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NEW FEATURES OF STRUCTURE OF THE CARPATHIAN FOREDEEP AND BASEMENT OF THE CARPATHIAN MTS

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The results of studies on the Carpathian Foredeep, carried out by the Author since 1971 and presented in some tens of published and unpublished reports (the majority of which cannot be cited here), well evidence decisive influence of angular unconformities on its genesis. The studies showed that sub-Miocene, sub-Cretaceous, and sub-Jurassic paleorelief, and older unconformities are more important than hitherto assumed (Figs 1, 7). The idea of the lack of "horst tectonics" in autochtoneous Miocene of the foredeep has been put forward and substantiated in the first report (3), some parts of which were published elsewhere (e.g. 4). The idea of horst tectonics of the foredeep, widely accepted till that time (14, 22, 16, 15) and even still accepted by some authors (e.g. 1), was shown to be completely invalid.

The change in views became unavoidable when the results of analysis of successions and distribution of thickness of autochtoneous Miocene members in the foredeep (23), compiled on the basis of well logs, became available. However, in the study (10), interpretation of structure of the foredeep was still tectonic.

The essential change in my views has been presented in 1971, in theses to the first report (3), where I presented extensive discussion of inappropriate interpretation of "tectonic discontinuities" known from seismic records. Subsequent papers (3, 4, 5, 6) gave several examples of inappropriate interpretation of "fault tectonic". The new interpretation focussed marked attention and became the subject of long scientific discussions, especially among oil geologists and geophysicists. After some time it became accepted by a large part of them and applied in studies and search.

In the above mentioned collective works carried out under my guidance it was shown that there is no direct relation between "fault tectonics" and discontinuous deformations (Fig. 3). I showed the former to be closely related to highly differentiated relief of Miocene bedrock. This is well emphasized by changes in thickness and lithology of the relevant strata.

In comparing features of five complexes traced between Cracow and Przemyśl (Fig. 6; see 3): sub-anhydrite beds, chemical series (salts, gypsum, anhydrites, and limestones), and three thick supra-anhydrite complexes (N_1^1, N_1^2, and N_1^3), the identification of which still remains valid, I came to the conclusion that all the "fault zones" shown in geological cross-sections and structural maps are untectonic in origin. Numerous large-amplitude "faults" or "fault zones" appear explainable in terms of insufficient knowledge of stratigraphy of the Miocene or previously used methods of interpretation of seismic data. A detailed analysis showed that "fault zones" interpreted on the basis of seismic data do not agree with borehole data. The subsequent laborious stratigraphic corelations of borehole columns, carried out on the basis of well log data in the years 1971–1972, showed that upthrown and downthrown sides of "faults" differ in succession of strata both in the case of Miocene and its basement. Taking this into account, I came to the conclusion (3) that in such zones we cannot speak about tectonic discontinuities but stratigraphic or sedimentary ones, related to highly differentiated relief of all the structural stages, including the base of Miocene. Analysis of almost all borehole columns (about 10,000 borehole and seismic data), carried out in the years 1973–1975, gave further support to this point of view.

It should be emphasized here that geophysical stratigraphic subdivision of Jurassic (Dogger and Malm) and Upper Cretaceous strata resting here unconformably on older bedrock (Figs. 1, 8, 9), gave further support for the above presented subdivision of the autochtoneous Miocene. The subdivision of Jurassic was discussed in detail elsewhere (12, 13), along with relation of these strata to overlaying Cretaceous or Miocene. (Figs 1, 8). The latter papers presented subdivision of Jurassic formation into 12 stratigraphic complexes (A for Dogger, and B–Ł for Malm), traceable in the regional scale. The studies showed that erosional truncation of Jurassic strata changes most quickly from the west eastwards as well as towards the Carpathians. The whole section is thinning out from over 1,000 m in the Tarnów – Dębica – Mielec area in the east to about 250 m west of Grobla, towards Cracow.

The present distribution of summative thickness of Malm in boreholes appears closely related to Early Cretaceous erosion in area of extent of Upper Cretaceous cover. Beyond this area, it reflects effects of subsequent, still more intense erosion from Paleocene and Early Miocene times, especially in places where Jurassic crops out directly beneath Miocene. The image of sub- and supra-Jurassic unconformities and stratigraphy of Jurassic sections appear consistent with both the geophysical stratigraphic subdivision of Jurassic and its relation to seven complexes differentiated in Upper Cretaceous (complex A – Cenomanian, and complexes B – G – Turonian and Senonian), the above mentioned five complexes of autochtoneous Miocene, and the next nine complexes A – I (4, 5, 6).

The seven complexes differentiated in Upper Cretaceous (A – Cenomanian sandstones complex, B – Turonian carbonate complex, and C – G – Senonian marly complexes) also display changes in original thickness, but smaller than autochtoneous Miocene. However, the complexes attaining 450 m in summative thickness reveal very large changes in secondary thickness, especially in the case of Senonian. This phenomenon is mainly traceable in zones regarded as "faults" by other authors and canyon sides or margins of sub-Miocene swells here. Summative thickness of Upper Cretaceous significantly changes, locally up to 300 m or more. Some canyons are so deep that pre-Miocene erosion resulted in lack of both Cretaceous and large part of Jurassic (Figs. 8, 9, 10).

In all the places where paleovalleys have been found in Miocene bedrock, anhydrite horizon as genetically independent of clastic sediments show concave structural forms. In turn, convex forms may be traced along top parts of swells. This phenomenon, also accentuated by thin sub-anhydrite strata, appears related to Miocene transgression proceeding earlier and quicker in paleovalleys incised in Mesozoic. Granulation, content of sand-size material, and stratigraphic succession of strata are markedly varying in both local and regional scale. My view on these questions were presented in reports from the years 1971 – 1975 (3, 4, 5, 6), in which it was shown that Miocene transgression here quickly entered area highly differentiated in morphology and deeply incised by erosion (Fig. 2). In places where sub-Cretaceous (usually Jurassic) surface rises in the form of paleorelief swells, Cenomanian and even parts of Turonian are missing. Sub-Miocene relief often follows in a marked degree the sub-Cretaceous (12, 13), and Jurassic swell zones traced beneath Upper Cretaceous and Miocene coincide with decrease in both original thickness of individual members of Upper Cretaceous and its total summative thickness.

I compared results of geophysical stratigraphic analysis of Upper Jurassic, Cretaceous and autochtoneous Miocene strata, carried out on the basis of well logs, and seismic profiles, to find numerous zones characterized by lack of reflexes. The zones, traceable along margins of sub-Miocene or sub-Cretaceous relief, are also characterized by sudden changes in either original or secondary thickness of the youngest members of Jurassic and Cretaceous and the lowermost Miocene (Figs. 1, 6, 8). The widest of them appear related to sudden changes in thickness of Miocene Figs 4, 5) and, in western part of the studied area, Miocene and Cretaceous (Figs. 7, 8). It also appeared that pre-Cretaceous and pre-Miocene erosion used and emphasized structural predispositions and lithological features of Jurassic strata. Part of zones of extinction of reflexes, formerly interpreted as "fault zones", may be explained as due to some other factors, e.g. methods of field works and inappropriate interpretation of seismic image ambiguous because of presence of disturbing and multiple or diffracted waves. Therefore, "fault zones" drawn on the basis of such seismic image or inaccurate stratigraphy fail to get support in results of thickness analysis of individual complexes.

It follows that the phenomenon of disappearance of

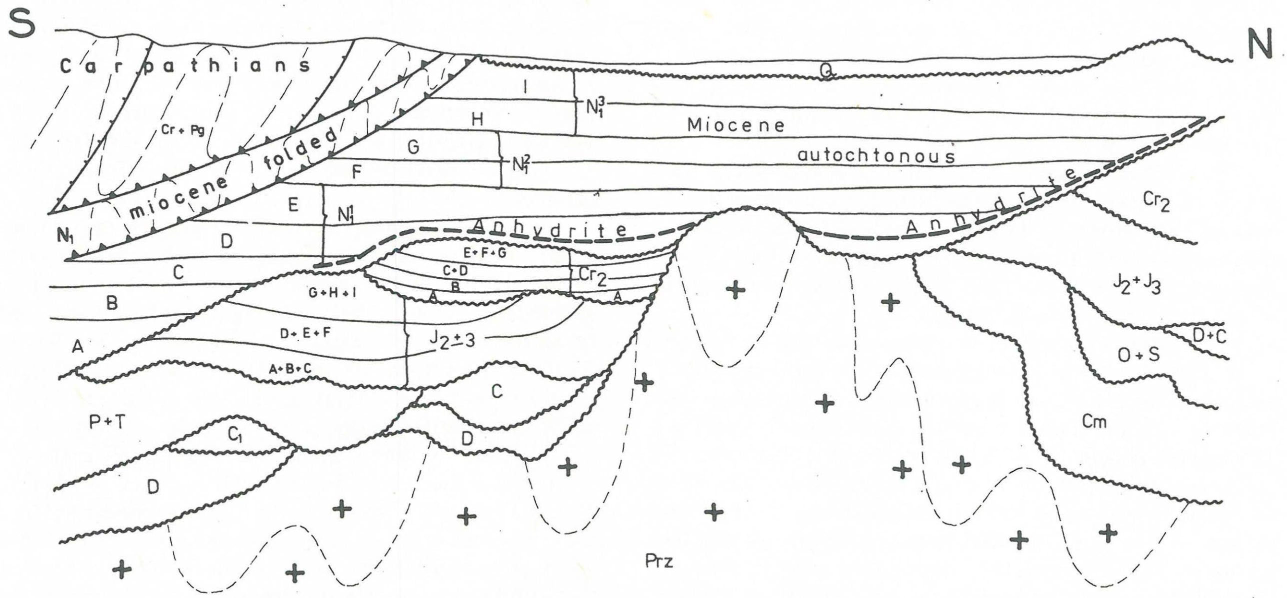


Fig. 1. Scheme of structural stages and subdivision of Miocene, Cretaceous and Jurassic in the Carpathian Foredeep on the basis of well log data.

