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FACIES DISTRIBUTIONS, PALEOCURRENTS AND PALEOTECTONICS OF THE PALEOGENE FLYSCH OF CENTRAL WEST-CARPATHIANS

(*Fig. 1—13*)

Abstract: Flysch basin of the central West-Carpathians has typical lateral and longitudinal current patterns. The origin of coarse-clastic marginal (proximal) facies including fluxoturbidites and olistholites is evidently dependent upon lateral supply. Fine-grained material was longitudinally transported. Strong lateral effects found by current study, were also there where no coarse-clastic material was supplied.

High tectonic activity of intrabasinal sources conditioned largescale gravitational mass movement and development of marginal facies. Coarse-clastic material was sporadically supplied by island and by tectonically stable land areas.

Flysch trough was formed on the basement folded by Cretaceous orogene, inheriting structural features of the basement. The northern margin of the trough is connected with orogenetic process and with submarine folding in outer Flysch geosyncline.

Introduction

There are still more sedimentologic works dealing with the facial model of the Flysch basin. In reconstructions the following factors are considered: 1. Distribution of facies and palaeocurrent system: 2. Petrographical character of rocks and types of sedimentary structures: 3. The relation of the lithic fill to tectonic setting.

Due to the high degree of the tectonic disturbance of the Flysch basins by folding, the former factors are difficult to be analyzed, the reconstructions being unreliable. With respect to this, the Flysch of the central West Carpathians has a suitable position, representing an additional trough connected with the outer Flysch geosyncline from the south. The trough was filled in a relatively short time (Eocene—Oligocene), then slightly folded, mainly on the contact with the klippen belt. Facies distribution and paleocurrent patterns indicate the supply of conglomerates, breccias with the development of sandstone facies from the tectonically active source areas to the basin. The development of these marginal coarseclastic facies was frequently erroneously identified with the basal formation, their genesis, however, was not accompanied with the shallow-water organogene limestones of the transgressive type, neither with the wave-action. The opinions about the origin of fine-grained material in the Flysch are not unambiguous. D. Andrusov, E. Köhler's (1963) palaeogeographic reconstructions proved that the source area might have been to the south of the Flysch basin. Especially D. Andrusov (1965) supposed the source of the Flysch clastics in the area of the Spish-Vepor land area and in the Orava cordillera. Neither F. Pícha (1965) did solve the problem of the source of

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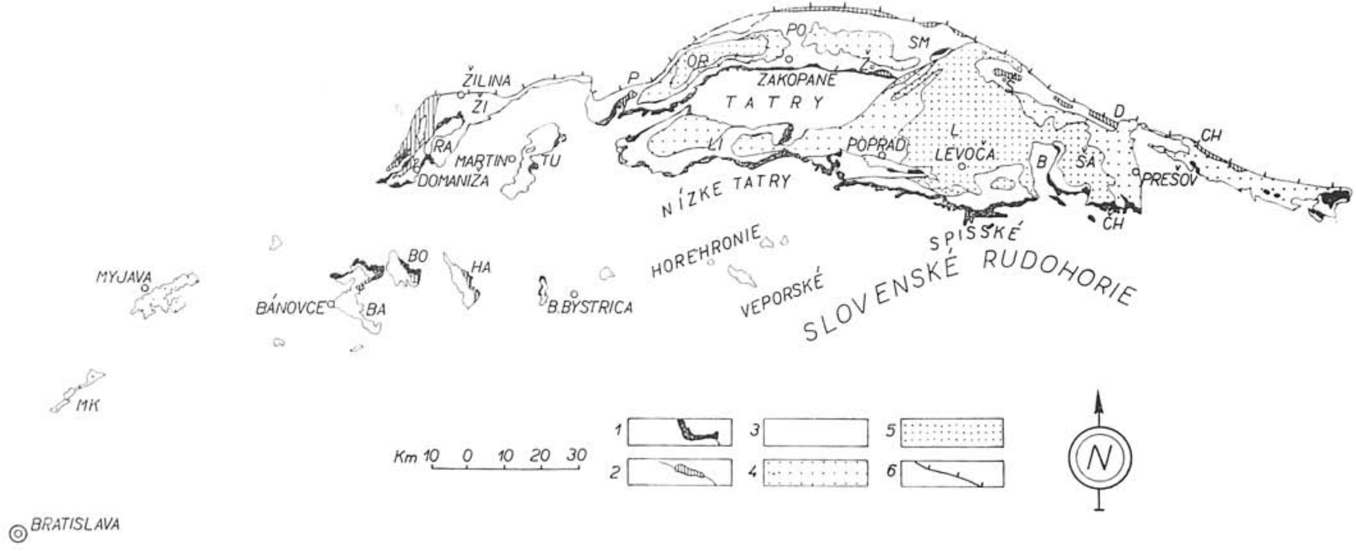

Fig. 1. General map of lithofacies of the Paleogene of central West-Carpathians (modified according to F. Chmelík 1967). 1 — Basal transgressive lithofacies (conglomerates, breccias, calcarenites, organogene nummulitic limestones, sandstones and silstones). 2 — Marginal facies of conglomerates, breccias and sandstones (fluxoturbidites, olistolithes). 3 — Claystone lithofacies (Flysch with predominance of claystones, graded organogene carbonatic breccias, menilite shales and variegated marls) in western depression Bánovce, Bojnice, Handlová, Turiec, Rajec and Žilina, with great amount of graded-bed ded sandstones, belonging to the typical claystone-sandstone Flysch (cf. Explanations 1 : 200 000, sheet Žilina, Banská Bystrica). 4 — Claystone-sandstone lithofacies (typical Flysch) with graded-bedded sandstones, deformational structures. Sandstone/Claystone rato 1 : 1, 2 : 1, 1 : 2. 5 — Sandstone lithofacies (coarse Flysch, conglomerate and microconglomerate Flysch, coarse graded beds of sandstones, pebble mudstones, claystone intraclasts, thin intercalations of claystones). 6 — Tectonic contact of the northern margin of the central-Carpathian Flysch with klippen belt. The Flysch is sharply cut off in different stratigraphical levels, and strongly folded along the whole course of the contact. Abbreviations: MK — Malé Karpaty Mts., Ba — Bánovce depression, Bo — Bojnice depression, Ha — Handlová depression, Ra — Rajec depression, Tu — Turiec depression, Ži — Žilina depression, Li — Liptov depression, Or — Orava, Po — Podhalie, L — Levočské hory Mts., Ša — Šarišské hory Mts., B — Branisko Mts., Č. H. — Čierna hora Mts., Sz — Szaflary, Š — Šambron, D — Drienica, Ch — Chmeľov, Ž — Ždiar, S. M. — Spišská Magura, P — Pucov.

fine-grained material, although the study of heavy minerals indicates the transport of psammitic material from lateral sources. The position of the source areas supplying the clastics into the basin, was solved in the regional study by R. Marschalko, A. Radomski (1960). The authors sought for the connection between the paleocurrent system and facies distribution, stressing the fact that the paleocurrent patterns offered a picture that cannot be contradicted without heavy arguments. This was illustrated by the analysis of the transport direction around the so-called „Tatra island", which showed that the currents were directed to the island especially in upper constituents of the Priabonian Flysch — and not in the reverse course —, and the material of the clastics was getting finer when nearer to the supposed „cordillera". Paleocurrent studies by S. Dżułyński and A. Radomski (1955), J. Jablonský (1961), T. Koráb et all. (1962), M. Mišík, O. Fejdiová, E. Köhler (1967), completed and exacted by the author's measurements in the last time, enlighten the problem of the filling of the basin, the position of source areas, and palaeotectonic development.

Stratigraphic-Facial Division of Palaeogene of Central West-Carpathians

The Palaeogene under study is to the south of the klippen belt, in continuous regions or in separated depressions or in smaller isolated basins (in geomorphological sense). In the north, the borderline against the klippen belt is tectonic (fig. 1). In the recent years (B. Leško 1960, A. Matějka 1961) equivalent Flysch facies were found in this tectonic unit, even older than the transgressive constituents of the Palaeogene of the West-Carpathians, that extended also to the south of the klippen belt into the area of the West-Carpathians. These developments will not be dealt with in the present article.

In the Palaeogene, the following lithofacies (F. Chmelík 1967) were distinguished, beginning with the base:

1. Basal transgressive lithofacies (non-Flysch)
2. Claystone lithofacies (Flysch with predominance of claystones and sub-Flysch)
3. Claystone-sandstone lithofacies (typical Flysch)
4. Intermediate and sandstone lithofacies (typical and coarse Flysch)
5. Marginal conglomeratic-sandstone lithofacies (Wildflysch)

Most stable on great extent is the basal lithofacies. The flysch lithofacies are passing into one another horizontally and vertically, and — although very extensive as to the area — they do not represent chronostratigraphic units. They cannot serve for the stratigraphical correlation, since they were affected by alterations, especially in direction to the source areas. They do not contain fossils, except planktonic foraminifera (A. Samuel 1965) and resedimented organic remnants.

