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Flysch Facies

STRESZCZENIE

Nazwę „flisz", wprowadzoną do literatury przez Studera (1827) stosujemy w odniesieniu do morskich osadów geosynklinalnych, o znacznej miąższości, które wykazują następujące własności:

1) Naprzemianległość ławic o grubszym ziarnie (np. piaskowców, wapieni okruchowych itp.) oraz ławic osadów pelitycznych (łupków, mułowców lub margli) [1].

2) Piaskowce są na ogół słabo przesortowane i zawierają spore ilości rozproszonej substancji ilastej.

3) Piaskowce bywają często uwarstwione frakcjonalnie. Może w nich występować również pozioma laminacja, drobne warstwowanie przekątne lub warstwowanie skorupowe.

4) Spągowe powierzchnie piaskowców są ostro zarysowane, stropowe zaś najczęściej niewyraźne.

5) Powierzchnie spągowe pokryte są zwykle licznymi hieroglifami.

6) Ławice piaskowcowe odznaczają się zwykle stałością miąższości.

7) Wskaźniki kierunkowe transportu w piaskowcach fliszowych odznaczają się często dużą stałością kierunków, zarówno wzdłuż rozciągłości poziomej ławic, jak też w przekrojach pionowych zespołów warstw o pokaźnej miąższości.

8) W obrębie fliszu występują „sub-facje", w których zaznacza się przewaga piaskowców bądź łupków. Pojawiają się one wielokrotnie w przekrojach serii fliszowych zalegając przeważnie zgodnie na podścielających je utworach fliszowych.

9) Skamieniałości we fliszu są rzadkie. W piaskowcach są one na ogół przemieszczone lub na drugorzędnym złożu. W łupkach pojawia się często mikrofauna o charakterze głębokowodnym lub pelagicznym.

10) Nie ma w utworach fliszowych żadnych śladów wynurzeń, w szczególności śladów stąpania zwierząt lądowych lub ptaków, spękań, napowietrznego wysychania, śladów kropel deszczu, pseudomorfoz kryształów soli itp.

11) Na powierzchniach stropowych piaskowców fliszowych nie ma prostolinijnych pręg falowych, a prądowe riplemarki należą do rzadkości.

12) Brak w piaskowcach fliszowych warstwowania przekątnego o dużych, płasko zapadających powierzchniach warstw skośnych, które by wypełniały sobą całą ławicę.

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[1] W dalszej części wszelkie osady gruboziarniste dla uproszczenia nazywać będziemy piaskowcami, natomiast osady pelitowe — łupkami.

13) Nie ma w utworach fliszowych skamieniałości płytkowodnych zwierząt i roślin żyjących na miejscu, a w szczególności brak jest utworów rafowych.

14) Brak jest w osadach fliszowych poważniejszych przejawów działalności wulkanicznej poza obecnością tufitów.

15) Nie występują we fliszu istotne zmiany w charakterze osadu poza wymienioną naprzemianległością piaskowców i łupków.

Wyszczególniony wyżej zespół cech można uważać za znamienny dla fliszu, choć żadna z poszczególnych własności sama przez się nie jest sprawdzianem przynależności danego utworów do facji fliszowej.

Przeważająca część utworów fliszowych zbudowana jest z piaskowców (piaskowce arkozowe, szarogłazy) przeławiconych łupkami. Rzadziej pojawia się flisz wapienny, w którym ławice o grubszym ziarnie zbudowane są z okruchowych wapieni, a rolę łupków spełniają margle. W szczególnych, również rzadkich przypadkach piaskowce fliszowe mogą być złożone z okruchów skał wulkanicznych (np. Taveyannaz flisz w Szwajcarii).

W osadach fliszowych wyróżnia się trzy zasadnicze „sub-facje" (por. Bertrand 1894, Wassojewicz 1948, Sujkowski 1957); 1 — flisz piaszczysty z wyraźną przewagą piaskowców nad łupkami, 2 — flisz normalny, w którym udział łupków i piaskowców jest mniej więcej jednakowy, oraz 3 — flisz łupkowy z wyraźną przewagą łupków nad piaskowcami.

Piaskowce fliszu piaszczystego są na ogół gruboławicowe (ponad 1 m). Wykazują one niektóre własności, jakie nie występują w normalnym fliszu lub należą w nim do rzadkości. Ławice piaskowców są często złożone z warstw powstałych w wyniku oddzielnych aktów osadzania, a zespolonych ze sobą w jedną całość wzdłuż śródławicowych powierzchni rozmywania. Piaskowce zawierają mniej substancji ilastej niż piaskowce fliszu normalnego, a ich stropowe powierzchnie bywają niekiedy wyraźnie zarysowane. Mogą też wystąpić widoczne zmiany w miąższości poszczególnych ławic. Pojawia się również zmienność w kierunkach transportu osadu między poszczególnymi ławicami, same zaś kierunki bywają zwykle skośne lub prostopadłe do przebiegu głównej osi zbiorników fliszowych.

Flisz normalny cechuje znaczna stałość kierunków transportu, które najczęściej są równoległe do dłuższej osi zbiorników fliszowych. Miąższość ławic nie przekracza na ogół 1 m.

We fliszu łupkowym ławice piaskowcowe są cienkie i drobnoziarniste.