Prz – Proterozoic, Cm – Cambrian, O – Ordowian, S – Silurian, D – Devonian, C – Carboniferous, P – Permian, T – Triassic, J – Jurassic, Cr – Cretaceous, Pg – Paleogene, N_1 – Miocene, Q – Quaternary.

Ryc. 1. Schemat pięter strukturalnych i podziału miocenu, kredy i jury w zapadlisku przedkarpackim na podstawie danych geofizyki wiertniczej.

Prz – proterozoik, Cm – Kambr, O – ordowik, S – sylur, D – dewon, C – karbon, P – perm, T – trias, J – jura, Cr_1 – kreda, Pg – paleogen, N_1 – Miocen, Q – czwartorzęd.

reflexes in Miocene, Cretaceous and Jurassic is mainly due to two reasons: 1) rock medium properties connected with sudden and discontinuous lithological or stratigraphic changes, and 2) methods of field works. I came to the conclusion that the long-accepted "fault" lines are connected with unusually high differentiation of sub-Miocene unconformity surface, especially canyon side zones or swells, responsible for rapid changes in thickness of Miocene or older strata. Despite of long discussions with collegues working on tectonics of this area, the idea was not shown to be invalid. Thus it may be stated that the more "faults" are shown in a given region, the less sufficient is knowledge of its geological structure. Moreover, this implicates that paleorelief, distribution of facies, and rates of wedging out of strata are more complicated than hitherto assumed, and methods of geophysical surveys unadjusted to such conditions.

In analysis of thickness of the identified complexes in the Carpathian Foredeep I used the principle that "fault" deformations cannot change thickness of diagenesed beds as synsedimentary or postsedimentary phenomena. In the former case, there could originate some subaqueous slumps in undiagenesed sediments, and in the latter – explanation of thickness changes as due to tectonics appears impossible (Fig. 3).

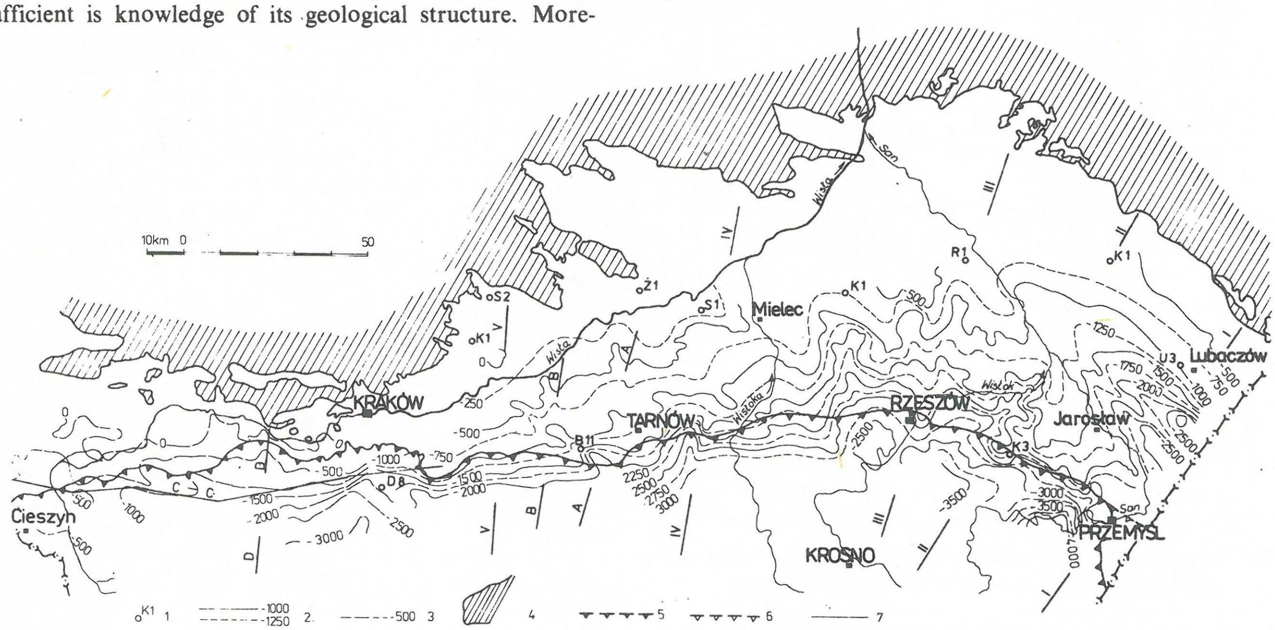


Fig. 2. Structural map of the base of autochtoneous Miocene in the Carpathian Foredeep.

1 – selected boreholes for location of the map, 2 – contours of base of Miocene (in 250 m intervals), plotted with the use of computer, 3 – contours of structural trends in base of Miocene, in 250 m intervals, 4 – erosional boundary of autochtoneous Miocene, 5 – external boundary of the Flysch orogene, 6 – Stebnik overthrust, 7 – cross-sections

Ryc. 2. Mapa strukturalna spągu miocenu autochtonicznego w zapadlisku przedkarpackim.

1 – wybrane otwory wiertnicze dla orientacji mapy, 2 – warstwice spągu miocenu co 250 m na podstawie konstrukcji wykonanej za pomocą EMC, 3 – warstwice trendów strukturalnych spągu miocenu co 250 m, 4 – granica erozyjna zasięgu miocenu autochtonicznego, 5 – zewnętrzna granica orogenu fliszowego, 6 – nasunięcie stebnickie, 7 – przekroje.

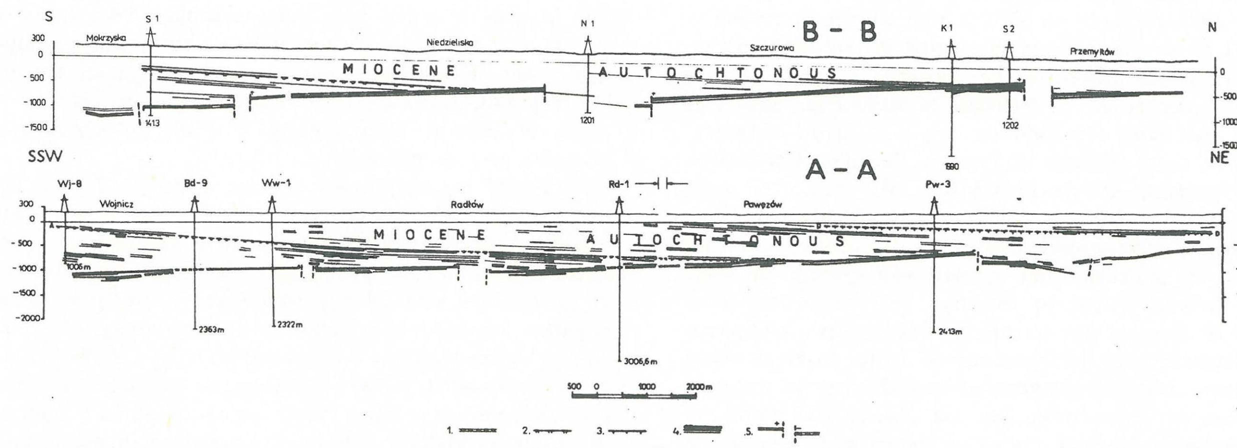


Fig. 3. Cross-sections A–A and B–B through the Carpathian Foredeep between Kraków and Tarnów, showing former tectonic interpretation of the Miocene and its basement.

1 – gypsum-anhydrite horizon, 2–3 – other seismic horisons, 4 – seismic horisons I, II, and III order, 5 – dislocations" and directions of downthrust.

Ryc. 3. Przekroje sejsmiczne A–A i B–B przez zapadlisko przedkarpackie w dawnej interpretacji tektonicznej miocenu i jego podłoża między Krakowem i Tarnowem.

1 – przewodnia granica refleksyjna w poziomie gipsowo-anhydrytowym, 2–3 – wyróżnione granice refleksyjne, 4 – granice refleksyjne rangi I, II, III, 5 – „dyslokacje" i kierunki zrzutu.

