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Tectonic evolution of marginal part of the Polish Flysch Carpathians in the Middle Miocene

Paleotectonic and paleogeographic analyses indicate that the Miocene depositional centers migrated towards northeast, to the outer parts of the epi-Variscan European Platform. The Carpathian overthrust movements were synchroneous with the development and migration of Miocene molasse basins in the foredeep. The ultimate tectonic pattern of the Outer Flysch Carpathians over Polish territory was formed in the Middle Miocene. In the western part it took place after the Early Badenian, whereas in the eastern part after the Early Sarmatian.

INTRODUCTION

Since the work by V. Uhlig (1907) the concept of the far-reaching overthrust of the Outer Flysch Carpathians over the Neogene molasses of the Carpathian Foredeep has been commonly accepted. This idea was subsequently developed in the papers by K. Tołwiński (1956), R. Ney (1968, 1976), M. Książkiewicz (1977*a*, *b*), S. Wdowiarz (1976, 1983), R. Unrug (1980, 1984), and N. Oszczypko and A. Ślączka (in press). Presently only the amplitude of this overthrust is discussed.

When discussing the Neogene evolution of the Flysch Carpathians and their relation to the foreland trough, important informations are obtained from the analysis of the Carpathian overthrust surfaces. This analysis enables the determination of the mutual relation of the faults in the Carpathians and in their substratum to the overthrust itself.

The surface of the Carpathian overthrust was analyzed by K. Konior (1981) in the western part of the Polish Carpathians and by S. Wdowiarz (1976) in the whole Polish segment. The latter has established that most of the faults in the substratum and in the marginal, Miocene part of the Carpathians are older than the Carpathian overthrust. R. Unrug (1980) has demonstrated that in the northern part of the Polish Outer Carpathians transverse, sinistral strike-slip faults are important. The blocks bordered by the strike-slip faults display clockwise rotation. Toward the south these faults vanish, and they do not continue in the Inner Carpathians.

Considering the evolution of the marginal part of the Carpathians the authors confined themselves to the Middle Miocene. This time-spatial restriction results from the presence beneath the Carpathians, of the autochthonous strata of this age. This strata constitute bench marks which allow to localize the margin of the Carpathians in the respective time intervals. By the palinspastic reconstruction, in order to simplify considerably the picture, the movement of the Carpathians towards the north was assumed, and the drill-holes ending in the platform strata of the Carpathians substratum were accepted as bench marks. The presented displacements of the Carpathian orogene with respect to the epi-Variscan European Platform are relative. They may result either from overthrusting of the orogene over the platform or from thrusting the platform under the orogene.

In this work the problem of the so-called deep folds (the Borislav–Pokutie folds of the Soviet geologists) and of the Stebnik unit (Sambor-Rożniatov unit) are purposefully not discussed. These problems lie with respect both to time and space, beyond the scope of this paper.

ANALYSIS OF THE CARPATHIAN OVERTHRUST SURFACE

The map of the overthrust-surface depth (Fig. 1) was elaborated basing on the 150 drill-holes located between Cieszyn and Przemyśl in the belt, 20 to 30 km wide. The surface of the overthrust is of regular shape. The outermost zone reproduces approximately the shape of the Carpathian overthrust margin. The most distinct are in its course the "Miocene embayments" of: Gdów, Pilzno and Rzeszów. In the western part, from Cieszyn to the Skawa river this surface dips gradually from the margin of the overthrust towards south with a gradient of 50 to 60 m/km, which corresponds to the inclination of ca. 3.5°. Only south of the Żywiec–Sucha Beskidzka line its inclination increases rapidly to ca. 12°, i.e. to the gradient of about 200 m/km. The gentle slope of the surface along the Carpathian margin continues as far as the Gdów Embayment in the narrow belt – 5–7 km wide. Further to the east the picture changes drastically. At the margin of the Carpathians the overthrust surface dips rapidly with a mean gradient of 250 m/km. its inclination in that area being 14°. In some places the inclination reaches even 26°. Towards south sloping of this surface is more gentle with inclination less than 10°, often decreasing down to 6°. The surface gradient in this area varies between 175 and 100 m/km.

Between Cieszyn and Rzeszów the surface of the Carpathian overthrust dips generally towards SSE with azimuth of ca. 170°. From Rzeszów to the eastern border of Poland this surface dips towards SSW with azimuth of about 210°.

There are several more or less distinct anomalies in the otherwise very regular shape of the surface of the Carpathian overthrust. In the westernmost part, to the east from Cieszyn (Fig. 1) in the SSE direction there is a distinct, ridge-like elevation of the surface, 10 to 12 km wide. Its amplitude against the regional tendency reaches 100 m. One may suspect that its origin is related to the Cieszyn ridge (T. Lenk, 1983). Further to the east, in Żywiec–Sucha Beskidzka area, the flattening of the overthrust surface is observed. The mean gradient of that surface to the NE from the flattened area is 60 m/km (3.5°) and to the west ca. 170 m/km (10°). In the very flattened area the gradient does not exceed 45 m/km (2.5°). An important

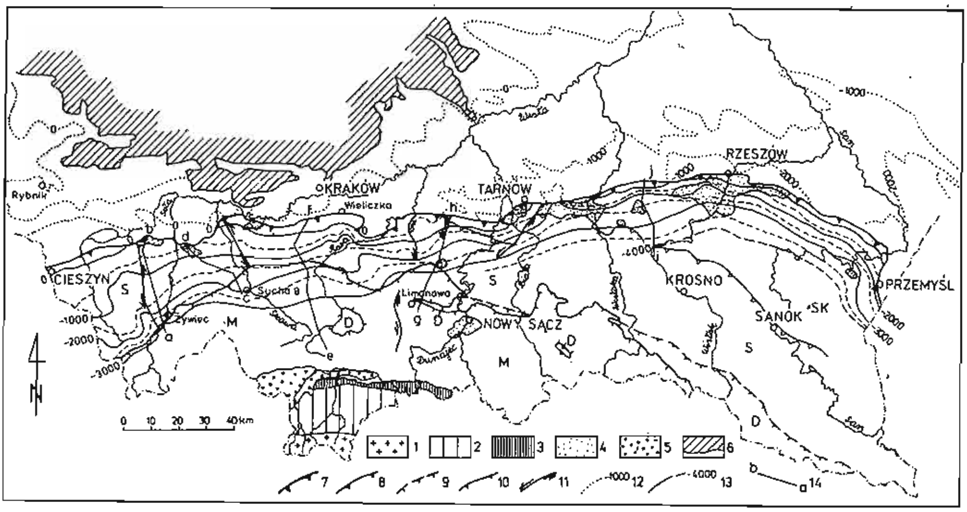

Fig. 1. Map of the Carpathian overthrust surface
Mapa powierzchni nasunięcia karpackiego

1 – crystalline core of the Tatra Mts with the High-Tatric unit and the Sub-Tatric unit; 2 – Podhale flysch; 3 – Pieniny Klippen Belt; 4 – marine Miocene strata over the Carpathians; 5 – Mio-Pliocene strata of the Orawa – Nowy Targ Valley; 6 – northern extent of the marine Miocene strata in the Carpathian Foredeep; 7 – front of the Carpathian overthrust; 8 – front of the Silesian-Subsilesian overthrust; 9 – front of the Dukla overthrust; 10 – front of the Magura overthrust; 11 – strike-slip faults; 12 – isobaths of the Miocene substratum in the Carpathian Foredeep; 13 – isobaths of the Carpathian overthrust; 14 – location of cross-section; SK – Skole unit; S – Silesian and Subsilesian units; D – Dukla, Grybów and Fore-Magura units; M – Magura unit

