales. At the type locality (Main Trough) and in adjoining areas it is developed as thick-bedded, coarse-grained sandstones with well pronounced large-scale cross-stratification, but some layers are graded, and horizontal lamination is also present. Several layers are structureless, while in others a distortion, which results from syndepositional slumping, is visible (Koszarski 1963) and some structures may be termed (after Dewey 1962) prolapsed bedding. Shaly interbeds are often lacking here, but lenticularity is strongly developed; there are no flutes. In the sections situated more to the west, the large-scale cross-bedding is absent or rare, while grading, sharp lower surfaces, and flutes are better developed. The thick-bedded sandstone layers are grouped into thick packets separated by thicker shaly interbeds with thin-bedded sandstones. The microfauna contains only agglutinate Foraminifera with *Rhabdammina abyssorum, Trochamminoides, Cystammina pauciloculata* (Jurkiewicz 1959), but it is much poorer as compared with assemblages of coeval shales occurring in other regions.

The origin of the Ciężkowice Sandstone was assigned to flows transitional between turbidity currents and sandflows (Dżułyński & al. 1959). As shown before, a large-scale cross-bedding indicates rather a deposition from a fully turbulent current which in all probability can be produced only by a shallow-water traction current. On the other hand, several layers display features common to beds deposited from suspension. In this situation, the following explanation is offered: during the sedimentation of the underlying Istebna Beds deposited, as we have seen, in the upper part of the upper bathyal zone, the marginal southern part of the Main Trough was filled up to near wave base. Traction currents operated in this shallow zone. They could bring sand to the very edge of the shallow zone, where it could then slide down in sandflows, or be transported by dense turbidity currents below the edge. This deposition could make the zone below the edge shallower to such an extent that traction currents operated in it, and deposited cross-bedded layers on the beds laid down by gravity processes. With adequate subsidence, a series of intermingled graded and cross-bedded sandstones could be formed.

In the complexes where cross-bedding prevails the ichnofauna is usually absent, or, if present, it is limited to simple, both hypichnial and endichnial burrows (assemblage *I*), with also some circular traces. But in sections where graded beds are common and thin-bedded intercalations are frequent, in addition to simple burrows some patterned forms appear, particularly spirals and networks (*Paleodictyon,* but with the tendency to form nets of the *"Pleurodictyon"* type). This is assemblage *II* displaying a low species diversity (fifteen ichnospecies).

The Ciężkowice Sandstone is conformably underlain and overlain by flysch deposits. Since it represents only a product of a transient and local shallowing of the basin, it is not justified to regard it as a *"faciès molassique"* within the flysch (Contescu 1964). It is likely that the deposits of this type were developed along the coasts of the Carpathian flysch basin during the deposition of many other members and that they represent "marginal facies" sought by Dżułyński & Smith (1964), but such beds, parental to flysch beds, were eroded away, or are hidden below the overthrusts.

The Ciężkowice Sandstone in the Magura Trough is also composed of thick-bedded sandstones with irregular and multiple bedding, but there is less lenticularity and no large-scale cross-bedding. This is a proximal deposit intermingled with variegated shales which contain a few *Trochamminoides* species, but the assemblage of Foraminifera is much poorer than that occurring in the coeval Variegated Shales. A poor ichnofauna is represented by assemblage *II.*

BELOVEZA BEDS (LOWER EOCENE, UPPER PART)

In the Magura Trough they cover the Variegated Shales. The shales are thicker than the thin-bedded sandstones which are horizontally and ripple-current bedded. Single, small-scale current bedding is quite frequent, while grading, except for gradational lamination, is uncommon. Flutes are not abundant, but their frequency increases in the upcurrent direction, i.e. eastwards, where thicker layers and marly interbeds are more common. On the whole, these beds have a distal character which tends to become more intermediate eastwards. The foraminiferal assemblages are very much the same as in the subjacent Variegated Shales, but the number of *Trochamminoides* species is smaller and in several places planktonic species have been found (Jednorowska & Węcławik 1965; Bieda, Jednorowska & Książkiewicz 1967). This, together with the presence of marly shales and marls, precludes a deposition below *CCD* level. The Beloveza Beds rival with the Ropianka Beds in the diversity of their ichnofauna (58 ichnospecies). Although simple burrows are abundant, there are several types of sculptured horizontal burrows, fairly numerous *Scolicia* and *Subphyllochorda,* while *Helminthopsis, Spirophycus, Cosmorhaphe* and *Helminthoida* are plentiful, and *Paleodictyon* represented by a variety of types. In the sections with marls, *Chondrites* is also present. Assemblage *V* characterizes the intermediate region, and assemblage *VI* the distal region. The very high diversity seems to suggest depths above 2000 m and the foraminiferal assemblages — generally bathyal depths. The middle part of the mesobathyal zone would probably be a good estimate.