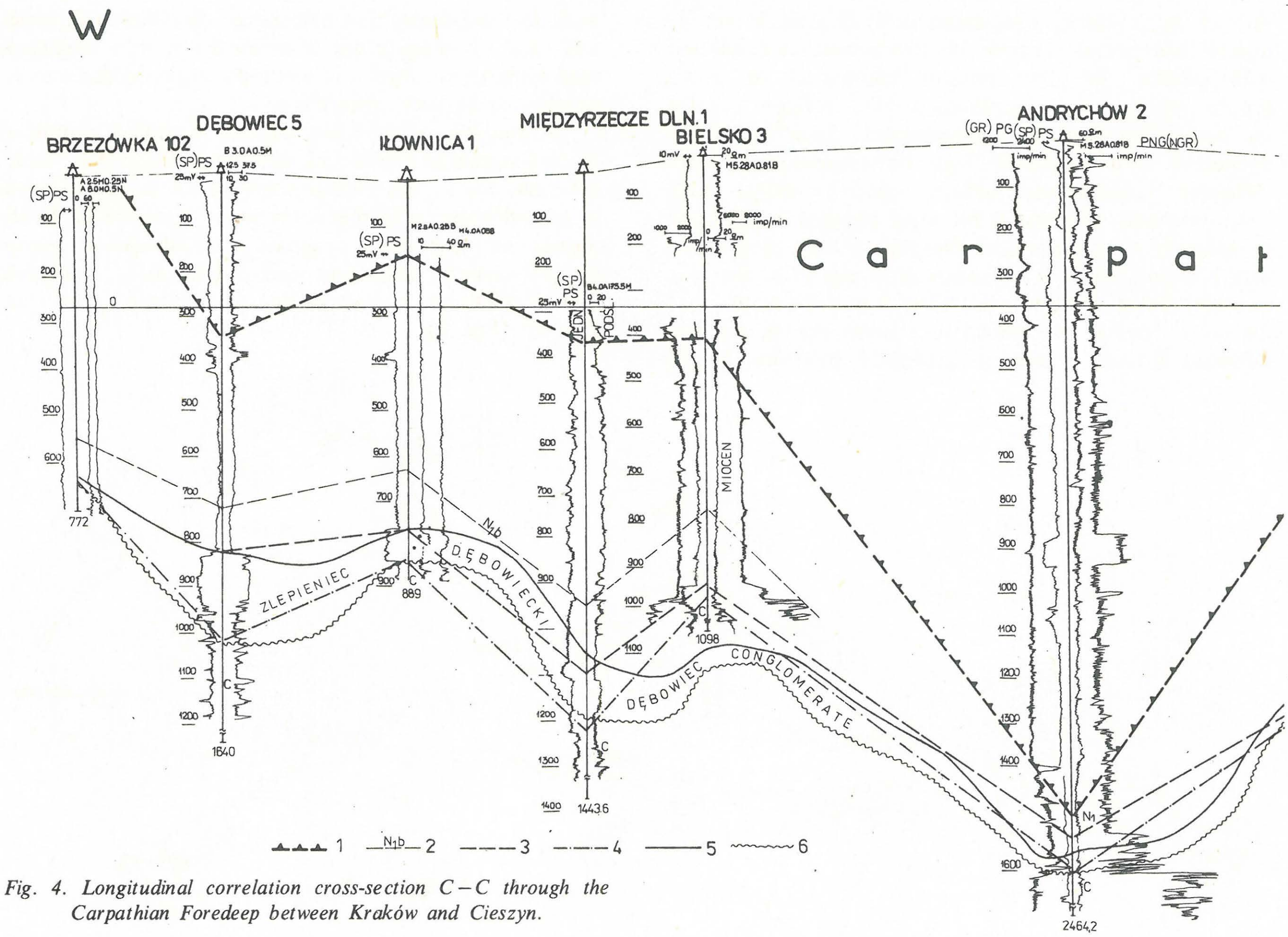


Fig. 4. Longitudinal correlation cross-section C–C through the Carpathian Foredeep between Kraków and Cieszyn.

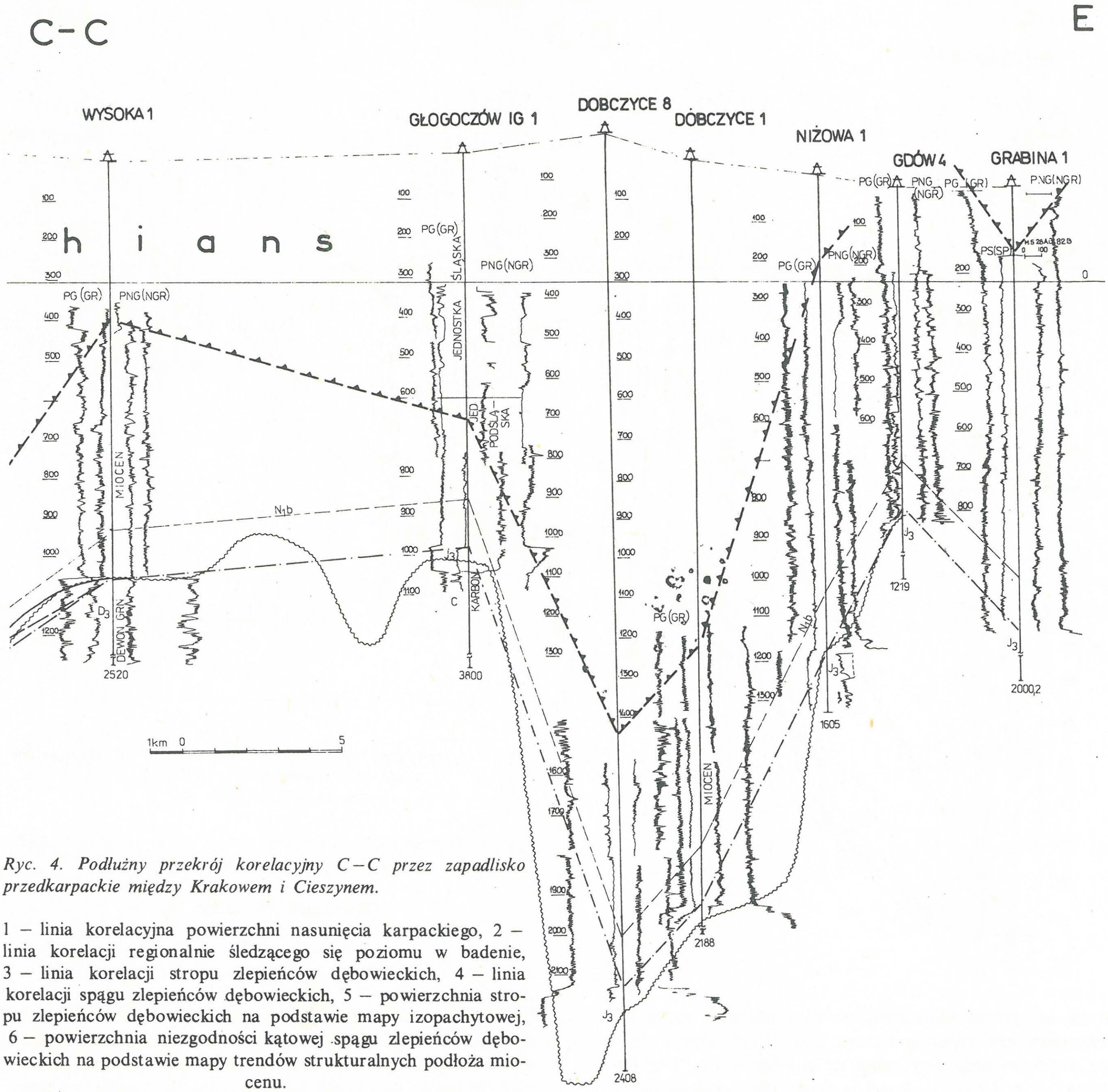
1 – correlation line of surface of Carpathian overthrust, 2 – correlation line of regionally traceable horizon in Badenian, 3 – correlation line of top surface of Dębowiec Conglomerates, 4 – correlation line of base of Dębowiec Conglomerates, 5 – top surface of Dębowiec Conglomerates after isopachyte map, 6 – angular unconformity surface at the base of Dębowiec Conglomerate after map of structural trends in Miocene basement.

The influence of the above findings has been significant, leading to changes in methods of seismic surveys and interpretations of their results, especially after introduction of numerical techniques, which, in turn, gave further support to my views presented in reports from the years 1971–1975 (3, 4, 5, 6). This is well shown by results of studies of several authors, presented in numerous papers and at various symposia. The growing evidence for the role of paleorelief it bedrock of individual structural stages also casts new light on origin of "fault tectonics" traced at basal surfaces of Triassic, Permian, Carboniferous, Devonian, and in Proterozoic. My studies on these questions are in progress but of may be already stated that geophysical stratigraphic analysis of Devonian and Carboniferous indicates that spatial arrangement of these strata is not related to tectonics but rather individual cycles of erosion. By tectonics I understand continuous and discontinuous deformations of strata. In areas where Devonian and Carboniferous sections display the youngest members of these formations we usually find swells of sub-Mesozoic bedrock, often in inversional relation to spatial arrangement of underlaying strata. That is why the most complete sections of Devonian may in extreme cases coincide with swells at the top and, at the same time, synclines at the base, and sections most strongly affected by erosion – to canyons, independently of spatial arrangement of strata. Similar phenomena are also common in Carboniferous.