1 – trzon krystaliczny Tatr wraz z jednostkami wierchową i reglową; 2 – flisz podhalański; 3 – pieniński pas skałkowy; 4 – morskie osady miocenu na Karpatach; 5 – mio-plioceńskie osady Kotliny Orawsko-Nowotarskiej; 6 – północny zasięg osadów miocenu morskiego w zapadlisku przedkarpackim; 7 – czoło nasunięcia karpackiego; 8 – czoło nasunięcia śląsko-podśląskiego; 9 – czoło nasunięcia dukielskiego; 10 – czoło nasunięcia magurskiego; 11 – uskoki przesuwcze; 12 – izobaty podłoża miocenu w zapadlisku przedkarpackim; 13 – izobaty nasunięcia karpackiego; 14 – linie przekrojów; SK – jednostka skolska; S – jednostka śląska i podśląska; D – jednostka dukielska, grybowska i przedmagurska; M – jednostka magurska

disturbance of the regular shape of the overthrust surface is observed to the SE from the Raba river valley. There occurs locally ridge-like elevation of the amplitude ca. 100 m. Its course is from Gdów "Embayment" to SSE towards Limanowa. To the east it is bordered by the depression of a similar amplitude and course. The latter is directed towards Nowy Sącz (Fig. 1). At the rim of the Flysch Carpathians there are visible characteristic undulations of the overthrust surface. The depressions of the surface are visible in the zones of occurrence of the Miocene outliers over flysch. They are the most distinct in the so-called Wojnicz and Pilzno "Embayments" (near Tarnów) and in the Rzeszów "Embayment". The occurrence of the Miocene outliers over depressions of the overthrust surface indicates that those depressions were formed before the Lower Badenian transgression, and they conditioned the development of the Miocene basins over flysch. These deflections caused also formation at the greater depth of the shear surface in the Miocene strata in front of the Carpathians. It occurred probably during the final stage of the thrusting movements. In consequence we observe between Tarnów and Rzeszów the occurrence of the Miocene slices at the margin of the Carpathians.

Different situation exists in the Gdów "Embayment" where the overthrust surface is elevated. Its origin is probably related to some substratum high, which

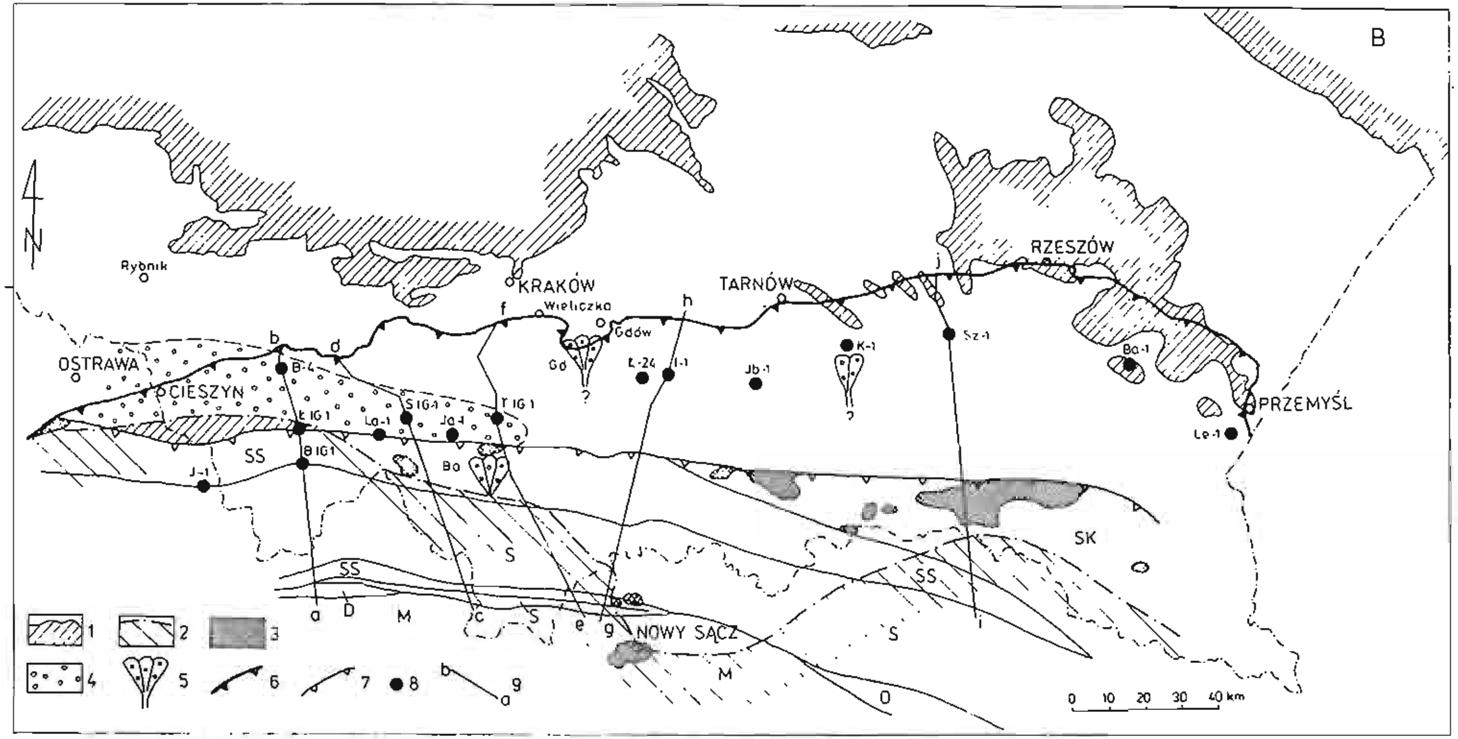

Fig. 2. Paleogeographic and palinspastic map of the Outer Carpathians and their foredeep in the Lower Badenian

Paleogeograficzna i palinspastyczna mapa Karpat Zewnętrznych i ich rowu przedgórskiego w dolnym badenie

1 – northern extent of the marine Miocene strata in the Carpathian Foredeep; 2 – southern shore of the Lower Badenian basin; 3 – erosional outliers of the Lower Badenian strata over the Carpathians; 4 – Dębowiec Conglomerates; 5 – submarine, delta and alluvial fans; 6 – present-day front of the Carpathian overthrust; 7 – front of the Carpathian overthrust in the Lower Badenian; 8 – main boreholes, including those establishing the southernmost extent of the autochthonous Miocene strata; 9 – location of the palinspastic cross-sections; SS – Subsilesian unit, S – Silesian unit; boreholes: J-1 – Jablonkov 1; B-4 – Bielsko 4; Ł IG-1 – Łodygowice IG 1; B IG-1 – Bystra IG 1; La-1 – Lachowice 1; S IG 1 – Sucha IG 1; Ja-1 – Jachówka 1; T IG 1 – Tokarnia IG 1; Ł-24 – Łąkta-24; I-1 – Iwkowa 1; Jb-1 – Jastrzębia 1; K-1 – Kowalowy 1; Sz-1 – Szufnarowa 1; Ba-1 – Bachórzec 1; Le-1 – Leszczyny 1; other explanations as given in Fig. 1

1 – północny zasięg morskich osadów miocenu w zapadlisku przedkarpackim; 2 – południowa granica basenu dolnobadeńskiego; 3 – erozyjne płaty osadów dolnobadeńskich na Karpatach; 4 – zlepieńce dębowieckie; 5 – stożki podmorskie, deltowe i aluwialne; 6 – współczesne czoło nasunięcia karpackiego; 7 – czoło nasunięcia karpackiego w dolnym badenie; 8 – ważniejsze otwory wiertnicze, w tym stwierdzające najbardziej południowy zasięg autochtonicznych osadów mioceńskich; 9 – linie przekrojów palinspastycznych; SS – jednostka podśląska; S – jednostka śląska; symbole otworów wiertniczych objaśnione wyżej; pozostałe objaśnienia jak na fig. 1

is situated several dozen kilometers to SE from the present Carpathians margin. Sinuate shape of the Carpathians margin was formed before the Early Badenian, due to the overthrusting of the marginal part of the Carpathians over the morphologically elevated elements of the platform substratum. This ridge might form the SE continuation of the "Kraków Bolt" (R. Ney, 1968). To the east from it contemporary overthrust surface was deflected. This might manifest itself on the surface by the morphological depression, which enabled the Lower Badenian transgression of the Miocene sea over the Carpathians as far as Nowy Sącz Valley (N. Oszczypko, 1973).

