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ON LINEAMENTS FOUND IN THE CARPATHIANS

(5 fig.)

Próba określenia wieku formowania się wgłębnych rozłamów w Karpatach

(5 fig.)

Abstract. The Pericarpathian and Peripieniny lineaments divide the lithosphere in the Northern Carpathians region into three blocks i.e. the Metacarpathian, Carpathian and Transcarpathian ones. These blocks are characterized by different thickness of the Earth's crust. The Carpathian block is the place where the cordilleras were downsucked and where are rooted the nappes of the external Carpathians. The formation of discussed lineaments started in Oligocene, and the main phase took place in Sarmatian-Pliocene.

International profiles of deep seismic soundings, were made a few years ago, across the Ukrainian, Polish and Czechoslovakian Carpathians; for the first time they threw some light on the structure of the lithosphere [1] in the region of the Carpathian Foredeep, the Outer Carpathians and the Central ones. Geophysical and geological interpretation of those profiles (fig. 1) was presented in two comprehensive works: the first one edited by V. B. Sollogub, D. Prosen and G. Militzer, published in Kiev in 1971, the other edited by Szénas Gyorgy, published in Budapest in 1972.

Profile V, whose northern part crosses the territory of Poland, was interpreted by J. Uchman in 1973.

Structure lithosphere under the Ukrainian Carpathians and their foreland was recently extensively interpreted by A. V. Čekunov (1972).

In connection with the results of deep seismic soundings accross the Carpathians, critical analyses of some aspects of deep tectonics of the Polish Carpathians basement appeared recently in Poland (A. Kisłow, 1973; R. Ney, 1973; W. Sikora, 1973).

[1] lithosphere = sedimentary layer + granite layer + basaltic layer + upper mantle (V. E. Chain 1973).

The main achievement of deep seismic soundings was the estimation of thickness of the Earth's crust in South-East Europe. V. E. Sollogub et al. (1971), as well as Szénas Gyorgy et al. (1972), assumed that the position of the Moho discontinuity changes stepwise along abyssal fractures (lineaments)[2] which divide the lithosphere into individual blocks.

During the last few years the science of lineaments became an independent section of geotectonics; up to now, however, a generally accepted definition of the notion „Lineament" (abyssal fracture) has been absent, neither has existed a generally accepted classification of lineaments. In the present paper I call a „lineament" a narrow (maximally up to a dozen or so kilometres) zone of dislocations in the lithosphere, separating blocks of various thickness of the Earth's crust.

In Soviet theoretical geology (where the science of lineaments has been widely developed), since A. Pejve (1945) wrote his first paper on this subject, a number of criteria derived from indirect data (V. E. Chain, 1973) have been taken into consideration to distinguish abyssal fractures, apart from direct criteria on the basis of deep seismic soundings. It should be made quite clear, however, that the main data which allow to detect an abyssal fracture result from the analysis of geophysical data.

The present paper is a continuation of research work on tectogenesis of the Polish Outer Carpathians. Earlier results of works on this subject were presented in two papers, published recently (W. Sikora, 1971a; 1971b).

THE RELATION OF THE CARPATHIAN OROGEN TO THE PLATFORM, ON THE EXAMPLE OF THE POLISH CARPATHIANS

It has been accepted since the time of M. Lugeon, V. Uhlig and M. Limanowski that nappe tectonics is a characteristic feature of the Carpathians. Along the transversal cross-section, the Polish Carpathians can be divided into the Central Carpathians and the Outer ones.

The Central Carpathians are built of sedimentary rocks of the Permian-Cenomanian age (T. Buday, M. Mahel et al., 1968; S. Sokołowski, 1959; E. Passendorfer, 1963), as well as of cristalline massifs of the Silurian-Carboniferous age (J. Burchard, 1971). Their folding and uplifting occurred probably in Turonian, since in Slovakia transgressive Emsherian sediments are resting on partly eroded folds and nappes of the Central Carpathians, as a postorogenic cover (T. Buday, M. Mahel et al., 1968). The postorogenic cover is younger in the Tatra

[2] In this paper the terms abyssal fractures and lineaments are considered synonyms.

Mountains, as it begins with the Middle Eocene deposits (W. Kuźniar, 1910; S. Sokołowski, 1959).

The Outer Carpathians are built, in the main, of flysch rocks of the late Jurassic-Aquitanian age (Bieda et al., 1963). The disappearance of the geosyncline conditions occurred there during the post-Paleogene orogenic revolutions. Flysch rocks were then detached from their substratum, nappes were formed and overthrust the Miocene molasses of the foredeep, whose basement constitutes a platform type sediments [3].

Between the Central and the Outer Carpathians there is a very diversified geological structure called, according to geological bibliography, the Pieniny Klippen Belt. Strata occurring there represent the time interval from Triassic to Oligocene. Up to now, the number of tectonic phases [4] in the Pieniny Klippen Belt has not been decisively established. Considering the fact, however that in the Pieniny Klippen Belt there are zones with continuous sedimentation from Cretaceous to Paleogene (W. Sikora, 1971a; O. Samuel, K. Borza, E. Kohler, 1972), it should be accepted that the complete inversion of partial geosyncline of the Pieniny Klippen Belt, followed by disappearance of the geosyncline occurred only in the post-Paleogene phases.

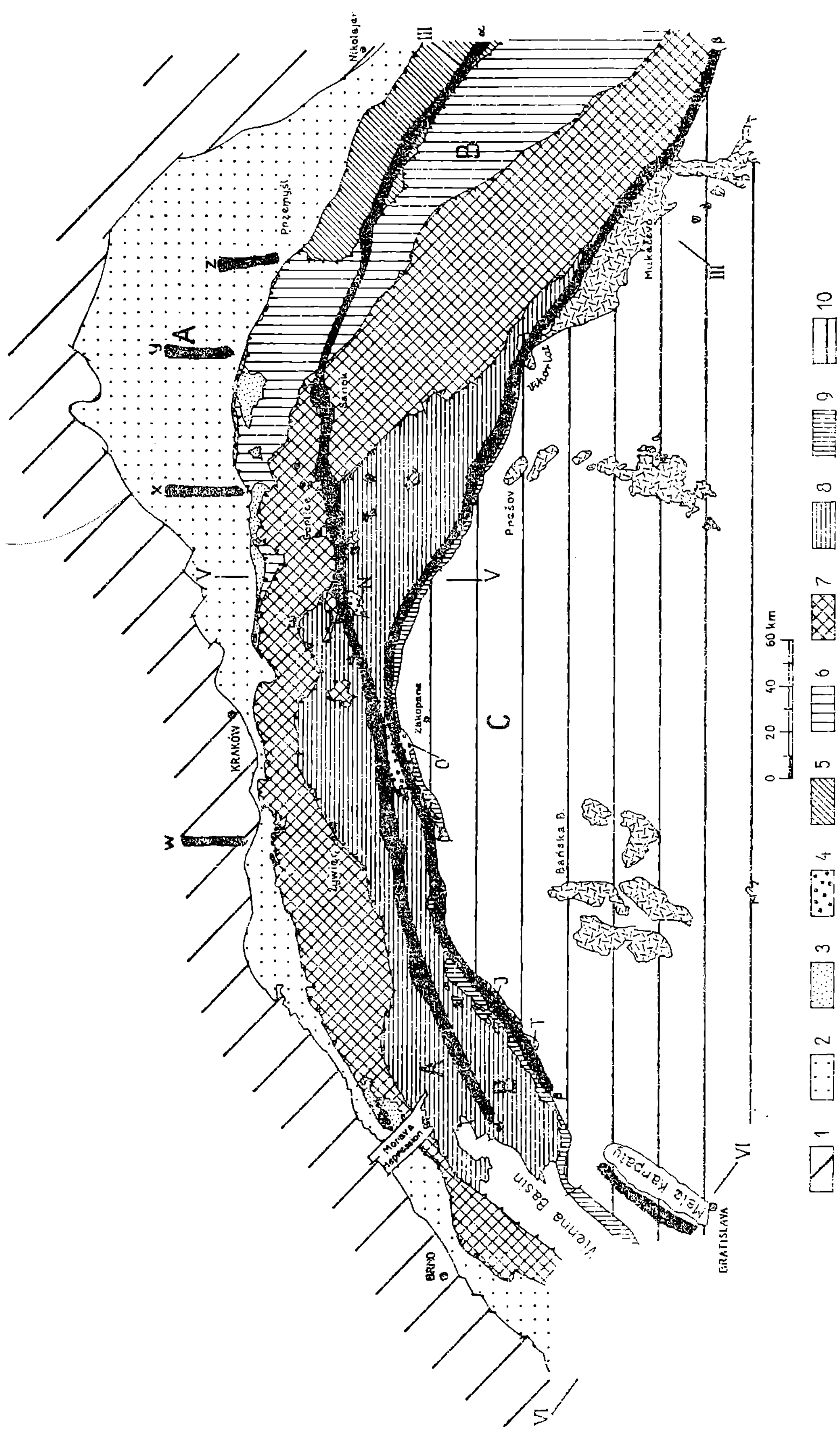
The relation of the Carpathian orogen to the platform basement, which is at same time the basement of the Carpathian Foredeep, was presented for the first time by V. Uhling in 1907. According to his interpretation, the Carpathian orogen is so overthrust on its foreland (according to W. Teisseyre, 1921, the foredeep on the platform basement is thrust under the Carpathian orogen) that the foredeep molasses occur even under the Central Carpathians. According to him, the distance of „en bloc" overthrust of the Carpathians on their foreland is about 80 kilometres, and the geosynclinal basement should occur only somewhere south of the High Tatra Mts. North of the High Tatra Mts. the orogen rocks are located on an extraneous basement (sunken platform).

The ultra-nappic conception was not supported in the following years, although none of the Polish geologists denied the nappe structure of the

[3] Soviet geologists (V. V. Gluško, S. S. Kruglov et al., 1971) distinguish two zones in the foredeep of the Ukrainian Carpathians: the outer zone, located on the platform and the inner one, located on the geosynclinal basement. The inner zone was further divided into two parts: the northern — Sambor and the southern — Pokucie—Borysław, where a sedimentary continuity between the Paleogene flysch and the Lower Miocene molasses has been proved (K. Tołwiński, 1927).

It has still been an open question whether folds and nappes of the outermost parts of the geosyncline, in which molasse deposits were laid down, should be regarded as belonging to the foredeep. Some scientists as, eg. J. Aubouin (1965) are of the opinion that the notion of foredeep is closely connected with that of a platform basement.

[4] The notion of tectonic phase is used in the present paper according to the definition by V. E. Chain (1964).



KRAKÓW
Przemyśl
Sanok
Zakopane
Prešov
Mukačevo
Vihorlat
Vienna Basin
Mala Karpaty
BRNO
BRATISLAVA
Morava depression
A
B
C
W
X
Y
Z
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1 2 3 4 5 6 7 8 9 10
11 12 V-V 13

Carpathians and far horizontal displacements (see the review of tectonics conceptions concerning the structure of the Polish Carpathians — M. Książkiewicz, 1972).