Istnieją dwojakiego rodzaju serie fliszowe. Jedne pojawiają się stopniowo lub nagle na osadach pelagicznych, najczęściej wapienno-marglistych, inne spoczywają na niefliszowych utworach transgresywnych. W pierwszym przypadku w spągu fliszu występują niekiedy skały wulkaniczne, intruzje i podmorskie wylewy (ofiolity, cieszynity itp.), które jednak zanikają w miarę rozwoju facji fliszowej. Flisz spoczywający na osadach transgresywnych pozbawiony jest skał wulkanicznych (pominąwszy tufity).

Osady fliszowe nigdy nie spoczywają bezpośrednio na powierzchni transgresji, lecz na transgresywnych niefliszowych osadach. Przejście od takich osadów do fliszu może być stopniowe albo odbywa się za pośrednictwem łupków lub margli, które w pewnych przypadkach mogą spoczywać bezpośrednio na powierzchni transgresji morskiej.

W stropie niektórych serii fliszowych widuje się podobne przejścia do utworów molassowych. Cechy fliszowe osadu zanikają stopniowo, pojawiają się natomiast w coraz większej ilości ławice piaskowcowe, których stropowe powierzchnie pokryte są riplemarkami. Często utwory zbudowane wyłącznie z takich ławic piaskowcowych przedzielonych łupkami, a więc już niefliszowe, oddzielają od schyłkowego fliszu łupki i margle.

Zgodnie z przyjętymi i dobrze uzasadnionymi poglądami flisz możemy określić jako jednofacjalną formację synorogeniczną złożoną w środowisku wyłącznie morskim i stosunkowo głębokim (niżej podstawy falowania na umownej granicy 200 m). Molassa natomiast jest osadem synorogenicznym po części też postorogenicznym, wielofacjalnym osadzonym w płytkowodnym zbiorniku i w znacznym stopniu na lądzie.

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Abstract. This paper discusses the characteristic features of flysch. The argument is presented that there is a need for the term flysch to be clearly understood as a facies term.

I. INTRODUCTION

The term flysch was introduced by Studer in 1827 to describe a series of shales and muddy sandstones (Upper Cretaceous) in the Siemmenthal area of Switzerland. Neither stratigraphic nor tectonic implications were included into original definition (Studer 1827). This important point was emphasized by Studer in 1872 „... Da der Name mich bequem schien um stratigraphisch noch nicht festbestimmte Schiefer zu bezeichnen, bediente ich mich desselben in rein petrographischen Sinn." (Studer 1872, p. 276).

The term was later extended to cover all sediments showing the same or similar features in other regions (see, Favre 1875 [1], Neumayr 1887, Bertrand 1894, Bogdanowicz 1902, Bośniacki 1911, Bonney 1912, Zuber 1918 ...).

Flysch became a confusing term partly because of stratigraphic and tectonic meaning given to it by some authors and partly because it was applied to descriptively and genetically different facies. This confusion grew around the term flysch soon after its inception and it led Studer (1843) to suggest that the term be abandoned.

In spite of confusion and a few attempts to discredit its general meaning (Boussac 1912, Eardley and White 1947), the term flysch has proved to be „a good one — in fact — extremely valuable term for which there is no substitute in the literature" (Fairbridge 1958).

While some of the Swiss and Austrian geologists still insist on limited usage of the term flysch and seek to give the name a stratigraphic or tectonic significance, Eastern European geolgists and most French and Italian authors have used the name to indicate a certain type of geosynclinal facies of no particular age. This view has been adopted by some English speaking geologists e. g. Pettijohn (1957), Cline (1960), McBride (1962) [2].

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[1] fide Keller 1947.

[2] See also the report of the Symposium: Some aspects of Sedimentation in

Large bodies of sediments which are similar if not identical to the Alpine or Carpathian flysch are of widespread occurrence and age though frequently they are known by local formation names only. The widespread occurrence of these similar sediments is, in itself, sufficient reason for grouping them under one name.

II. CHARACTERISTIC FEATURES OF FLYSCH

The term flysch should be applied to thick sequences of marine detrital sediments which show the following diagnostic features [1].

1) Marked alternation of fine-grained sediments such as shale marls, mudstones and silts, with coarse sediments such as sandstones or detrital limestones. For the sake of simplicity the coarse sediments will be henceforth in this article called sandstones and the fine-grained sediments, shales.

2) The sandstones are usually moderately sorted and contain a considerable proportion of clay-grade material which is identical in composition to the shale between the sandstones.

3) The sandstones show sharply defined bottom surfaces whereas the top surfaces are usually indistinct and there is a transition from sandstone to shale.

4) The bottom surfaces of the sandstones commonly display a profusion of sole markings (hieroglyphs), both of inorganic and organic origin.

5) The sandstones often show graded bedding which may be obvious in the field. Fine sandstones often show small scale lamination, current ripples and convolute lamination.

6) Few variations of thickness or composition of sandstones can be seen in any exposure of flysch, but the variations of thickness that do occur are most marked in the direction which is transverse to the direction of transportation.

7) Sedimentary directional features may show a marked constancy over large areas and a given direction of sediment transportation may persist in thick rock units.

8) Within the broad sequence of the flysch facies there are sub-facies in which fine or coarse sediments predominate. These subfacies vary in space as well as in time and are usually conformable.

9) Flysch often contains slump deposits, pebbly mudstones or pebbly sandstones. In some sequences there are clays with exotic blocks of considerable size.

10) Fossils in flysch are rare. The upper portions of shaly layers may contain microfossils. These are usually pelagic or deep-water

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Orogenic belts held by the Geological Society of London in 1961 (*Proc. Geol. Soc. London*, No. 1587, pp. 69—80, 1961).