HIEROGLYPHIC BEDS (MAINLY MIDDLE EOCENE)

This is a very extensive member, present both in the Main and Magura troughs. Its sedimentological character has been well recognized by Ślączka (1963) and Simpson (1970) and, although varying from place to place in some details, it is on the whole fairly uniform. This is a complex of regularly alternating thin-bedded sandstones and shales, often in equal proportions but shales predominate in some areas. Gradational lamination, horizontal and ripple-current lamination are dominating types of bedding, flute casts are in some areas very abundant. On the whole, an intermediate deposition may be inferred, though areas distal and peripheral to the main flow are also marked. Agglutinate species strongly predominate in the microfauna with *Cyclammina amplectens, C. rotundidorsata, Rhabdammina abyssorum, R. linearis, Reophax pilulifer,* several species of *Trochamminoides, Spiroplectammina spectabilis, Eggerella propinqua, Haplophragmoides scitulus* (Jurkiewicz 1959; Bieda, Jednorowska & Książkiewicz 1967). Calcareous species are on the whole lacking, but in some places they do occur. *Chilostomella ovoidea* and other species are reported from the Magura Zone and numerous planktonic species of *Globigerina* and *Globorotalia* have been discovered (Jednorowska & Węcławik 1967). The trace fossils are not very abundant (thirty five ichnospecies) with common *Scolicia* and *Spirophycus,* rare *Helminthoida* and *Paleomeandron,* common *Protopaleodictyon,* but extremely rare *Paleodictyon. Zoophycos* is frequent locally (assemblage *IV*). The presence of *Cyclammina* suggests depths not exceeding 1000 m and, therefore, the upper mesobathyal zone is here suggested.

In the axial zone of the Main Trough, the Hieroglyphic Beds are partly replaced by argillaceous or marly beds with *Cyclammina amplectens, Trochamminoides proteus, Eponides umbonatus, Gyroidina soldanii* and fairly abundant planktonic Foraminifera (Geroch & Gradziński 1955; Huss 1957). Depths ranging between 400 and 1000 m are probable.

PASIERBIEC SANDSTONE (MIDDLE EOCENE)

It partly replaces the lower part of the Hieroglyphic Beds in the Magura Trough. Coarse-grained sandstones and conglomerates are the main component. Grading is generally well developed, but is occasionally absent, flutes are rather frequent. Microfauna is poor, but *Cyclammina amplectens* is present. The ichnofauna does not differ fundamentally from that of the Hieroglyphic Beds (assemblage *III*), but the diversity is lower (twenty ichnospecies). This is a proximal deposit, formed in a number of coalescing fans (Dżułyński & al. 1959), probably at the outlets of submarine canyons (Simpson 1970), at depths only slightly smaller than those at which the Hieroglyphic Beds were deposited.

ŁĄCKO BEDS (MIDDLE EOCENE)

This is again a facies partly replacing laterally the Pasierbiec Sandstone and the Hieroglyphic Beds. In most cases it consists of sandstone-marl-shale or marl-shale sequences (Fig. 5). Shales are clayey and contain *Cyclammina amplectens, Trochamminoides coronatus* and others, *Rhabdammina linearis, Cystammina pauciloculata,* while *Nummulites* occur in sandstones and conglomerates and sponge spicules, calcareous Foraminifera, and locally abundant Radiolaria occur in marls. The ichnofauna, of a rather low diversity (twenty five ichnospecies) contains numerous *Chondrites,* some winding types, and few patterned traces (assemblage *IV*).

