Tectonics of the consolidated basement of the Polish Carpathians

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Based on the results of magnetotelluric soundings a sketch of the main tectonic elements of the consolidated basement of the Polish Flysch Carpathians and a number of longitudinal profiles and cross-sections have been drawn. The sketch as well as the sections allowed for developing a concept about major tectonic pattern of the consolidated basement in this part of the Carpathians. Morphology of the consolidated basement surface of the Carpathians is very diversified. Depth to the top of the basement surface varies from several hundred meters in the western part of the Carpathians to around 20 km in the south-eastern part. Generally, the surface drops from the north-west toward the south-east. The drop is not uniform, and it has a discontinuous character.

In the tectonics of the consolidated basement of the Carpathians, in the territory of Poland, three major elements influencing its structure are distinguished. These are two transverse, generally SW–NE oriented fault zones (A–A and B–B), where the basement is dipping eastward. The third element, of a comparable meaning to the other two, is a longitudinal zone of the basement dipping southward — „regional basement slope".

The first of these large fault zones, the transverse and western-most one (A–A), runs from Babia Góra to the region of Rzeszotary. The dislocated area lying to south-east of the fault zone is lowered by about 8.5 km in its southern part and about 2 km in its northern part. The second, transverse B–B fault zone follows the Wysowa–Sędziszów Małopolski line. The dislocated area lying to the east of this fault zone is lowered by several kilometers to maximum of 12 km in the southern part. The entire eastern block is moved along the fault 40 km to the north. The B–B zone separates the central block from the eastern one. The third major tectonic element is the described earlier zone of the regional basement slope (Fig. 2). It is a longitudinal element which remodels the consolidated basement of the Carpathians in the southern direction. Along this zone, there is an abrupt block-wise lowering of the consolidated basement to the south.

The two transverse dislocation zone A–A and B–B, discussed earlier, divide the consolidated basement of the Polish Carpathians into three regions. The western region located to the west of the A–A zone, the central region between the A–A and B–B zones, and eastern region located to the east of the last zone (B–B). The consolidated basement of the western region is relatively shallow, at the depth from one to four kilometers. This region is technically calm. The central and eastern blocks are two-fold, separated by the regional basement slope into the elevated northern part and lowered southern part.

An outlined general framework of the tectonics of the consolidated basement of the Polish Carpathians is a present-day representation, yet it was finally formed in the Neogene. We can assume that in the Early Neogene (probably at the turn of the Oligocene and Miocene) the northern plate collided with the Carpathian block. In the Lower Miocene, along the boundary between the northern plate and the Carpathian block, the latter was dropped from a few kilometers in the west to several kilometers in the east. After the lower Miocene, probably at the Middle/Upper Miocene interface, the Carpathian block started to disjoin. It was fractured along the A–A zone and, in its eastern part, rotationally shifted by about 40 km to the north-east. In the west, the western block was formed. The eastern part, apart from being shifted and rotated, was additionally lowered by a few kilometers towards the south. In the Upper Miocene a fracture along the B–B zone took place, and, as in the previous stage, the eastern part was rotationally transferred by ca 40 km to the north-east. Thus, the net shift, along the A–A and B–B line was about 80 km. The eastern part was divided along the B–B line into the central and eastern blocks. The eastern block, moreover, is lowered by a few kilometers to the south. This process is accompanied by a development of a set of oblique slip faults of various directions.

Key words: *areal geology, Polish Carpathians, magnetotelluric surveys, deep sounding, basement tectonics, fault zones, regional patterns, Neogene*

Introduction

In the area of the Polish Flysch Carpathians, magnetotelluric research has been continued since 1975 under the initiative and commission of the Polish Geological Institute.

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Magnetotelluric and telluric coverage of the entire area of the Carpathians was carried out from 1986 to 1990. In this period 518 magnetotelluric soundings were made along 61 profiles. These profiles were located perpendicular to the axis of the Carpathian arc. All magnetotelluric work was rendered by the Agency for Geophysical Research (Przedsiębiorstwo Badań Geofizycznych) in Warsaw. First research results have been presented by: Święcicka-Pawliszyn