[1] These features of flysch rocks have been noted by many authors. The reader is referred to the publications of Tercier (1947), Vassoevich (1948, 1951), Książkiewicz (1947, 1952, 1958 a), Allemann (1957), Sujkowski (1957), Lombard (1958), Seilacher (1958), Kuenen (1958, 1959), Birkenmajer (1959), Dżułyński and Żak (1960), Trümpy (1960).

benthonic organisms. The sandstones may contain displaced (redeposited) or reworked fossils.

11) Absence of shallow water benthonic fauna in situ and in particular bioherms and biostromes.

12) Absence of features suggestive of subaerial conditions i.e. sun-cracks, raindrop imprints, salt crystal pseudomorphs and foot imprints of land animals and birds.

13) Absence of wave ripple marks on top surfaces of sandstones and scarcity of other current ripples on these surfaces.

14) Absence of conspicuous evidence of volcanic activity other than fine-grained tuffites.

15) Scarcity of large scale cross-stratification and the absence of large scale low-angle cross strata covering the whole thickness of the beds.

16) Absence of rapid variations, both laterally and vertically in the composition of sediments, other than variations due to the alternation of sandstones and shales.

None of the above features, however, are in themselves indicative of flysch.

III. DIFFERENT LITHOLOGIC TYPES OF FLYSCH

There are different types of flysch depending on the composition of the rocks included.

Sub-arkoses, sub-greywackes and greywackes (in the meaning of Pettijohn 1957) are the most common sandstones in flysch. Shales and siltstones are the most common components of fine-grained portion of it.

In some flysch sequences there are also redeposited and reworked detrital limestones. These are quite common in the Siemmenthal flysch, Niesen flysch and particularly in the flysch of Liechtenstein (Allemann and Blaser 1951).

Some flysch limestones, known, in the Alpine literature under a name of „dichte Flysch-Kalksteine" are very fine-grained and in hand specimen hardly distinguishable from the lithographic „pelagic" limestones. Thin sections, however, reveal frequently delicate current bedding and many beds show well developed scour markings on the bottom surfaces.

The limestones may be associated with sandstones, e. g. a single graded bed may be composed of sand at the bottom, limestone higher up and pass into shale at the top. On the other hand many graded beds are entirely composed of limestone fragments and calcareous dust. When the majority of „sandstones" in a flysch formation are actually redeposited limestones, then the formation is called limestone flysch (flysch calcaire of the French authors). Typical examples of this type of flysch are the „Flysch à Helminthoides" a considerable part of the flysch of Liechtenstein in the Alps and the Cieszyn (Teschen) beds the Sinaia and Comarnic beds [1] in the Carpathians.

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[1] In a paper of Tercier (1947), (p. 194) it is claimed that the term flysch in the Carpathians is subject to serious ambiguity and that many of the alleged flysch rocks in this area would not be identified as flysch by the Alpine geologist. This is certainly not the case. The Sinaia beds (pointed out by Tercier as an exam-

All the features which are characteristic of flysch sub-arkoses or greywackes are to be found in these flysch limestones (see Książkiewicz 1952, Allemann 1957). It should be noted however, that the limestone flysch is quantitatively of minor importance and appears usually at the base of some flysch sequences.

Another type of flysch and again a clear indication of the independence of the term flysch from a purely lithological meaning is the Taveyannaz flysch (Switzerland) which consists mainly of redeposited volcanic fragments (Quervain 1928).

A very special type of flysch is the „wild-flysch" (Kaufman 1886) which consists of huge masses of dark clays with various „exotic" blocks usually much older than the sediment in which they are embedded. The exotic blocks may be hundreds or even thousands of metres across the wild-flysch appears usually as masses of considerable extent and thickness which have played an important role in tectonic processes.

The term clays or argilites with exotics is used for similar deposits which are less extensive not considerably affected by tectonics and when the size of exotic boulders is smaller than in the wild-flysch proper.

IV. SEDIMENTARY ENVIRONMENT OF FLYSCH

Today opinion is still divided on the question of the sedimentary environment of flysch. Although it is now more and more widely accepted that the flysch rocks represent a facies laid down in marine environment below wave base (see e.g. Keller 1947, Tercier 1947, Książkiewicz 1952, 1958, Sujkowski 1957, Kuenen 1957, 1958, Trümpy 1960, Oulianoff 1960), contrary opinions are still being held (Zeil 1960, Mangin 1962). This controversy is an old one. A deep water origin of flysch was e. g. maintained by Fuchs (1895) and contrary views were presented by Zuber 1901, Abel (1926) and Karny (1928).

Sedimentary features which are seen in flysch are not diagnostic in themselves of any particular depth. The biohieroglyphs now being used as evidence in favour of a deep water origin of flysch (Seilacher 1954, Cloud 1961) are not entirely reliable criteria.

Since, however, similar markings have been found on the floor of the present deep-sea (Vialov and Zenkovich 1961) the bio-hieroglyphs cannot be regarded as an evidence against the deep-water origin of flysch.

At no time have foot imprints of land animals and birds been found in flysch[1], this and the absence of

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ple of such a misuse) do not differ from, for example, a considerable portion of the Liechtenstein flysch or flysch calcaire in the French Alps. The bulk of the Sinaia beds is flysch proper (Murgeanu et al. 1964). As indicated by Patrulius et al. (1962), only the lower part of these rocks represents an approach to the „pre-flysch" in the meaning of Trümpy (1960). Here, as in the similar Alpine series there is no sharp boundary between flysch and „pre-flysch" type of sediments.