According to the interpretation presented above, the sandstone-marl sequences in the Łącko Beds (first described by Żytko 1961) have been formed by the same currents which in the proximal zone deposited the Pasierbiec Sandstone. On entering the more distal, and presumably deeper part of the sea-floor that was covered with calcareous mud, these currents mixed sand with it and formed in the depositional stage the sand-marl sequence. The shales with agglutinate Foraminifera represent the indigenous deposit in the area situated beyond the zone of calcareous deposition. It is possible that irregularly stratified marls, with no sandy or argillaceus interbeds (Nowy Sącz region), represent relic parts of the original calcareous muds not reworked by turbidity currents. Taking all this into account, one may assign mesobathyal depths as the depositional site of the Łącko Beds.

SUB-MENILITE GLOBIGERINA MARLS (UPPER EOCENE)

After the deposition of the Hieroglyphic Beds and their equivalents, the flysch sedimentation ceased for some time in the Main Trough and pelagic sediments were deposited. Planktonic Foraminifera are the main component, but some arenaceous species (*Reophax pilulifer, Haplophragmoides scitulus*) and *Eponides umbonatus* are also present (Blaicher 1961). The predominance of planktonic species indicates an outer neritic or upper bathyal depth, but the last-named species and the agglutinate forms argue instead for upper bathyal depths, and the absence of *Trochamminoides* for the exclusion of greater depths.

SUB-MAGURA AND MAGURA BEDS (UPPER EOCENE — OLIGOCENE?)

They rest on the Hieroglyphic Beds in the Magura Trough. The two members have many features in common. The features of intermediate deposition prevail in the northern part of the basin: sandstones moderately thick-bedded, shaly interbeds fairly thick, grading well displayed, and flutes abundant. In the southern area, sandstone beds are on the whole thick, shaly interbeds thin, grading less pronounced or absent at all, flute casts less abundant. Unsorted, thick-bedded sand-

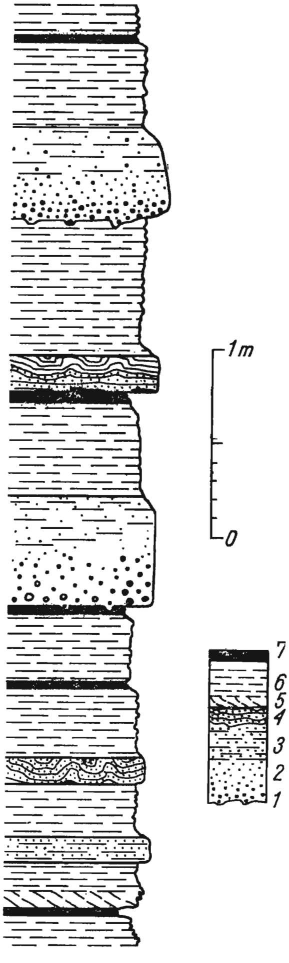

Fig. 5. Sand-marl type of sequences in the Łącko Beds (Middle Eocene)

1 Conglomerate or coarse-grained sandstone, 2 medium-grained sandstone, 3 fine-grained sandstone, horizontally laminated, 4 very fine-grained sandstone with ripple-current bedding and convolution, 5 current bedding in marls, 6 laminated marl, 7 argillite

stones may be either grain-flow deposits (Simpson 1970), or products of high-concentration flows (as obtained experimentally by Middleton 1967b). Occasional, though very rare cases of large-scale cross-stratification (e.g. Tylmanowa in the Dunajec River valley) imply that the depth of deposition sometimes approached the wave base and could not, on the whole, be very great. The microfauna is scarce, and even agglutinate Foraminifera are rare. The species *Rhabdammina abyssorum, R. linearis, Reophax pilulifer, Cribrostomoides subglobosus, Trochamminoides coronatus, Lituotuba lituiformis, Cystammina pauciloculata* have been found in the northern facies (Jednorowska 1968), and calcareous Foraminifera: *Eponides umbonatus, Gyroidina soldanii, Globorotalia, Globigerina, Globigerinoides* also occur in a number of localities. All this may suggest upper mesobathyal depths. The evidence for the southern facies is less clear, as the agglutinate species are very rare, but planktonic species and *Eponides umbonatus* are reported (Bieda, Jednorowska & Książkiewicz 1967). The southern facies has probably been deposited at shallower depths than the northern one, an inference concurrent with its more proximal character.

The ichnofauna of the Magura Beds is rather poor, with simple burrows, winding *Taphrhelminthopsis*, and very few patterned forms, while *Zoophycos* is abundant, particularly in the southern facies (assemblage *II*). Species diversity low (20 ichnospecies).