Yet, there remains a question whether or not there are any fault zones in the Carpathian Foredeep. The answer to this question may be at present positive but only theoretically as "faults" shown in various maps merely represent interpretations not based on any firm evidence. Therefore, it may be stated that horst-tectonics interpretations of this area are missing support in borehole and geophysical data. "Faults" are here known from surface mapping only and, at present, it is rather difficult to prove any zones of tectonic discontinuity in both autochtoneous Miocene and its bedrock.

Previous biostratigraphic studies and new data show that sub-Miocene unconformity surface is overlain by various members of Miocene in area between Cieszyn and Przemyśl in the Carpathian Foredeep. Introduction of geophysical stratigraphy techniques made it possible to gather unequivocal evidence for a change in age of strata directly overlaying the unconformity from the Badenian in zones situated furthest southwards beneath the Carpathians to much younger (upper supra-anhydrite members of Lower Sarmatian) and usually arranged in overstepping way in previously elevated zones such as so-called Rzeszów Island. In the latter case chemical deposits did not originate at all. Early Sarmatian transgression reached with delay also some other paleovalleys-separating local swells.

Geophysical stratigraphy of Sarmatian made it possible to identify two stages in evolution of outer part of the Car-



Ryc. 4. Podłużny przekrój korelacyjny C–C przez zapadlisko przedkarpackie między Krakowem i Cieszynem.

1 – linia korelacyjna powierzchni nasunięcia karpackiego, 2 – linia korelacji regionalnie śledzącego się poziomu w badenie, 3 – linia korelacji stropu zlepieńców dębowieckich, 4 – linia korelacji spągu zlepieńców dębowieckich, 5 – powierzchnia stropu zlepieńców dębowieckich na podstawie mapy izopachytowej, 6 – powierzchnia niezgodności kątowej spągu zlepieńców dębowieckich na podstawie mapy trendów strukturalnych podłoża miocenu.

pathian Foredeep: one, connected with Badenian transgression, and the other, connected with rapid deepening of the basin and flooding of the diversified paleorelief in Early Sarmatian. The rates of sinking of the paleorelief in Badenian and Sarmatian were higher than those of sedimentation and the lack of any important reflection of the paleorelief in development of young members of autochtoneous Miocene indicates that it became markedly evened at that time. Arrangement of Miocene cover between the Carpathians and northern boundary of its extent indicates that we are dealing here with a set of huge Upper Badenian and especially Lower Sarmatian sedimentary fans. All the fans are directed towards the platform and not the Carpathians as hitherto assumed by some authors. I think that the major alimentary area was not situated in the platform nor Holy Cross Mts but in the destructed Carpathians. All the sub-Miocene valleys become deeper and deeper incised by erosion towards the Carpathians and they are preserved in the fossil state because of wedging out of Miocene members in the opposite direction (Figs. 6, 7). Diversified sub-Miocene relief is additionally accentuated by distribution of chemical (gypsum–anhydrite and salt) deposits, exceptionally sensitive to differences in bathymetry of rapidly subsiding floor of the foredeep.

According to a view widely accepted in the literature, contact of autochtoneous Miocene and overthrusted Stebnik unit or Flysch Carpathians is tectonic in character. However, results of my studies show that overthrusting of the Carpathians and Stebnik unit should be regarded as related to orogenic stress in the Flysch orogene, at first responsible for folding of strata and thereafter for thrusting them in the form of nappes over the foreland. It may be stated that the thrusted over orogen is not delineated from below by any surface of tectonic shear of autochtoneous Miocene strata (Fig. 1). I think that it is delineated by a slide surface, still active nowadays. Frontal part of the orogene was acting as a barrier for sedimentation in the Carpathian Foredeep (Figs. 4, 5, 7). Mobile, frontal margin was gradually moving forwards

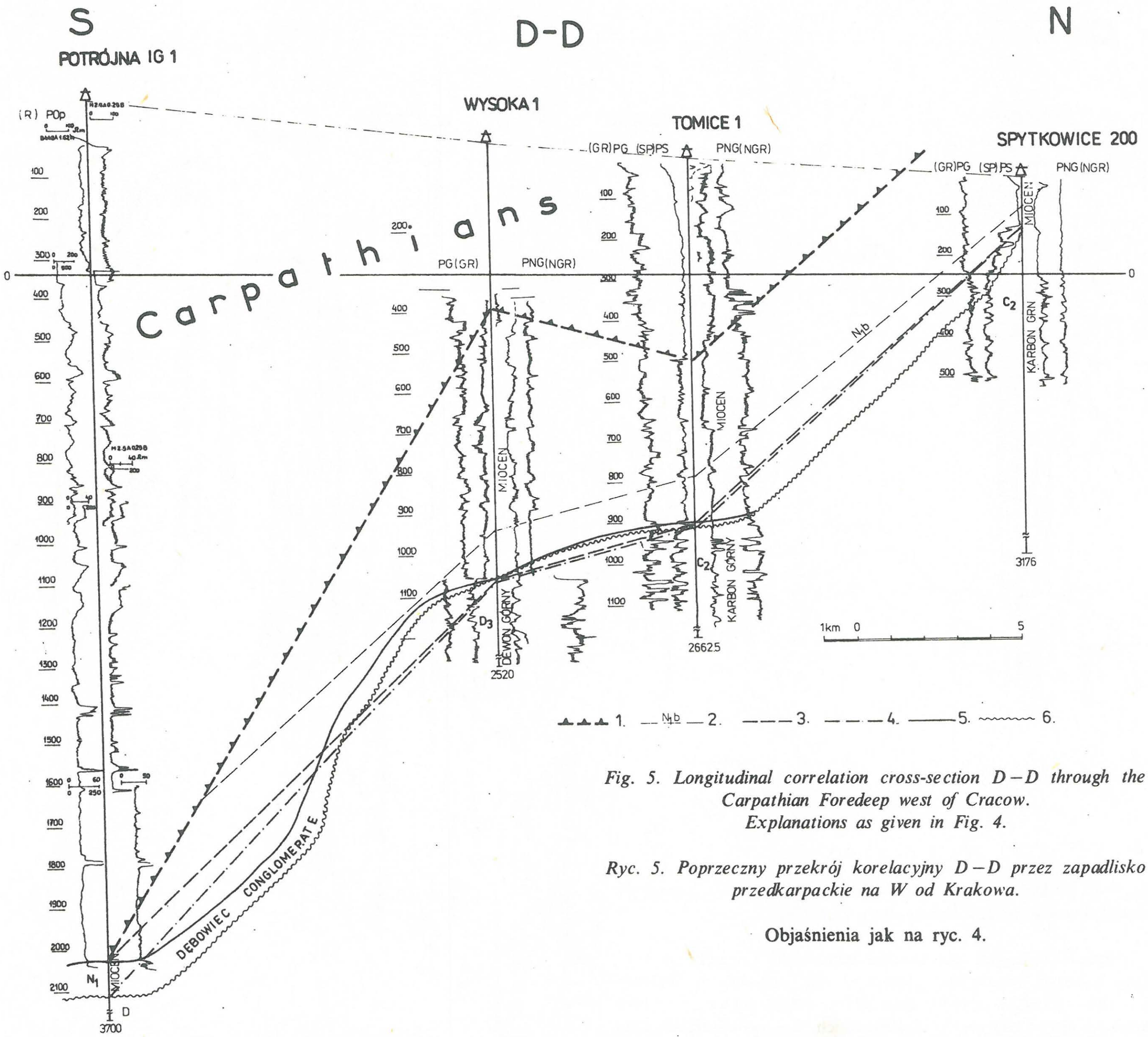


Fig. 5. Longitudinal correlation cross-section D–D through the Carpathian Foredeep west of Cracow. Explanations as given in Fig. 4.

Ryc. 5. Poprzeczny przekrój korelacyjny D–D przez zapadlisko przedkarpackie na W od Krakowa.

Objaśnienia jak na ryc. 4.

in the course of sedimentation over autochtoneous Miocene members, entering further and further into the sinking platform area and using its configuration. The overthrust of orogene, proceeding from the geosyncline outwards, was steadily limiting sedimentation of the youngest members of that autochtone (Fig. 7). The basin was still deep at these times in some zones in front of the overthrusting orogene as flysch masses overthrusted en-block or in the form of olistolites were completely submerging in its waters at depths below waving base. This may explain the fact that autochtone series become older and older towards inner parts of the orogene. I think that there is fairly high probability of finding autochtoneous strata markedly older than the Miocene (i.e. Paleogene or even Cretaceous in age), resting directly on platform basement of the geosyncline. This clearly follows from the enclosed scheme of structure of the foredeep (Fig. 1).