[1] In a discussion on the paper of Mangin (1962 b), M-me Rech-Frollo states that during her excursion to the Polish Carpathians, together with Prof.

subaerial drying cracks excludes the possibility of tidial flat and very shallow water origin of flysch. Structures superficially resembling the casts of sun-craks have invariably been found to be structures associated with post-depositional processes such as initial slumping or sandstone dyke formation (Dżułyński and Radomski 1956, Książkiewicz 1958, Birkenmajer 1959).

More reliable data on the depth of flysch troughs are provided by palaeontological evidence. These have been recently elaborately treated by Książkiewicz (1961). We mention only that, as already noted by many authors any break in the inflow of clastics in the flysch basins was followed by the appearance of pelagic sediments. The latter have yielded deep water foraminifera (Pokorny 1958) and in some instances deep water fish fauna with species provided with light organs (Jerzmańska 1959).

Additional support for the conclusion that the flysch rocks were deposited in relatively deep waters is provided by the fact that the pelagic sediments in flysch, usually of insignificant thickness can be traced at the same stratigraphic position over considerable distances.

It is hardly possible to make a precise estimation of the range of depth of flysch seas. One can assume, following Książkiewicz (1961) that by average, the depth of many flysch seas was about 1000 m.

Much has been written recently on the life conditions in the flysch basins (Książkiewicz 1961). Although these conditions were not prohibitive to the development of bottom life, they were not really favourable to it. Numerous bio-hieroglyphs are closely associated with the surfaces of sandstones but the shales frequently show a delicate lamination, not disturbed by the activity of bottom animals. Well developed bioturbate structures (Richter 1936) are either absent or present in insignificant quantity[1].

The bottom muds of many flysch basins were presumably under semi-euxinic conditions[2] (Książkiewicz 1961), but this should not be generalized.

Violent gravity mass movements, although disastrous for the existing bottom dwellers must have acted as powerful ventilating agents (Dżułyński and Ślączka 1958, Wood and Smith 1959) and created, for some time, favourable conditions for life. However, the decomposition of organic matter, brought down by turbidity currents depleted the amount of free oxygen available for benthonic life (Książkiewicz 1961). Thus conditions favourable for bottom dwellers in many flysch seas were limited to short time intervals.

M. Książkiewicz she saw abundant foot imprints of birds in flysch. We are authorized by Prof. Książkiewicz to say that he has never noticed any foot imprints of birds in the Carpathian flysch. It should be noted that some bio-hieroglyphs on bottom surfaces of flysch sandstones may bear a superficial similarity to foot imprints of birds. Presumably the structures identified as foot imprints of birds from flysch by Mangin (1962) belong to this group.

[1] These structures are more common in the „sandy sub-facies" of flysch (see p. 253).

[2] According to some authors arenaceous foraminifera in flysch are indicative of low temperatures and low oxygen content (see Gohrbandt et al. 1960).

V. SEDIMENTATION OF FLYSCH

There is little doubt that the violent mass redeposition played an important role in the sedimentation of flysch. Turbidity currents, sediment flows, submarine avalanches slump and combined movements of all sorts of flows resulted in the formation of a sequence which is characterized by the positive features listed on p. 254 (see Książkiewicz (1952, 1956a, b, 1960a, b), Kuenen and Carozzi (1953), Vašiček (1954), Crowell (1955), Kuenen (1959)...

The concept of turbidity currents as a major agent in the sedimentation of flysch, already well founded by Kuenen's experiments (Kuenen 1950, Kuenen and Migliorini 1950, Kuenen 1951a, Kuenen and Menard 1952) has recently received further experimental support by the production of all the principal types of sole markings (of inorganic origin) by means of artificial turbidity currents (Dżułyński and Walton 1963).

A considerable portion of the fine rocks in flysch such as silts and shales originated also from turbidity currents (Passega 1954, Dżułyński and Radomski 1955, Radomski 1960). The flocculation of clay particles need not prevent long transport in suspension; on the contrary the floccule being highly porous and of very low specific gravity (Sherman 1953) and because of increased surface area presented to the current may be carried away further than individual clay particles [1].

Although the theory of turbidity currents provided a solution to the hitherto perplexing problem of flysch sedimentation, the term flysch must not be substituted by the term „turbidite sequence". The latter may occur in facies entirely different from flysch (Kuenen 1951a, b, Carozzi 1955).

The shaly layers, which contain numerous pelagic foraminifera mark an approach to the pelagic conditions proper. However, true pelagic sediments in flysch series are volumetrically insignificant.

VI. SUB-FACIES OF FLYSCH

The sub-facies of flysch may differ in the proportion of sandstones to shales, in the thickness of beds, in the predominant sedimentary structures, in the presence of certain characteristic minerals or rocks and in the type cement or character of shales (Sujkowski 1957). All these sub-facies are rock-stratigraphic units.

Following Bertrand (1894) and Vassoevich (1948) one can differentiate three principal sub-facies of flysch:

1 — sandy flysch (facies a flysch grossier — Bertrand 1894, „coarse flysch" — Vassoevich 1948)

2 — normal flysch

3 — shaly flysch (flysch schisteux — Bertrand 1894).

In general terms, normal flysch is made up of approximately equal proportions of sandstones and shales, though there may be considerable

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[1] For sediment with median particle of one micron, the effective density of suspended floccule is not 2.65 gm/cm³ but 1.4 gm/cm³ (Sherman 1953).

deviations to either side. The sandstones of the normal flysch are usually of medium thickness (up to 1 m) and display all the characteristic features indicative of flysch sandstones.