PALINSPASTIC RECONSTRUCTION OF THE MARGINAL PART OF THE POLISH CARPATHIANS IN THE MIDDLE MIOCENE

The authors have assumed in this work a multi-stage development of the Carpathian overthrust. There is an extensive evidence supporting this concept. Significant are the results of investigations by A. Jurkova (1979), who demonstrated, that the Silesian-Moravian Beskides were overthrusted at least in two stages: after the Karpathian and after the Lower Badenian. In the Polish Carpathians the multi-stage movements are suggested by the occurrence of the flysch olistostromes in the autochthonous and para-autochtonous Miocene strata of different ages. The oldest olistostromes known from the autochthonous strata of the Sucha Formation (A. Ślączka, 1977), which is covered by the Stryszawa Formation are dated as belonging to the Ottnangian-Karpathian (J. Strzępka, 1981). The flysch olistostromes occur also in the para-autochthonous Biegonice Formation included in the Karpathian (N. Oszczypko, 1973, 1982). In the vicinity of Cieszyn the olistostromes of the Subsilesian unit are known (Zamarski Member of the Dębowiec Formation), which lie over the Karpathian strata, and are covered by the Lower Badenian Dębowiec Conglomerates (W. Buła, D. Jura, 1983). The youngest olistostrome horizon was found in the Middle Badenian salts of the Wieliczka deposit (K. Kolasa, A. Ślączka, 1984).

While discussing the sedimentation of the Badenian salts, A. Garlicki (1979, p. 31) has written: "...Northward displacement of the flysch nappes in the Carpathian Foredeep considerably restricted area of the evaporite sedimentation, as compared to the area over which the deposition of the older Badenian strata took place (Skawina Beds and Przemyśl Beds) ...". B. Cisek (1983) has arrived at the similar conclusions as regards the Badenian and Lower Sarmatian strata.

In the present paper not only position of the Carpathian margin at the respective stages is considered, but also contemporary mutual relation between the respective units of the Outer Carpathians. In the latter case the authors were guided by the occurrence of the Miocene strata over flysch and by the analysis of the relation of the lateral faults to the Magura overthrust and Carpathian overthrust. As to the reconstruction of the width of the Subsilesian unit in the Lower Badenian, a post Lower Badenian tectonic doubling ascertained in the area of Wadowice and Andrychów (K. Konior, 1981), was taken into account. Considered is also the problem of the Subsilesian tectonic windows in front of the Magura overthrust (Żywiec window, Wiśniowa window and Żegocina zone). Because of the occurrence in the Żegocina zone of the folded Lower Badenian strata among the strata of the Subsilesian unit (K. Skoczylas-Ciszewska, 1960) it has been accepted that those windows formed before the Lower Badenian.

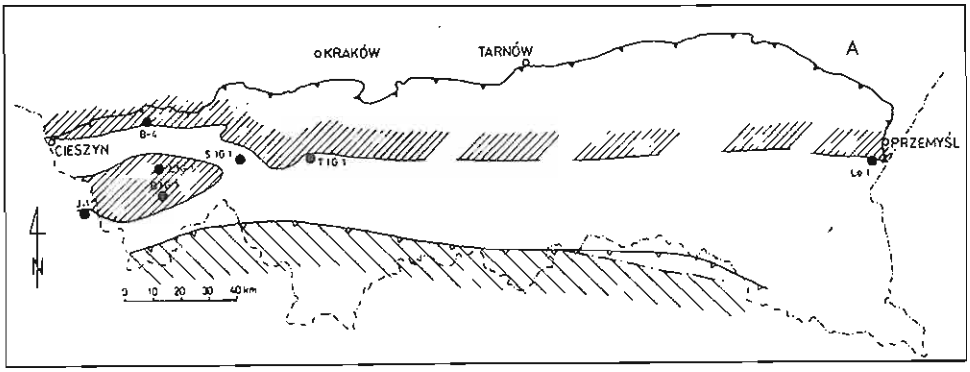

Fig. 3. Paleogeographic and palinspastic map of the Outer Carpathians and their foredeep in the Karpathian

Paleogeograficzna i palinspastyczna mapa Karpat Zewnętrznych i ich rowu przedgórskiego w karpatianie

Explanations as given in Fig. 2

Objaśnienia jak na fig. 2

The reconstruction is based on the geological cross-sections transverse with respect to the marginal part of the Carpathians (Fig. 1). According to the established positions of the autochthonous Miocene strata of different ages, the positions of the Carpathians margin (and of the particular units margins) for the respective ages were suitably displaced, so as to allow for the creation in these periods of the appropriate Miocene basins (Figs. 2 – 5). In the case of the extensive Badenian and Sarmatian basins, the authors confined themselves to considering only their southern shores. By these reconstructions the minimum extent of the overthrusts was accepted. This follows from the assumption that the contemporary margin of the Carpathian overthrust was situated directly to the south from the established extent of the Miocene strata of this age. In this way several palinspastic cross-sections (Figs. 6 – 10) were constructed for the following periods: the Karpathian, the Lower Badenian, the Middle and Upper Badenian, and for the Sarmatian.

Informations concerning occurrence of the Karpathian strata in the substratum of the Polish Western Carpathians are scarce. The most data concern Cieszyn – Bielsko area. In the Karpathian included is Zebrzydowice Formation known among others from the boreholes: Cieszyn IG 1, Zebrzydowice 13 and Zabrzydowice 14. These are slightly calcareous claystones and mudstones of the thickness from 8 to 130 m (W. Buła, D. Jura, 1983). This formation is preserved in the central part of the paleo-valley eroded in the Carboniferous strata. In the Karpathian included are also the Bielsko Beds (K. Konior, W. Krach, 1965; R. Ney et al., 1974) found in the borehole Bielsko 4. These are mudstones and sandstones of a thickness about 160 m. Relatively well developed section of the Lower Miocene strata was drilled in the borehole Sucha IG 1 (A. Ślączka, 1977). Beneath the Skawina Formation, the Stryszawa Formation was found, which is developed as a mudstone-shale series with intercalations of dark sandstones with anhydrite cement. In the lowermost part the Stachorówka Conglomerates occur. They contain both, the Carpathian material (shales and variegated marls), and clasts of the Devonian rocks. The thickness of this formation is 330 m, including 140 m of conglomerates. Its age was established to be Karpathian – Ottnangian ? (J. Strzępka. 1981). This for-

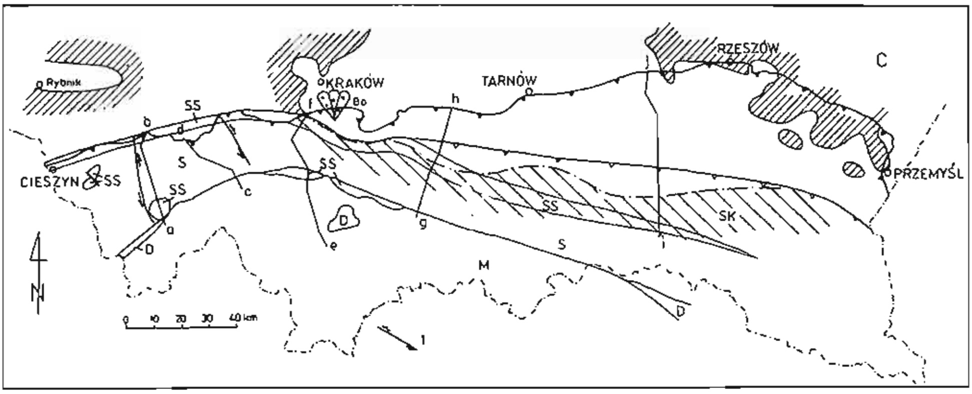

Fig. 4. Paleogeographic and palinspastic map of the Carpathians and their foredeep in the Middle Badenian (period of chemical sedimentation)