For many years nobody tried to establish the southern extent of the platform basement under the Carpathians. An insight into this question was provided by deep bore-holes performed in last time. The extent of the platform basement is located far under the overthrust flysch not farther, however, than the axis of regional gravimetric minimum that runs parallel to the Pericarpathian Lineament, somewhat south of it (fig. 1) (K. Żytko, 1965; Z. Olewicz, 1968; S. Wdowiarz, S. Jucha, 1968; Z. Roth, 1968; A. Ślączka, 1970; W. Sikora, 1971b; A. Kisłow, 1973, L. Koszarski, W. Sikora, S. Wdowiarz et al.; L. Koszarski, W. Sikora in press). Only R. Ney (1973) in his interpretation of structure of the Polish Carpathians establishes the delineation of the platform basement in the northern part of the Pieniny Klippen Belt, regarding the belt zone as a subduction one (also compare I. F. Dewey, J. M. Bird, 1970).

THE COURSE OF THE PERICARPATHIAN LINEAMENT

In 1970 a conception was brought forward (L. Koszarski, W. Sikora, K. Żytko in R. Osika, 1971[5]) that the boundary between the basement, non-regenerated by alpine orogeny on which the foredeep

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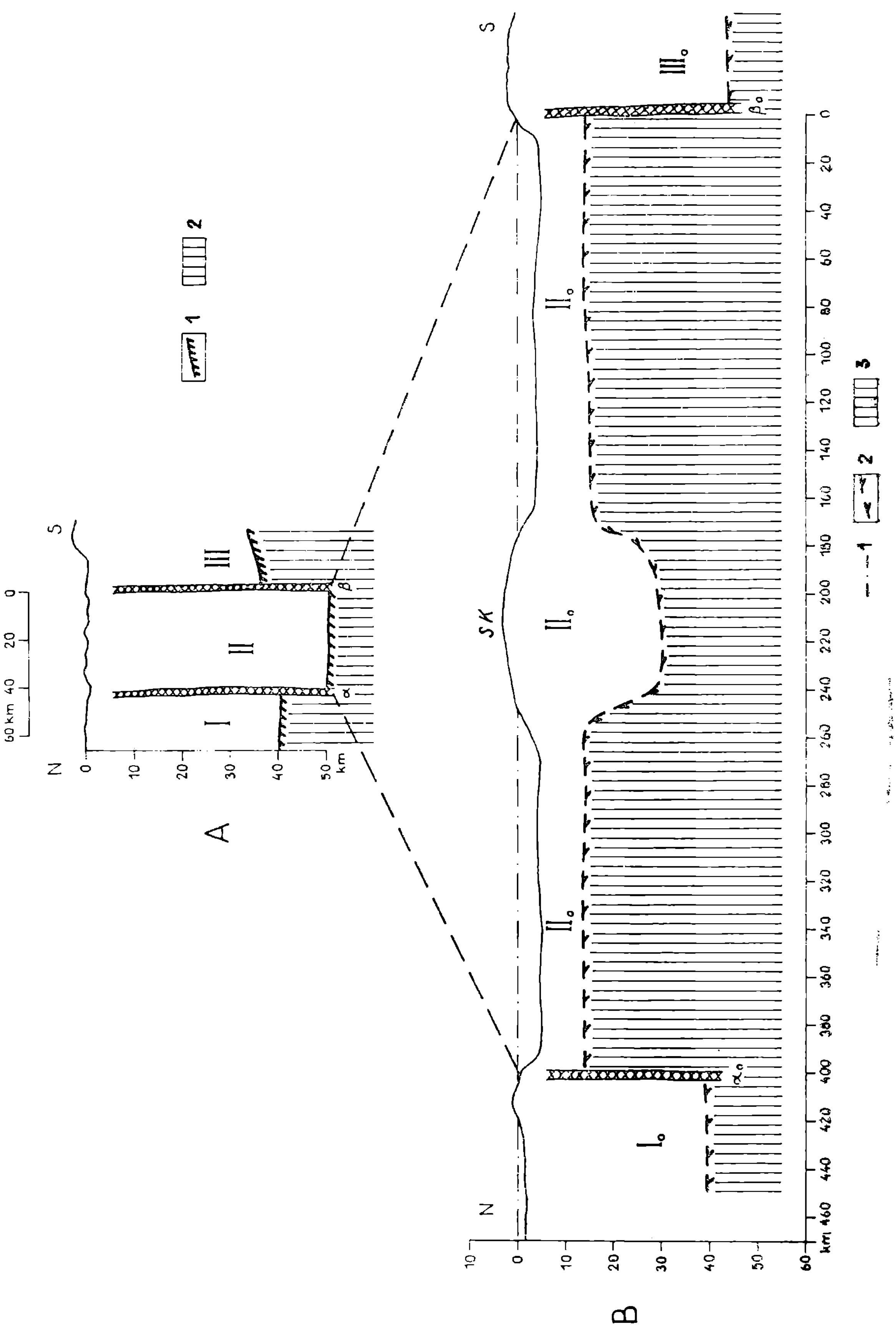
Fig. 1. Tectonic sketch map of the Polish, Ukrainian and Czechoslovakian Carpathians. 1 — platform; 2 — foredeep founded on the platform; 3 — erosional relicts of the Miocene molasses resting on the Outer Carpathian flysch; 4 — intermontane depressions: T — Trenčin, I — Ilava, O — Orawa—Nowy Targ, N — Nowy Sącz. Outer Carpathians: 5 — Stebnik unite (inner zone of the foredeep founded on the geosynclinal basement); 6 — Skole unite; 7 — Subsilesian, Silesian, Dukla, Grybów, Fore-Magura units; 8 — Magura unit; 9 — Pieniny Klippen Belt; 10 — Central Carpathians; 11 — significant Neogene volcanic rocks; 12 — lineaments: α — Pericarpathian, β — Peripieniny; 13 — lines of deep seismic soundings; A — Metacarpathian block; B — Carpathian block; C — Transcarpathian block. Presumed transversal lineaments: w — Banska Bistrica, x — Prešov—Gorlice, y — Vihorlat—Sanok, z — Przemyśl—Mukačevo (after Mahel et al. 1973, changed)

Fig. 1. Szkic tektoniczny polskich, ukraińskich i czechosłowackich Karpat. 1 — platforma; 2 — rów przedgórski założony na podłożu platformowym; 3 — erozyjne resztki molas mioceńskich na fliszu Karpat zewnętrznych; 4 — zapadliska śródgórskie; T — Trencina, I — Ilavy, O — Orawy — Nowego Targu, N — Nowego Sącza. Karpaty zewnętrzne: 5 — jednostka stebnicka (wewnętrzna strefa rowu przedgórskiego założonego na podłożu geosynklinalnym); 6 — jednostka skolska; 7 — jednostki podśląska, śląska, dukielska, grybowska, przedmagurska; 8 — jednostka magurska; 9 — pieniński pas skałkowy; 10 — Karpaty wewnętrzne; 11 — ważniejsze wystąpienia neogeńskich wulkanitów; 12 — wgłębne rozłamy: α — rozłam perykarpacki, β — rozłam perypieniński; 13 — linie profilów głębokich sondowań sejsmicznych; A — blok metakarpacki, B — blok karpacki, C — blok transkarpacki. Przypuszczalne rozłamy poprzeczne: w — Bańska Bystrzyca, x — Preszów—Gorlice, y — Vihorlat—Sanok, z — Przemyśl—Mukaczewo (wg Mahel et al. 1973, zmienione)

[5] The programme of drilling works in the Carpathians presented in conference in the Geological Institute in Kraków in July 1970.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was formed, and the basement partly under alpine regeneration is represented by a zone of lineaments in the Polish Carpathians. This zone is marked out by concentration of gravity izolines on the northern margin of gravimetric minimum and runs along the Stary Sambor—Domaradz—Nowy Sącz—Nowy Targ—Kysucke—Nove Mesto line.

The results of international deep seismics soundings, published in the following year, showed that the abyssal fracture, for which the term „Pericarpathian" [6] was suggested (W. Sikora, 1973), occurs on the northern „steep margin" of the regional gravimetric minimum and is rooted beneath the Moho discontinuity. The above data show that at least in the case of the Ukrainian, Polish and Czechoslovakian parts of the Carpathians, the northern „steep margin" of the gravimetric minimum marks out a very important boundary, distinct in the whole lithosphere.

In profile V, which crosses the Polish Carpathians more or less at the meridian of Nowy Sącz, the disparity in hypsometric situation of the Moho discontinuity on both sides of the Pericarpathian lineament is about 8 kilometres (fig. 2). The lineament was drawn as a vertical one (Sollogub et al., 1971; J. Uhman, 1973), and its surface projection occurs at the boundary between the Magura and the Silesian nappes. This is only accidental, however, since the Pericarpathian lineament cuts across individual nappes in the Polish Carpathians and its surface projection occurs according to place at various points of the Carpathian flysch nappes (fig. 1).

[6] The term „Pericarpathian lineament" was used to stress its peripheral situation in relation to the Carpathian geosyncline basement (see below). The present situation of the lineament inside the Carpathians (fig. 1) is a result of the fact that erosion of flysch nappes on the Metacarpathian block has not proceeded too far yet. In case of erosional truncation of the farther 6—8 kilometers of the flysch, the Pericarpathian lineament will mark out, more or less precisely, the boundary between the Carpathians and their foreland; It will then be peripheral in relation to the Carpathian orogen.

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Fig. 2. Moho discontinuity in the Carpathians. A — recent situation along the geophysical profile V (acc. to Uchman, 1973): 1 — Moho discontinuity; 2 — upper mantle; I — Metacarpathian block; II — Carpathian block; III — Transcarpathian block; α — Pericarpathian lineament; β — Peripieniny lineament. B — hipothetical situation after the subherzynian phase (Upper Createceous): 1 — sea level, 2 — Moho discontinuity; 3 — upper mantle; I_0 — Metacarpathian block (Early Metacarpathian); II_0 — Early Carpathian block (partial geosyncline of the Outer Carpathians); III_0 — Early Transcarpathian block (Central Carpathian land); α_0 — Early Pericarpathians lineament; β_0 — Early Peripieniny lineament; SK — Silesian cordilliera

Fig. 2. Zmiana położenia granicy Moho w Karpatach. A — Położenie współczesne na profilu nr V (wg Uchmana, 1973): 1 — granica Moho; 2 — górny płaszcz; I — blok metakarpacki; II — blok karpacki; III — blok zakarpacki; α — rozłam perykarpacki; β — rozłam perypieniński; B — hipotetyczne położenie po fazie subhercyńskiej (górna kreda): 1 — poziom morza; 2 — granica Moho; 3 — górny płaszcz; I_0 — blok metakarpacki (starometakarpacki); II_0 — blok starokarpacki (cząstkowa geosynklina Karpat zewnętrznych); III_0 — blok starozakarpacki (ląd Karpat wewnętrznych); α_0 — rozłam staroperykarpacki; β_0 — rozłam staroperypieniński; SK — kordyliera śląska

In profile III, which crosses the Ukrainian Carpathians, the extent of „vertical displacement" of the Pericarpathian lineament is about 12 kilometres (fig. 2). The situation shown by the authors of comprehensive works (V. B. Sollogub et al., 1970) is not so simple as in profile V. Two lineaments that join together in their lower part at the Moho discontinuity are shown there. The lineaments are bent northward and the surface projection of the southern branch occurs, more or less, at the boundary between the Sambor and the Pokucie-Borysław zones. The southern branch of the lineament corresponds probably to the Borysław lineament (abyssal fracture), distinguished by M. S. Jaryš, N. J. Turčanenko and C. B. Zajac (1973).