When the sandstones markedly predominate, the term sandy flysch is used. There may appear some features which are rare or absent in normal flysch e. g. the appearance of thick multiple and composite beds with few sole markings and relatively sharply defined top-surfaces (sand flows). Large scale cross stratification may also occur, although as a rule they are limited to elongate scours within the sandstone beds. The sandstones contain less clay grade material than it is the case with the normal flysch and wedging out of beds is also relatively common. Some of these sandstones have been described under a name of „fluxo-turbidites" (Dżułyński, Książkiewicz and Kuenen 1959).

When the shales markedly predominate, the term shaly flysch is used. The sandstones which occur are usually thin bedded, fine-grained, laminated or rippled on a very small scale.

Extensively developed sandy flysch may; 1- form a belt of coarse clastics, parallel to the original feeding slopes, 2- extend as a tongue or fan into the realm of normal or shaly flysch, 3- in special cases fill the whole trough.

The sandy flysch commonly exhibits lateral filling, i. e. the transportation of clastics transverse or oblique to the longer axes of troughs [1] and a variety of current directions in different sandstone beds. Such a variety reflects similar types of variations in the direction of current structures in the lateral extension of particular turbidite beds (these variations, however, escape our observation because of the discontinuity of exposures).

Normal and shaly flysch show rather constant directions of supply in vertical sections and over large areas. The predominant direction of currents structures is here parallel to the longer axis of troughs (longitudinal filling, Kuenen 1957). This peculiar behaviour of current structures, already observed by Grossheim (1946) and Vassoevich (1951) has been recognized as a feature common to many geosynclinal flysch zones by Sanders (see Kuenen and Sanders 1956). Kuenen (1957) explains the occurence of longitudinal currents assuming that the flysch basins were filled from one end by deposits from large rivers. While this may hold true for some flysch troughs the growing volume of data seems to confirm the explanation set forth by Książkiewicz (1956a), namely that longitudinal filling is largely confined to the central parts of troughs and result from turbidity currents flowing from the sides towards the central areas and finally travelling along the length of the troughs. This explanation is in agreement with the observations of Menard (1955) on contemporary submarine turbidity currents and may be easily demonstrated experimentally. An alternative hypothesis to explain the longitudinal filling, suggested by Dżułyński and Ślączka (1958) implies two stages in the sedimentation of a flysch trough. Stage one — primary sedimentation by transverse currents; stage two — uplift of parts of the centre of

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[1] For discussion on the problem of different kind of filling in the flysch troughs the reader is referred to the publications of Kuenen (1957, 1958), Książkiewicz (1956, 1960), Dżułyński and Ślączka (1958), Dżułyński, Książkiewicz and Kuenen (1959).

the trough leading to „secondary transverse" i.e. longitudinal currents, this time along the axis.

The passage from sandy to normal and shaly flysch tends to appear along the direction of sediment transportation. This indicates that the sandy flysch might have been deposited nearest the slope or shore, normal flysch further off and the shaly flysch still further from the source (as suggested by several authors).

Such a relationship, however, is not always the case. There are instances in which the shaly facies seems to be situated nearer the source than the sandy flysch (Książkiewicz 1960a). This may happen, for example, when the clastics are being transported by very dense and strong turbidity currents flowing from one or few localized discharge areas (e.g. outlets of submarine canyons, see Crowell 1955). Near the discharge area the sideways spreading of such currents is restricted and relatively narrow tongues of coarse clastics may be flanked by shaly sediments.

In some flysch troughs, opposing directions of sediment transportation may occur. The sequence of strata deposited in the central parts of such basins show an alternation of sandstone beds with opposing directions (Dżułyński and Ślączka 1958). Opposing directions although at first considered as very rare, occur in many flysch series.

VII. REMARKS ON PALAEOTECTONIC SIGNIFICANCE OF FLYSCH AND ITS SUBFACIES

It is widely recognized that the flysch facies originated in response to orogenic movements in „cordilleras" flanking deep troughs subjected to a prolonged subsidence (Bertrand 1894, Nowak 1927, Kraus 1932, Leupold 1933, Tercier 1947, Książkiewicz 1956, 1957, 1960, and others). For this reason Vassoevich (1959) designates flysch as a „geotectonic formation".

The alternation of coarse and fine beds should not in itself be considered to be evidence of tectonic changes. However, the appearance of large sandy flysch units in normal or shaly flysch is indicative of an increased rate of erosion, consequent upon increased rate of uplift of the source areas (Książkiewicz 1960, Contescu and Mihailescu 1961). This may also be due to the migration of shore lines towards the site of flysch deposition, but this, too, usually follows an increased tectonic activity and uplift.

Superficial tectonic movements are usually sudden and of short duration. They occur at intervals. Thus the repeated uplifts in the source areas give rise to a succesion of sandy flysch inclusions or „megarhythms" (Książkiewicz 1960) which is very characteristic of flysch (see Łoziński 1925, Nowak 1927, Sujkowski 1938, 1957). The first response to such movements comes from unconsolidated sediments on the slope. Indeed, mud-flows and slumps are frequently seen at the base of sandy flysch inclusions.

The influx of large amounts of clastics, resulting from increased rates of erosion in the source areas is usually slightly delayed. This influx, however, may continue for a long time after the upward movements ceased and until erosional equilibrium has been restored to conditions similar to those before the movements commenced.