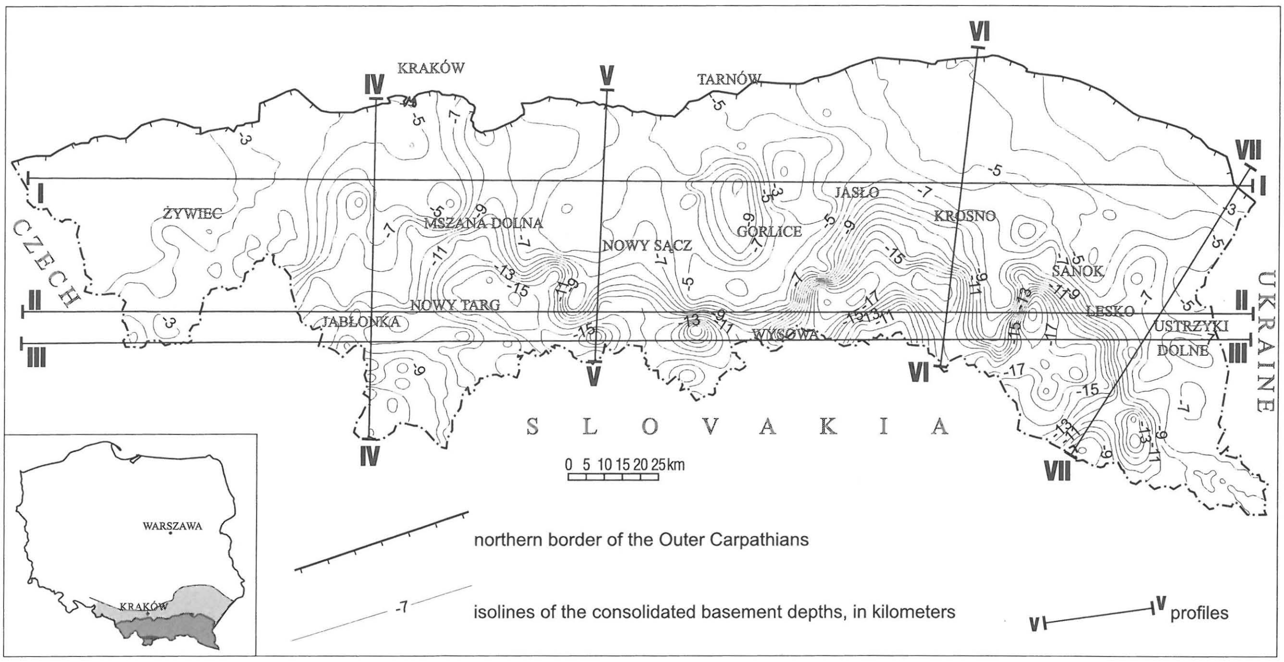

Fig. 1. Map of the depth of the consolidated basement of the Carpathians

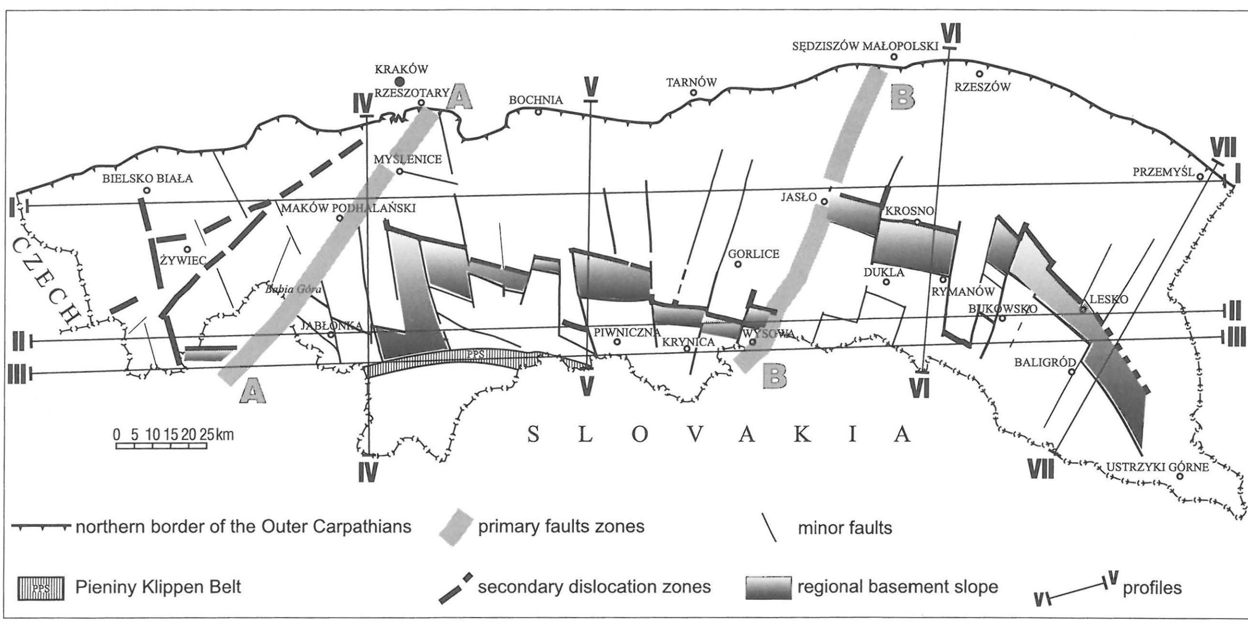

Fig. 2. Sketch of the main elements of the consolidated basement of the Polish Carpathians

& Molek (1975); Bachan (1981); Molek & Oraczewski (1988); Molek & Klimkowski (1991); Święcicka-Pawliszyn (1980, 1984); Ryłko & Tomaś (1995); Żytko (19970.