The surface projection of the northern branch occurs at the boundary between the East-European platform and the outer part of the Carpathian Foredeep, founded on the platform basement.

In profile III another deep lineament occurs south of the southern branch of the Pericarpathian lineament. South of the lineament the Moho discontinuity rises from 65 kilometres in depth to about 55 kilometres. It is possible that this lineament encloses the zone of the Borysław—Pokucie folds from the south (the inner zone of the Foredeep founded on the geosynclinal basement). Those folds probably end in the Polish East Carpathians and, in consequence, the lineament mentioned above also disappears; therefore it cannot be observed either in profile V or in profile VI.

In profile VI, which cuts the NW end of the Vienna Basin, the difference in situation of the Moho discontinuity is very small. In this profile the surface projection of the Pericarpathian lineament occurs in the southern part of the Magura nappe, with molasse deposits of the Vienna Basin superimposed on it.

It is easy to see that the Pericarpathian lineament forms an arc of smaller radius than the arc that constitutes the erosional margin of the Carpathian flysch. It is one of the reasons why flysch nappes, founded on the platform basement, are torn up into isolated blocks that are compensated both in the longitudinal and the cross-sections (L. Koszarski, W. Sikora in press). Finally, the line of the Pericarpathian lineament establishes the boundary, north of which flysch nappes are certainly not rooted.

THE COURSE OF THE PERIPIENINY LINEAMENT

Another regional deep lineament has been found thanks to international seismic soundings. In surface projection in profiles III and V it appears in the Pieniny Klippen Belt, while in profile VI in the northern slope of the Male Karpaty (V. B. Sollogub et al., 1970). This regional lineament is not genetically connected with the Pieniny Klippen Belt exclusively, since in profile VI its situation is projected on a surface of about 20 kilometres south of the Pieniny Klippen Belt. Therefore, at a certain distance this lineament also cuts across alpine structures of the Central Carpathians. It is possible that the unusual widening up to over 20 kilometres of the Pieniny Klippen Belt in the Vàh Valley in Czechoslovakia is connected with recession southward of the Peripieniny lineament, in relation to the Pieniny Klippen Belt.

The greatest extent of „vertical displacement" of the Moho discontinuity can be observed in profile III. It reaches here more than 20 kilometres while, at the same time, the „hanging wall" represents the region south of the lineament, called the Transcarpathian one by Soviet geologists (V. V. Gluško, S. S. Kruglov et al., 1971). In profile VI, similarly as in the Pericarpathian lineament, the extent of „displacement" is small and difficult to read. In any case, it does not exceed 5 kilometres.

THE METACARPATHIAN, CARPATHIAN AND TRANSCARPATHIAN BLOCKS

In cross-section, the lithosphere of the Ukrainian, Polish and Czechoslovakian Carpathians, as well as of their close foreland, is divided by two deep lineaments; the Pericarpathian and the Peripieniny ones into there main blocks.

a) I suggest the name „Metacarpathian block" to the region north of the Pericarpathian lineament, corresponding to the area of the foredeep situated on the platform basement (cf. W. Sikora, 1973). Thickness of the Earth's crust in this block in profile III is about 52 kilometres; in profile V — about 40 kilometres; in profile VI — 33—35 kilometres.

b) I suggest the name „Carpathian block" to the region between the Pericarpathian lineament and the Peripieniny one. Thickness of the Earth's crust in profile III is from 55 to 65 kilometres; in profile V — about 50 kilometres; in profile VI — about 35 kilometres.

c) I suggest the name „Transcarpathian [7] block" to the region south of the Peripieniny lineament. A very small thickness of the Earth's crust is a characteristic feature of this block. In profile III it is about 25 kilometres; in profile V — from 25 to 35 kilometres; in profile VI — from 28 to 30 kilometres.

The Carpathian block that represents the root of the Carpathian orogen is shaped like a wedge, narrowing westward. At the same time

[7] This name is connected with the region of the Ukrainian Carpathians, where the „displacement" of the Peripieniny Lineament is over 20 kilometres and where the „upthrown side" (Transcarpathian block) does not belong, in the geographical sense, to the Carpathians; compare: „Transcarpathian Russia", „Transcarpathian depression", „Transcarpathian lineament" (in the region of the Ukrainian Carpathians — the Peripieniny lineament).

the thickness of the Earth's crust diminishes constantly from east to west, from 65 kilometres in profile III to about 35 kilometres in profile VI.

The same tendencies can be observed in the Metacarpathian block. The thickness of the Earth's crust diminishes here from 52 kilometres in profile III, through 40 kilometres in profile V, to 33 kilometres in profile VI. On the other hand, a contrary tendency can be observed in the Transcarpathian block, where the thickness of the Earth's crust in profiles V and VI is from 28 to 35 kilometres, while in profile III — about 25 kilometres. It implies that, in general, the Earth's crust thickness diminishes in a west-east direction, which is contrary to the direction found in the Metacarpathian and the Carpathian blocks. If purely mechanical criteria concerning the origin of the Peripieniny lineament were used, we would then have to do with a *„sui generis"*, pivotal lineament.

In the case of the Carpathian and the Metacarpathian blocks the thicker the Earth's crust is, the deeper the top of the granito-metamorphic layer (consolidated basement) occurs. In the Ukrainian Carpathians and in the eastern part of the Polish Carpathians the basement is located much deeper than in the western part of the Polish Carpathians and in the Czechoslovakian Carpathians; it had already been recognized by J. Smoleński in 1919.

It seems necessary to regard also abyssal transversal fractures as alpine structures to give even the most general characteristics of individual blocks. Unfortunately, a valid longitudinal profile of deep seismic soundings has been lacking, so far; it does not allow an immediate recognition of such transversal lineaments. There are, however, intermediate data allowing a conclusion that in the Carpathians there occur transversal lineaments whose roots reach the Earth's upper mantle.

Thanks to deep seismic soundings in the Carpathians, there is not doubt now that the regional gravimetric minimum results partly from great thickness of the Earth's crust under the Carpathian block and also, possibly, from a specific structure of the Earth's upper mantle under it (also cf. A. V. Čekunov, 1972). It can be assumed then that great disturbances in the course of axis of the gravimetric minimum in the Carpathians are reflected in irregularities of structure in the Earth's crust and its upper mantle. Thus the disjunction of axis of the minimum (shown in fig. 1 as a deflexion of the Pericarpathian lineament) lying, more or less, at the meridians of a) Przemyśl, b) Sanok, c) Gorlice, d) Żywiec probably correspond to abyssal transversal fractures whose roots reach below the Moho discontinuity.

It is not unlikely that the deep transversal lineaments also took a great part in formation of the Vienna Basin, superimposed on the Carpathians. They may also be the cause of the fact in profile VI such sharp hypsometric contrasts of the Moho discontinuity on both sides of the Pericarpathian and the Peripieniny lineaments cannot be observed.

REFLECTION OF ABYSSAL FRACTURES IN THE GEOLOGICAL SURFACE STRUCTURE AND THEIR CONNECTION WITH LATE OROGENIC VULCANISM AND EARTHQUAKES

The connection of deep lineaments with post-orogenic depressions seems unquestionable today (V. E. Chain, 1973). Relatively large depressions, i.e. the Nowy Sącz depression and the Orawa—Nowy Targ one (fig. 1) were formed along the Pericarpathian lineament. Their formation was probably also conditioned by the fact that in the zone where they occur the Pericarpathian lineament and the Peripieniny one approach each other very closely. It resulted in weakening of the Earth's crust in this area and in formation of intermontane depressions. It is interesting to observe that the two lineaments approach each other most closely at the same meridian as the biggest narrowing of the foredeep in front of the flysch Carpathians takes place. This fact may suggest that the two phenomena are genetically related.

South of the Pericarpathian lineament thrust planes of individual tectonic units are steeper than in the region north of the lineament. Along the Pericarpathian lineament an abrupt upheaval of thrust planes of higher units onto lower ones can be observed; today it is marked by the presence of tectonic promontories and outliers (K. Żytko, 1965). Since the Pericarpathian lineament cuts transversaly individual Carpathian nappes, the structure of flysch masses in the Polish East Carpathians differs from the tectonics in the West Carpathians. The majority of flysch masses in the East Carpathians belong to the Carpathian block and they are founded on a deeply sunken basement, while nappes in the West Carpathians belong mostly to the Metacarpathian block and are overthrust upon relatively shallowy situated formations of the foredeep. A short characteristic of the structure of flysch rocks located north and south of the Pericarpathian lineament is quoted after L. Koszarski and W. Sikora (in press): „Flysch rocks over the Carpathian block, especially in the tectonic depression of the eastern part of the Silesian unit, called the Central Carpathian Depression, appear in the form of folds running at a distance of tens of kilometres. This relatively monotonous structure is apparent, however, since detailed surface examinations and drillings showed that the majority of antyclines that display recumbent limbs on the surface are undercut by thrust planes. The latter form deeply rooted scales (overthrust folds). Such an arrangement of folds can be also found in that part of the Skole unit that lies south of the Pericarpathian lineament (the Ukrainian Carpathians). Flysch nappes located over the Metacarpathian block, which can be easily seen in the Czechoslovakian Carpathians and in the Polish West Carpathians, are disrupted and torn up to plates by transversal and longitudinal faults (overthrusts). In this way individual parts of nappes appear in the form of detached blocks, separated from one another by formations belonging to over- or underlying flysch units".

It is not unlikely that formation of the very narrow Pieniny Klippen Belt at a long distance (the Polish, East Slovakian and Ukrainian Carpathians) should be connected with the fact that at the very distance the course of the Klippen Belt is in line with that of the Peripieniny lineament. The width of the Klippen Belt increases and may exceed 20 kilometres in the Vàh Valley, where the Peripieniny lineament „escapes" southward into the region of the Central Carpathians. The Peripieniny lineament is also marked by the postorogenic depressions of Ilava, Trenčin and Orawa—Nowy Targ (fig. 1).

Undoubtedly, there must be a relation between vulcanism and abyssal fractures whose roots reach to the Earth's mantle. According to recent theories (A. E. R i n g w o o d, 1972), focuses of the andesite vulcanism, so characteristic of the late orogenic vulcanism in the Carpathians, were situated below the Earth's crust, in the mantle. Effusions of lava are concentrated in some places only along the Pericarpathian lineament. It allows an assumption that those effusions reached the Earth's surface in certain privileged zones, especially there where subcrustal abyssal fructures cross one another. We can assume then that there exist deep subcrustial transversal lineaments along the lines: Bańska Bystrica—Zazriva—Żywiec; Prešov—Gorlice; Vihorlat—Sanok, and Mukačevo—Przemyśl (fig. 1), despite the fact that, so far, they have not been proved by means of deep seismic soundings. The already mentioned disruptions and disturbances of axis of the Carpathian gravimetric minimum are located along those lines. All the evidence points to the fact that those phenomena are genetically related. It also allows a supposition that the „disruptions" of axis of the gravimetric minimum are accompanied by intrusions connected with late orogenic vulcanism. The latter are, however, hidden deeply under the flysch cover.