Previous studies showed that both the Carpathian-Stebnik orogen (9, 2) and autochtone (3–6) display gradual diachroneous migration of various sedimentary, stratigraphic and structural processes, in direction from the interior of the Carpathian arc outwards. Individual complexes of the autochtoneous Miocene are thinning out towards the platform, which indicates that the eroded Flysch Carpathians acted as the major source of clastic material. Outlets of rivers flowing from the Carpathians to Miocene basin may be localized from distribution of deltaic fans only. However, some information may be also obtained from preservation of some embayments infilled with Miocene sediments underlain by the flysch, or huge overlapping deltaic fans in areas of Cieszyn, Gdów, Tarnów, Rzeszów, and east of Przeworsk in the Carpathian foreland. It follows that the overthrusted orogen was strongly eroded and its paleorelief did not survive, in comparison with that of the platform, buried under autochtoneous Miocene (Fig. 7). That is why treatment of the Holy Cross Mts as the major alimentary area is erronous. Processes acting in the foredeep area were constructive, and those from the area of overthrusted Carpathians – destructive. The wealth of Carpathian material in Miocene sediments, especially the presence of microfauna pseudo-associations redeposited from eroded flysch series, support the above point of view. It follows that the share of material supplied from northern foreland of the Miocene basin (i.e. area where erosion started much earlier) was subordinate. Relief of sub-Miocene surface is much older than autochtoneous Miocene cover and material removed from that area has been deposited in Early Miocene and Paleogene times on platform basement situated nowadays beneath the Carpathian Flysch and far from its northern margin (Fig. 7). This is well shown by the mode of widening of sub-Miocene paleovalleys. Such sedi-

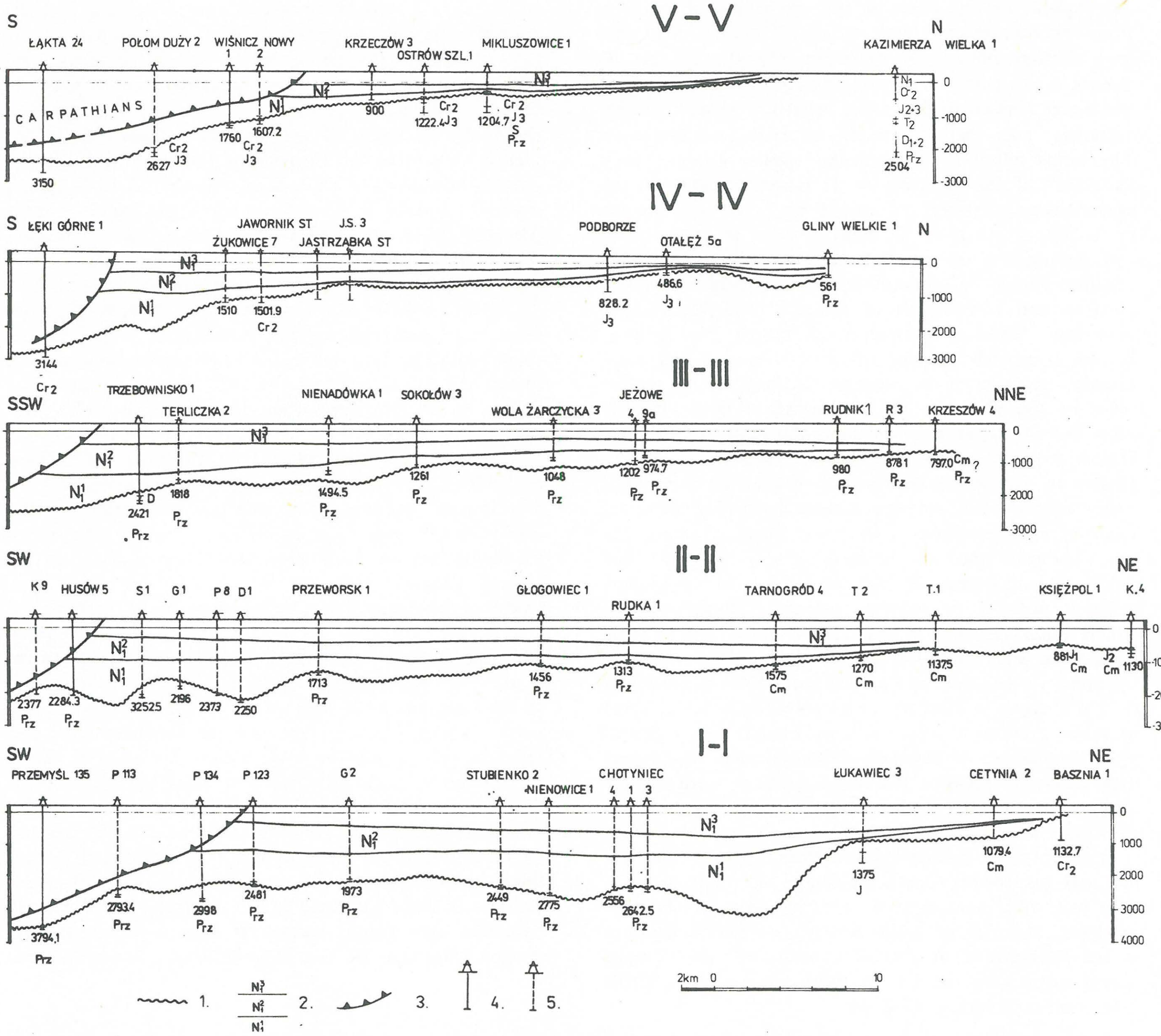


Fig. 6. Cross-sections through the Carpathian Foredeep east of Cracow.

1 – sub-Miocene unconformity surface after structural map compiled by the plotter technique (1985), 2 – stratigraphic boundaries delineated on the basis of well log data, 3 – boundary of overthrust of Carpathian-Stebnik orogene, 4 – boreholes at cross-section line, 5 – boreholes projected at cross-section line.

Ryc. 6. Przekroje przez zapadlisko przedkarpackie na E od Krakowa.

1 – powierzchnia niezgodności podmioceńskiej na podstawie mapy strukturalnej wykonanej techniką plotterową (1985), 2 – granice stratygraficzne wyznaczone na podstawie korelacji danych geofizyki wiertniczej, 3 – granica nasunięcia orogenu karpacko-stebnickiego, 4 – otwory wiertnicze na przekrojach, 5 – otwory wiertnicze rzutowane na przekrój.

mentary conditions may be also inferred from the presence of deep canyons infilled with clastic (including conglomeratic) material in the Upper Silesia and Moravian part of the Bohemian Massif (Figs. 4, 5).

The unusually diversified sub-Miocene relief, locally with amplitudes up to 1,000 m or more (as follows from calculations based on thickness of the autochtone infill in deepest canyons between Bochnia and Brzesko south of Gliwice, and Tarnów and Pilzno), appears most similar to that known from periphery of the foredeep in vicinities of Cracow (Fig. 2). This is the case of deeply incised canyons of left tributaries of the Vistula River between Krzeszowice and Ojców, and partly the Miechów Synclinorium and margins of the Holy Cross Mts. In the latter, some forms of relief were markedly evened by erosion as basement-building material appeared there less resistant to weathering than Jurassic and Paleozoic in the Cracow area.

An analysis of paleothickness versus thickness distribution of complexes differentiated in autochtoneous Miocene cover, carried out in the last years with the use of statistical techniques, gave highly interesting results. It showed significant and often very strong relations of present thickness of a complex and depth to its base. The obtained data confirmed that spatial arrangement of Miocene in the foredeep has not been affected by any significant postsedimentary tectonic modifications and, therefore, it mainly displays original features of Miocene sedimentary basin and not the hitherto overestimated postsedimentary, especially tectonic ones. Our similar statistical analyses of distribution of autochtoneous Miocene facies in the foredeep and spatial arrangement of strata failed to give any support for the views on tectonic nature of the foredeep (synsedimentary "fault tectonics" model). The analyses showed statistically significant relations of e.g. the present depth pattern of strata of autochtoneous Miocene and facies (shown to be mainly related to share of sandy material), and share of sandy material and thickness. The latter relation unequivocally speaks againts "fault tectonics" of the Miocene or its basement, even in the synsedimentary aspect. It should be noted that in the mathematical analysis of configuration of basin floor and distribution of material we assumed that eventual relations should be reflected in present spatial and depth patterns and distribution of facies in individual autochtoneous Miocene complexes. Although the patterns became somewhat changed due to compaction and additionally accentuated by isostatic loading of the paleorelief by the Miocene, the mathematic relations clearly show that they are not of secondary but primary character. Quantitative data show that share of sandy material increases in paleorelief depressions, decreasing on swells, where sediments are thinner and more clayey. The identified relations in distribution of thickness, share of sandy material (as established on the basis of well log data), and depths of occurrence of individual Miocene complexes, made it possible to compile numerous isopachyte and isolith maps for any of the differentiated stratigraphic complexes. This question of quantitative evaluations of thickness distribution at the background of quantitatively treated changes in lithology in the foredeep were neglected in earlier studies of other authors. That is why methods of extrapolation of borehole thickness and lithological data on areas between individual drillings, used by the latter, were characterized by high arbitrariness and impossibility to correct eventual errors.

The obtained mathematical models for borehole data for three parameters (depth, thickness, and share of sand-size material), were used to predict values of share of sand-size material in areas between individual drillings at the background of grid of coordinates, and compile isolith maps with the use of plotter technique and the calculated algorhithms (Fig. 6).

Finally, it should be stated that statistical analyses carried out with reference to grid of coordinates gave further support to the above discussed close relations of lithology and thickness and depth of occurrence of the Miocene complexes. At the same time the obtained data essentially question all the hitherto presented views on tectonic origin of the Carpathian Foredeep as related to activity of either syn- or postsedimentary "faults". Moreover, they make it possible to state that autochtoneous Miocene strata still display original statistical relations, typical of the sedimentary basin. This is further supported by some other data, graphically expressed in well logs.