Basal Transgressive Lithofacies, Its Sediments and Evolution

Stratigraphic correlation studies in the last years (D. Andrusov, E. Köhler 1963, R. Marschalko, M. Váňová 1963, O. Samuel, J. Salaj, M. Váňová 1964, E. Köhler 1966, 1967, F. Chmelík 1967) pointed out to the rocks of the transgressive cycle in the whole area of the central West-Carpathians covering the Mesozoic-Palaeozoic complexes formed by the Cretaceous orogene. This stable association of rocks may be observed in the profiles of the transgressive lithofacies: Basal carbonatic breccias and less polymict conglomerates alternate or replace with calcarenites, less frequently with carbonaceous subgraywackes. In the upper part there are nummulitic biostromes or pecten pholadomya associations with sandstones and siltstones. The study of the age of nummulitic biostromes serves for the reconstruction of the progress of transgression and enlighting the role of subsidence in relation to the Flysch facies (fig. 2).

Transgression and development of the organogene facies in the Palaeocene and Lower Eocene (Yppresian) are connected predominantly with the klippen sedimentary area, and passing on the consolidated block of the West-Carpathians only in the Myjava — and Pružina-Domaniža-Žilina region. The maximum development of the transgression took place in the Upper Lutetian. It annected the whole area of the West-Carpathians, except the so-called Liptov island and a part of the Spišsko-veporské rudohorie Mts. The transgression developed symmetrically from the periphery to the centre, along the SWW-NE and NW-SE lines. At the end of the Upper Lutetian, the trough formed on the NW, N, NE margins of the Carpathian arch, was filled by the coarseclastic marginal facies.

After the Middle Priabonian, the connection of the Levoča and Horehronie sedimentary areas took place. The development of the Priabonian Flysch is shifted over the whole area of the central West-Carpathians. Interesting is the fact, that facial comparisons and correlations did not show any continuous transitions between non-Flysch transgressive facies and the Flysch, although they could seemingly follow from the simultaneous development in the basin. Over the transgressive base there is always a claystone or a Flysch lithofacies with planktonic foraminiferal associations, and without shallow-water organogene limestones. Abrupt biofacial changes indicate that the shallow-water trangressive facies sank due to the negative movements, and since they were nowhere substituted by the typical Flysch, the author supposes that the Flysch is not a shallow-water facies. Its course indicates the direction of the maximum subsidence and the course of the bathymetric axis of the basin, following the Cretaceous tectonic structures, in the period of the Lutetian and Priabonian.

Flysch Lithofacies and Their Composition

The claystone lithofacies: consists of predominantly gray and dark calcareous claystones. Most frequent are there carbonatic breccias with nummulites, viz. in the Bánovce, Bojnice, Handlová, Rajec, Žilina, Turiec, Orava

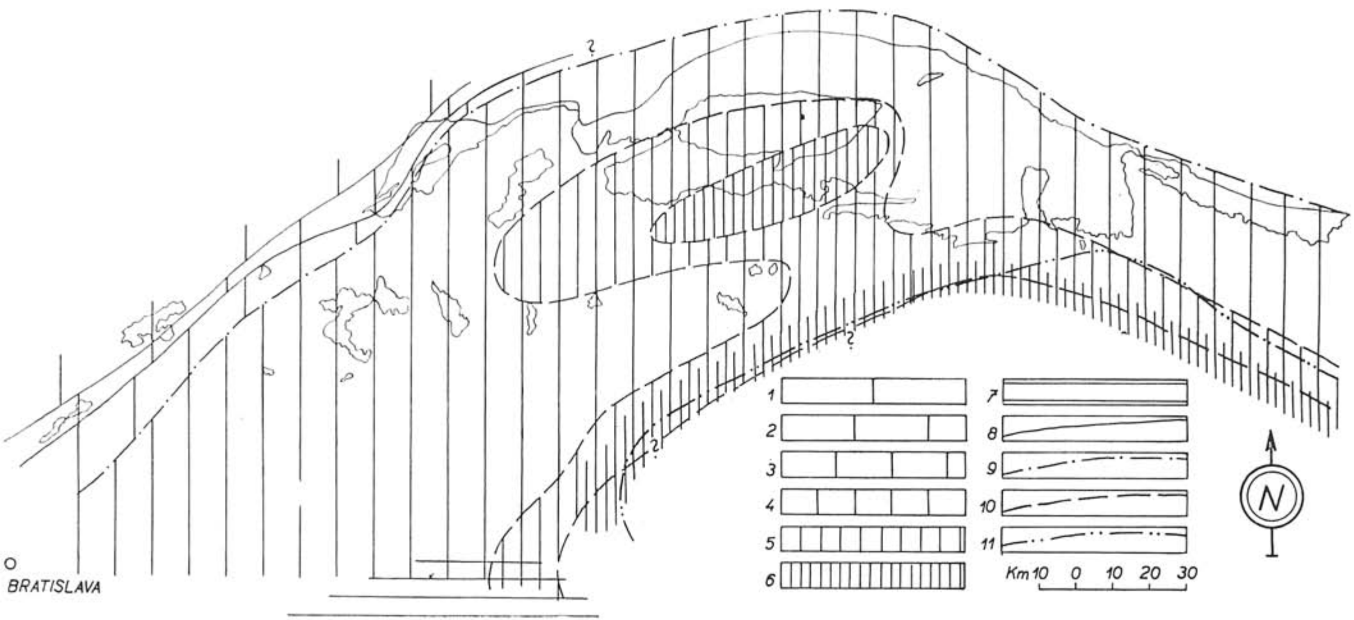

Fig. 2. Palaeogeographical sketch of the progress of transgression in the Paleogene of central West Carpathians. 1 — Extension in Palaeocene, 2 — in Lower Eocene, 3 — in Lower Lutetian, 4 — in Upper Lutetian (Biarritzian), 5 — in Lower Priabonian, 6 — in Middle Priabonian with the ending in Upper Priabonian, 7 — Epicontinental sea of the central Hungarian Mts. from the Lower Lutetian to the Lower Oligocene (after J. Seneš 1965), 8 — Supposed extention within the Lower Eocene to Biarritzian, 9 — Supposed borderline and actual borderline of distribution from the Biarritzian to the Lower Priabonian, 10 — Supposed and actual extension from the Lower Priabonian to the Upper Priabonian, 11 — Supposed extension in the Upper Priabonian and Lower Oligocene. Reconstruction on the ground of data by D. Andrusov, E. Köhler (1963), R. Marschalko, M. Váňová (1963), O. Samuel, J. Salaj, M. Váňová (1963), O. Samuel (1965), D. Andrusov (1965), E. Köhler (1966), R. Marschalko (1967).

depressions, up to Podhalie and Spišská Magura. The breccias are coarse-grained, graded and or structureless, of considerable thickness (10 m) (fig. 3, 4). They arose due to the activity of coarse grain flow, sandflows and turbidity currents. In claystones there are still small beds (5—200 cm) of graded sandstones with the interval of lower parallel and current-ripple lamination. In the western depressions, sandstones and breccias form in claystones frequent accumulations, therefore the claystone lithofacies may be ordered to the typical Flysch and Wildflysch. In the claystone lithofacies there are local accumulations of Mn oxid-carbonatic ores, muddy limestones and dolomites Fe, variegated claystones with resedimented mikrofauna, and menilite beds with cherts. Stratigraphically, the claystone lithofacies belongs to the Uppermost Lutetian to Middle Priabonian (fig. 5). In the course of its genesis there was a poorer supply of clastics. Mineralogic study of F. P í c h a (1965) pointed out to the high concentration of pyrite in the area of Podhalie, Spišská Magura and Šambron, and to the non-aerated euxinic environment of claystone, inconvenient for any form of life.

T h e c l a y s t o n e - s a n d s t o n e l i t h o f a c i e s: developed gradually

Fig. 3. Slightly graded-bedded breccia with unrounded, predominantly carbonatic material, alternating with predominance of claystone in the Flysch. Lateral transport direction. Breccias represent the last clastic constituents of the fading-out sources, tectonically highly mobile. Milpoš, to the NW of Sabinov. Photo by R. M a r s c h a l k o.