Paleogeograficzna i palinspastyczna mapa Karpat i ich rowu przedgórskiego w badenie środkowym (okres sedymentacji chemicznej)

1 – strike-slip faults; other explanations as given in Fig. 1 and 2

1 – uskoki przesuwcze; pozostałe objaśnienia jak na fig. 1 i 2

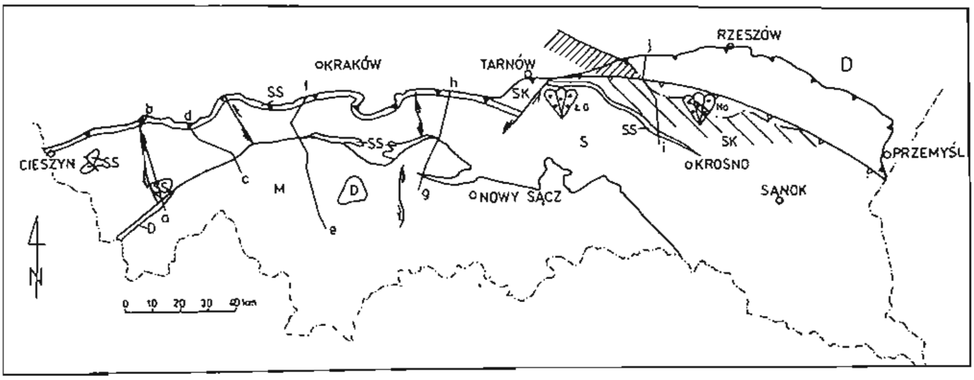

Fig. 5. Paleogeographic and palinspastic map of the Carpathians and their foredeep in the Upper Badenian

Paleogeograficzna i palinspastyczna mapa Karpat i ich rowu przedgórskiego po górnym badenie

Explanations as given in Fig. 1, 2 and 4

Objaśnienia jak na fig. 1, 2 i 4

mation is underlain by red and brown shales and sandstones with subordinate conglomerate intercalations. The flysch olistostromes were found in it (black and red shales, mainly of the Paleocene age) – A. Ślączka (1977). Beneath the Miocene strata the Upper Carboniferous deposits were drilled. The common feature of the strata included above to the Karpathian is their occurrence beneath the Dębowiec Conglomerate. Following the same principle one might include into the Karpathian also strata lying beneath the Dębowiec Conglomerate in the borehole Tokarnia IG 1. To the south from the described zone, the Karpathian strata were not unambiguously established. In the boreholes Bystra IG 1 and Łodygowice IG 1 in the substratum

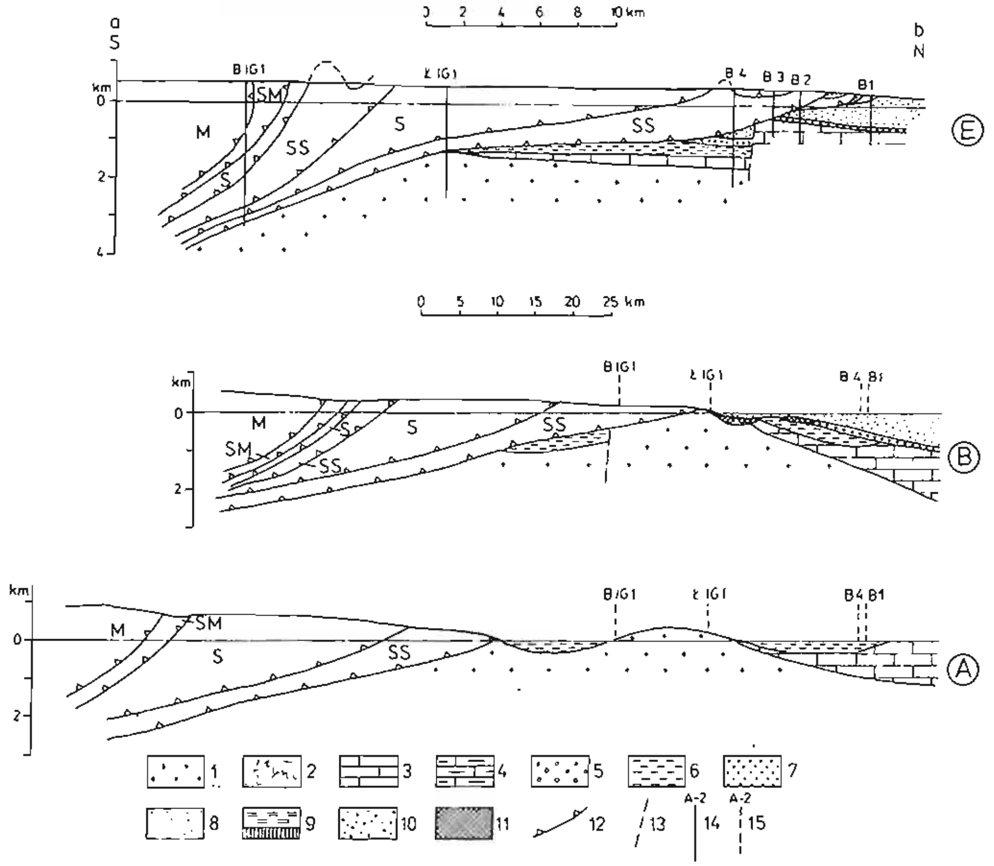

Fig. 6. Geological and palinspastic cross-sections along the line a – b

Przekrój geologiczny i palinspastyczny wzdłuż linii a – b

1 – Prekambrian crystalline basement; 2 – phyllites and metaargillites (Precambrian-Lower Cambrian?); 3 – undivided Palaeozoic; 4 – undivided Mesozoic; 5 – Sucha Formation (Lower Miocene); 6 – Karpathian strata; 7 – Dębowiec Conglomerate (Lower Badenian); 8 – Skawina Formation (Lower Badenian); 9 – Middle and Upper Badenian; 10 – Lower Sarmatian; 11 – flysch olistostromes; 12 – overthrust fronts; 13 – dislocations; 14 – boreholes; 15 – positions of boreholes after palinspastic restoraton; D – Dukla and Grybów units; SM – Fore-Magura slice; (A) – Karpathian; (B) – Lower Badenian; (C) – Middle and Upper Badenian; (D) – Lower Sarmatian; (E) – present day pattern; other explanations as given in Fig. 1 and 2

1 – prekambryjskie podłoże krystaliczne; 2 – fyllity i metaargility (prekambr-kambr dolny?); 3 – paleozoik nierozdzielony; 4 – mezozoik nierozdzielony; 5 – formacja z Suchej (dolny miocen); 6 – osady karpatianu; 7 – zlepieniee dębowiecki (baden dolny); 8 – formacja skawińska (baden dolny); 9 – baden górny i środkowy; 10 – sarmat dolny; 11 – olistostromy fliszowe; 12 – linie nasunięć; 13 – dyslokacje; 14 – otwory wiertnicze; 15 – ówczesne położenie otworów wiertniczych; D – jednostka dukielska i grybowska; SM-luska przedmagurska; (A) – karpatian; (B) – baden dolny; (C) – baden środkowy i górny; (D) – sarmat dolny; (E) – obraz współczesny; pozostałe objaśnienia jak na fig. 1 i 2

of the Subsilesian unit the blocks of this unit were drilled, along with metamorphic rocks of the substratum cemented with dark sandy mudstones. According to W. Ryłko, K. Żytko (1980) these olistostromes may belong to the Karpathian. To the south from the Cieszyn ridge the Karpathian strata were established in the deep borehole Jablonkov 1 (E. Menčik, 1984). It is the southernmost occurrence of the Karpathian strata known.