In the hitherto used economic classification of Polish oilbearing geological regions, boundaries of the Carpathian Foredeep were delineated by extent of Miocene and margin of the Carpathians (7, 8), i.e. in arbitrary way. Extent of the foredeep is here interpreted as wider, also comprising areas beneath the Carpathians, delineated by theoretical inner extent of still insufficiently well known autochtone (not of Miocene age only), obscured by the overthrusted orogene. This interpretation refers to the concept of R. Ney (21). So defined foredeep consists of the better known outer part, stretching in front of the present Carpathian-Stebnik overthrust, and inner one, representing Miocene or older basement of the overthrusted Carpathian Flysch. In Poland, the two parts are roughly the same in size: the outer (sometimes called as Pogórze) is about 17,000 sq. km in area, and the inner (basement of the Carpathians at least so far as the Pieniny Klippen Belt) – about 18,000 sq. km. All the borehole data and reflexion seismic profiles made within the frame of search for hydrocarbons in Miocene and older basement of the foredeep, show that the basement represents a continuation of the young platform of the Polish Lowlands, covered by the autochtoneous Miocene and overthrusted Carpathian-Stebnik orogen. Sedimentary cover of the Platform comprises Meso-Paleozoic strata resting on Proterozoic basement and deeply eroded. It should be stated that erosional incision of the Meso-Paleozoic cover became

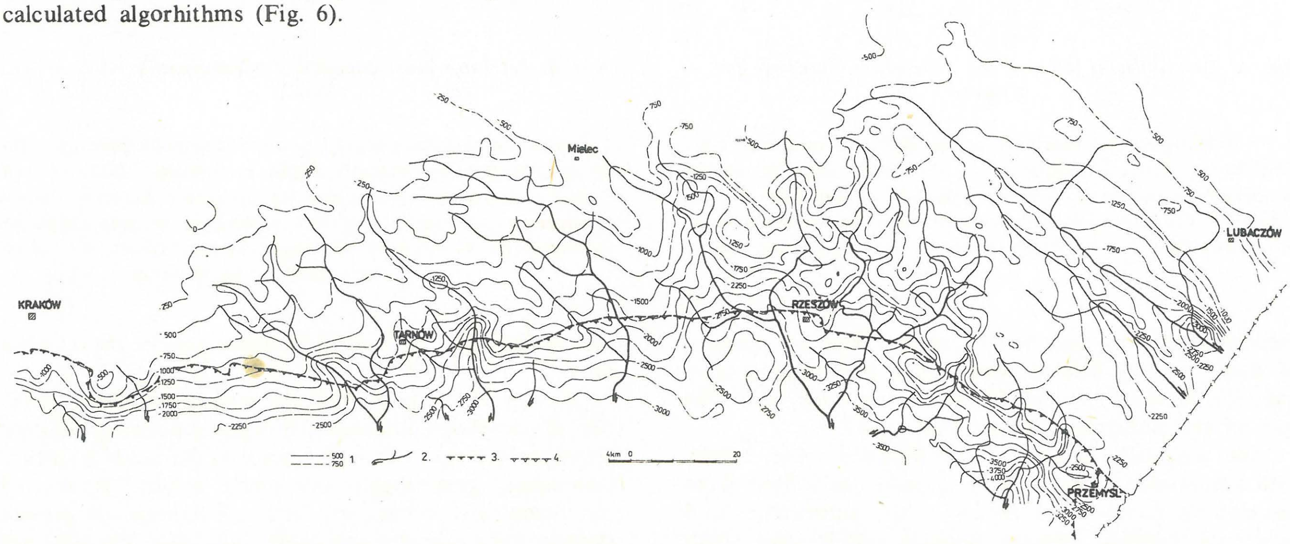


Fig. 7. Map of paleorelief and burried river network at the base of autochtoneous Miocene between Cracow and Przemyśl in the Carpathian Foredeep.

1 – present-day contours of base of Miocene on the basis of all the available borehole and seismic data (1985), 2 – burried river channels and directions of flow before Miocene transgression, 3 – outer boundary of overthrusted Carpathian Flysch, 4 – Stebnik overthrust.

Ryc. 7. Mapa paleoreliefu i pogrzebanej sieci rzecznej w spągu miocenu autochtonicznego zapadliska przedkarpackiego między Krakowem i Przemyślem.

1 – współczesne warstwice spągu miocenu na podstawie wszystkich danych wiertniczych i sejsmicznych (1985), 2 – koryta rzek zasypanych i kierunki spływu wód przed transgresją miocenu, 3 – zewnętrzna granica nasuniętego fliszu karpackiego, 4 – nasunięcie stebnickie.

completely or at least partly evened in both the outer part of the foredeep and beneath the Carpathians. The scale of erosional truncation increases towards inner parts of the Carpathians (Fig. 7), in direction in which are oriented paleovalleys of rivers frowing from the geosyncline foreland. Paleovalleys incised in platform cover widen beneath the Carpathians and join with one another in the form of river network buried beneath the autochtone and thick series of folded flysch (Figs. 4, 5). The thickness of the flysch exceeds here convential drilling depth and reflexion seismic profilling fails to give information on the basement, which completely excludes possibilities of interpretation at distances 20 – 30 km from the present front of the overthrusted flysch series (Figs. 2, 7).

The lack of reflexes in the above zone is explained in different ways. According to some authors, it is due to sucking downwards and compression of floor of sedimentary basin of the Flysch Carpathians. Other authors differentiate two types of basement: platform and geosynclinal. Boundary of areas differing in the type of basement, still insufficiently defined, is drawn on the basis of refraction seismics in the zone Nowy Targ – Nowy Sącz, Krosno, Sanok, and Chyrów. According to the third group of views, the extinction of seismic reflexions from the Carpathian basement may be due to too thick cover of the folded flysch, unfavourable for the used methods of profilling.

I think that the above phenomenon of extinction of reflexions from the basement of the orogen is mainly due to its seating at large depths and, therefore, thickness of folded and overthrusted flysch strata. The used methods of reflexion seismics still remain ineffective for mapping basement at depths from 5 to 10 km and greater, which makes it necessary to improve them. I regard the basement of the Polish Carpathians orogen as not geosynclinal but platform in character. However, this view cannot be tested nowadays by drillings nor reflexion seismics. That is why any adopted concept will remain not based on drilling nor seismic data and, therefore unverifiable and depending on the accepted interpretation of origin of the Carpathian geosyncline. The lack of reflexion seismics data on the basement occurring at depths over 5,000 m cannot be treated as evidence in favour of any of the above views on its structural style. This is especially the case of these views on structure of the Carpathian geosyncline and particularly its orogenic part, which project structural information concerning flysch series on the basement. That is why markedly closer connections of the basements of outer part of the Carpathian Foredeep and Carpathians, shown by results of studies on their sedimentary covers, may give better basis for more accurate interpretations. The latter point of view seems unequivocal as it is based on the above presented scheme of stratigraphic succession and distribution of thickness of strata formed in the foredeep and in large part nowadays covered by the overthrusted flysch (possibly also Mesozoic) orogen. The autochtone rests on Meso-Paleozoic or older basement of the young platform, subjected to high rate subsidence from the Cretaceous till Sarmatian. It appears that there is no geosynclinal basement in boundaries of the Polish Flysch Carpathians.

Some interpretations of deep-seated basement of the Carpathian orogen in refraction or magnetotelluric profiles (e.g. in 17) indicate presence of major "escarpments" and large depth of occurrence of the consolidated basement. In my opinion "escarpments" in the flysch basement may be due to huge thickness and lithological properties of the autochtone resting on Meso-Paleozoic plat-