It would be beyond the scope of this paper to discuss the variety of important palaeogeographic and palaeotectonic problems which arise in connection with the detailed current mapping in various flysch troughs [1]. There is still much to be worked out concerning the rising intrageosynclinal tectonic lands, particularly when in two parallel troughs the direction of palaeocurrents points toward one source but the sediments in both troughs differ lithologically. Asymmetry in the structure of cordillera has been invoked to explain such differences (Książkiewicz 1956, b). In dealing with the missing source areas one should also consider a possibility of large sideways displacements which might have existed between different tectonic and sedimentary units (Pavoni 1961).

VIII. VOLCANISM AND FLYSCH DEPOSITION

The bulk of flysch should be looked upon as a typical non-volcanic assemblage. Few volcanic rocks (other than tuffites) reported from the flysch (e.g. ophiolites in the Penninic realm of the Alps, teschenites in the Cieszyn beds or the volcanic rocks in the Sinaia beds) are limted to the base of those flysch sequences which succeed thick pelagic sediments (see p. 256). A considerable part of these volcanic rocks is, in fact, limited to the pre-flysch in the meaning of Trümpy (1960).

Flysch rocks which overlie a transgressive series (see p. 256) are entirely devoid of any volcanic rocks, other than water laid tuffites. Depending on the absence or presence of volcanic rocks at the base of flysch, one can differentiate, after Contescu (in press) the „eu-flysch" and „mio-flysch" sequences. It should be noted, however, that volcanic activity ceased in these zones during the accumulation of the flysch proper.

IX. BOUNDARIES OF FLYSCH FACIES

Vertical boundaries

Whenever flysch sediments occur above a surface of transgression they are invariably separated from that surface by a series of sediments other than flysch. The link between transgressive non-flysch sediments and flysch proper is usually provided by shales or marls (Kraus 1932, Tercier 1947, Allemann 1957, Trümpy 1960). Depending on the character of sediments underlying the flysch one can distinguish two types of passages:

Type 1. Flysch succeeds a thick series of marine pelagic deposits.

Type 2. Flysch succeeds transgressive or shallow water deposits.

The first type of succession is exemplified by the Prätigau flysch (Switzerland) which develops from Bündnerschiefer built up of impure thin-bedded fine limestones, calcareous marls and shales with few layers of very fine-grained sandstones (Nänny 1948). The transition from the

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[1] The reader is referred to the publications of Książkiewicz (1956 a, b, 1960 a, b), Kuenen (1958), Dżułyński and Ślączka (1958), Dżułyński, Książkiewicz and Kuenen (1959), Hsu (1959).

pelagic sediments below to the flysch proper is accomplished through the pre-flysch type of rocks (Trümpy 1960). Such a case can be seen also in the Cieszyn and Sinaia beds in the Carpathians. The lowermost parts of these beds consist of pelagic limestones and marls with abundant Aptychi. The above mentioned rocks should be included into the pre-flysch type of beds.

Still other examples of the first type of succession are offered by the „couches rouges" in the Préalpes médianes (Tercier 1947) or the Scaglia in the Southern Alps (Vonderschmitt 1938, Gandolfi 1942).

In all these cases the underlying sediments although frequently devoid of reliable depth criteria are considered as relatively deep water pelagic deposits. The passage to the flysch proper is either rapid (as in the case of Scaglia) or very gradual. The appearance of flysch above thick calcareous deposits of the pelagic type is frequently heralded by lenses or inclusions of limestone conglomerates and breccias.

The commencement of flysch sedimentation when the flysch succeeds a transgressive series is shown by Eocene flysch sequences in the Alps and in the Carpathians. As examples we may mention: the Aiguille d'Arves flysch (Barbier 1948, 1956), the Grès d'Annot flysch (Gubler 1958, Stanley 1961) of the Alps and in the Carpathians the Podhale flysch, Poland (Kuzniar 1910, Radomski 1958) and the Eocene flysch sequences in Maramures (Marmaros), Roumania (Patrulius, Dimitrescu and Bleahu 1952). Still another example is provided by the Maestrichtian flysch of Niesen (Lugeon 1938).

In all cases mentioned, the profiles through the flysch sequences are very similar and in places practically identical.

The transgressive series at the base of the Tertiary flysch is comprised of various conglomerates (partly non-marine), non-flysch sandstones, numulitic limestones, shales, marls and in places even lacustrine deposits, as for example at the base of the Grès d'Annot in the vicinity of Lausanne, French Alps (Stanley 1961). All these rocks pass laterally into one another.

In some cases the shaly link between the transgressive non-flysch and overlying flysch sediments is narrow and the term „transgressive flysch" has been frequently used although this expression is not precise. There may be a continuous vertical passage from non-flysch sandstones and conglomerates of the transgressive series into the flysch proper. Tracing the sandstones in such a sequence one can observe the increase of features diagnostic of the flysch facies with increasing distance from the base. More frequently the link between the transgressive series and flysch is provided by shales or marls. Occasionally these sediments are the only link between the surface of transgression and the flysch. There is no doubt that the change of the sedimentary environment from shallow to deeper conditions (which prevailed during the sedimentation of flysch — see p. 251) must have been accomplished during the deposition of shales or marls. These rocks may be deposited at any depth, provided the supply of coarse terrigeneous material or the formation of limestones is restricted. When fossils are absent or not diagnostic with regard to the depth it is hardly possible to distinguish deep water from shallow water shales and marls. Globigerina marls which so frequently underlie the flysch may contain Lithothamnium biostromes (e.g. Wangenkalk in the area north of Habkern in Switzerland — see Gigon 1952), otherwise however they are not distinguishable from deep water Globigerina marls.