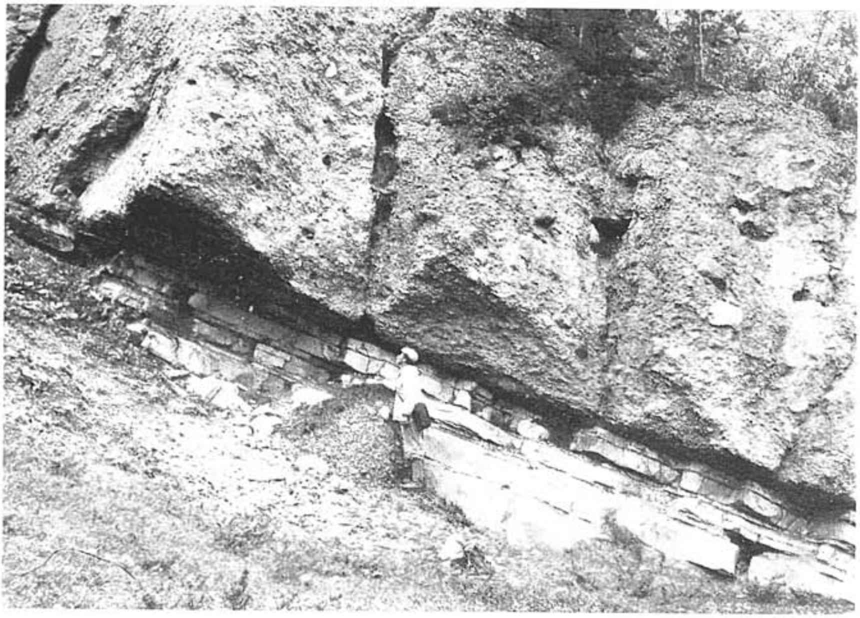

Fig. 4. Non-sorted breccias alternating in the Flysch with fine-grained clastic material. Transport of coarse breccias and finagrained homogene sandstone was lateral, uni-directional. Marginal facies of Bánovce depression. Radiša quarry. Photo by R. M a r s c h a l k o.

from the claystone lithofacies. It exists in Liptov, Orava, Levočské pohorie Mts., where it is either replaced by the sandstone lithofacies, or is completely faded-out. In classical development, this lithofacies may be found to the east of Prešov, along the southern margin of the klippen belt. The sandstone claystone ratio is either alterating or equilibrated 1 : 1. Beds, in some places even 5 m thick, are well graded-bedded, accompanied on the top by the interval of parallel, current-ripple and convolute lamination. Thick ungarded beds (massiveness) with disturbed structures, intraclasts and slabs of claystones are especially abundant in the Šarišské and Levočské hory Mts. Deformations of whole bed sequences into sedimentary slump folds are quite usual. Linear structures are well-preserved. The age diapason is fluctuating within the Lower Priabonian and Upper Priabonian in the western zone (Myjava-Žilina) up to Middle Eocene (fig. 5).

T h e i n t e r m e d i a r y a n d s a n d s t o n e l i t h o f a c i e s: developed mainly in the Levočské and Šarišské hory Mts., where it is replaced by marginal lithofacies — Wildflysch (R. M a r s c h a l k o 1961, 1964). It may be also found in Orava and Podhalie. Generally, the sandstone lithofacies is characterized by high content of coarse-grained, graded and structureless beds of sandstones, and thin intercalations of dark claystones. Coarse slabs of claystones in sandstones reach even 1 m thickness, being chaotically distributed in beds. Slump over-

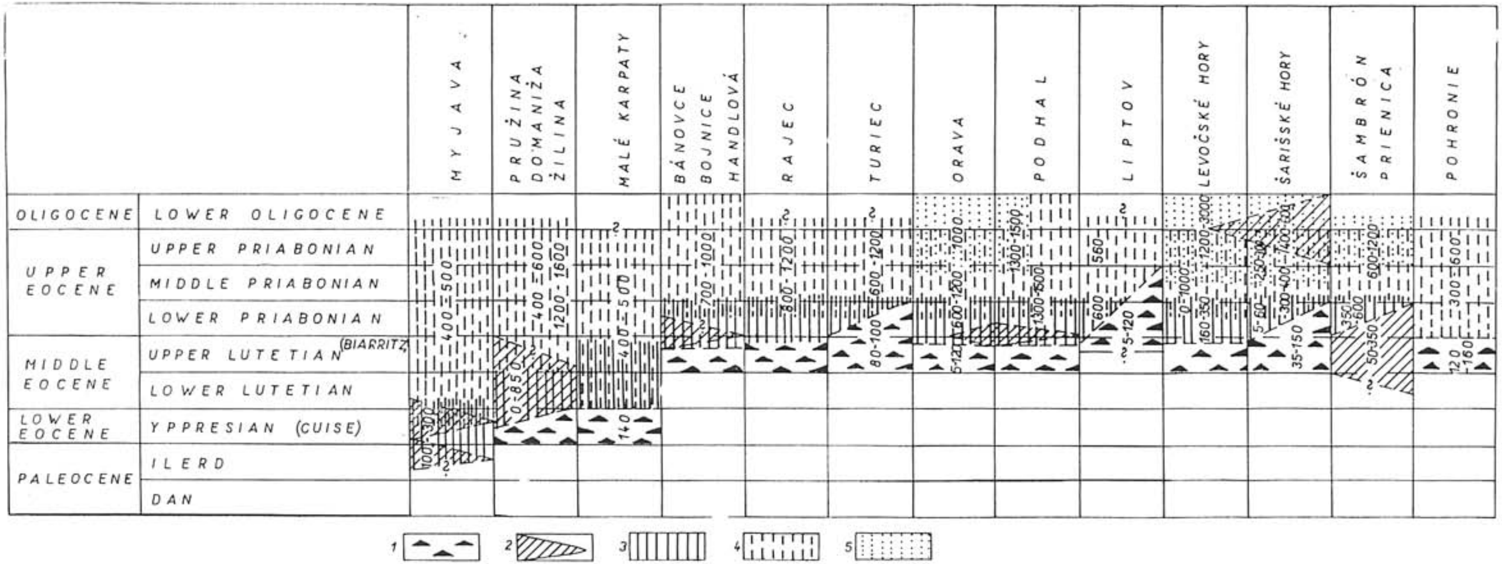

Fig. 5. General stratigraphic table of the Central West Carpathian Paleogene in the separate regions, depressions and mountain ranges. 1 — Basal transgressive lithofacies. 2 — Marginal Flysch lithofacies (Wildflysch — fluxoturbidites). 3 — Claystone lithofacies (Flysch with predominance of claystones). 4 — Claystone-sandstone lithofacies (Typical Flysch). 5 — Sandtsone lithofacies (Typical and coarse Flysch). Stratigraphical table compiled according D. Andrusov, E. Köhler (1963), F. Chmelík (1967), E. Köhler (1966, 1967), R. Marschalko (1966b, 1967), R. Marschalko, M. Váňová (1963), O. Samuel (1965), O. Samuel, J. Salaj, M. Váňová (1963), M. Váňová (1962, 1964).

folds present in beds with the interval of parallel and current-ripple lamination indicate the origin of these beds by combination of grain flows and turbidity currents. Frequently also coarse-grained graded beds were found, wit hout upper lamination intervals. The sandstone lithofacies arose due to the abrupt supply of the great amount of clastic material into the basin. They are typically Flysch, and according to N. B. Vassoevich's (1960) classification, they belong to the coarse Flysch at the margin of cordilleras. The author's (1966) correlation study showed the transition of sandstone lithofacies into marginal. As for age, the sandstone lithofacies belong to the Upper Priabonian and Lower Oligocene.

Textural Characteristics of Flysch Sandstones

Petrographical research of the Flysch sandstones (F. Pícha 1965, J. Bromowicz, Z. Rowinski 1965, R. Marschalko 1966) showed the low degree of structural and mineralogical maturity of clastics. The clastics belong to the group of lithic graywackes and subgraywackes in the sense of F. J. Pettijohn (1957). High content of matrix points out to greater density of the transport medium. Very low degree of roundness of unstable components, bad sorting and high content of matrix, point out to the rapid deposition by turbidity currents as well as to the low washing of psammites. Coarse-grained graded beds and thick ungraded beds (massiveness), increased content of intraclasts and index of slumping testify to the influence of gravitational transport and nearness of sources. No substantial petrographical differences in the composition of Flysch graywackes and subgraywackes have been found. Thus it may be supposed that neither the sources of the clastic material were essentially changed. There was a change only in the intensity of the supply of clastics, manifested in the ratio of psammites, psefites and pellites in the separate lithofacies.

Marginal Flysch Lithofacies and Types of Sediments

They represent extensive lenses and prisms composed of the series of conglomerates, breccias, sandstones in the claystone lithofacies and in the claystone-sandstone Flysch of the Myjavská hornatina Mts., in Bánovce (fig. 4) Bojnice, Handlová, Horehronie, Pružina-Domaniža-Žilina, Orava, Pucov, Podhalie, Ždiar depressions, in the zone of Szaflary, Šambron, Drienica, Chmeľov (fig. 6). In the Šarišská hornatina and Levočské pohorie Mts. they are pass into the sandstone lithofacies.

The main common feature of these lithofacies is the development of sediments deposited by gravitational flowing of coarse-clastic masses over steep submarine slopes. In some there were exotic blocks thick several to 100 m, that arose by sliding or rock-fall from the steep cliff faces down to the basin. These olistholites (E. Beneo 1956) from predominantly carbonatic, slightly metamorphosed, and granitic rocks, are known in Myjava and Pružina, Pucov, Ždiar, Šarišská hornatina Mts. The greatest existing block was of 150 × 400 m in size, rested in Flysch with predominance of claystones to the NW of Sabinov (Urbánek 1936).