It is not unlikely that the zone of intrusions in the sedimentary layer of the crust runs along the Peripieniny lineament and manifest at those places where vulcanites occur on the surface.

It seems that the relation between earthquakes and lineaments, as well as zones of tectonosphaere disturbances of the Benioff type has been altogether proved (L. R. S y k e s, 1972). J. K. Š č u k i n and J. B. D o b r e v (1973) presented an analysis of relationships between deep lineaments and hypocentres of earthquakes in the East and South Carpathians. In the East Carpathians the epicentres of earthquakes are visibly concentrated along Peripieniny lineament. According to Ščukin and Dobrev's analysis, these hypocentres are located in the Earth's crust. The remaining hypocentres in the East and South Carpathians and in the Balkans do not leave the Earth's crust either, except for the Vrancea region where subcrustal hypocentres were found at a depth of 100—200 kilometres.

Unlike in the Peripieniny lineament, in the Pericarpathian one of the East Carpathians the linear arrangement of epicentres of earthquakes is only slightly marked there (J. K. Ščukin, T. B. Dobrev, 1973). They are also of a much smaller intensity than those along the Peripieniny lineament, which is a discriminating feature in the two lineaments.

The Peripieniny lineament was also discovered and confirmed by means of geoelectromagnetic methode (A. J. Bondarenko et al., 1972). There appears an anomaly in variations of the geomagnetic field in the area of this lineament. According to the authors of the paper mentioned above, the area of the Peripieniny lineament represents a zone of higher conductivity. In such an area inductive currents should concentrate and anomalies in variations of the geomagnetic field should occur. The Pericarpathian lineament lacks this characteristic, and it is also one of the main discriminating features in the two lineaments, i.e. the Peripieniny lineament and the Pericarpathian one.

THE PERIPIENINY LINEAMENT AND THE PROBLEM OF EARLY ALPINE DEEP LINEAMENTS

The term „Peripieniny Lineament" was introduced to the geological bibliography by M. Maška and V. Zoubek (1960). They assumed that the lineament was founded in Precambrian; it was to separate two different geotectonic and petrographic provinces. The opinion that there must have existed a deep lineament along the Pieniny Klippen Belt was shared, supported, and developed by Soviet geologists (K. M. Łaźko, D. P. Rezvoj, 1962; S. S. Kruglov, S. J. Smirnov, 1967; V. V. Gluško, S. S. Kruglov et al., 1971). All the same, specific data justifying the Precambrian age (M. Maška and V. Zoubek, 1960), or a not precisely defined pre-Jurassic period (V. V. Gluško, S. S. Kruglov et al., 1970) of formation of the lineament are absent in all these analyses. A short, critical evaluation of these opinions was given by M. Książkiewicz, 1972); he wrote at the conclusion of his paper (p. 110): „The course of the Klippen Belt is parallel to the course of the Carpathian arc. There is no evidence to claim that this course is a reflection of some old structural lines, and not a product of alpine orogeny. It is groundless to claim, either, that along the Klippen Belt there existed a dislocation in the basement before alpine orogeny".

It should be also added here that, for example, in the Polish West Carpathians all regional structural lines in the Carpathian basement of the platform type reach the Pericarpathian lineament at a considerable angle, while their extension reaches, at a similar angle, the Peripieniny lineament. It happens even in the case of such an old line as the structural suture that separates from the east the Precambrian Cieszyn Plate from the Kraków zone of Hercynian foldings, superimposed on the Caledonian ones (L. Koszarski, W. Sikora in press). Therefore, the prealpine structures in the West Carpathian Foreland as well, as in their platform basement, run in an entirely different direction (generally speaking, NW—SE) than the Peripieniny and the Pericarpathian lineaments; the latter extend in the NE—SW direction in this part of the Carpathians.

There is no foundation for accepting the opinion that in the region where the Carpathian flysch geosyncline was later founded, the Caledonian or the Hercynian directions should have been different from those that can be observed today in the Carpathian Foreland (W. Sikora, 1971b).

The Peripieniny lineament runs in the alpine direction and its extent agrees with the extent of folds occurring on the surface; therefore it should be accepted that the Peripieniny lineament dates back to a period not older than the alpine one.

The Central Carpathians underwent folding and orogenic movements for the first time in the Subhercynian phase (M. Książkiewicz, 1972; T. Buday, M. Mahel et al., 1968). At that time the geosyncline disappeared completely. The process of transformation of the geosyncline into orogen is connected with thickening of the Earth's crust — formation of the orogen roots (J. H. F. Umbgrove, 1947, see also A. Heim: Geologie der Schweiz, Leipzig 1919/1922). Such roots should have been formed under the central Carpathians as result of their folding and uplifting. At that time, i.e. in Upper Cretaceous, the thickness of the Earth's crust under uplifted Central Carpathians should have exceeded the average, characteristic of the continents, which is 40 kilometres (V. E. Chain, 1973). On the other hand, the geosyncline of the flysch Carpathians was existed and developed north of the Central Carpathian land. Under it, the Earth's crust should have been thinner at that time than its average thickness. If we assumed, after L. Koszarski and K. Żytko (1965), that in Upper Cretaceous troughs of the flysch geosyncline reached a depth of 5000 metres, we should accept the view that the Earth's crust under the flysch sea had a very small thickness. It should then be of a suboceanic or subcontinental character.

It is not unlikely that the two different types of the Earth's crust were in contact with each other along a deep lineament or along a zone of deep lineaments. Such a zone of deep lineaments at the boundary of the Outer and Central Carpathians in Upper Cretaceous is assumed by M. Książkiewicz (1963, 1972).

It should be accepted, on the analogy of the above reasoning, that the thinned crust under the flysch sea adjoined the Earth's crust of a much greater thickness from the north. The latter was finally formed during the Caledonian and Hercynian orogeny, or even earlier — in the case of pre-Cambrian blocks. We can thus conclude that the partial geosyncline of the flysch Carpathians was limited from the north by a deep lineament which acted as a border lineament [8] in this case.

Another problem should be now considered — whether the two lineaments, occurring in Upper Cretaceous (the initial stage of formation of these lineaments should be connected with the beginning of the Carpathian geosyncline and thus with Triassic), could be identified with the Pericarpathian lineament and the Peripieniny one, recently recorded by geophysical methods. I suggest to call the former lineaments the Early Pericarpathian and the Early Peripieniny ones. Two basic groups of facts and data seem to speak against such an identification.

1) The Early Peripieniny lineament in Upper Cretaceous had the Earth's crust thicker (root) than the average in the southern limb, and thinner in the northern one (fig. 2b). It is contrary to the recent Peripieniny lineament, where the Earth's crust is thinner that the average in the southern limb and thicker (the recent root of the orogen) in the northern one (fig. 2A). If we accepted orogenic theories of fixism, these data would allow us to identify the Early Peripieniny lineament with the Peripieniny one. It should only be accepted then that the direction of phased and chemical changes at the boundary: the Earth's Upper mantle — the Earth's crust had a reverse symbol in the Transcarpathian and Carpathian blocks in Upper Cretaceous. In Upper Cretaceous physico-chemical processes caused thickening of the Earth's crust in the Transcarpathian block and its thinning in the Carpathian one. Today these processes take an opposite direction.

The whole thing becomes much more complicated when we consider the great shortening of basement of the Carpathian geosyncline.

2) At the meridian of Kraków the distance between the Pericarpathian and the Peripieniny lineaments is about 15 kilometres. On the other hand, it can be accepted that the width of partial flysch geosyncline in Upper Cretaceous was about 400 kilometres. H. Świdziński (1971) specified the minimum width after straightening of folds and nappes in the West Carpathians: it is about 120 kilometres. If we add to it a 40 kilometres overthrust „en bloc" of the Carpathians on their foreland that can be observed in the Kraków—Zakopane cross-section, we get a value of about 160 kilometres. Still twice as much should be added to it to cover the straightening of nappes of the Pieniny Klippen Belt, as well as the cordilleras. The latter, together with a part of surrounding flysch deeps, were downsucked far into the Earth's mantle (see below). Summing up, we get a value of about 300 kilometres. Recently some Soviet geologists

[8] Some geotectonic conceptions assume that geosynclines were in contact with surrounding platform areas by means of abyssal fractures (V. E. Chain, 1973).

considered the width of the flysch sea to be 500 kilometres (V. N. Utrobin, 1973). I have accepted the mean value of about 400 kilometres for the estimates presented below. The same value should be also accepted in the case of the distance occurring in Upper Cretaceous between the Early Pericarpathian lineament and the Early Peripieniny one in that part of geosyncline that corresponded to the Polish West Outer Carpathians. The two pairs of lineaments, i.e. the Early Peripieniny — the Early Pericarpathian and the Peripieniny the Pericarpathian, cannot be identified with each other. They take a different position in space and as far as time is concerned, they differ from each other in the period of shortening of the geosyncline and its transformation into orogen. The mechanism of this process has not been fully investigated, so far; therefore it has been left out in the present paper. It comes out of the very fact of great shortening of the partial geosyncline of the Outer Carpathian that identification of the two pairs of lineaments, described above, is impossible. Moreover, comparing the two values, i.e. 400 and 15 kilometres, we get the value of basement shortening of the partial geosyncline of the Outer Carpathians. This shortening can be expressed by the fraction 400/15, which gives a value of a 26-time shortening (W. Sikora, 1973; L. Koszarski, W. Sikora in press). The value of the shortening diminishes eastward, as the Carpathian block widens; still it is an enormous shortening if the whole course of the Carpathian block is considered (fig. 2).

The above reasoning points out to the fact that the Early Pericarpathian and Early Peripieniny lineaments cannot be identified with the Pericarpathian and Peripieniny ones. They take a different position in space and in time.

THE PROBLEM OF ALPINE METAMORPHISM

The great shortening of sedimentary layer basement in the Carpathian block (at least 10 times in profile V) must have resulted in the physical-chemical rebuilding of this basement. The highest part of the upper mantle was transformed into a basaltic layer; it is reflected in a very low position of the Moho discontinuity in the Carpathian block, when compared with its higher situation during the existence of the geosyncline, as well as before its foundation (fig. 2B).

It is difficult to evaluate the relationship between the granito-metamorphic layer and the basaltic one, since the Conrad discontinuity in the Carpathians, except the Ukrainian Carpathians, is very poorly outlined (Sollogub et al., 1970). Considering the bitumen exploration in the Carpathians, it is very important to find out by what is represented the upper part of the granito-metamorphic layer in the Carpathian block.

It can be seen from theoretical data that heat flow that reaches the surface is two or three times higher than the normal in the orogenic period (the period when the geosyncline disappeared and was transformed into orogen) (A. Ritman, 1966). Theoretical curves of the increase of heat flow in the Ukrainian Carpathians during the orogeny are presented in figure 3. The increased heat production in the period when the Carpathian orogen was formed must have caused the thermo-regional metamorphism of sedimentary rocks of the Carpathian geosyncline. Those rocks were downsucked inside the orogen (Figs. 4 and 5).