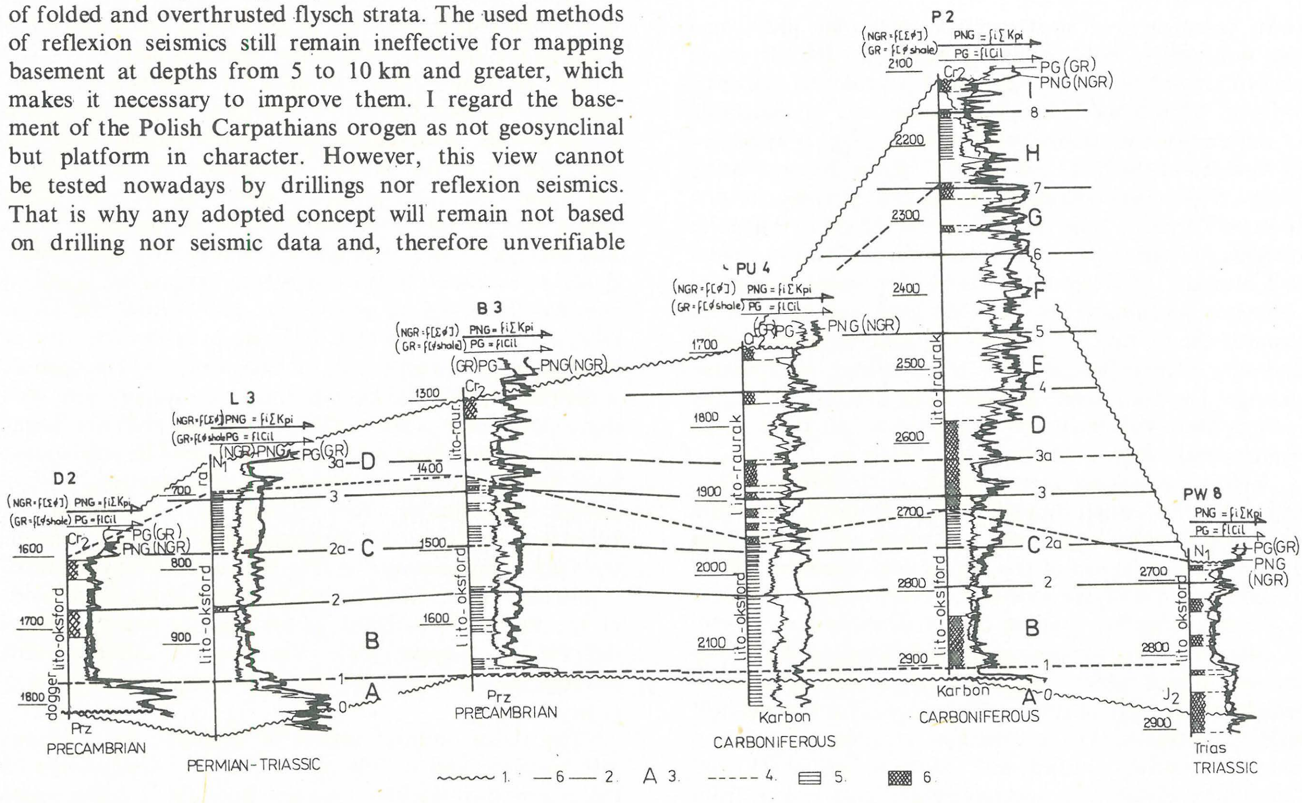


Fig. 8. Correlation of Jurassic strata in area east of Cracow.

1 – angular unconformity surface, 2 – guide stratigraphic boundaries delineated on the basis of well logs, 3 – stratigraphic complexes differentiated on the basis of well log correlations, 4 – lines of lithostratigraphic correlations in the hitherto accepted subdivision of Malm, 5 – packets of strata undoubtedly characterised by increased porosity, 6 – packets of undoubtedly imprevious strata.

Ryc. 8. Ciąg korelacyjny jury na E od Krakowa.

1 – powierzchnia niezgodności kątowej, 2 – przewodnie granice stratygraficzne na podstawie korelacji wykresów geofizyki wiertniczej, 3 – wyróżnione kompleksy stratygraficzne na podstawie korelacji wykresów geofizyki wiertniczej, 4 – linie korelacji litostratygraficznej w dotychczasowym schemacie podziału malmu, 5 – pakiety warstw o jednoznacznie zwiększonej porowatości, 6 – pakiety warstw o własnościach jednoznacznie nieprzepuszczalnych.

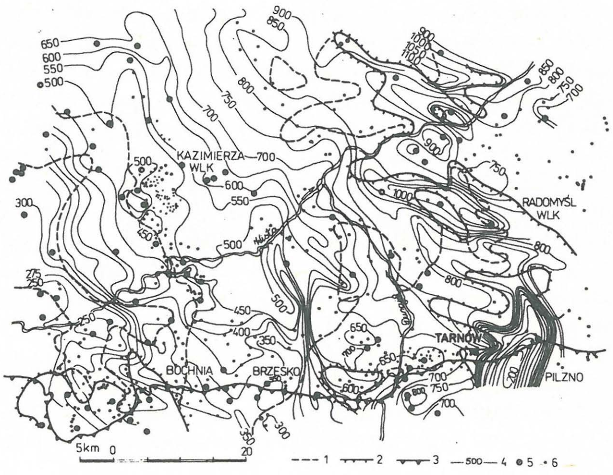


Fig. 9. Distribution of thickness of Malm in the Cracow – Tarnów area.

1 – extent of Cenomanian, 2 – extent of Cretaceous, 3 – margin of Carpathians, 4 – isopachytes of Malm, 5 – boreholes penetrating Jurassic, 6 – boreholes stopped in Jurassic.

Ryc. 9. Mapa miąższości malmu na obszarze Kraków – Tarnów.

1 – zasięg cenomanu, 2 – granica zasięgu kredy, 3 – brzeg Karpat, 4 – izopachyty miąższości malmu, 5 – otwory przebijające jurę, 6 – otwory nawiercające jurę.

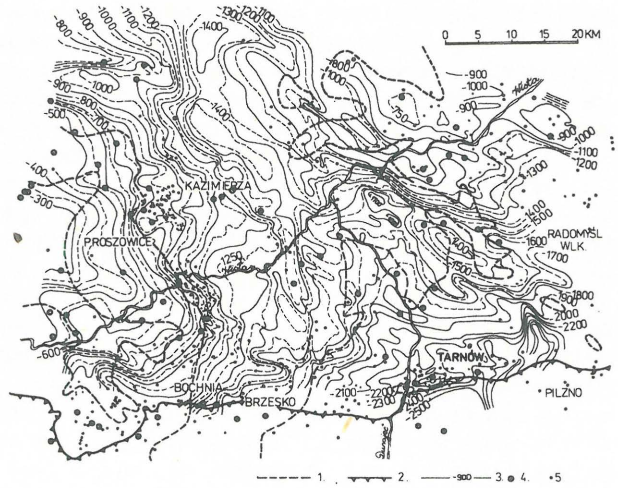


Fig. 10. Superposition structural map of the base of the Malm in the Cracow – Tarnów area.

1 – extent of Miocene, 2 – margin of Carpathians, 3 – contours of base of Malm, 4 – boreholes penetrating Jurassic, 5 – boreholes stopped in Jurassic.

Ryc. 10. Mapa strukturalna superpozycyjna spągu malmu w obszarze Kraków – Tarnów.

1 – zasięg miocenu, 2 – brzeg Karpat, 3 – warstwice spągu malmu, 4 – otwory przebijające jurę, 5 – otwory nawiercające jurę.

form basement and most probably markedly older than the well-known autochtoneous Miocene. The depth of occurrence of the first "escarpment" would be markedly varying, from 6 to 20 km. I treat the area of extinction of reflections from deepseated basement (Fig. 7) as related to foreland of the first "escarpment" along the zone Nowy Targ – Nowy Sącz – Krosno – Sanok and possibly further, towards Chyrów. This may be a zone of great change in thickness of the autochtone, resting on platform basement and overlain by overthrusted Carpathian series. The autochtone is presumably of the Paleogene age and further towards the Central Carpathian Depression, Dukla Folds, and inner parts of Magura unit, of the Paleogene – Cretaceous age. The autochtone in these areas also rests on deeply incised Meso-Paleozoic and Precambrian platform in an overstepping way, similarly as the Miocene.

Refraction seismic surveys made in the Moravy area, where the Bohemian Massif plunges beneath the Foredeep and Flysch Carpathians, unequivocally showed that limit velocities typical of the massif and basement of the foredeep and the Flysch zone do not correspond to the same layers but often to younger covers in the foredeep and, in extreme cases, deeper-seated and more strongly diagenesed Flysch series. Similar incompatibilities of limit velocities and types of strata were reported from the Ukrainian Carpathians (1), i.e. foreland of geosyncline, basement of foredeep infilled with Miocene sediments, and Carpathian Flysch. The phenomenon is also known from the Polish Carpathians, where some authors draw "consolidated basement" at depths 15 – 25 km in the Central Carpathian Depression south of Krosno – transversal refraction seismic section Opole Lubelskie – Rzeszów – Dukla. The basement, presumably covered with Paleozoic strata, would be rapidly "shallowing" to c. 10.0 – 12.5 km depth in the Dukla unit. I am inclined to explain this phenomenon in similar way as Czech, Slovakian, and Soviet geologists, i.e. by relating it to more advanced consolidation in the Dukla unit than in the case of the flysch series infilling the Central Carpathian Synclinorium.

On the basis of results of the above studies on the Carpathian Foredeep, I made an attempt to present the major developments achieved in time which passed since the last meeting of the Balkan Association in our country, i.e. since 1963. The questions discussed here are those which may be solved on the basis of the available borehole and geophysical data and not by assuming any definite model of evolution of the Carpathian geosyncline. General concepts of origin of geosyncline are beyond the scope of this paper. I do not treat the concept of development of the Carpathian geosyncline, its basement, and foredeep as a definite scheme and do not aim to create any new geodynamic concept as the available data seem still insufficient for such a generalization. However, it should be emphasized here that some views presented in the literature appear already unacceptable. This is especially the case of the hypothesis of the nature of consolidated basement beneath the Carpathian geosyncline. The basement displays features of the platform one and not geosynclinal in the boundaries of the Polish Carpathians, at least as far southwards as the Pieniny Klippen Belt. Therefore, a differentiation between this basement and that of the Carpathian Foredeep is pointless.

The above outlined history of evolution of the basin as a foredeep and its relation to gradual overthrusting of the Carpathian-Stebnik orogen indicate a close relation to "en bloc" subsidence of basement of the platform type. The loss of mass in area of the subsiding platform has been compensated in part by the autochtone (nowadays occurring beneath the Carpathians) but mainly the overthrusted flysch series (Fig. 4).