Another frequent type of sediments is represented by „pebble mudstones" of J. C. Crowell (1957). They are formed by pebbles and fragments of hard and soft semi-plastic and plastic rocks (intraclasts) in clayey-sandy matrix (fig. 7, 8). These rocks represent whole scales of transitions in the marginal facies of the Šarišské hory Mts. (R. Marschalko 1961, 1966 b), Levočské hory Mts. (P. Gross 1963), in Podhalie (A. Radomski 1958, K. Grzybek, B. Halicki 1958), in Orava (M. Mišík, O. Fejdiová, E. Köhler 1967).

Most frequent are non-sorted or graded bedded coarse-grained sandstones and breccias with frequent structures pointing out to their origin in sandflows and gravely-sandflows (fig. 9). These sediments called fluxoturbidites by S. Dżułyński, M. Książkiewicz and Ph. H. Kuenen (1959), arose from watery slides or avalanches of noncohesive gravel and sand. This is a mechanism analogous to the sandflows observed in submarine canyons (P. Shepard 1965).

From these three groups of sediments, especially fluxoturbidites participate

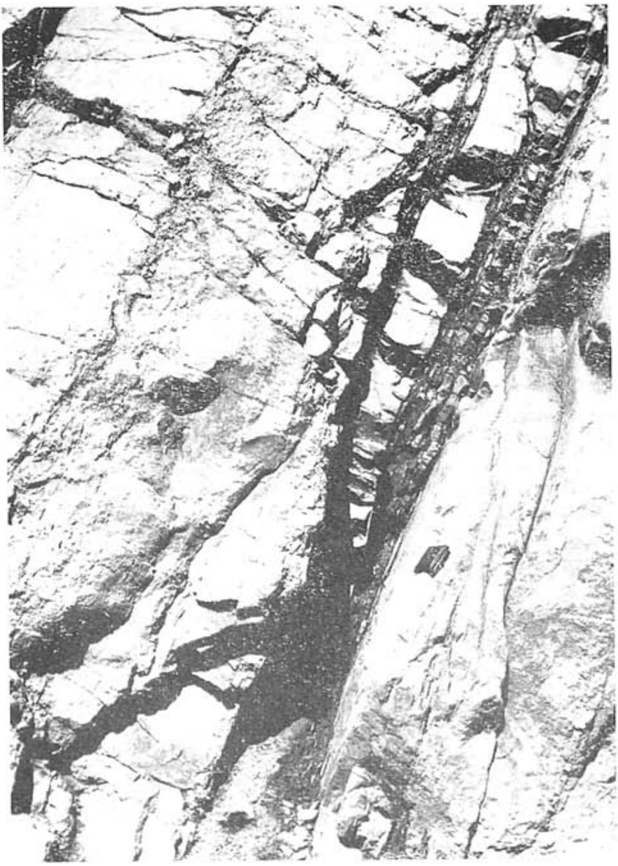

Fig. 6. Coarse-grained breccias, conglomerates and sandstones, frequently non-sorted, form a part of coarse-clastic prisms in the northern margin of the Flysch zone, in the belt of Szaflary, Šambron Drienica. Lateral transport direction. The cut of the railroad Kamenica, of Lipany-Ciře. Photo by R. Marschalko.

in the forming of marginal Flysch facies. Because of their coarse-clastic character. the marginal facies were frequently erroneously ordered to the basal transgressive lithofacies (F. Chmelík 1963). there is. however. a number of features differentiating the marginal facies from breccias and conglomerates of the transgressive type. Such are: large blocks of organogene and nummulitic limestones present in submarine slides and in fluxoturbidites. large claystone intraclasts indicating processes of submarine erosion caused by gravitational transport. bad sorting of clastics and the absence of wave and shallow-water characteristics.

Marginal facies remind of the extensive fans or prisms. or lenses wedging out from the source in direction to the axis of the basin. by their shape. In cross-sections perpendicular to the transport direction. according to the existing exposure. the following zones may be considered most extensive: the interrupted Szaflar-Šambron-Chmeľov zone. at least 180 km long and max. 350 m thick (Lower Lutetian? — Lower Priabonian). the Pružina-Žilina zone. 30 km long and 850 m thick (Lower Eocene — Upper Lutetian?) the Bánovce-

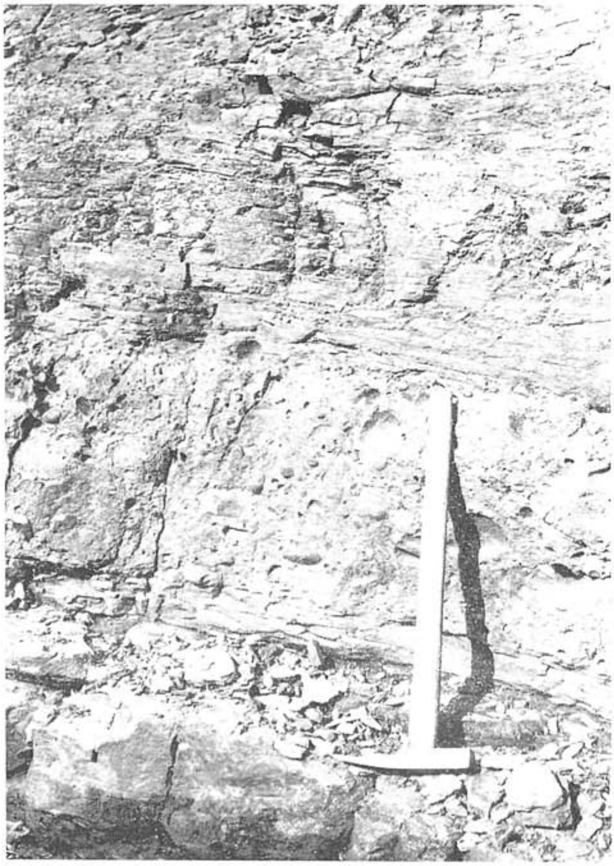

Fig. 7. The bed of pebble mud-stone type. In the surplus sandy — clayey matrix there „flow" pebbles and synsedimentary slabs of claystones and sandstones. Marginal facies of Šarišská hornatina Mts.. Široké in the brook V. Svinka. Photo by R. Marschalko.

Handlová zone, 40 km long and 400 m thick (Upper Lutetian—Lower Priabonian?), the zone of conglomerates near Ždiar, 10 km long, and 250 m thick (Upper Lutetian—Lower Priabonian), and the zone of the Šarišská hornatina Mts., 10 km long and 400 m thick (Upper Priabonian—Lower Oligocene). The spatial dimensions of these facies depended upon tectonic activity of mobile sources producing spasmatically large amounts of the clastics in various stages of the development of the basin.

Thickness of Flysch of Central West-Carpathians

The Flysch of the northern zone from Pružina through Orava, Podhalie, Levočské and Šarišské hory Mts. shows greatest thickness. In the continuous area of the Levočské hory Mts. the thickness of 3000 m in average was valued by F. Chmelík (1967), not excluding even 5000 m. It has been found out, that the fluctuation of thickness was connected with the speed of local supply from lateral sources, and last but not least also with the influence of submarine

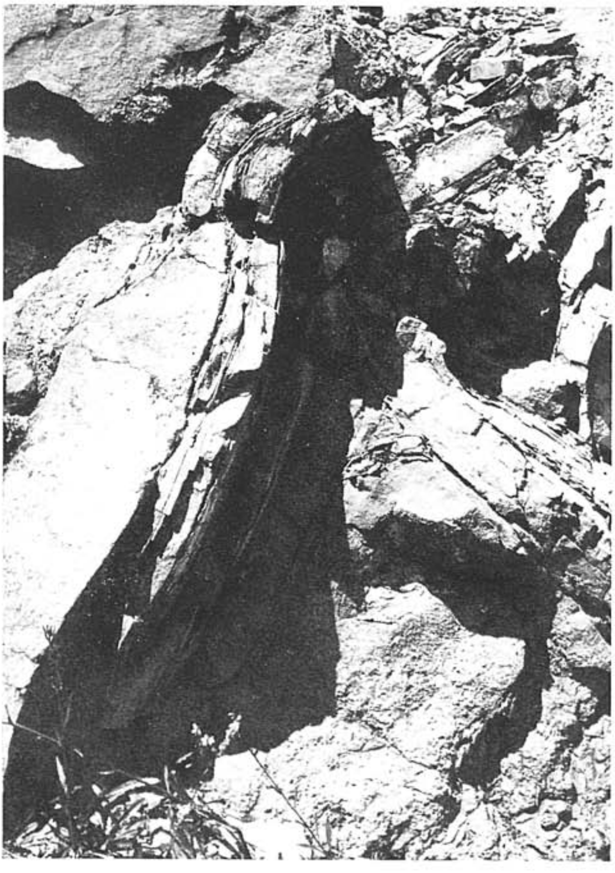

Fig. 8. Intraclasts of deformed beds arising in gravitational movement of clastic matter. Kamenica, cut of the railroad Lipany-Čirč. Photo by R. Marschalko.