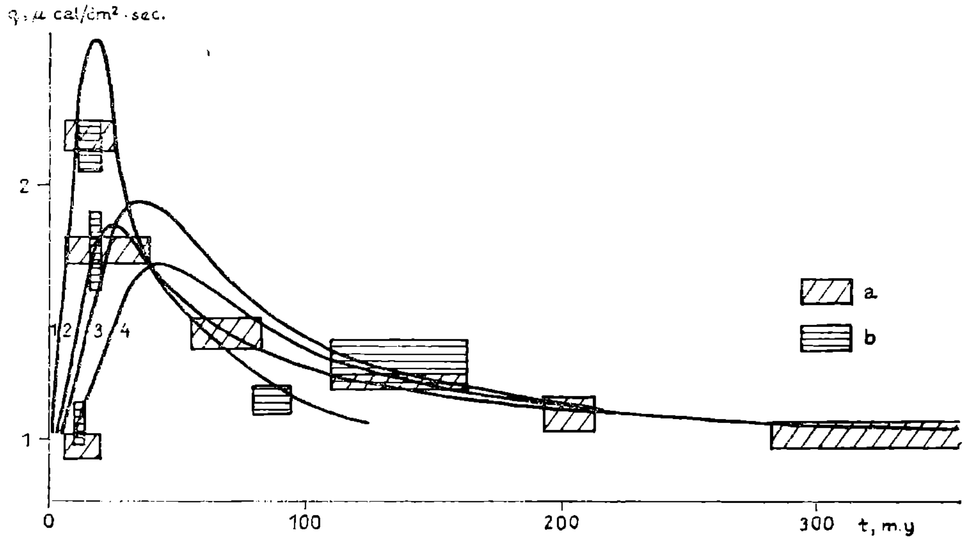

Fig. 3. Heat flow and age of folding (acc. to Kutas and Gordienko, 1972). Observed values of heat flow: a — mondial mean; b — in the Ukrainian SSR. Theoretical curves are constructed accepting the following parameters of additional heat source (numbers on the sketch): 1—2: time span of activity of source $= 30 \cdot 10^6$ yrs, intensity $Q = 1{,}3 \cdot 10^{-12}$ cal/ccm.s, depth h = respectively 25 and 45 kms; 3—4: time span $= 50 \cdot 10^6$ yrs, $Q = 0{,}9 \cdot 10^{-12}$ cal/ccm.s, h = 40 and 60 kms

Fig. 3. Zależność potoku cieplnego od wieku fałdowania (wg Kutas i Gordienko, 1972). Obserwowane wartości potoku cieplnego: a — średnia światowa; b — na obszarze Ukraińskiej SSR. Teoretyczne krzywe otrzymano przy następujących parametrach dodatkowego generatora ciepła (liczby na schemacie): 1—2: czas działalności generatora = 30 milionów lat, jego intensywność $Q = 1{,}3 \cdot 10^{-12}$ kal/cm³. s, głębokość występowania h = odpowiednio 25 i 40 km; 3—4: $\tau = 50$ milionów lat, $Q = 0{,}9 \cdot 10^{-12}$ kal/cm³ · s, h = 40 i 60 km

It is not unlikely that the Carpathian block is a place where, on the one hand, cordilleras together with the adjoining flysch deeps were downsucked (also see E. Kraus, 1942; M. Książkiewicz 1972; V. N. Utrobin, 1973); on the other hand, it is a place where the majority of nappes of the flysch North Carpathians were rooted. After downsucking, the sedimentary cover of cordilleras, as well as their crystalline cores, must have been metamorphosed and became components of the new alpine granitic and basaltic layer. Also root of the flysch nappes should have equally metamorphosed (Figs. 4 and 5).

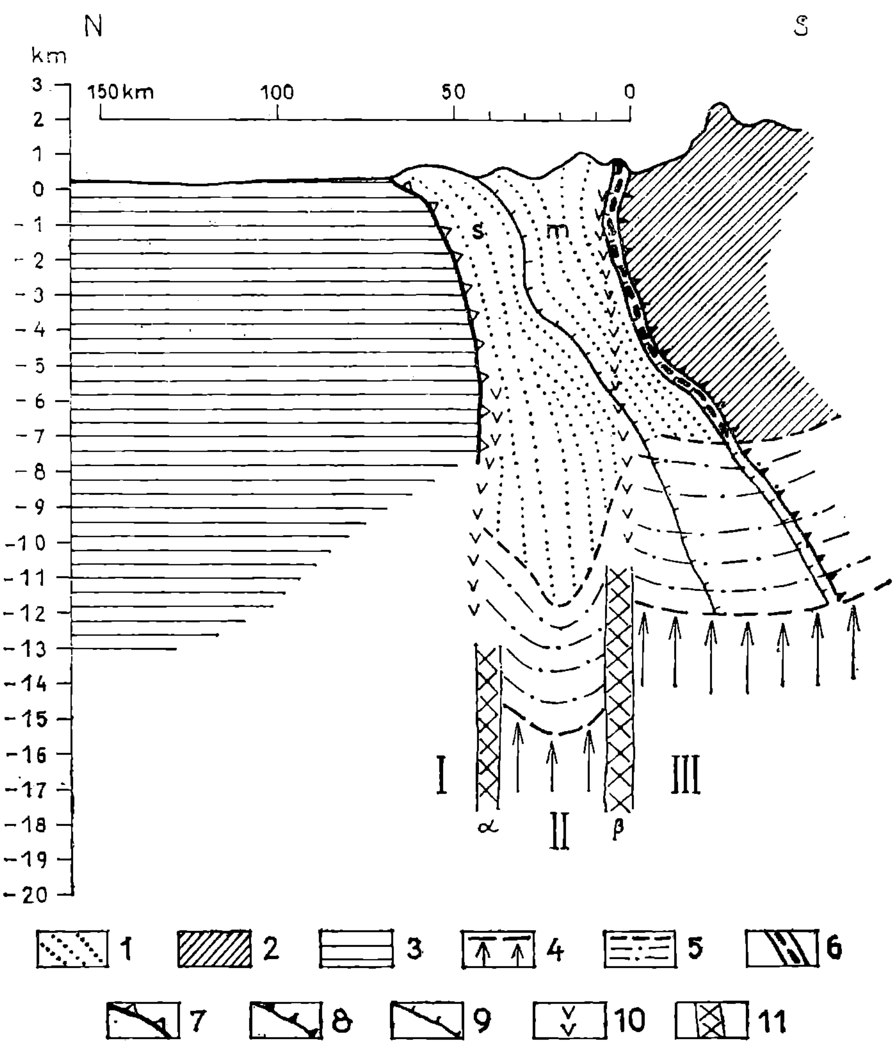

Fig. 4. Geological interpretation of geophysical profile V (vertical scale exagerated). 1 — flysch of Outer Carpathians; 2 — Central Carpathians; 3 — Carpathian foreland; 4 — supposed position of the top of green schist facies; 5 — supposed position of the anchimetamorphosed flysch; 6 — Pieniny Klippen Belt; 7 — Outer Carpathian overthrust; 8 — Central Carpathian overthrust; 9 — overthrusts of the Outer Carpathian units; 10 — magma channels; 11 — lineaments; 1 — Metacarpathian block; II — Carpathian block; III — Transcarpathian block; α — Pericarpathian lineament; β — Peripieniny lineament; s — Skole, Subsilesian, Silesian and Fore-Magura units; m — Magura unit

Fig. 4. Geologiczna interpretacja profilu nr V (skala pionowa przewyższona). 1 — flisz Karpat zewnętrznych; 2 — Karpaty wewnętrzne; 3 — przedpole Karpat; 4 — przypuszczalne położenie stropu facji zieleńcowej; 5 — przypuszczalna pozycja anchimetamorficznie zmienionego fliszu; 6 — pieniński pas skałkowy; 7 — płaszczyzna nasunięcia Karpat fliszowych na przedpole; 8 — płaszczyzna nasunięcia Karpat wewnętrznych; 9 — płaszczyzny nasunięć jednostek Karpat zewnętrznych; 10 — kanały doprowadzające magmę andezytową i bazaltową; 11 — wgłębne rozłamy; I — blok metakarpacki; II — blok karpacki; III — blok zakarpacki; α — rozłam perykarpacki; β — rozłam perypieniński; s — jednostka skolska, podśląska, śląska i jednostki przedmagurskie; m — jednostka magurska

The following data confirm the possibility of existence of metamorphosed rocks of the alpine cycle in the Carpathians:

1) Examples of alpine metamorphism, of which the youngest is 35—40 million years (E. Niggly, 1972). They were found in the Alps (in surface

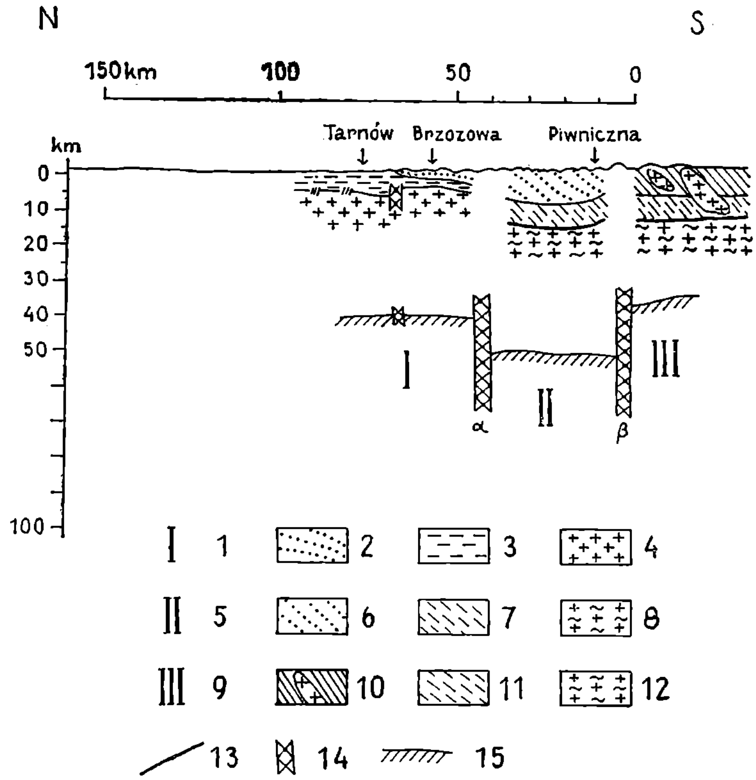

Fig. 5. Geological interpretation of the geophysical profile V (horizontal scale equals the vertical one). 1 — Metacarpathian block; 2 — Outer Carpathian nappes (flysch, Cretaceous — Oligocene); 3 — sedimentary rocks of the Carpathian foreland (Cambrian to Cretaceous and Miocene molasses); 4 — consolidated basement (Rhyphean); 5 — Carpathian block; 6 — Outer Carpathian nappes; 7 — zone of alpine anchimetamorphism („very low stage"); 8 — consolidate basement (zone of „low stage" metamorphism, chiefly metamorphosed flysch of the Outer Carpathians; 9 — Transcarpathian block; 10 — Central Carpathian nappes with allochthonous cristalline cores; 11 — Central Carpathian nappes with cristalline cores (zone of alpine anchimetamorphism); 12 — consolidated basement (zone of „low stage" metamorphism, chiefly metamorphosed rocks of Central Carpathian nappes); 13 — top of the granitometamorphic layer (position in Metacarpathian block acc. to Uchman, 1973); 14 — lineaments, α — Pericarpathian lineament, β — Peripieniny lineament; 15 — Moho discontinuity

Fig. 5. Geologiczna interpretacja profilu V (skala pionowa nieprzewyższona). 1 — blok metakarpacki; 2 — płaszczowiny Karpat zewnętrznych (flisz, kreda — oligocen); 3 — utwory osadowe przedpola Karpat (kambr — kreda i mioceńskie molasy); 4 — skonsolidowane podłoże (ryfej); 5 — blok karpacki; 6 — płaszczowiny Karpat zewnętrznych; 7 — strefa anchimetamorfizmu alpejskiego („very low stage"); 8 — skonsolidowane podłoże („low stage", głównie zmetamorfizowany flisz Karpat zewnętrznych); 9 — blok zakarpacki; 10 — płaszczowiny Karpat wewnętrznych z allochtonicznymi jądrami krystalicznymi; 11 — płaszczowiny Karpat wewnętrznych z allochtonicznymi jądrami krystalicznymi (strefa anchimetamorfizmu alpejskiego); 12 — skonsolidowane podłoże (strefa niskiego metamorfizmu — „low stage", głównie zmetamorfizowane utwory płaszczowin Karpat wewnętrznych); 13 — górna granica warstwy granitowo-metamorficznej (położenie w bloku metakarpackim wg Uchmana, 1973); 14 — wgłębne rozłamy, α — rozłam perykarpacki, β — rozłam perypieniński; 15 — granica Moho

conditions), therefore in the orogen whose development resembles that of the Carpathians.