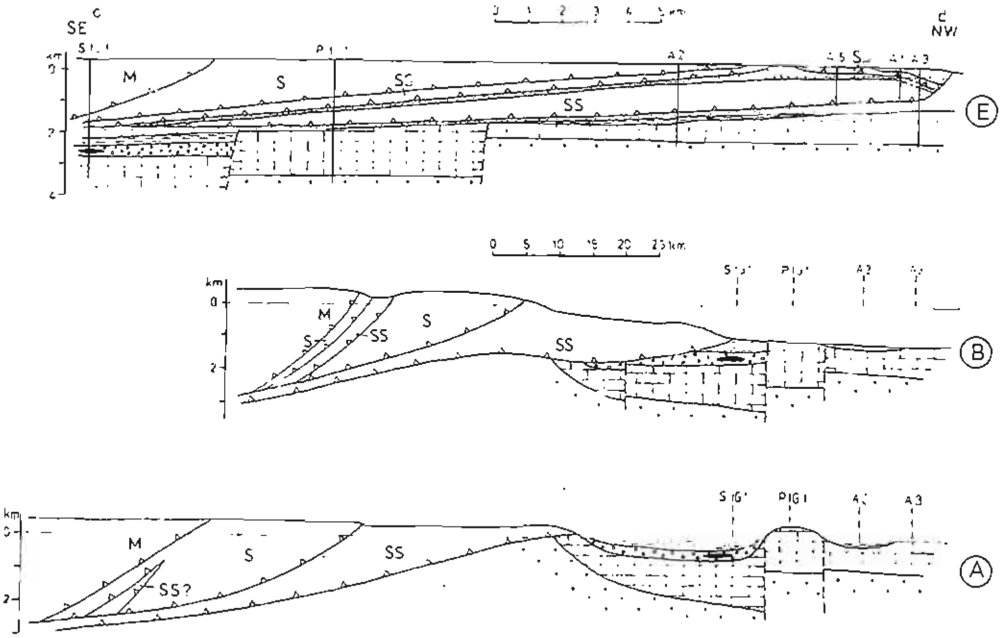

Fig. 7. Geological and palinspastic cross-section along the line c–d according to N. Oszczypko and A. Ślączka (in press), simplified

Przekrój geologiczny i palinspastyczny wzdłuż linii c–d według N. Oszczypki i A. Ślączki (praca w druku), uproszczony

Explanations as given in Fig. 6

Objaśnienia jak na fig. 6

East from Kraków the autochthonous Karpathian strata were not found as yet. Only in the borehole Leszczyny 1 (Fig. 2), to the south from Przemyśl at the depth 4620–4739 m the Stebnik Beds were drilled probably in the autochthonous position. They are overlain by the 350 m thick grey shale complex intercalated with sandstone which contain anhydrite, gypsum and calcite veinlets, and are included in the autochthonous Miocene. On the other hand, between Przemyśl and the Raba river valley the allochthonous strata of the Lower Miocene (Balice Beds and Stebnik Beds) were found in the numerous boreholes beneath the Carpathian overthrust (R. Ney, 1968; R. Ney et al., 1974). This evidence suggests that somewhere further to the south there existed the Lower Miocene basin linked with the basin developed in the area: Cieszyn–Tokarnia–Sucha–Jablónkov.

Basing on the above presented facts a presumable position of the basin in the Karpathian was reconstructed (Fig. 2). Taking into account the occurrence of the flysch olistostromes in the Karpathian strata, one may suppose that the margin of the Carpathian overthrust was situated at that time in the immediate vicinity of the southern shore of the basin. Such suggestions were expressed previously (N. Oszczypko, 1982; N. Oszczypko, A. Ślączka, in press).

By use of the palinspastic cross-sections (Figs. 6–8) the contemporary position of the Carpathians margin, as well as of the respective units were reconstructed. This margin was situated from 45 to 80 km further to the south from its present

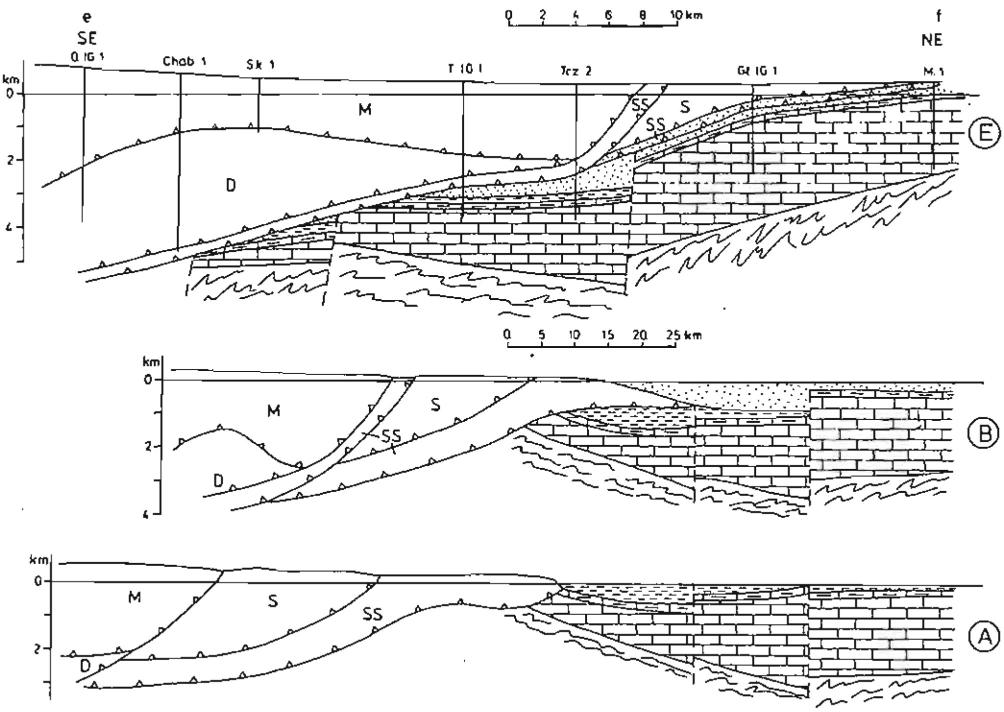

Fig. 8. Geological and palinspastic cross-section along the line e–f
Przekrój geologiczny i palinspastyczny wzdłuż linii e–f

Explanations as given in Fig. 6
Objaśnienia jak na fig. 6

position in the western and eastern part, respectively. These are minimum values because of the assumed basin width. Allowing for the shortening of the Subsilesian and Silesian units, the presumable breadths of the respective units were reconstructed for the Karpathian (Figs. 6–9).

After the Karpathian the margin of the Flysch Carpathians moved further 25 to 30 km to the north (Fig. 3). In the region of the Moravian Gate to the SW from Ostrava, the Carpathians reached then their present position (*vide* A. Jurkova, 1979). In the eastern part, the Carpathians margin was situated about 60 km further to the south as compared to its present position. Probably during that movement there occurred shearing inside the Subsilesian unit and its doubling in front of the Magura unit (Fig. 3). This was the beginning of the formation of the Żywiec window and Żegocina zone.

In the earliest Badenian the Carpathians margin composed of the strata of the Subsilesian unit, was placed over the Cieszyn–Slavkov ridge (Fig. 6). At the Carpathians margin the great slumps were formed covering the Karpathian strata. These slumps are preserved as olistostromes of the Subsilesian unit (Zamarski Member, *vide* W. Buła, D. Jura, 1983). At that time also the olistostromes known from the boreholes Bystra IG 1 and Łodygowice IG 1 might form (W. Ryłko, K. Żytko, 1980).