MENILITE BEDS (EOOLIGOCENE)

This member, developed in the Main Trough, usually begins with silicites followed by bituminous shales and, in marginal areas, with sandy intercalations. The sandstone intercalations in the northern zone (the Kliwa Sandstone), with irregular geometry and often ungraded, are regarded by Dżułyński & Smith (1964) as a non-flysch deposit. However, Żgiet (1963) reports graded and composite bedding in elements *I* which pass into elements *II*, in addition to an amalgamated bedding and channelling. Proximal deposition, with fluxoturbidites, is suggested. Perfectly graded sandstones occur in the southern (Dukla) region.

The microfauna is usually absent. In the siliceous beds, diatoms have been found. Bituminous shales are barren. Surprisingly, very rich assemblages of Foraminifera have been found at a few points. A few agglutinated species (*Cyclammina*) and *Chilostomella, Eponides umbonatus*, several species of *Uvigerina, Nodosaria* and some Radiolaria are reported by Liszka (1957) from one locality. On the strength of this composition, he presumes considerable depths and normal salinity. A rich assemblage of Foraminifera was also described by Liszka (1961) from sandy clays of olistostromal origin. Shallow-water forms (*Elphidium, Nummulites, Asterocyclina*, etc.) occur together with species typical of deeper waters, like *Robulus cultratus, Bulimina elongata, Eponides umbonatus, Cassidulina, Uvigerina*, etc. Both these occurrences suggest a depth not much differing from that at which the underlying Globigerina Marls were deposited.

The Menilite Beds are known for abundant fish remains. According to Jerzmańska (1968) and Jerzmańska & Kotlarczyk (1968), the ichthyofauna in the lower part of the Menilite Beds is bathypelagic (*Scopeloides, Vinciguerria, Myctophidae*) and suggests a depth below 200 m, probably of several hundred meters. In the middle part of these beds is a neritic-sublittoral assemblage with *Glossanodon, Hipposyngnathus, Trachinus*, and again, in the upper part, bathypelagic assemblages appear. Bathypelagic fish are extensively distributed in the Menilite Beds of the Carpathians, as they occur in the Rumanian (Pauca 1934) and Czechoslovakian (Kalabis 1948) parts of these mountains.

It seems then that the Menilite Beds formed in the basin of upper bathyal depths which underwent a transient, and possibly local shallowing.

The ichnofauna is extremely poor, evidently because of semi-euxinic conditions, and roughly corresponds to assemblage *II*.

KROSNO BEDS (OLIGOCENE)

The sedimentary features of this very thick (about 3000 m) member are variable. In the lower part, thick-bedded, roughly graded or ungraded sandstones seem to prevail, while thin-bedded, horizontally and ripple-current laminated sandstones predominate towards the top. Shaly interbeds become thicker toward the top of the succession. Mudflow deposits are more common in the lower part.

There is a wealth of mechanical sole marks (Dżułyński & Ślączka 1959; Dżułyński 1963), particularly in the middle sub-division, which on the whole displays features of intermediate deposition, while the lower part at least in some places is proximal in character.

The microfauna is poor and rare. The agglutinate Foraminifera, which predominated in nearly all older members of the succession, give way to calcareous types. In this respect the Krosno Beds approach the type of the Upper Cretaceous Guipozcoa Flysch (Herm 1965). There are several occurrences of planktonic Foraminifera, radiolarians and diatoms also being not uncommon. There are a number of species indicating a rather deep-water environment, such as *Bulimina elongata, B. ovata, Uvigerina mediterranea, Chilostomella ovoidea, Gyroidina soldanii, Sphaeroidina bulloides, Pullenia bulloides, Robulus cultratus, Melonis pompilioides* (*cf.* Huss 1957; Gucik & Morgiel 1960; Jurkiewicz 1961c; Morgiel & Sikora 1963). These forms occur either in indigenous shales, or in olistostromal beds. In the latter instance, they are mixed with undoubtedly shallow-water species, like e.g. *Quinqueloculina lamarckiana* d'Orb., *Cibicides pseudoungerianus* Cushm., *Amphistegina lessoni* d'Orb., *Streblus beccarii* L. (*cf.* Gucik & Morgiel 1960; Morgiel & Sikora 1963). As the essentially deep-water agglutinate species are lacking, except for *Rhabdammina linearis, Trochammina globigeriniformis* and *Haplophragmoides* cf. *scitulus*, the microfauna seems to indicate an upper bathyal zone.