2) On the basis of paleotemperature analysis an additional source of heat was found in the Carpathians. It became active 40—45 million

years ago, in a period on the turn of Eocene and Oligocene (R. J. K u t a s, V. V. G o r d i e n k o, 1972).

The additional source of heat caused rising of geotherms in the Carpathian block, as well as in the Transcarpathian one. That process resulted in thermo-regional metamorphism of root parts of nappes in the Outer Carpathians. The theoretical evaluations (R. J. K u t a s, V. V. G o r d i e n k o, op. cit.) point to the fact that on the turn of Miocene and Pliocene a temperature of about 250—300°C was found at a depth of 10—12 kilometres in the Carpathian block. According to H. G. F. W i n k l e r (1970), it is the temperature at which anchimetamorphic process („very low stage") take place. At a depth of 14—16 kilometres, however, at that period, i.e. on the turn of Miocene and Pliocene, there was a temperature of about 400°C, i.e. the temperature at which green schist metamorphic facies („low stage") is formed. It can then be assumed that at a depth of 14—16 kilometres in the Carpathian block there runs an upper boundary of the „consolidated basement" of the Carpathian flysch (Figs. 4 and 5). Unlike in the Metacarpathian block where the „consolidated basement" has been proved to be of Precambrian, Rhyphean, Caledonian or Hercynian age (J. Z n o s k o, 1966; W. P o ż a r y s k i, 1973) by means of deep drillings, in the Carpathian block the metamorphosis of rocks appear to occur in the alpine cycle. The formation of granitic plutons is closely connected with the alpine metamorphism in the Carpathians. A. G a n s s e r (1973), in his deep cross-section of the Alps, places Pliocene granitic plutons already at a depth of about 15 kilometres. It is not unlikely that alpine granitic plutons can be also found not so far from the surface both in the Carpathian and Transcarpathian blocks. In plutonic contact zones the downsucked flysch could undergo a higher stage of metamorphism than the „low stage". If the supposed plutons were big enough, the boundary of green schist facies, as well as the corresponding boundaries of other facies, could have a higher hypsometric location than 14—16 kilometres in some sections of the Carpathian block.

The above reasoning points to the fact that the „consolidated basement" in the Carpathian block, observed by means of geophysical refractive methods (A. Ś l ą c z k a, 1970; G. B o j d y s et al., 1973), may represent the zone of anchimetamorphic flysch, as well as that of green schists that originated from flysch, at boundary velocities of about 6 kilometres per second, since the boundary velocities for the both types of rocks are practically equal at a depth of below 8000 metres (J. S k o r u p a, 1973).

Rising of the surface of the „consolidated basement" south of the axis of gravimetric minimum can be related with local thermal metamorphism that undoubtedly took place on the margin of the Peripieniny lineament.

The latter made way, among others, for magmas of the subsequent vulcanism (Fig. 4 and 5).

THE AGE OF LINEAMENTS

Since the nature of deep lineaments, as well as their relationship with other surfacial phenomena are not very clear yet, the estimation of age of the Pericarpathian and the Peripieniny lineaments must be highly hypothetical.

That type of deep lineaments that were discovered in the Carpathians, had been formed as a result of a slightly different character and intensity of physico-chemical processes on both sides of the lineament. These processes resulted in an increased or decreased thickness of the crust; in consequence the Moho discontinuity took a higher or lower position in relation to the surface.

It has been proved by means of experiments that gabbro (basalt) can be transformed, into garnet — granulite and finally into eclogite (D. H. Green, A. E. Ringwood, 1972), of which the Earth's upper mantle may be built (G. C. Kennedy, K. Ito, 1972), at least under the continents (W. E. Chain, 1973). Still, a reverse process is possible, as well. The former one makes the lithosphere volume decrease by 10—12%, and the Earth's surface lower (formation of depressions). The other process makes the Earth's crust thicken and, in consequence, it makes the Earth's surface upheave (W. E. Chain, 1973). In both cases there must be a change of hypsometric location of the Moho discontinuity to a new position, higher or lower in relation to the original one. The diversified volume changes of lower parts of the Earth's crust should result in mechanical strains in upper parts of the crust. They should also be released by means of mechanical dislocations which, as in the case of the Peripieniny lineament, made way for raising basaltic magma from reservoirs in the Earth's upper mantle to the surface (V. V. Gluško, S. S. Kruglov, 1971; R. J. Kutas, V. V. Gordienko, 1972).

In the case of the Carpathians the difference in hypsometric location of the Moho discontinuity in the Metacarpathian, Carpathian and Transcarpathian blocks should be related with the formation of a Neogene „root" of the Earth's crust in the Carpathian block, also with the disappearance of hypothetical Subhercynian „root", and then with additional thinning of the Earth's crust in the Transcarpathian block.

The formation of the „root" under the Carpathian block was presumably a sustained process; all the same, the essential acceleration of the process could not have occurred before cordilleras of the Carpathian sea had been downsucked inside the mantle, or before an additional source of heat had become active. Since the process of waning of cordillera activity took place during Upper Oligocene (S. Dżułyński, A. Ślączka, 1958), and the beginning of activity of the additional source of heat in the Carpathians happened at the turn of Eocene and Oligocene [9] (R. J. Kutas, V. V. Gordienko, 1972), it can be concluded that intensive formation of the lineament started in Oligocene. R. J. Kutas, V. V. Gordienko are of the opinion that the Peripieniny lineament was formed only in the phase, when first volcanic eruptions connected with the lineament took place. It may be assumed however, that the appearence of rhyolite vulcanism in Burdigalian (T. Buday, M. Mahel et al., 1968) evidences not exactly the beginning of lineament formation but „reaching" the granito-metamorphic layer by the lineament during its „journey upwards".

The second, younger phase of acceleration of the Peripieniny abyssal fracture formation in the Carpathians took place in Sarmatian-Pliocene. The following data give evidence to that fact: the main phase of formation of intermontane depressions connected with the Peripieniny lineament, i.e. the depressions of Trenčin, Ilava and Orawa—Nowy Targ, took place in Sarmatian-Pliocene. The main phase of subsequent vulcanism in the Carpathians [10] also occurred in the same period (T. Buday, M. Mahel et al., 1968; V. V. Gluško, S. S. Kruglov, 1971).

Apart from that, the studies done by Kutas and Gordienko (1972) point to the fact that since, more or less, the Middle Miocene the heat flow had been more intensive in the Transcarpathian block than in the Carpathian one. It may give evidence to the fact that the process of formation of the Earth's crust on both sides of the Peripieniny lineament was a diversified one; it also indirectly helps estimation of the age of its further formation.

CONCLUSIONS

The Pericarpathian and Peripieniny lineaments, discovered by means of deep seismic soundings, divide the Earth's crust into three blocks, in a transversal cross-section of the Carpathians. These blocks are, going from the north:

— the Metacarpathian block: thickness of the crust from 52 kilometres in the east to 33 kilometres in the west;
— The Carpathian block (the recent root of orogen): thickness of the crust from 65 kilometres in the east to 35 kilometres in the west;
— the Transcarpathian block: thickness of the crust from 25 kilometres in the east to 30 kilometres in the west.

[9] A change of structural plan of the Carpathian geosyncline (L. Koszarski, W. Sikora, 1968), may be connected with this phenomenon.

[10] Recently M. Książkiewicz (1972) related the formation of intermontane depression in the Carpathians to vulcanism.

Breakings and disruptions of axis of the gravimetric minimum, whose northern „steep margin" is in line with the course of the Pericarpathian lineament give evidence to the fact that there exist transversal lineaments in the Carpathians that reach as far as the Moho discontinuity.

After the Subhercynian phase the partial geosyncline of the Outer Carpathian was delimited by longitudinal deep lineaments;

a) the Early Pericarpathian one, which constituted a boundary between the geosyncline and the platform;
b) the Early Peripieniny one, which represented the boundary between the geosyncline of the Outer Carpathians (the Early Carpathian block) and the Central Carpathian land — the Early Transcarpathian block. The two pairs of lineaments, i.e. the Pericarpathian and the Peripieniny lineaments and the Early Pericarpathian and the Early Peripieniny ones, cannot be identified with each other because of their different situation in time and in space.

During the Postpaleogene foldings the consolidated basement under partial geosyncline of the Outer Carpathians underwent a more-than-ten--time shortening. The Carpathian block is a place where cordilleras of the flysch sea (ocean), together with the adjoining flysch deeps were downsucked.

The Earth's crust in the Carpathian and the Transcarpathian blocks is an alpine new growth; the upper part of the granito-metamorphic layer in the Carpathian block is probably represented mainly by metamorphosed flysch.

Deep lineaments in the Carpathians are young ones. The process of their formation began in Oligocene and has been going on until today. The main phase of acceleration of formation of those lineaments took place in Sarmathian-Pliocene.

The young age of the lineaments does not deny the possibility that hypothetical deep lineaments, no longer found today, might have been present in Triassic or Jurassic. They might have constituted a boundary for the partial geosyncline of the Outer Carpathians from the south and from the north.

The analysis, presented above, only slightly touches the problem of relationship between the processes taking place in farther parts of the Earth's tectonosphaere and the final stage of formation of the flysch Carpathian orogen. Undoubtedly, such a relationship must exist. This thought is expressed by the representatives of the committee „Upper Mantle Project", in their foreward to the work „The Upper Mantle" (1972): „We now have the general idea that what happens on the surface of the earth is controlled (to a much larger degree than was previously supposed) by processes in the mantle".

The process of evolution of the Carpathian geosyncline and its relationships with the upper mantle needs a more comprehensive analysis, and not only from the point of view of the „plate tectonics" theory since, as it is stressed by the authors mentioned above: „It should be emphasized that data collected at the present testify in favour of plate tectonics, but that the final decision will come when direct data about the structure of the oceanic crust — at least the second layer — have been obtained by drilling".