The clastics in the transgressive series are derived directly from the substratum. This, however, is not necessarily the case with the succeeding flysch. Thus the shales linking the transgressive series with the flysch, separate different clastics, derived from different sources.

The upper boundary of flysch is rarely seen. In some areas there are passages between the flysch and molasse type of sediments (Trümpy 1960). We give two examples: In the Alps the final stage of flysch sedimentation is visible in the „Hilfernschichten" (Stampian) exposed at Steinibach, north of Fluehli in Switzerland (Frölicher 1933, Haus 1937) [1]. Here, the lower part of the succession consists of sandstones and shales of the flysch facies. Higher in the succession structures which are not typical of flysch begin gradually to appear. Well defined top surfaces become more common and they are covered by linguoid current ripples. Marls follow, which in turn are overlain by another sequence of sandstones and shales. This part of the succession differs markedly from flysch in that sharply defined upper surfaces of sandstones are covered by a profusion of linear and other ripples. Nevertheless, sole markings both scour and tool and many other so common in flysch are extremely abundant. The sole markings in themselves are not enough to merit calling these sediments flysch.

The ripple-marked beds are overlain by conglomerates of the Nagelfluh type, presumably of fluviatile origin.

Another example of an upper boundary of flysch facies is provided by the Aptian — Lower Albian flysch in Roumania. In Valea Jepilor the upper part of the Aptian flysch shows many sandstone layers with current-rippled top surfaces. This sequence is overlain by the Raciu breccia, a sediment which may be either a deep or shallow water deposit. The breccia is succeeded by a sandy facies with rippled top surfaces- obviously of shallow water origin. This in turn is covered by huge masses of Bucegi conglomerates (see Murgeanu and Patrulius 1957, Murgeanu, Patrulius, Contescu and Jipa 1961). These conglomerates, although in some parts probably of marine origin (Panin et. al. 1963) are to a large extent a continental fluvial deposits. Patrulius (1960), uses the term molasse for these deposits [2].

Lateral boundaries of flysch

The lateral boundaries of flysch are seldom visible.

In some instances, the distal boundary of flysch can be imagined to be one of thinning away of the sandstone beds and a passage into fine-grained pelagic sediments (Vassoevich 1948) or shales. The latter

[1] It is only the tectonic significance given to the term flysch which has led to, the Hilfernschichten being regarded as „non-flysch". The series in question was originally designated as flysch (Schider 1913) and in fact its lower part is in all respects identical with the Sub-Alpine flysch. As Furrer (1949) pointed out „...die Sedimente der Molasse, hier als stampische Hilfernschichten ausgebildet, unterscheiden sich makroskopisch kaum von denjenigen des subalpinen Flyschs. Auch im Dünnschliff sind keine besondern Unterscheidungsmerkale zu erkennen" (Furrer l. c. p. 116).

[2] „...C'est la molasse du premier paroxysme mésocrétacé (préalbien)". (Patrulius l. c. p. 148).

were not necessarily laid down at the greatest depth of the sedimentary basin (Vasiček 1953).

Interfingering of flysch with clastic rocks of non-flysch character may be observed in the Oligocene strata of the Polish Carpathians. Here, a part of the Krosno flysch which was derived from the active intrageosynclinal tectonic lands (Dżułyński and Ślączka 1958), passes into a series of black menilite shales, towards the margin of the Carpathian geosyncline (Koszarski and Żytko 1959, Jucha and Kotlarczyk 1961). These shales, in the area of the Skole nappe, include large bodies of the „Kliwa" sandstones which show few if any diagnostic features of the flysch proper and may be considered as non-flysch sandstones (Dżułyński and Kotlarczyk 1962).

In the Alps, a passage from flysch into non-flysch sandy shelf sediments has been recently described by Stanley (1961).

Tracing the sandy flysch towards the source of clastics one can expect to find a „marginal" facies composed of relatively clean, well sorted conglomerates and more pure sandstones than it is the case with the flysch proper. Presumably a part of the Niesen breccia, which Studer, differentiated from flysch (see Trümpy 1960) may be regarded as an example of such a marginal sediment.

X. EXAMPLES OF FLYSCH OUTSIDE THE ALPINE BELT

It is clear from many recent publications that the flysch facies occurs in various geosynclinal zones of different age. Well documented flysch rocks have been already reported from the Pre-Cambrian (Dangeard, Dore and Juignet 1961).

We give here a few examples from those sequences only which are familiar to us. Needless to say, these examples can be multiplied as presumably all major geosynclines have their own flysch zones (Bertrand 1894).

In the British Isles the majority of the Lower Palaeozoic greywackes in Southern Uplands of Scotland (Walton 1955, 1956, Kelling 1961, Craig and Walton 1962), Wales (Kopstein 1954, Bassett 1955, Cummins 1957, 1959, Wood and Smith 1959) and in Ireland (McKerrow and Campbell 1960, Weir 1962) are flysch sediments.

There are many flysch series in the Lower Palaeozoic of the Appalachians, for example the Martinsbourg formation (McBride 1962), a part of the Grand Pitch formation (Neuman 1962). The Lower Carboniferous of the Ouachita Mts. also contain well developed flysch facies (Cline 1960). The Chico group in California (Cretaceous) the Tyee formation (Eocene) in Oregon and the Loansome formation (Callovian) present other examples of typical flysch sequences.

XI. DIFFERENCES BETWEEN FLYSCH AND MOLASSE

The term flysch has been historically linked with molasse.