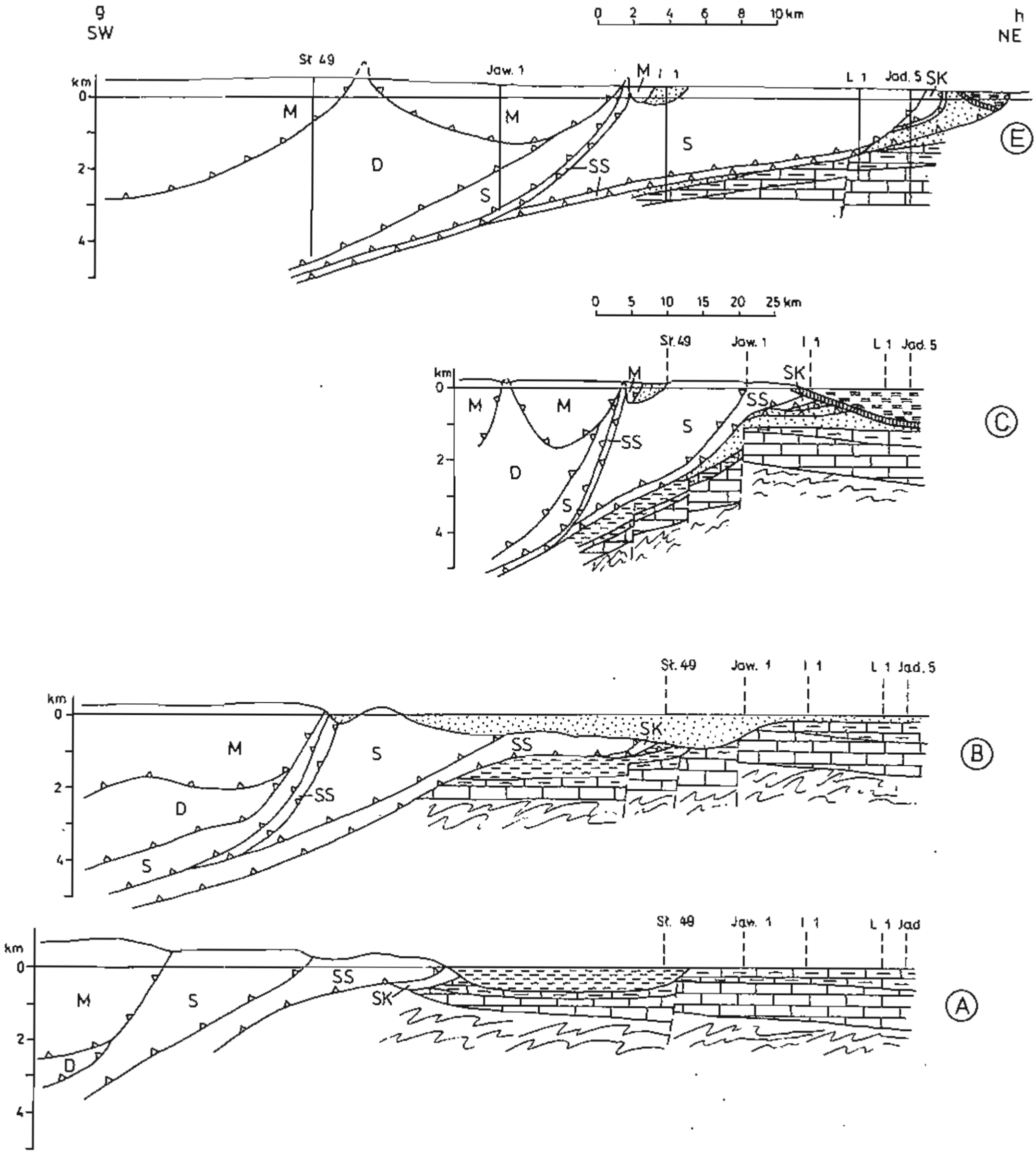

Fig. 9. Geological and palinspastic cross-section along the line g – h
Przekrój geologiczny i palinspastyczny wzdłuż linii g – h

Explanations as given in Fig. 6
Objaśnienia jak na fig. 6

After overthrusting, the axis of the Miocene basin and the zone of maximum subsidence were displaced towards the north. The platform substratum in front of the Carpathians, as well as the marginal part of the Flysch Carpathians were subject to the differentiated negative movements, which had conditioned the Lower Badenian marine transgression. These movements commenced at the foot of the Cieszyn – Slavkov ridge. Sedimentation of the Dębowiec Conglomerate started there. These conglomerates were deposited over Zamarski Member olistostromes (Fig. 6). The main source area was Cieszyn ridge, but part of the material came from the marginal part of the Carpathians. To the west from Cieszyn in the area of the Moravian Gate, the main depositional basin was located in the marginal part of the Subsilesian unit (*vide* A. Jurkova, 1979). Initially the sedimentation of the Dębowiec Conglomerates was taking place in the fluvial environment, and subsequently in the deltaic environment (Fig. 3). The further lowering movements in the Carpathian Foredeep and in the marginal part of the Carpathians enabled the Lower Badenian transgression. Over the Cieszyn – Slavkov ridge its extent went beyond the limit of Dębowiec Conglomerates. Diversified relief of the Carpathians enabled the Lower Badenian sea to transgress in a bay-like pattern. To the south from Sucha marine flooding reached the margin of the Silesian unit (Fig. 7). Further to the east an extensive embayment formed, which covered the Skole, Subsilesian and Silesian units, and partly the Magura unit (Figs. 8 and 9). The remainder of that transgression are numerous outliers of the Lower Badenian strata in the Carpathians. Both in the Carpathian Foredeep and in the Carpathians proper, the clayey-sandy deposits included in the Şkawina – Baranów Formation formed. In the littoral zones sandy strata and lithotamnion limestones were formed. Most probably the Lower Badenian transgression did not cover the "Rzeszów Island" and some other raised ridges of the substratum, which presenly occur beneath the Carpathian overthrust (Fig. 3).

By the end of the Lower Badenian, presumably in the connection with the thrust displacement of the Carpathians margin, the more intense delivery of the clastic material from the Carpathians is distinct. At that time by the southern shore of the basin the coarse clastic material was deposited over the Carpathians. These strata were ascertained in the area of Bacharowice (Fig. 3). They are considered the product of the gravity mass movements of the debris-flow type, deposited in the littoral and sublittoral marine environment at the foot of the cliff coast (M. Doktor, 1983). A little further to the north from the Carpathians margin the coarse clastic strata known from the region of Gdów were deposited. According to M. Doktor (1983) those are products of the gravelly delta, which formed directly at the river mouth. It cannot be excluded however, that it was a submarine fan deposited at the mouth of submarine canyon.

After the Lower Badenian, the axis of the basin moved further to the north, stabilizing at the Rybnik – Wieliczka – Przemyśl line (A. Garlicki, 1979). The sedimentation of the Middle Badenian chemical rocks had begun then. According to R. Gradziński et al., (1976) the necessary condition for the gypsum precipitation was a five-fold reduction of the basin capacity. This reduction resulted from the displacement of the shore-line to the north due to the overthrusting of the Flysch Carpathians and to their uplift. The amplitude of this overthrusting averaged at 25 km. The direct evidence of that overthrust is the lack of chemical deposits beneath the Carpathian overthrust to the west from the Raba river valley, and occurrence of the flysch olistostromes in the salt deposit of Wieliczka (K. Kolasa, A. Ślączka, 1984). The occurrence of these olistostromes is an evidence of the presence of the Carpathians margin at the southern shore of the basin.