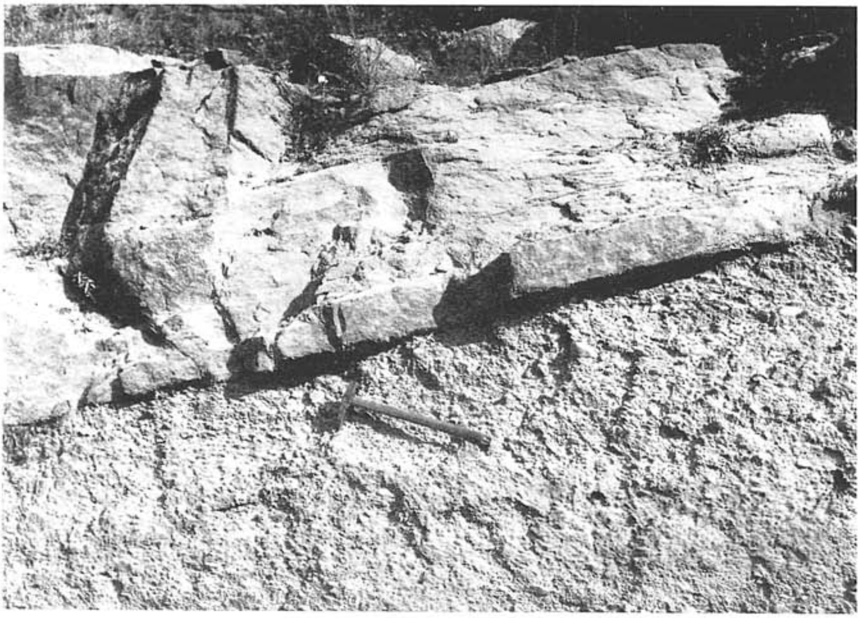

Fig. 9. Upper contact of conglomerates and sandstones. Lateral transport direction, the same in sandstones and conglomerates. Fluxoturbidites. Marginal facies of Sarisškä hornatina, Križovany, cut of the road. Photo by B. M a r s c h a l k o.

erosion of earlier facies by gravitational transport. The Flysch in the Bojnice-Handlová depresion shows much lower values of thickness: 700—1000 m (O. F r a n k o, P. G r o s 1964), primary thickness in Horehronie (Hron river valley) is 300—600 m according to E. P l a n d e r o v á and all. (1965). The Flysch of the latter area shows less reductive character, too.

Although the data on the thickness of the Flysch are distorted due to post Paleogene erosion, still they may indicate that the maximum thickness of the accumulated deposits i. e. the structural axis, corresponds to the bathymetric axis of the basin, as it has been already shown earlier (cf. fig. 2, 5).

Palaeotransport in Flysch Facies

Current direction was determined on the ground of measuring of the linear structures, as e. g. various types of scour and tool markings, then by the study of cross stratification of the so-called current-ripple lamination, by the following of internal oriented structures, especially in coarse clastics. Deformational structures were studied in relation to primary slopes. Determination and reconstruction of current direction depended upon convenient exposures. These were obstructed by synclinal structure of the Paleogene, especially in the earlier Lower-Priabonian facies. In younger facies, owing to denudation and morphologic dissection, the Paleogene was better available, therefore reconstructions are more reliable.

Lower Priabonian

On the base of the Lower Priabonian (fig. 10), in coarse-clastic marginal lithofacies of the Szaflar-Šambron-Drienica zone, the main current direction from NE to SW and SSW, from NW to SE an SSE, and from N to S, was determined. These currents were characterized by considerable dispersion, observed always from a certain point. Differences were not too strict in beds above one another, they were due to the sequences placed and compared among each other. The unidirectional transport of coarse-clastic material indicates evidently lateral direction of filling. The nature of fanlike dispersion of currents in marginal lithofacies was observed in the Bánovce-Handlová depression from SE to NW and N, in Pucov and near Ždiar — from S to N and to NE. In conglomeratic fluxoturbidites near Ždiar, this direction was stable all over the sequence, coming out of one central point.

It is difficult to suppose the distribution of currents in the axis of the basin. Material of the clastics was somewhere badly sorted and coarse, so that it was impossible that long tonguelike bodies passing far away from the axis of the basin with the end longitudinal orientation could have been formed by this material. It is more probable to have been deposited in the form of fans near the point of the entering of material. Extension on larger surfaces in the axis of the basin may be supposed only in the areas of the entering of greater amounts of sand (Šambron, Drienica, Bánovce, Domaniža).

Middle Priabonian

In the Flysch lithofacies with prevalence of claystones, in the Bánovce, Handlová, Turiec, Rajec depressions, and in the southeastern part of Orava (fig. 11) the longitudinal filling of the SW-NE direction predominates. In the later area, in the claystone-sandstone Flysch there suddenly appears lateral filling, that was also followed in the Liptov depression, especially in its northern-western part. In the northern part of Orava, and in Podhalie, there predominate longitudinal filling directions, in the existing bordering of the Flysch. Transverse direction is important in the Bánovce and Handlová depressions, while in the Liptov depression its role is decreasing. Exceptional current directions were there in the area of the Šarišské and Levočské hory Mts. viz. from the S to NW, N and NE to the area of the klippen and northern Flysch basins. The situation was similar to the east of Prešov. Poor data on the incomplete exposures of the Flysch sequences in Horehronie (Hron r. valley) indicate the distribution of current direction from the SE to NW and W.

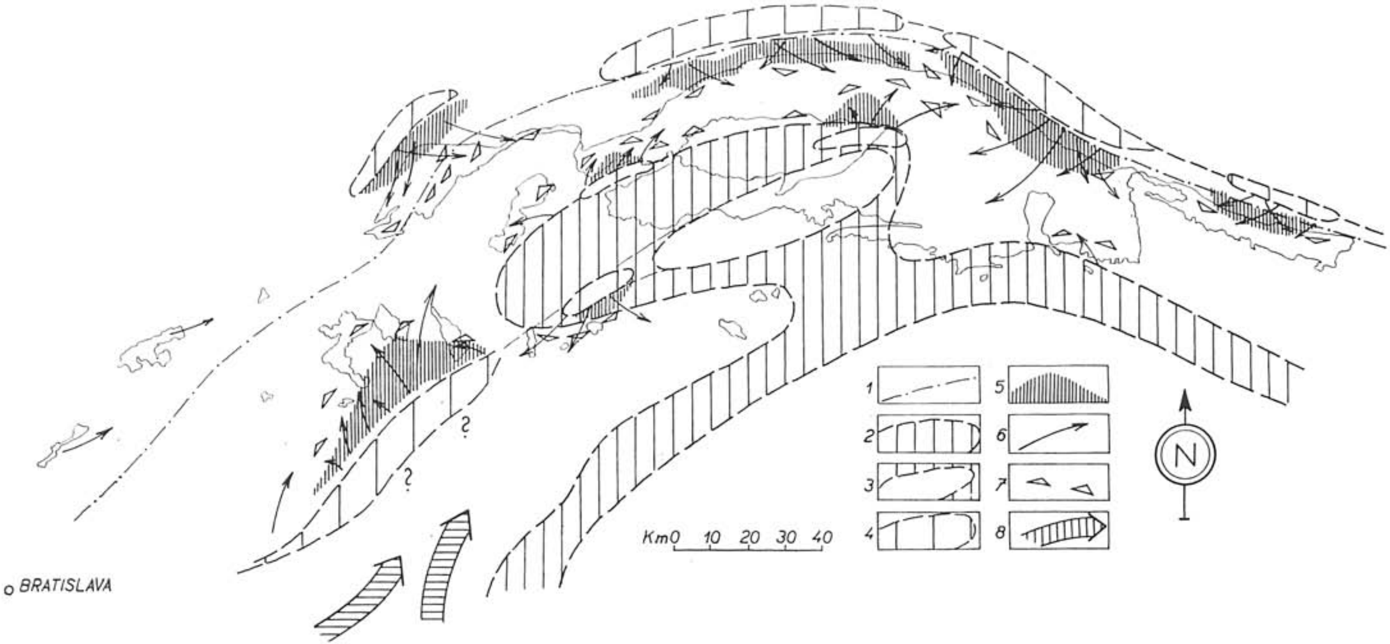

Fig. 10. Palaeogeographical sketch of central Carpathian Paleogene on the base of the Lower Priabonian. 1 — Supposed northern borderline of Biarritzian transgression, to the south of the latter the development of the Flysch facies with claystones predominating. This supposed line represents the extension of the West Carpathian block (before the transgression of the Biarritzian) in comparison with the sedimentary area of klippen belt. 2 — Supposed and actual Lower Priabonian transgression with development of littoral and neritic facies, nummulitic biostromes and pectenid pholadomya associations. 3 — The zones of emergence (islands and land areas of tectonic stable character). 4 — Zones tectonically strongly activated (cordilleras). 5 — Marginal facies of conglomerates, breccias, olistholites fluxoturbidites, turbidites. 6 — Paleocurrent direction of clastics. 7 — Extensive accumulations of graded organogene carbonate breccias and sandstones with the supposed transport direction. 8 — Communications of facies of epicontinental sea of the central Hungarian Mts.