The evolution of the Carpathian geosyncline should be also discussed from the point of view of other theories, e.g. from the point of view of Van Bemmelen's relativistic theory (1972), which seems to be able to explain certain facts connected with the structure of the Carpathians better than the „plate tectonics" theory in the unmodified shape.

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STRESZCZENIE

Treść. Głębokie sondowania sejsmiczne wykryły istnienie w Karpatach dwóch wgłębnych rozłamów, które dzielą Karpaty północne na trzy bloki: metakarpacki, karpacki i zakarpacki. Bloki te mają różną miąższość skorupy ziemskiej. Blok karpacki jest miejscem, gdzie zostały wchłonięte kordyliery cząstkowej geosynkliny Karpat zewnętrznych oraz gdzie zakorzeniają się w głównej mierze płaszczowiny fliszowe. Wgłębne rozłamy zaczęły formować się w oligocenie, a główna faza przyspieszenia formowania się rozłamów przypada na sarmat-pliocen.

Przeprowadzone przed paroma laty międzynarodowe profile głębokich sondowań sejsmicznych, które poprzecznie przecięły Karpaty ukraińskie, polskie i czechosłowackie, rzuciły po raz pierwszy światło na budowę całej litosfery [1] na obszarze przedkarpackiego rowu przedgórskiego, Karpat zewnętrznych i Karpat wewnętrznych. Geofizyczna i geologiczna interpretacja tych profilów (rys. 1) została przedstawiona w dwóch zbiorczych pracach: pierwszej pod redakcją V. B. Sollogub, D. Prosen i G. Militzer wydanej w Kijowie w 1971 r. oraz drugiej pod redakcją Szénas Gyorgy wydanej w Budapeszcie w 1972 r.

Profil nr V, którego północna część przebiega przez terytorium Polski, został zinterpretowany przez J. Uchmana, 1973 r.

Budowa litosfery pod ukraińskimi Karpatami i ich przedpola była ostatnio szeroko zintepretowana przez A. V. Čekunova (1972).

W nawiązaniu do wyników głębokich sondowań sejsmicznych przez Karpaty również w Polsce ukazały się ostatnio opracowania omawiające niektóre aspekty budowy podłoża polskich Karpat (A. Kisłow, 1973; R. Ney, 1973; W. Sikora, 1973).

Podstawowym osiągnięciem głębokich sondowań sejsmicznych było określenie grubości skorupy ziemskiej w południowo-wschodniej Europie. V. B. Sollogub et al., 1971, Szénas Gyorgy et al., 1972, przyjęli, że położenie granicy Moho zmienia się skokowo na wgłębnych rozłamach, które dzielą litosferę na poszczególne bloki.

W ciągu ostatnich kilku lat nauka o wgłębnych rozłamach rozrosła się w samodzielny dział geotektoniki, jednakże brak jest niestety do chwili obecnej ogólnej przyjętej definicji pojęcia „wgłębny (głębinowy) rozłam" oraz brak jest ogólnie przyjętej klasyfikacji wgłębnych rozłamów. W niniejszym opracowaniu wgłębnym (głębinowym) rozłamem nazywam wąską (maksymalnie do kilkunastu km) strefę zaburzeń w litosferze oddzielającą bloki o różnej miąższości skorupy ziemskiej.

STOSUNEK OROGENU KARPACKIEGO DO PLATFORMY NA PRZYKŁADZIE KARPAT POLSKICH

Po raz pierwszy stosunek orogenu karpackiego do podłoża typu platformowego będącego równocześnie podłożem rowu przedkarpackiego przedstawił Uhlig w 1907 r. W jego interpretacji orogen karpacki jest

[1] Litosfera = warstwa osadowa + warstwa granitowa + warstwa bazaltowa + górny płaszcz (V. E. Chain, 1973).

tak daleko nasunięty na swoje przedpole (w interpretacji W. Teisseyra, 1921, rów przedgórski na podłożu platformowym jest podsunięty pod orogen karpacki), że molasy zapadliska występują nawet pod Karpatami wewnętrznymi. W jego interpretacji amplituda nasunięcia „en bloc" Karpat na swoje przedpole wynosi około 80 km, a podłoże typu geosynklinalnego ma się znajdować dopiero gdzieś na południe od Wysokich Tatr. Na północ od nich utwory orogenu spoczywają na obcym dla siebie podłożu (pogrążonej platformie).

Tej ultranappistycznej koncepcji nie podtrzymano w latach późniejszych, chociaż nikt z tektoników polskich nie negował płaszczowinowej budowy Karpat i dalekich horyzontalnych przesunięć (patrz przegląd koncepcji tektonicznych dotyczących budowy polskich Karpat — M. Książkiewicz 1972).

Przez wiele lat nie próbowano określać południowego zasięgu podłoża typu platformowego pod Karpatami. Dopiero po odwierceniu pewnej ilości głębokich wierceń w Karpatach takie próby podjęto rysując zasięg podłoża typu platformowego głęboko pod nasuniętym fliszem, jednakże nie dalej jak po oś regionalnego minimum grawimetrycznego (fig. 1), która biegnie równolegle do rozłamu perykarpackiego nieco na południe od niego (K. Żytko 1965; Z. Olewicz 1968; S. Wdowiarz, S. Jucha, 1968; Zd. Roth, 1968; A. Ślączka, 1970; W. Sikora, 1971b; A. Kisłow, 1973; L. Koszarski, W. Sikora, S. Wdowiarz (1974); L. Koszarski, W. Sikora w druku). Tylko R. Ney (1973) w swej interpretacji wgłębnej budowy Karpat polskich granicę podłoża platformowego kreśli na północnym obrzeżeniu pienińskiego pasa skałkowego uznając strefę pasa jako strefę subdukcji (porównaj także J. F. Dewey, J. M. Bird, 1970).

PRZEBIEG ROZŁAMU PERYKARPACKIEGO

Rozłam ten przebiega mniej więcej wzdłuż linii Stary Sambor—Domaradz—Nowy Sącz—Nowy Targ—Kysucke—Nowe Mesto. Pokrywa się on mniej więcej z przebiegiem północnego „stromego brzegu" minimum grawimetrycznego.

Na profilu V różnica położenia hipsometrycznego „Moho" po obu stronach rozłamu wynosi ca 8 km. Rozłam ten został narysowany jako pionowy (Sollogub et al., 1971; J. Uchman, 1973) i jego powierzchniowa projekcja wypada na granicy jednostki magurskiej i śląskiej. Jest to jednak tylko przypadek, gdyż rozłam perykarpacki tnie skośnie w polskich i czechosłowackich Karpatach poszczególne jednostki tektoniczne i jego projekcja powierzchniowa wypada w zależności od miejsca w różnych punktach Karpat fliszowych (fig. 1).

Na profilu III amplituda „zrzutu" rozłamu perykarpackiego wynosi ca 12 km.

Na profilu VI, który tnie NW zakończenie basenu wiedeńskiego, różnica położenia granicy Moho po obu stronach rozłamu jest bardzo mała (ca 5 km).

PRZEBIEG ROZŁAMU PERYPIENIŃSKIEGO

Międzynarodowe sondowania sejsmiczne stwierdziły jeszcze jeden regionalny wgłębny rozłam, który na profilu III i V przypada w projekcji powierzchniowej na pieniński pas skałkowy, zaś na profilu VI przypada na północny skłon Małych Karpat (V. B. S o l l o g u b et al., 1970). Ten regionalny rozłam nie jest genetycznie związany wyłącznie z pienińskim pasem skałkowym, gdyż na profilu VI położenie jego projektuje się na powierzchni ca 20 km na S od pienińskiego pasa skałkowego. Tak więc na pewnym odcinku rozłam ten tnie skośnie alpejskie struktury również i Karpat wewnętrznych. Być może niezwykłe rozszerzenie się pienińskiego pasa skałkowego do ponad 20 km w dolinie Wagu w Czechosłowacji wiąże się właśnie z cofnięciem ku S w stosunku do pienińskiego pasa skałkowego, rozłamu perypienińskiego.

Największą amplitudę „zrzutu" powierzchni Moho obserwuje się na profilu III. Wynosi ona tutaj ponad 20 km, przy czym „skrzydło wiszące" reprezentuje obszar leżący na południe od tego rozłamu, który geolodzy radzieccy (V. V. G l u š k o, S. S. K r u g l o v, 1971; i inni) nazwali r o z ł a m e m z a k a r p a c k i m. Na profilu VI amplituda „zrzutu" podobnie jak i przy rozłamie perykarpackim jest mała i trudna do odczytania. W każdym razie nie przewyższa ona 5 km.

BLOK METAKARPACKI, KARPACKI I ZAKARPACKI

Dwa wgłębne rozłamy perykarpacki i perypieniński dzielą w przekroju poprzecznym litosferę w Karpatach ukraińskich, polskich i czechosłowackich oraz na ich bezpośrednim przedpolu na trzy zasadnicze części (bloki).

a) obszar na N od rozłamu perykarpackiego, a odpowiadający obszarowi rowu przedgórskiego założonego na podłożu typu platformowego, proponuję nazwać blokiem metakarpackim (porównaj W. S i k o r a, 1973). Miąższość skorupy ziemskiej w tym bloku na profilu III = ca 52 km; na profilu V = ca 40 km; na profilu VI = 33—35 km.

b) obszar pomiędzy rozłamem perykarpackim, a perypienińskim proponuję nazwać blokiem karpackim. Miąższość skorupy ziemskiej na profilu III wynosi od 55—65 km; na profilu V = ca 50 km; na profilu VI = ca 35 km.

c) obszar na południe od rozłamu perypienińskiego proponuję nazwać blokiem zakarpackim [2]. Cechą tego bloku jest bardzo mała miąższość skorupy ziemskiej. Na profilu III wynosi ona ca 25 km; na profilu V = 25—35, zaś na profilu VI = 28—30 km.

Blok karpacki reprezentujący korzeń orogenu karpackiego ma postać zwężającego się ku W klina, przy czym grubość skorupy ziemskiej konsekwentnie zmniejsza się od E ku W. Od 65 km na profilu III do ca 35 km na profilu VI.

Te same tendencje obserwujemy w bloku metakarpackim. Miąższość skorupy ziemskiej zmniejsza się tutaj od 52 km na profilu III poprzez 40 km na profilu V, do 33 km na profilu VI. Natomiast odwrotne tendencje obserwujemy w bloku zakarpackim, gdzie miąższość skorupy ziemskiej na profilu VI i V wynosi od 28—35 km zaś na profilu III ca 25 km. Znaczy to, że miąższość skorupy ziemskiej ogólnie rzecz biorąc zmniejsza się z zachodu na wschód, a więc odwrotnie, niż to ma miejsce w bloku metakarpackim i karpackim. Jeśliby zastosować mechaniczne kryteria odnośnie do sposobu powstawania rozłamu perypienińskiego, to mielibyśmy do czynienia ze *sui generis* rozłamem nożycowym.