At that stage of the overthrusting, to the west from Kraków, the Carpathian overthrust reached approximately its present position (Fig. 4). In the eastward direction, the Carpathians margin was placed about 40 km further south as com-

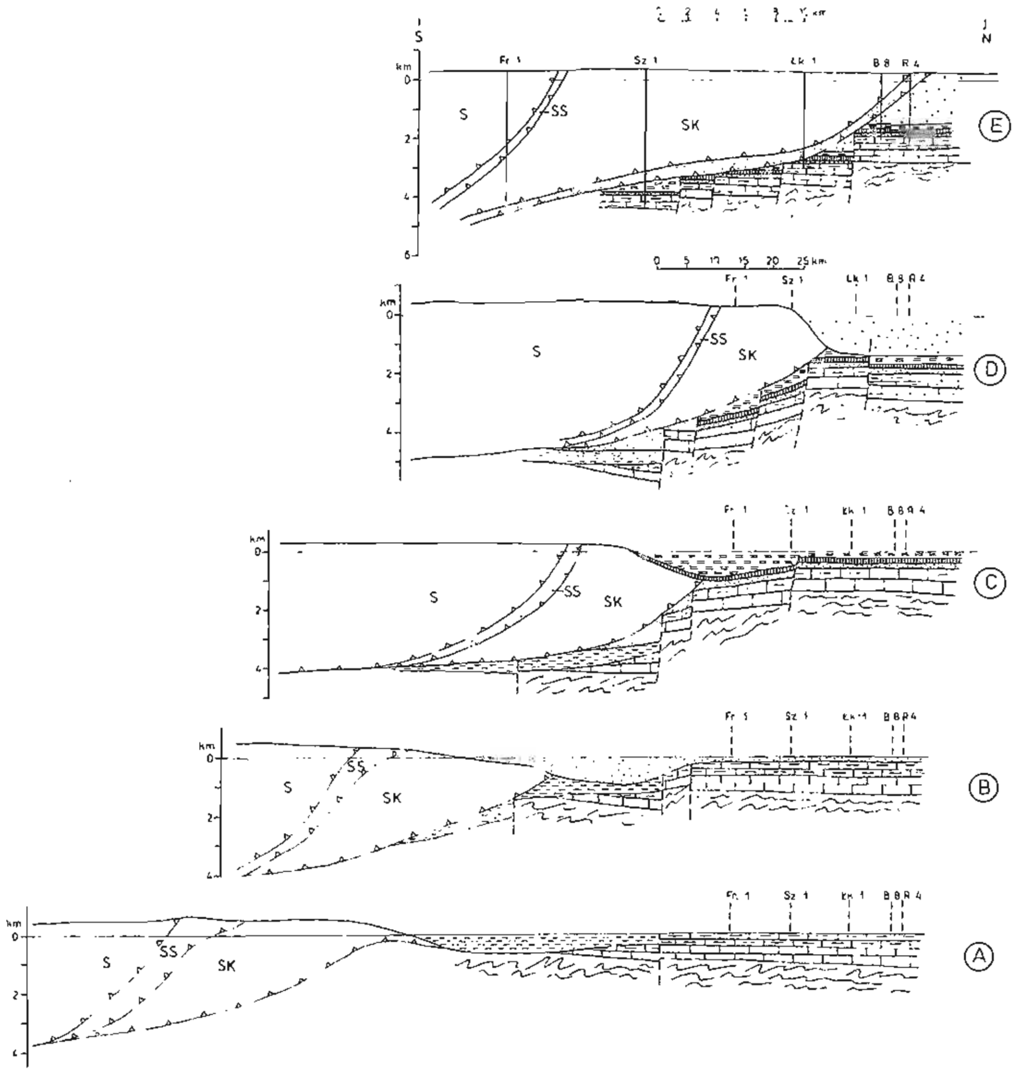

Fig. 10. Geological and palinspastic cross-section along the line i–j
Przekrój geologiczny i palinspastyczny wzdłuż linii i–j

Explanations as given in Fig. 6
Objaśnienia jak na fig. 6

pared with its present position. Besides these displacements, also significant deformations inside the Flysch Carpathians took place at that time. They are the most distinct in the western part. The Subsilesian unit has undergone nearly complete surficial reduction due to the tectonic doubling (Fig. 4). In the course of this reduction sinistral strike-slip faults of Soła and Skawa rivers formed. Along these faults the elements of the Subsilesian unit were displaced and subjected to the counter-clockwise rotation. At the same time in the contact zone between the Pieniny Klippen Belt and the Magura unit, the strike-slip faults was formed, both sinistral and dextral (K. Birkenmajer, 1983). The ultimate formation of the Żywiec window took place. To the east from the Dunajec river the Subsilesian unit had probably also undergone partial reduction.

In the western part, at the final stage of these movements already after the strike--slip faults formation, the Magura unit was submitted to the last thrusting and the slight bending movements. It partly covered the Soła and Skawa rivers dislocations then. This thrusting movement of the Magura unit is distinct as far as the Dunajec river valley. This is proved by the thrusting of the unit over the Lower Badenian strata of Iwkowa (Fig. 9). In the final stage of these thrusting movements probably the tectonic windows in the Magura unit were formed.

After the accumulation of the chemical deposits was finished, the axis of the basin was again slightly displaced to the north. The basin deepened. Due to the lowering movements the Rzeszów "Island" was flooded. In the region of Kraków the Bogucice Sands, commonly of a turbidite character, were deposited (M. Otfinowski, 1981). To the north they are substituted by a more distal facies. The origin of these sands may be related to the submarine fan developed in the vicinity of the tectonically active margin of the Carpathians (Fig. 4).

Following the end of the Badenian sedimentation, east from the Dunajec river the Carpathians moved about 20 km to the north (Fig. 5). At that time the sinistral strike-slip fault of Łekawka was formed (the dislocation zone Tarnów – Nowy Sącz according to R. Unrug, 1980). To the east of that dislocation the Subsilesian unit was nearly completely reduced and thrust along with the Silesian unit over the Upper Badenian strata of the Pilzno Embayment, the latter lying over the Skole unit. Also the Magura unit was thrust, forming the Łużna and Harklowa Peninsulas.

In the Early Sarmatian, due to the general regression of the sea, the area of the intense subsidence and accumulation was moved towards the area of the Rzeszów „Island", and to the north of it. In the vicinity of the tectonically active Carpathians margin in the shallow embayment the coarse clastic strata from Nockowa were formed (M. Doktor, 1983), which are interpreted as the fan delta (Fig. 5). Further to the west, in the part of the Carpathians which was not flooded by the sea a gravel--sandy alluvial fan known from Łęki Górne by Tarnów was formed (M. Doktor, 1983). After the Lower Sarmatian the marginal part of the Carpathians between Tarnów and Przemyśl was submitted to the last movement towards the north, reaching the present-day position (Fig. 10). The amplitude of this movement may be estimated at 10 to 15 km.

CONCLUSIONS

In the course of the paleotectonic and paleogeographic analyses, the migration of the Miocene depositional centers towards the north-east was ascertained. This sedimentation was including gradually larger and larger fragments of the platform. The most intense subsidence and accumulation took place, as a rule, in front of the Carpathians with respect to their contemporary position. These processes were accompanied by the disjunctive tectonics; older in the south-western part, and younger in the north-western one. This supports the thesis of S. Wdowiarz (1976), that the faults in the substratum are older than the overthrust and they do not continue in it.

After the Karpathian, as a result of the thrusting movements in the Carpathians the foreland of the Magura unit was subject to the reduction of about 60%. Such value was previously reported by M. Książkiewicz (1956). It was referred however to the shortening of the whole Outer Carpathians geosyncline due to the folding and overthrusting. Because of that reduction the Subsilesian unit was extremely diminished. This took place in the Early Badenian. Before the Early Badenian. breaking and doubling of the Silesian unit occurred in front of the Magura unit. The remnants of this doubling (or manifold reduction) are the "Subsilesian windows" occurring in that zone. Following the Early Badenian in the Outer Carpathians the main strike-slip faults were formed – the Soła, Skawa and Łękawka (Dunajec) faults. These faults are synchronous with the overthrusting in the marginal part of the Carpathians and are partly covered by the Magura overthrust. This allows for the two different interpretations of the mechanism of the final stage of the Magura overthrust. It might be the ultimate thrusting of the Magura unit or the thrusting of its foreland, synchronous with the Carpathian overthrust. At that stage the tectonic windows in the Magura unit could also form.