In the lower part of the Krosno Beds, bathypelagic fish fauna has been found at a few points (Jerzmańska 1960; Jerzmańska & Jucha 1963).

The ichnofauna is poorly represented in most sections of the Krosno Beds. Places with more abundant trace fossils occur in the eastern part and the number of species generally increases eastward, i.e. in the principal downcurrent direction. The paucity of trace fossils may be due to a fairly strong bottom erosion, as evidenced by the abundance of flute casts: the predepositional traces could be swashed out by bottom currents. The trace fossils may be classified mainly as assemblage *II*, with very low species diversity (not greater than ten); and in the distal area, where some meandering and net-like traces are also met with as assemblage *III* with a somewhat higher species diversity (about twenty).

On the strength of these data it may be presumed that the Krosno Beds have been deposited in the lower part of the upper bathyal zone. In some parts, this depth was possibly smaller; in others, greater.

PODHALE FLYSCH (UPPER EOCENE — OLIGOCENE)

During the Middle and Upper Eocene a new trough developed south of the Magura Trough. The sedimentation commenced here at first with conglomerates and nummulitic limestones, followed by an about 2500 m thick flysch series. Its sedimentary features are known from Radomski's (1958) work. In the Polish part, features indicating the intermediate region of deposition are predominant. The microfauna is very poor, most commonly absent, but in the lower part a few species of *Chilostomella* and *Bulimina elongata* have been found along with some agglutinate species and globigerinas (Bleicher 1973). Upper bathyal depths may here be inferred. The ichnofauna is scarce, with few meanders and networks (assemblages *III*, with a low species diversity).

CONCLUSIONS

The Carpathian Flysch is a marine, deep-water deposit. There is ample evidence that each flysch sequence is due to instantaneous deposition from a sediment-laden current, and not to a prolonged sedimentation.

Concepts which assign the deposition of the Carpathian flysch to paralic, estuarine, or littoral environments are untenable. This is indicated by both the sedimentary features and the microfaunal composition. The indigenous assemblages contain several species of Foraminifera, the distribution of which in present-day seas is marked by preference for depths generally below the neritic zone. There are also a number of species closely related to Recent deep-water species. Most of the Carpathian flysch was deposited at bathyal, presumably mostly upper bathyal depths (*cf.* Fig. 4).

There is a good correlation between the depth estimates based on sedimentary features and microfaunistic composition, and those inferred from the character and diversity of trace fossil assemblages. The number of patterned types is considerably larger in the beds to which greater depths have been assigned on the basis of sedimentological and microfaunistic evidence.

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Institute of Geology
of the Jagiellonian University
Oleandry 2a, 30-063 Kraków, Poland
Cracow, February 1975

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M. KSIĄŻKIEWICZ

BATYMETRIA KARPACKIEGO BASENU FLISZOWEGO

(Streszczenie)

Flisz karpacki jest głębokowodnym osadem morskim. Poglądy przypisujące mu powstanie w środowisku paralicznym, estuariowym lub litoralnym nie są uzasadnione, na co wskazują zarówno cechy sedymentacyjne jak też charakter mikrofauny. Następstwo struktur w ławicach fliszowych oraz pozytywna korelacja między rozmiarami struktur erozyjnych dolnych powierzchni ławic a grubością i gruboziarnistością ławic wskazują, że ławice fliszowe osadzały się szybko z prądów o zmniejszającej się prędkości, a nie były wynikiem powolnej sedymentacji (*vide* fig. 1—2 i 5 oraz pl. 1—2). Autochtoniczne zespoły otwornicowe zawierają wiele gatunków współczesnych, które żyją głównie lub wyłącznie poniżej strefy nerytycznej (*por.* tab. 1). Na podstawie cech sedymentacyjnych i zespołów mikrofaunistycznych przedstawiono próbę oznaczenia zmian głębokości w basenie (fig. 4). Stwierdzono także, iż w utworach osadzonych w większych głębokościach ichnofauna zawiera więcej form siatkowych i meandrujących aniżeli w osadach utworzonych w głębokościach mniejszych (*por.* fig. 3). Flisz karpacki osadzał się przeważnie w strefie batialnej, najczęściej w jej górnej części (200—600 m).