Upper Priabonian

Current patterns (fig. 12) in the western depressions were similar to those in the Middle Priabonian, with longitudinal transportation predominating from the SW. In the sandstone lithofacies of Orava, current direction shows strong lateral effects from the W and NWW to the E. In the claystone-sandstone Flysch of the Liptov depression, there are subsidiary directions from the SW, and more important ones — from the NW to SEE.

In the sandstone Flysch of the Levočské hory Mts. there are two dominant current patterns. The older current direction is that from the NE to SW and SWW, being well identifiable mainly along the northern margin of the Levočské hory Mts. Slight effects of this current direction may be observed up to Horehronie (Hron r. valley). Another important direction from the SE occurs mainly in the coarse Flysch to the north of the Čierna Hora Mts., passing to the NW and NWW into the sandstone Flysch of the Levočské hory Mts. where it crosses the preceding one. At the southeastern ending the longitudinal current direction passes from the sources covered with sedimentary Neogene formations.

Longitudinal and Lateral Filling, Facies Distribution, and Bathymetric Axis of Basin

It may be generally stated that in the Flysch basin lateral filling had the most important role in the Lower and Upper Priabonian, while in the Middle Priabonian, especially in its northwestern part there is longitudinal transport on larger extent (Malé Karpaty Mts. — Podhalie).

Lateral supply is indicated by coarseclastic marginal facies, developed bilaterally on the sides of the northern trough, as well as by beds of carbonatic and organogene breccias inserted in claystone and claystone-sandstone lithofacies. Yet, the stratigraphic correlation (fig. 5) clearly shows that marginal facies in the Lower Priabonian fade-out due to the stop of the supply of clastic material from the lateral sources. The formation of these facies conditioned the steep lateral slopes of the trough, and stressed its bathymetric axis. Thus in comparison of the distribution of the current pattern in the Middle Priabonian (fig. 11), the predominating longitudinal transport in the southwestern part of the trough should enter into the „prepared" trough from the SW, and to follow the trough up to the Podhalie in Poland. In the southwestern part of Orava, there is, however, a thick lateral component of transport (cf. R. Marschalko, A. Radomski 1960, J. Jablonský 1961, M. Mišík and all. 1967). Sandstone-claystone Flysch is abruptly replaced by claystone, showing evident proofs about lateral supply. Thus we may suppose, that longitudinal filling passing into the southwestern Orava is only secondary. This opinion is also supported by the comparison of data about the thickness of the Flysch of equivalent facies. While in the Turiec area it is 600—1000 m, in Orava it increases to 1600—2200 m (cf. fig. 5).

In the eastern part, the current patterns (fig. 11) showed that in the Middle-

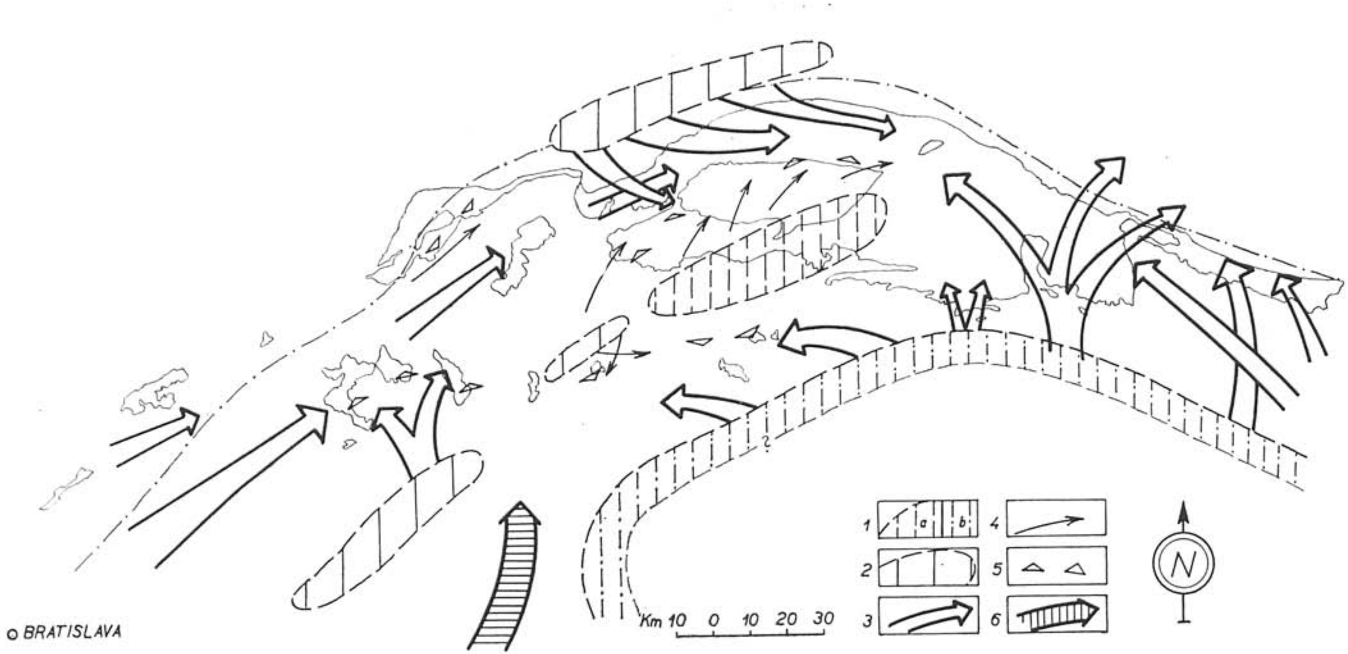

Fig. 11. Palaeogeographical sketch of the central Paleogene of the West-Carpathians in the Middle Priabonian. 1. A. — Determined Middle Priabonian transgression with development of littoral, neritic facies, nummulitic biostromes and pectenid associations. 1. B. — Supposed development of transgression on the Vepor-Spish land area. 2 — Zones tectonically strongly activated (cordilleras). 3 — Main palaeocurrent direction in sandstones. 4 — Additional palaeocurrent direction in sandstones. 5 — Beds of gradedded oranogene carbonate breccias and sandstones with the supposed transport direction. 6 — Communications of facies of the epicontinental sea of the central Hungarian Mts.

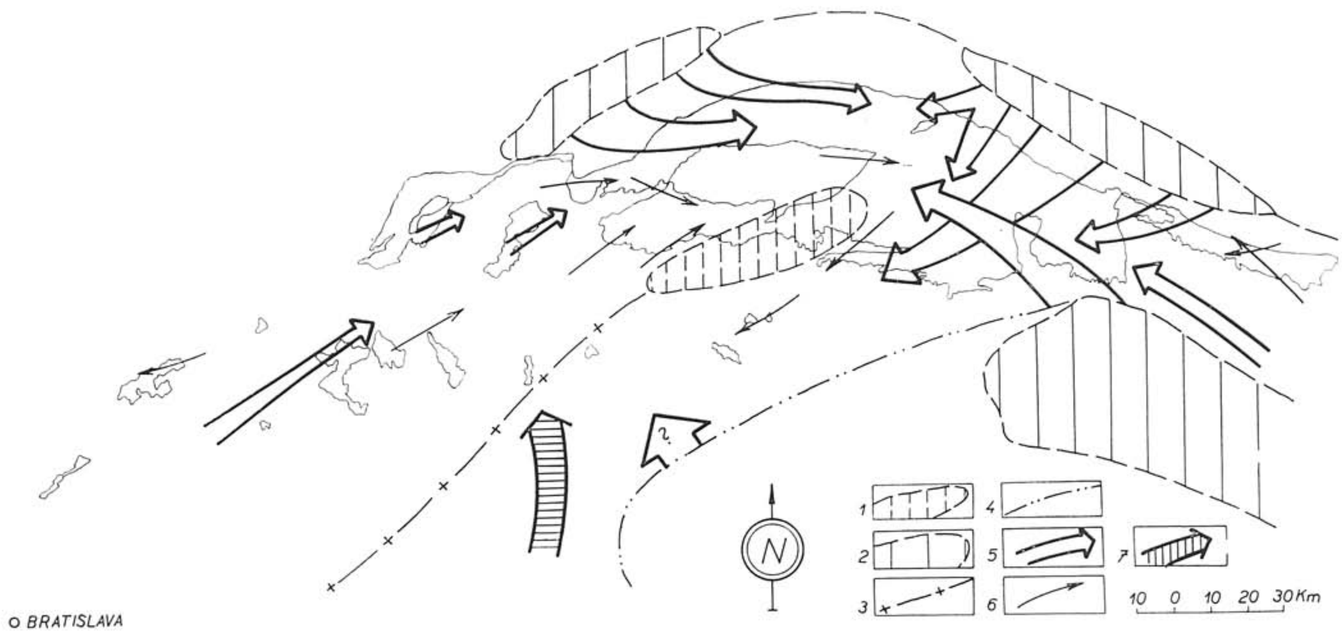

Fig. 12. Palaeogeographical sketch of the central Paleogene of the West-Carpathians at turn of the Upper Priabonian and Lower Oligocene 1 — Submarine ridge with transgression ended in the Upper Priabonian. 2 — Zones tectonically strongly activated (cordillera). 3 — The zone dividing the Flysch of the northern trough from less typical Flysch facies and mixed epicontinental facies of the southern trough. 4 — Supposed borderline of the Vepor-Spish continent. 5 — Main palaeocurrent direction of sandstone material (coarse Flysch). 6 — Palaeocurrent direction in sandstones with thin beds with graded bedding or with beds with lower parallel, and ripple-cross lamination. 7 — Communications of facies of the epicontinental sea of the central Hungarian Mts.