There have been three usages of the term molasse:

1 — in a purely petrographic meaning to indicate a certain type of sandstone with rounded feldspathic grains cemented by calcite (Cayeux 1927). This meaning has now been abandoned.

2 — in a stratigraphic meaning to include a broad zone of Oligocene and Miocene deposits in front of the Alpine chain.
3 — in an environmental and tectonic meaning to indicate a series of sediments which accumulated in front of rising folded chains.

A characteristic feature of molasse sediments is the variety of facies and rock types. This was pointed out by Studer (1825).

There are conglomerates and sandy conglomerates of non-marine and marine origin, sandstones both of marine, brackish and non-marine origin, marls shales marine and lacustrine limestones, coquina beds lignite deposits and evaporites.

One outcrop of normal flysch is usually sufficient to identify the rocks as flysch. This obviously cannot be done with molasse deposits. There are no sedimentary structures which are characteristic of the molasse structures known from all sedimentary rocks can occur. A detailed description of some common sedimentary structures in the molasse has been recently given by Bersier (1958), Briel (1962).

Among the many facies which make up molasse there may be also flysch (Radomski 1960), although it seems to be limited mostly to the lower part of the molasse formation and does not play a significant role in the whole picture of the molasse sediments.

The prevailing character of the molasse deposits clearly indicates a shallow water and partly non-marine environment. It is also the shallow water environment which explains the striking variety of facies and rock types. In flysch basins a change of several tens of metres affecting the position of the bottom could not be reflected in the sedimentation: in the molasse basins even a small uplift of a few metres, or conversely, might have produced a drastic change over large areas.

Besides local and frequent variations in particular molasse sections, there are also conspicuous changes in this formation along the Alpine belt. In Switzerland great masses of Nagelfluh conglomerates are the most characteristic rocks in the molasse. In the Carpathians conglomerates of this type are developed only locally and in front of the northern Carpathians they are limited to insignificant bodies. This is so because the Polish Carpathians, built mainly of friable flysch sandstones, could not provide suitable materials for conglomerates. Instead, extensive deposits of marls, shales, sandstones and evaporites accumulated. Although the name molasse is here not currently used the rocks in question are in fact marine molasse deposits.

If we consider the flysch and molasse in terms of geologic formations the relations and differences are as follows.

Flysch is a syn-orogenic formation which is largely made up of one essential type of facies, laid down below the wave base (i.e. approximately below the 100 m level).

Molasse is syn-orogenic and partly also post-orogenic a multifacies formation laid down generally in shallow water, marine and non-marine environment in piedmont and in intramontane basins.

In spite or because of the variety of facies, the molasse as a whole retains its individuality. It appears at the closing stages of orogenies. Presumably each folding episode within a given geosynclinal belt which was followed by differential uplift might have had its own molasse deposits. These however are seldom preserved. The Bucegi conglomerates, provide one the rare examples (see p. 257).

Used without any particular stratigraphic meaning the term molasse can be adopted to cover similar deposits outside the Alpine belt [1].

XII. SEDIMENTARY FACIES FREQUENTLY CONFUSED WITH FLYSCH

Concluding our discussion on flysch and molasse we direct attention to two particular types of facies which have been frequently confused with the flysch.

The first is the already mentioned sequence of shales and sandstones with sharply defined top-surfaces covered by a multitude of ripples (see p. 257). For want of a better term we refer to this type of clastic sequences as the sandy facies with rippled top-surfaces. The sandstones are not graded and may show large scale, low-angle cross-stratification. There may be sole markings on the bottom surfaces of the sandstones but these structures are not enough to merit calling these sediments flysch. The foot imprints of birds and land animals may occur on the top-surfaces of sandstones.

The above mentioned facies is common in molasse but not limited to this formation. There are sequences in both geosynclinal zones and basins outside geosynclinal belts in which this type of sediments may attain a considerable thickness. As examples we mention the Cambrian quartzitic sandstones in the Holy Cross Mountains, Poland (Dżułyński and Żak 1962), the Gras Valley formation (Triassic) in Nevada (Silberling and Roberts 1962) and the Upper Mancos shales (Cretaceous) in Arizona (Repenning and Page 1956).

The second type consists of a regular alternation of shales and sandstones. The latter are muddy, poorly sorted and particular beds can be traced over considerable areas without any significant changes in character and thickness. There may be graded bedding and the bottom surfaces of sandstones are frequently covered by a profusion of sole markings. Some sandstone beds grade upwards into the shales while other show sharply defined top-surfaces with ripples, occasionally mud-cracks and foot imprints of birds or land animals i.e. the features never encountered in the flysch. The mudstones or shales may also contain non-marine or brackish fossils.

This is, presumably, the series which Zeil (1960) took for the flysch and concluded that the flysch facies must have been laid down in a shallow water environment.

The sediments under consideration represent, in fact, a shallow water turbidite sequence (see Kuenen 1958). They originate under conditions „when heavy, sediment-laden flows sweep down to the shallow, water-filled reservoir, where they continue to flow under impetus gained in the steep mountain slopes" (Dżułyński and Walton 1963). Experiments indicate that the turbid flows entering into quiescent water spread easily, producing all sorts of sole markings, depositing a typical turbidite, even in those cases in which the depth of water does not exceed the thickness of the turbid flow (see Dżułyński and Walton l.c.). The turbid flow deposits discussed above, although in many respects similar to the flysch sediments must not be confused with the flysch facies.

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[1] For instance the Upper Carboniferous arkoses and the Myślachowice conglomerates in Southern Poland may be regarded as a Carboniferous molasse.

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