ODZWIERCIEDLENIE WGŁĘBNYCH ROZŁAMÓW W POWIERZCHNIOWEJ BUDOWIE GEOLOGICZNEJ I ICH ZWIĄZEK Z SUBSEKWENTNYM WULKANIZMEM I TRZĘSIENIAMI ZIEMI

Związek wgłębnych rozłamów z zapadliskami postorogenicznymi zdaje się dzisiaj nie ulegać wątpliwości (V. E. Chain, 1973). Na linii rozłamu perykarpackiego utworzyły się stosunkowo duże zapadliska Nowego Sącza oraz Orawy—Nowego Targu (fig. 1). Powstanie tych zapadlisk uwarunkowane zostało przypuszczalnie także okolicznością, że w strefie, gdzie one występują, rozłam perykarpacki i perypieniński podchodzą bardzo blisko do siebie, co w konsekwencji spowodowało osłabienie skorupy ziemskiej w tym obszarze i powstanie zapadlisk śródgórskich. Interesującą rzeczą jest to, że maksymalne zbliżenie się do siebie obydwóch tych rozłamów leży mniej więcej na tym samym południku co największe zwężenie rowu przedgórskiego przed czołem Karpat fliszowych, co sugeruje, że te dwa zjawiska pozostają w genetycznym związku. Na południe od rozłamu perykarpackiego powierzchnie nasunięć poszczególnych jednostek na siebie są bardziej strome niż w obszarze położonym na północ od rozłamu i właśnie na linii rozłamu perykarpackiego następuje nagłe spłycenie się powierzchni nasunięć wyższych jednostek na niższe, co zaznacza

[2] Nazwą tą nawiązuję do obszaru Karpat ukraińskich, gdzie rozłam perypieniński ma ponad 20 km „zrzutu" i gdzie „skrzydło wiszące" (blok zakarpacki) w sensie geograficznym nie należy już do Karpat; porównaj — „Ruś zakarpacka", „zapadlisko zakarpackie", rozłam zakarpacki na odcinku Karpat ukraińskich = rozłamowi perypienińskiemu.

się dzisiaj obecnością półwyspów i czapek tektonicznych (K. Żytko, 1965).

Ponieważ rozłam perykarpacki przecina skośnie poszczególne płaszczowiny karpackie, dlatego też np. budowa mas fliszowych w polskich wschodnich Karpatach, gdzie większa ich część należy do bloku karpackiego i spoczywa na głęboko pogrążonym fundamencie, różni się od budowy płaszczowin w polskich zachodnich Karpatach, które na przeważającym obszarze należą do bloku metakarpackiego i są nasunięte na stosunkowo płytko zalegające utwory rowu przedgórskiego.

Analiza danych geofizycznych i rozmieszczenie wulkanitów daje możliwość wyznaczenia również poprzecznych struktur alpejskich, głębinowych rozłamów. Linie tych hipotetycznych wgłębnych rozłamów są pokazane na fig. 1.

Analiza rozmieszczenia hypocentrów trzęsień ziemi w Karpatach oraz rozmieszczenia subsekwentnych wulkanitów wskazuje, że są one związane z rozłamem perypienińskim, a być może również z rozłamem perykarpackim.

PROBLEM ALPEJSKIEGO METAMORFIZMU

Na południku Krakowa odległość między rozłamami perykarpackim i perypienińskim wynosi ca 15 km. Jeśli przyjąć, że w górnej kredzie szerokość geosynkliny Karpat zewnętrznych wynosiła ca 400 km (por. H. Świdziński, 1971; V. N. Utrobin, 1973), to porównanie tych dwóch wielkości, to znaczy 400 i 15 km, daje nam wielkość skrócenia podłoża geosynkliny Karpat zewnętrznych, które to skrócenie wyraża się ułamkiem 400/15, co daje wielkość 26-krotnego skrócenia. Idąc w kierunku wschodnim wielkość tego skrócenia zmniejsza się w miarę rozszerzania się bloku karpackiego, ale i tak skrócenie to na całej rozciągłości bloku karpackiego jest skróceniem olbrzymim (fig. 2).

Olbrzymie skrócenie podłoża warstwy osadowej w bloku karpackim (na profilu V co najmniej 10-krotne) musiało spowodować fizykochemiczną przebudowę tego podłoża. Najwyższa część górnego płaszcza została przekształcona w warstwę bazaltową, o czym świadczy bardzo niskie położenie granicy Moho w bloku karpackim w stosunku do wyższego położenia tej granicy tak w okresie życia geosynkliny, jak i przed jej założeniem (rys. 2B).

O stosunku warstwy granitowo-metamorficznej do bazaltowej trudno jest cokolwiek powiedzieć, ponieważ granica Konrada w Karpatach z wyjątkiem Karpat ukraińskich jest bardzo słabo zarysowana (Sollogub et al., 1970). Natomiast niesłychanie ważnym zagadnieniem, chociażby ze względu na poszukiwanie bituminów w Karpatach, jest danie odpowiedzi na pytanie, co reprezentuje górna część warstwy granitowo-metamorficznej w bloku karpackim.

Z danych teoretycznych wiadomo, że potok cieplny dochodzący do powierzchni jest w okresie orogenicznym (okres likwidacji geosynkliny i przekształcania się jej w górotwór) 2—3 razy wyższy aniżeli normalny (A. Ritman, 1966). Teoretyczne krzywe przedstawiające wzrost potoku cieplnego w Karpatach ukraińskich w okresie orogenicznym przedstawia figura 3. Zwiększona produkcja cieplna w okresie formowania się górotworu karpackiego musiała spowodować metamorfizm termiczno-regionalny tych skał osadowych geosynkliny karpackiej, które zostały wciągnięte w głąb górotworu (fig. 4 i 5).

Jest bardzo prawdopodobne, że blok karpacki jest miejscem, gdzie z jednej strony zostały wciągnięte w głąb (wessane) kordyliery wraz z przylegającą do nich częścią rowów fliszowych (porównaj także E. Kraus, 1942; M. Książkiewicz, 1972; V. N. Utrobin, 1973), a z drugiej strony miejscem, gdzie zakorzenia się większość płaszczowin północnych Karpat fliszowych. Po wessaniu pokrywa osadowa kordylier, tak zresztą jak i ich trzony krystaliczne musiały zostać zmetamorfizowane i weszły w skład nowej alpejskiej warstwy granitowej i bazaltowej. W równej mierze powinny ulec metamorfizmowi korzeniowe partie płaszczowin fliszowych (fig. 4 i 5).

WIEK ROZŁAMÓW

Ponieważ sama natura wgłębnych rozłamów, jak również ich związek ze zjawiskami przypowierzchniowymi nie są jeszcze zbytnio jasne, określenie wieku wgłębnych rozłamów perykarpackiego i perypienińskiego musi być w dużej mierze hipotetyczne.

Wgłębne rozłamy tego typu, jakie zostały wykryte w Karpatach, zawdzięczają swe powstanie w pierwszym rzędzie nieco odmiennemu charakterowi i różnej intensywności procesów fizyko-chemicznych przekształcających skorupę ziemską po obu stronach rozłamu, w rezultacie czego zwiększała się lub zmniejszała jej grubość, a co za tym idzie, powierzchnia Moho zajmowała wyższą lub niższą pozycję w stosunku do powierzchni.

Zostało udowodnione eksperymentalnie, że gabro (bazalt) może przechodzić za pomocą fazy pośredniej granatowego granulitu w eklogit (D. H. Green, A. E. Ringwood, 1972), z którego może być zbudowany górny płaszcz ziemi (G. C. Kennedy, K. Ito, 1972) przynajmniej pod kontynentami (W. E. Chain, 1973). Jest również możliwy i odwrotny proces. Pierwszy z nich powoduje zmniejszanie się objętości litosfery o 10—12% i opuszczanie się powierzchni ziemi (powstanie zapadlisk). Drugi proces powoduje grubienie skorupy ziemskiej i w konsekwencji podnoszenie się powierzchni ziemi (V. E. Chain, 1973). W obu przypadkach musi nastąpić zmiana hipsometrycznego położenia powierzchni Moho z pierwotnego położenia na nowe, wyższe lub niższe w stosunku do położenia pierwotnego. Zróżnicowane zmiany objętości w dolnych partiach skorupy ziemskiej powinny doprowadzić do naprężeń mechanicznych w górnych partiach skorupy i wyładować się w mechanicznych dyslokacjach, które jak w przypadku rozłamu perypienińskiego były drogami, którymi magma bazaltowa z ognisk w górnym płaszczu ziemi wydostawała się na powierzchnię (V. V. Gluško, S. S. Kruglov, 1971; R. J. Kutas, V. V. Gordienko, 1972).

W przypadku Karpat różnice położenia hipsometrycznego Moho w bloku metakarpackim, karpackim i zakarpackim należy wiązać z formowaniem się neogeńskiego „korzenia" skorupy ziemskiej w bloku karpackim oraz z likwidacją hipotetycznego subhercyńskiego „korzenia", a później z dodatkowym ścienieniem skorupy ziemskiej w bloku zakarpackim.

Formowanie się „korzenia" pod blokiem karpackim było przypuszczalnie procesem długotrwałym, jednakże zasadnicze przyspieszenie tego procesu nie mogło się odbyć przed wciągnięciem (wessaniem) kordylier morza karpackiego w głąb skorupy. Ponieważ zanik działalności kordylier przypada na wyższy oligocen (S. Dżułyński, A. Ślączka, 1958), a początek działalności dodatkowego źródła ciepła w Karpatach przypada na przełom eocenu i oligocenu [3] (R. J. Kutas, V. V. Gordienko, 1972) można wyciągnąć wniosek, że początek intensywnego formowania się rozłamu przypada na oligocen. R. J. Kutas, V. V. Gordienko uważają, że rozłam perypieniński został uformowany dopiero po fazie sawskiej, kiedy to nastąpiły pierwsze wybuchy wulkanów związanych z tym rozłamem. Można jednak sądzić, że pojawienie się ryolitowego wulkanizmu w burdygale (T. Buday, M. Mahel et al., 1968) świadczy nie tyle o początku formowania się rozłamu, ile o „dojściu" tego rozłamu w swej „wędrówce w górę" do warstwy granitowo-metamorficznej.

Druga, młodsza faza przyspieszenia formowania się rozłamu perypienińskiego w Karpatach przypada na sarmat-pliocen. Świadczą o tym następujące dane: główna faza tworzenia się zapadlisk śródgórskich związanych z rozłamem perypienińskim, tj. zapadlisk Trenčina, Ilavy i Orawy—Nowego Targu przypada na sarmat-pliocen. Na ten sam okres przypada też główna faza wulkanizmu subsekwentnego w Karpatach [4] (T. Buday, M. Mahel et al., 1968, V. V. Gluško, S. S. Kruglov, 1971).

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[3] Być może z tym zjawiskiem jest związana zmiana planu strukturalnego geosynkliny Karpat (L. Koszarski, W. Sikora, 1968).

[4] Ostatnio M. Książkiewicz (1972) wiąże powstanie śródgórskich zapadlisk w Karpatach z wulkanizmem.

Ponadto badania K u t a s a i G o r d i e n k i (1972) wskazują, że mniej więcej od połowy miocenu potok cieplny był bardziej intensywny w bloku zakarpackim niż w bloku karpackim, co może świadczyć o zróżnicowanym przebiegu tworzenia się w tym czasie skorupy ziemskiej po obu stronach rozłamu perypienińskiego, datując w sposób pośrednio wiek jego dalszego formowania się.

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