Priabonian claystone-sandstone Flysch the borders of the trough determined by a chain of Lower-Priabonian cordillera in the north, were broken. The lateral supply of currents from the extensive southern source into the outer Flysch basin was conditioned by deepening of the basin with the respective modification of slopes to the north. Thus the supposition by M. Ksiażkiewicz, B. Leško (1959), J. Nemčok (1961), Z. Stráník (1965) about the so-called connection of the Magura sedimentary area with the central-Carpathian, was affirmed. This current direction is actually lateral, perpendicular to the bathymetric axis diverging with the tectonic axis of the West-Carpathians, (fig. 13).

The picture of the distribution of sandstone Flysch (coarse Flysch) in the Upper Priabonian is best illustrated by current study (fig. 12). Its rise is connected with the stages of penetration of great amount of gravels and sands from the surrounding sources into the basin. Three different extensive places of the supply of clastic material were determined by measurements. Beginning with these places, the diminishing of grains, of thickness of beds and slump structures, as well as development of gradually fading-out facies, may be observed.

Erosive cutting of the underlying claystone-sandstone lithofacies (fig. 1) — as it may be observed on the northern margin of the Levočské hory Mts., Šarišské hory Mts., and in Orava, has been conditioned by abrupt supply of clastics to the basin. Intraclasts of these rocks may be found far from the supposed places of erosion in the points of supply. I has been found that the effect of the filling in the area of the Levočské and Šarišské hory Mts. was centripetal from the NE and SE sources. Since transport proceeded in these directions into the lower areas, there may be expected the crossing of two bathymetric axes in the area of the Levočské pohorie Mts. The decrease of the number of proximal characteristics farther to the northwest and southwest is a sign of the manner of filling as well as of the configuration of the basin and of the development of bathymetric axes. The latter are characterized by the same main directions of structural units of the NE-SW course and by the same turn of these units to the SE (cf. R. Marschalko, P. Gross 1968).

Types of Source Areas and Origin of Clastic Material

Intrabasin Sources of Clastic Material

By the study of the distribution of transgression and material composition of basal conglomerates and breccias (F. Pícha 1965, F. Chmelík 1967, D. Andrusov 1965, R. Marschalko 1966 a, b) pointed out to the fact that the pre-transgressive relief of the West-Carpathians out of the area of the Vepor-Spiš rudohorie Mts. (R. Marschalko 1966) consisted of the Mesozoic carbonatic rocks. The share of the rocks of crystalline and of granitoides of Variscian and pre-Cambrian age, was rather low, which may be explained by incomplete exposures of crystalline cores. Morphologic dissection of the existing crystalline cores is of post-Tortonian age, which has been proved by the analysis of pre-Neogene basement by T. Buday, V. Špička 1967. Yet in the Flysch facies in the course of the whole Priabonian (D. Andrusov 1965, F. Pícha 1965, F. Chmelík 1967, Š. Kahan 1965, M. Mišík and all. 1968, A. Radomski 1958) there are exotic pebbles and blocks of unknown origin in the present-day West-Carpathians. This occurrence is enigmatic especially in the Flysch facies with longitudinal transport. This indicates the necessity of the intrabasin sources of clastic material.

Such sources are best indicated by marginal facies on the base of the Lower Priabonian. According to transversal current patterns, areal distribution, thickness, and composition of clastics of these facies, more or less continuous zone of sources rimming the Flysch trough from the north (fig. 10), may be determined. Pebble material shows that the zone has been formed by crystalline of unknown age, composition and structure, and of Mesozoic carbonatic rocks (mantle). The zone separated the klippen sedimentary area from the central-Carpathian, as it may be followed in works by M. Ksiażkiewicz (1956), K. Birkenmajer (1958), R. Marschalko, A. Radomski (1960), D. Andrusov, E. Köhler (1963), Z. Stráník (1965). It is now impossible to follow the zone because of the tectonic character of the contact of the klippen belt with the central-Carpathian Palaeogene, and the discontinuous exposures of marginal facies in the existing outcrops, that does not correspond to the 200 km length of the zone, neither to its width (5—10 km). In some places, isolated lenses of breccias, prisms of fluxoturbidites as well as olistholites (Middle Triassic-Malmian) are not accompanied with sandstones. In other places (Šambron), great amount of sandstones and conglomerates with identic transport direction was supplied. This may indicate that the source zones were tectonically highly active, therefore there is great production of marginal coarseclastic prisms, lenses and depositional fans. This dependence was already expressed by Ph. H. Kuenen (1958) in the analysis of intrageosynclinal sources. If considering less typical proximal characteristics of some developments between Sabinov and Šambron, as e. g. good sorting, regularity of beds and high share of sandstones, we may suppose that the source zone was 8—12 km to the NE from the place of the present-day outcrops. Later on, denudation affected a considerable amount of especially coarse clastics nearer to the point of the filling.

Along the southern margin of the northern trough there was a zone of discontinuous source areas with limited extent, supplying in the Lower Priabonian carbonatic coarse-clastic material or rocks of unknown origin to the Flysch basin (E. Passendorfer 1959). In some marginal facies (Pucov, Ždiar), there is a considerable amount of intraclasts of transgressive facies (nummulitic limestones) or of claystone facies, pointing out to an active submarine process of abrasion of these lithofacies by gravitational transport. It may prove again, that the marginal facies were not connected with the basement of the formation, representing rather rapid accumulations in subsiding zones below the steep slopes of cordilleras. The areal distribution and extent of marginal facies in the Lower Priabonian cannot be followed because of its synclinal structure, yet the author supposes no considerable increase as for the thickness of marginal facies in direction to the axis. This may be indicated mainly by the rapid deposition of these facies, their „pouring out" below the steep slopes, and especially not too extensive sources. Gradual fading-out of these sources was reflected in the development of carbonatic breccias indicating lateral transport.

F. Pícha's (1965) investigations showed, however, that also the Flysch facies without greater amount of conglomerates, might have been derived from lateral sources. It was proved by the study of heavy minerals in the western depressions (Handlová, Turiec, Liptov, Orava). In predominantly longitudinally transported material of the claystone and claystone-sandstone Flysch from the SE to NW, extremely abruptly grew the amount of garnet, in the area of Orava and Liptov. This petrographically indicated local supply was earlier affirmed by current measurings of R. Marschalko, A. Radomski (1960), and J. Jablonský (1961). F. Pícha supposed that the source composed of garnet schists and gneisses supplied material also to coarse-grained sandstone facies, therefore the chronological diapason of this zone extended to the Middle and Upper Priabonian. The absence of coarse conglomeratic clastics, normal in proximal zones, may be explained by these facts: 1. the gneiss and schistose sources need not produce coarse clastics, 2. sandstone facies were derived from older Cretaceous Flysch of the klippen belt (cf. M. Mišík and all. 1968).

A Special Case of Intrabasin Source

Reactivation and elevation of basement, and resedimentation of older Flysch facies represent a special example of sources of the Flysch in the central West-Carpathians. Transport directions in sandstone facies in the northern part of the Levočské hory Mts. started from places where in the Middle Priabonian the bathymetric axis of the trough was running. Currents show reversed direction (fig. 12), transporting clastic material from the Middle Priabonian and earlier Flysch sequences of the Magura and klippen basins. It looks like if also the old source zone were reactivated. B. Leško (1960) placed this zone between the klippen area and the Magura Flysch. Resedimentation of older Flysch is indicated by frequent sandstone pebbles in sandstones, slabs of claystone intraclasts older than the Middle Priabonian, and resedimented Cretaceous microfauna (O. Samuel 1960).