The above data show that it will be difficult to find convincing evidence for geosynclinal basement beneath the Polish Flysch Carpathians. The geosyncline was developing directionally outwards which is reflected by time migration of zone of erosion of its foreland and sedimentation in the foreland (leading to burial of relief), and migration of orogenic zone. The sequence of stages in the development is best shown by age of sediments infilling postorogenic hinterland deeps, including the central (Podhale) Flysch or patches of Miocene, always resting on older parts of the orogen. The folding orogen, successively comprising younger strata, was gradually thrusting outwards onto still younger autochtone. The age of the overthrusting may be fairly accurately established with reference to the youngest autochtone series but only in the front of the orogene. Foldings are always older than the overthrusting, as they are due to earlier, permanent stress conditions in the orogen, responsible for still continuing, continuous tangential overthrusting movement.

If the fore-Carpathian basin extends as the foredeep as far as the Pieniny Klippen Belt and basement in this part of the Carpathians is of the platform type, it is unnecessary to look for relations of the Carpathian Flysch orogen and root zone of the geosyncline.

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STRESZCZENIE

Na tle analizy powierzchni niezgodności kątowej w spągu pięter strukturalnych kompleksu skał osadowych oraz genezy „tektoniki uskokowej" autor przedstawił koncepcję rozwoju geosynkliny odmienną od wielu innych. Szczegółowa analiza pięter strukturalnych w pokrywie osadowej zapadliska przedkarpackiego i w podłożu Karpat, przeprowadzona w kilkunastu opracowaniach analitycznych i syntetycznych w Instytucie Wiertniczo-Naftowym AGH od 1967 r. do chwili obecnej, których nie sposób zacytować, doprowadziła do wyciągnięcia ważnych wniosków o rozwoju geosynkliny karpackiej. Zdaniem autora (4, 3) dzisiejsze zapadlisko przedkarpackie wypełnione miocenem stanowi tylko zewnętrzną część geosynkliny, podobnie jak to przedstawił R. Ney (21) i sięga daleko pod Karpaty.

Autor identyfikuje więc podłoże platformowe tak przyjętego zapadliska z podłożem orogenu karpackiego, stanowiącego wewnętrzną, najstarszą jego część. Analizując następstwo warstw w miocenie autochtonicznym, kredzie, jurze i w formacjach starszych za pomocą metod stratygrafii geofizycznej, na podstawie wyników profilowań otworów, autor doszedł do wniosku jeszcze w latach 1971–73 (3), że dawna „tektonika zrębowa" nie da się utrzymać w zapadlisku przedkarpackim. Została ona wprowadzona do literatury jako niewłaściwa forma interpretacji danych sejsmicznych lub niedokładnego rozpoznania stratygrafii związanej ze zjawiskami w urozmaiconym reliefie powierzchni niezgodności kątowej (5, 6).

W spągu każdej formacji geologicznej nie tylko w zewnętrznej części zapadliska przedkarpackiego przed czołem Karpat, ale także w podłożu Karpat można wyróżnić te same powierzchnie niezgodności kątowej: 1) podmioceńską, głównie utworzoną w paleogenie, 2) podcenomańską, 3) podjurajską, 4) podtriasową, 5) podpermską, 6) poddolnokarbońską i 7) poddewońską oraz starsze (ryc. 6). Największe rozcięcie erozyjne zapadliska miało miejsce w okresie paleogeńskim (ryc. 7, 8, 9). Deniwelacje w obszarach występowania kanionów lub garbów w spągu miocenu w przeliczeniu na miąższość warstw miejscami dochodzą do 1000 m.

Strefom tym towarzyszą nie tylko regionalne, ale także lokalne wyklinowania warstw, posiadające nietektoniczną genezę. Przedstawione i udokumentowane poglądy autora (3, 4, 5, 6) o niewłaściwej interpretacji różnych zjawisk w formie „tektoniki zrębowej" nie tylko w miocenie autochtonicznym, podawanej przez licznych autorów, wzbudziło żywą dyskusję, szczególnie w środowisku polskich geologów naftowych. Strefy „uskokowe", jak to autor wykazał w licznych opracowaniach, mają ścisły związek z ukształtowaniem bardzo urozmaiconego reliefu podłoża każdego piętra strukturalnego i zostały mylnie zinterpretowane na podstawie starszych danych sejsmicznych, jako zjawiska tektoniczne, a nie erozyjne (22, 16, 14, 15 i in).

W świetle omawianych badań autor wysunął tezę, iż czoło Karpat w formie sfałdowanego i nasuwającego się orogenu fliszowego stanowiło w przeszłości ruchomy brzeg wewnętrzny rowu przedgórskiego. Przesuwał się on stopniowo w czasie, poczynając od mezozoiku do dziś na zewnątrz, po coraz to młodszych ogniwach autochtonu rowu przedgórskiego lub miejscami po utworach młodej platformy, w wyniku naprężeń w górotworze. Powierzchnia nasunięcia fliszu karpackiego nie jest więc powierzchnią ścinającą tektonicznie warstwy autochtonu, ale powierzchnią ślizgu. Analiza miocenu autochtonicznego z zewnętrznej części zapadliska doprowadziła autora do wniosku, iż pod Karpatami fliszowymi na platformowym podłożu spoczywają (przekraczająco) kolejno coraz to starsze utwory autochtoniczne do paleogenu, a być może kredy i jury włącznie. We wszystkich dotychczas wykonanych wierceniach przebijających podłoże stwierdzono bowiem, że nad utworami mezo-paleozoiku platformy (głęboko rozciętymi erozyjnie) leżą coraz to starsze utwory autochtonu geosynkliny lub flisz nasunięty jest bezpośrednio na platformę.

Autochton ten spoczywa w omawianej zewnętrznej części geosynkliny niezgodnie na starszym podłożu, które uległo daleko idącemu obniżeniu pod koniec paleogenu i w miocenie. Autor nie widzi więc pod polskimi Karpatami fliszowymi podłoża geosynklinalnego. Szybkość pionowa obniżania się podłoża platformowego w czasie jest podobna zarówno w podłożu Karpat fliszowych, jak i na zewnątrz dzisiejszego czoła orogenu karpacko-stebnickiego, jednak przesuwa się ona stopniowo na zewnątrz. Autor stwierdził, że rozcięcie erozyjne podłoża platformowego rośnie pod Karpaty fliszowe.

W świetle badań refrakcyjnych i wykonanych metodą magnetotelluryczną (17), zdaniem autora, „skarpy" i głębokość ich zalegania w podłożu fliszu mogą być związane z dużą miąższością warstw autochtonu leżącego na podłożu platformowym geosynkliny, podobnie jak to ma miejsce u czoła lub na przedpolu dzisiejszych Karpat. Jeżeli dzisiejsze czoło Karpat lub jednostki stebnickiej jest rodzajem „skarpy", to na przedpolu następnej „skarpy", widocznej na linii Nowy Targ–Nowy Sącz–Krosno–Chyrów, w podłożu Karpat może występować również gruby autochton paleogeńsko-dolnomioceński. W strefie tej zanikają bowiem refleksy od głębszego podłoża.

Wyniki badań refrakcyjnych z obszaru Moraw na Masywie Czeskim wchodzącym pod zapadlisko i Karpaty, podobnie jak i w Karpatach ukraińskich (1) wskazują jednoznacznie, że prędkości graniczne Masywu Czeskiego lub podłoża zapadliska przedkarpackiego oraz strefy fliszowej nie odpowiadają tym samym warstwom. Podobne zjawisko ma miejsce na przekroju refrakcyjnym Opole Lubelskie–Rzeszów–Dukla, gdzie w jednostce dukielskiej podłoże skonsolidowane geosynkliny miałoby występować na głębokości 10–12,5 km i podnosiłoby się z głębokości 15–25 km centralnego synklinorium karpackiego. Autor skłonny jest tłumaczyć to zjawisko, podobnie jak geolodzy czescy, słowaccy i radzieccy, większą konsolidacją fliszu jednostki dukielskiej, zwłaszcza w głębszych poziomach, a nie wiązać go ze skonsolidowanym podłożem geosynkliny.

W świetle przedstawionej koncepcji trudno się dopatrzyć podłoża geosynklinalnego pod polskimi Karpatami fliszowymi. Rozwój geosynkliny karpackiej, rozwijającej się kierunkowo obejmował kolejno na zewnątrz: przesuwanie się strefy erozji przedpola, sedymentacji w rowie przedgórskim z zasypaniem reliefu i przemieszczaniem się strefy orogenicznej. O kolejnych stadiach rozwoju orogenu karpackiego najlepiej świadczy wiek utworów wypełniających postorogeniczne rowy zagórskie, w tym także flisz centralny (podhalański) lub miocen leżący płatami na fliszu, spoczywający zawsze na starszym orogenie. Fałdujący się orogen karpacki obejmujący kolejno coraz to młodsze utwory nasuwał się stopniowo na zewnątrz na jeszcze młodszy od niego autochton. Dokładny wiek nasunięcia się orogenu wyznacza wiek najmłodszych utworów autochtonu, ale tylko u jego czoła. Wiek fałdowania jest zawsze starszy od nasunięcia, co jest wywołane powstaniem wcześniejszych, permanentnych naprężeń górotworu, powodujących ciągły, styczny ruch nasuwczy, trwający do dziś.