It follows from these considerations that the overthrusting movements in the marginal zone of the Carpathians were synchronous with the development and migration of the Miocene molasse basins in their foreland. This process is a continuation over the platform, of the similar phenomena which were taking place in the Outer Flysch Carpathians in the Pieniny Klippen Belt beginning from the Laramian movements.

The transition from the flysch to the molasse sedimentation was caused by the considerable increase in the rate of development and migration of the basins, which took place between the Oligocene and Miocene. In consequence, the overthrust surface became more and more flat. This phenomenon is well illustrated by the Figs. 6 to 10, where more outer overthrust surfaces are flatter. Sloping of the outermost elements is such, that at places gravity flows could occur, producing flysch olistoliths in the Miocene strata.

The relationship between the steepness of the overthrust surfaces and the thickness of the molasse deposited over the foreland was also confirmed. In the western part of the Polish Carpathians, where the thickness of the Miocene strata is small, the overthrust surface is more flat than in the eastern part, which is typified by the large thicknesses of the Badenian and Sarmatian strata. This regularity could be probably extended over the flysch strata.

The present knowledge does not allow to construct an unambiguous model of the tectonic evolution of the Western Carpathians in the Neogene. One may consider however the two different ways of development, depending on the role (stabile or mobile) played by the epi-Variscan European Platform.

In the first model the peripherial foreland basins develop at places where lateral displacement (overthrusting) of the folded rock masses over the adjacent lithospheric plates takes place (C. Beaumont, 1981). Under the overburden in front of the overthrusted strata, a trough is formed and filled with deposits derived mainly from the orogenic belt. Well documented example of how such model works, was recently presented by A.B. Hayward (1984), who considered the relation of the ophiolitic Lycian nappe (Western Taurides at the Antalya Bay, southwestern Turkey) to the Miocene foredeep situated over the stabile carbonate platform. Progressive displacement of the Lycian nappe, the facies migration, variable sedimentation rates of the Miocene deposits, as well as the subsidence of the carbonate platform, compose analogies between this area and the Carpathian Foredeep.

In the second model, which attracts more attention, the folded belt represents a tectonic suture formed as a result of the collision of the lithospheric plates. In front of the foldbelts the zone of intense subsidence and accumulation forms. At the subsequent stage, due to the underthrusting of the foreland, this zone undergoes folding and the accumulation zone moves outwards (*vide* D.R. Kingston et al., 1983). This model explains well the formation of the synchronous autochthonous Miocene strata in the Carpathian Foredeep, the narrow zone of the allochthonous Miocene strata in front of the overthrust, as well as para-autochthonous Miocene strata over the Carpathians. The flat overthrusting of the Carpathian orogene over the foreland may explain the lack, of a volcanic arc, in the Western Carpathians, back from the presumed subduction zone at the Pieniny Klippen Belt (*vide* R. Ney, 1976; M. Książkiewicz, 1977*b*).

Similar models of the tectonic evolution of the Northern Carpathians were presented recently (D.D. Burchfiel, L. Royden, 1982; T. Pescatore, A. Ślączka, 1984; N. Oszczypko, A. Ślączka, in press).

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ТЕКТОНИЧЕСКАЯ ЭВОЛЮЦИЯ КРАЕВОЙ ЧАСТИ ПОЛЬСКИХ ФЛИШЕВЫХ КАРПАТ В СРЕДНЕМ МИОЦЕНЕ

Резюме

Статья посвящена эволюции краевой части польских флишевых Карпат в период от карпатиана до нижнего сармата. Было составлено несколько палинспатических профилей и палинспатическо-палеогеографических карт. Была проанализирована морфология поверхности карпатского надвига.

В результате палеотектонического и палеогеографического анализа была выяснена миграция миоценовых центров осадконакопления в северо-восточном направлении на все более внешние фрагменты эпиварисцийской Европейской платформы. Области самого интенсивного опускания и аккумуляции всегда располагались вблизи актуального фронта Карпат. Дизъюнктивная тектоника на форланде Карпат синхронизировалась с седиментацией и замерала сразу после надвига Карпат, вследствие чего поверхность надвига отличается правильностью форм, ненарушенных разрывами в основании (С. Вдовяж, 1976).

Внешние флишевые Карпаты в Польше в своем современном виде окончательно сформировались в среднем миоцене. На западе это произошло раньше, сразу после нижнего бадена, а на востоке только после нижнего сармата. Вследствие среднемиоценовых надвиговых движений, форланд магурского элемента был редуцирован на 60%. В начальной стадии произошло срезание и раздвоение подсилезского элемента. Результатом этого раздвоения являются „подсилезские окна" на фронте магурского элемента. После нижнего бадена почти полностью был ликвидирован подсилезский элемент. Он выполнил свою роль „тектонической смазки" для внутренних элементов. В то же время образовались главные сдвиго-сбросы внешних Карпат: Сола, Скава и Лонкавка.

В статье показаны также две модели тектонической эволюции Карпат в зависимости от роли (подвижной или стабильной), какую можно приписать эпиварисцийской Европейской платформе.

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EWOLUCJA TEKTONICZNA BRZEŻNEJ CZĘŚCI POLSKICH KARPAT FLISZOWYCH W ŚRODKOWYM MIOCENIE

Streszczenie

Przedstawiono ewolucję brzeżnej części polskich Karpat fliszowych od karpatianu do dolnego sarmatu. Wykonano szereg przekrojów palinspastycznych oraz map palinspastyczno-paleogeograficznych. Przeprowadzono analizę morfologii powierzchni nasunięcia karpackiego.

W wyniku analizy paleotektonicznej i paleogeograficznej stwierdzono migrację mioceńskich centrów depozycyjnych ku północnemu wschodowi, na coraz bardziej zewnętrzne fragmenty epiwaryscyjskiej platformy europejskiej. Obszary najintensywniejszej subsydencji i akumulacji znajdowały się zawsze u aktualnego czoła Karpat. Tektonika dyzjunktywna na przedpolu Karpat była synchroniczna z sedymentacją i wygasła bezpośrednio po nasunięciu się Karpat. W wyniku tego powierzchnia nasunięcia uzyskała regularny kształt, niezaburzony uskokami w jej podłożu (S. Wdowiarz, 1976).

Obecny obraz tektoniczny zewnętrznych Karpat fliszowych na terytorium Polski uformował się ostatecznie w środkowym miocenie. W części zachodniej miało to miejsce wcześniej, już po dolnym badenie, natomiast w części wschodniej dopiero po dolnym sarmacie. W wyniku środkowomioceńskich ruchów nasuwczych przedpole jednostki magurskiej uległo redukcji o około 60%. W początkowym etapie nastąpiło ścięcie i zdwojenie jednostki podśląskiej. Pozostałością tego zdwojenia są „okna podśląskie" u czoła jednostki magurskiej. Po dolnym badenie nastąpiła prawie całkowita likwidacja jednostki podśląskiej. Spełniła ona rolę „smaru tektonicznego" dla bardziej wewnętrznych jednostek. W tym czasie powstały również główne uskoki przesuwcze Karpat zewnętrznych: Soły, Skawy i Łąkawki.

W pracy przedstawiono również dwa modele ewolucji tektonicznej Karpat w zależności od roli (mobilnej lub stabilnej), jaką można przypisać epiwaryscyjskiej platformie europejskiej.