Extrabasin Source of Clastic Material

The material to the Flysch basin was supplied also by the Vepor-Spish land area (D. Andrusov 1965) in addition to the intrabasin sources. The land area included a part of Vepor-Spish rudohorie Mts., and the northeastern and northewestern parts of central-Hungarian mountains. In the south and west, by the Pannonian epicontinental sea extended ower the land area, sometimes communicating into Horehronie (Hron r. valley) by its facies through the southern trough. The extent of the land area exceeded the extent of all intrabasin sources together. The land area composed predominantly of low-metamorphosed and high-metamorphosed zones of crystalline and of the carbonatic rocks of the Mesozoic, supplied the graywacke and subgraywacke, and conglomeratic material mainly to the eastern part of the Flysch basin. The development of marginal facies and the supply of immense amount of sand into the Flysch of the Levočské and Šarišské hory Mts. in the Priabonian and Lower Oligocene, indicate largescale changes in the configuration of this land area. It is not quite clear, why the same amount of material has not been supplied also to the sedimentary area to the south of the Nízke Tatry (Low Tatra) Mts., although the development of the southern Flysch trough had started as well. This may evoke a supposition about the land area supplying material mainly to the southern Pannonian seas (E. V a d á s z 1960, J. S e n e š 1965).

Development of Flysch Basin and Paleotectonics

Basing on the study of relation of source zones to the filling, several stages connected with paleotectonics may be distinguished in the development of the basin. The forming of longitudinal northern trough was preceded by extensive development of marginal prisms. The high slopes of the latter offered conditions for the rise of the axis of basin in the north.

The trough axis in the Lower Priabonian (fig. 13A) showed Alpine structural features, since it followed the bend of older Cretaceous structural units of the West-Carpathians. The dividing line runs approximately along the post-Cretaceous lines on the contact of Pienides, Tatrides and Veporides. While the northern trough with its Tatrid basement was tectonically highly mobile, the southern one with its Vepor basement was less mobile and conditioned only the development of less typical Flysch of smaller thickness.

The greatest thickness of deposits was found in the northern trough, and it was connected with the shifting of bathymetric axis. The existing northern border is secondary (tectonic), and a part of sediments belonging to proximal facies of the northern source zone, was denuded off. Primary spatial reduction caused absorption of the source zones of the northern region in the Priabonian. Till now it has not been found out what thickness of accumulations and width of the zone was affected by erosion after the horizontal tectonic transport of the West-Carpathian block on the klippen belt. Basing on some recalculations (cf. p. 88) the shortening on 15—20 km may be expected in comparison with the existing tectonic bordering of the Flysch against the klippen belt. The width of this zone should be added in reconstructions of the horizontal reduction of the geosyncline.

Tectonic Position of Flysch Basin in Development of Carpathian Geosyncline

The Palaeogene Flysch of the central West-Carpathians occupies a particular position in relation to orogene. The Flysch developed in subsiding trough, the basement of which was formed by Cretaceous orogene. Considerable subsidence of basement, increased accumulation of clastic material on the northern margin of the trough, caused asymmetrical shape in the N-S cross-section. Subsidence was evoked by further compressive downbuckle of the folded basement or by the extension of the latter. If considering the crystalline nature (granites, high-metamorphosed crystalline) of the basement of the Mesozoic nappes in the West-Carpathian block, and its low compressibility, then tension may be admitted

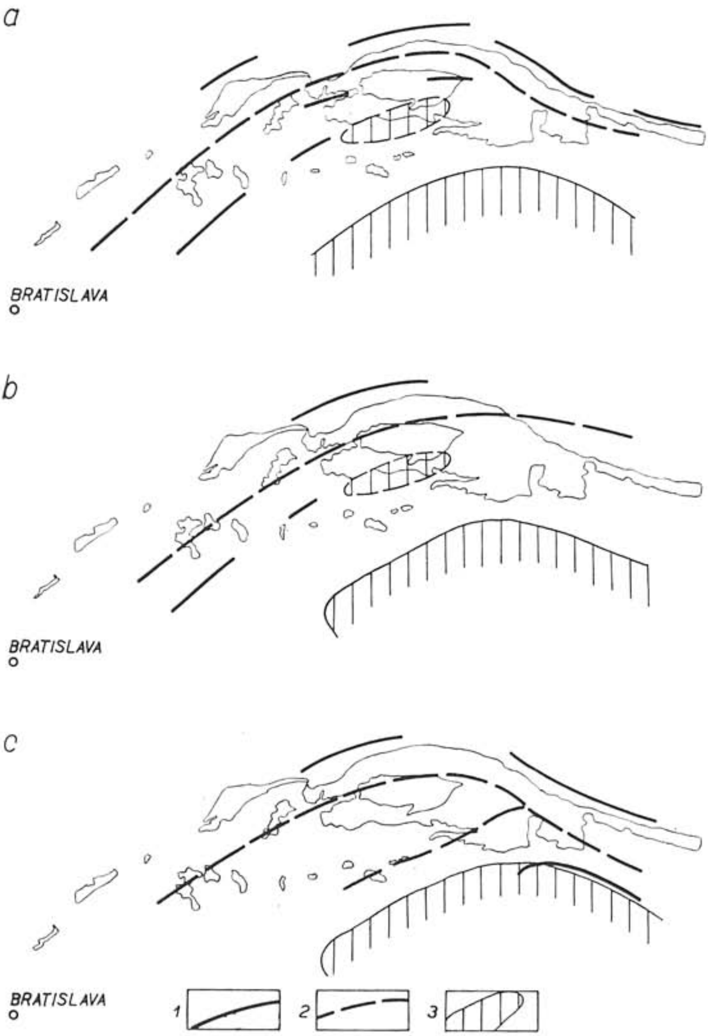

Fig. 13. The course of bathymetric axis of basin and position of intrabasin and extrabasin sources. A. On the base of the Lower Priabonian. B. Middle Priabonian. C. Upper Priabonian to Lower Oligocene.

1 — The zone tectonically strongly activated (cordillera). 2 — Bathymetric axis of the Flysch basin. 3 — The zone of emergence (islands and land areas of tectonic stable character).

as the cause of the subsidence of the folded basement too. These movements were mutually completing one another, subsidence of the basement and increase of sediments being controlled by them. Earlier study of clastic dikes (R. M a r s c h a l k o 1965) showed the revival these movements in the contact of old thrust fault planes of crystalline basement of Gemerides, Veporides, Tatrides, and Pienides. The control of old deep structures of the basement in the development of the Flysch basin was reflected in direction of paleocurrent systems within subsiding zones of the basement, and in detail activity of these structures in tectonic mobility of intrabasin sources, mainly at the beginning of the development of the basin. In spite of these facts, the Flysch basin shows only partial characteristics of the late-geosynclinal tectonics in the sense of the division by J. A u b o i n (1965), since the northern margin of the trough developed simultaneously in the neighbourhood of the folding klippen belt, and partly of the Magura Flysch (M. K s i a ż k i e v i c z, B. L e š k o 1959). Gradually northwards migrating orogene affected the activity of the trough. The fading-out of the source zone on the contact of the klippen sedimentary area with the central Palaeogene Flysch and slight folding of the northern margin of the Paleogene Flysch in the West-Carpathians prove continuity and connection of the basin with the proceeding orogene.

Summary

1. The Palaeogene of the central West-Carpathians from the base consists of transgressive facies and Flysch facies. No denticulated connection of these facies has been observed, since Flysch developed in a basin with subsiding basement. Thus Flysch cannot be considered a shallow-water near-shore facies; it is developed in greater depth and limits the bathymetric axis of the basin in the Priabonian.

2. Flysch facies show perpendicular, transverse, and longitudinal current patterns. The perpendicular ones have proximality well-indicated by coarse-grained lenses and prisms of fluxoturbidites, olistholites. In longitudinal patterns, fine-grained clastics were predominating. In these, lateral supply is indicated by lithology, current measurings also in places without the supply of coarse-clastic conglomeratic material.

3. Intrabasinal cordilleras, uplift of basement and extrabasin land areas have been distinguished as sources. The intrabasinal sources represent tectonically highly active zones, with the course identic with structural lines of the Ist order. Such are the thrust fault planes of the crystalline of Veporides and Tatrides. On the northern margin of the Flysch basin, these sources consisted of the crystalline and Mesozoic material of unknown origin. Cordilleras of the southern zone (Nitra, Bystrica, eastern Tatra Mts.) were formed by the mantle Mesozoic units of Tatrides. The uplift and reactivation of the Flysch basement of the basin represent another important source of the clastic material. Reactivation was conditioned most probably by submarine folding. The Vepor-Spish land

area is quite extensive, exceeding the simultaneous intrabasin sources, and separating the Flysch basin from the epicontinental Priabonian sea of the central Hungarian Mts. Communication of its facies might have been to the south of the land area up to the Horehronie region. This existed in the time of the intense tectonic activity, supplying clasic material to the northeastern part of the Flysch basin as well as to the outer Flysch basin. Till the present it has not been found out whether the material was also supplied to the northern Flysch trough (western part), although that cannot be completely excluded.

4. The Flysch basin developed in close connection with the structure of the basement. The basin inherited older Alpine structural elements, and was formed within these lines. The rise of the uplifted margins of the trough was in causal connection with reactivation of source areas, and represented the first phase of filling. The second phase was represented by longitudinal and lateral transport. The third phase was accompanied by great amount of clastic material and by the filling of the trough.

Translation by E. Jassingerová.

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