In the basement of the Flysch Carpathians, under the Meso-Paleozoic platform deposits (Oszczypko et al., 1989) there is a series of the Precambrian crystalline and metamorphic deposits that is described in the literature as a crystalline basement or a consolidated basement. Until now the crystalline basement of the Polish Carpathians has been recognized by non-numerous (ca 30) boreholes (Karnkowski, 1977). The boreholes reached phyllites, that are metamorphosed to various degrees and often strongly folded, and crystalline rocks in singular cases. Information about rocks building the crystalline basement of the Carpathians is often incomplete and refers only to spots. Fortunately, this information may be supplemented by the results of magnetelluric survey from the Carpathians. Comparison of the resulting picture of the consolidated basement morphology with facts known from deep boreholes and from interpretation by other geophysical methods, particularly seismic ones, indicates that the depths of the basement interpreted from magnetotelluric soundings are obtained with a high degree of certainty. Thus, it might be assumed that the „traced horizon of low specific resistivity" corresponds with the consolidated basement and actually reflects the depth of basement (Fig. 1).

Based on the results of the magnetotelluric soundings a sketch of the main tectonic elements of the consolidated

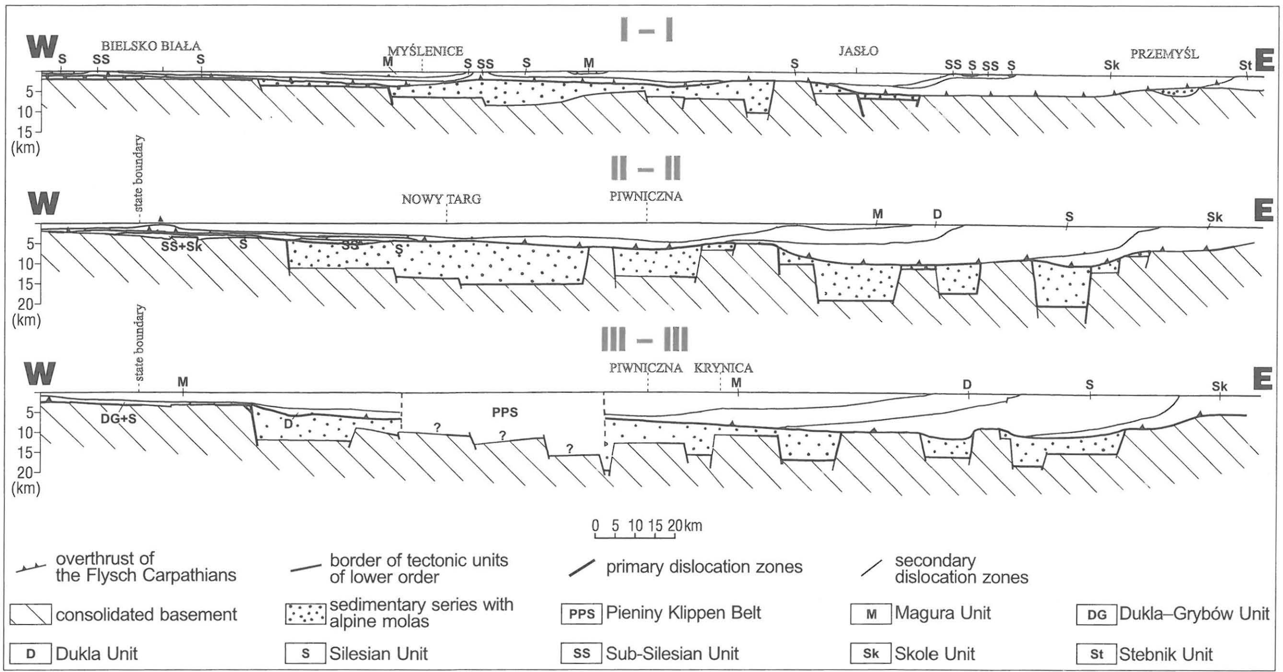

Fig. 3a. Longitudinal geological profiles

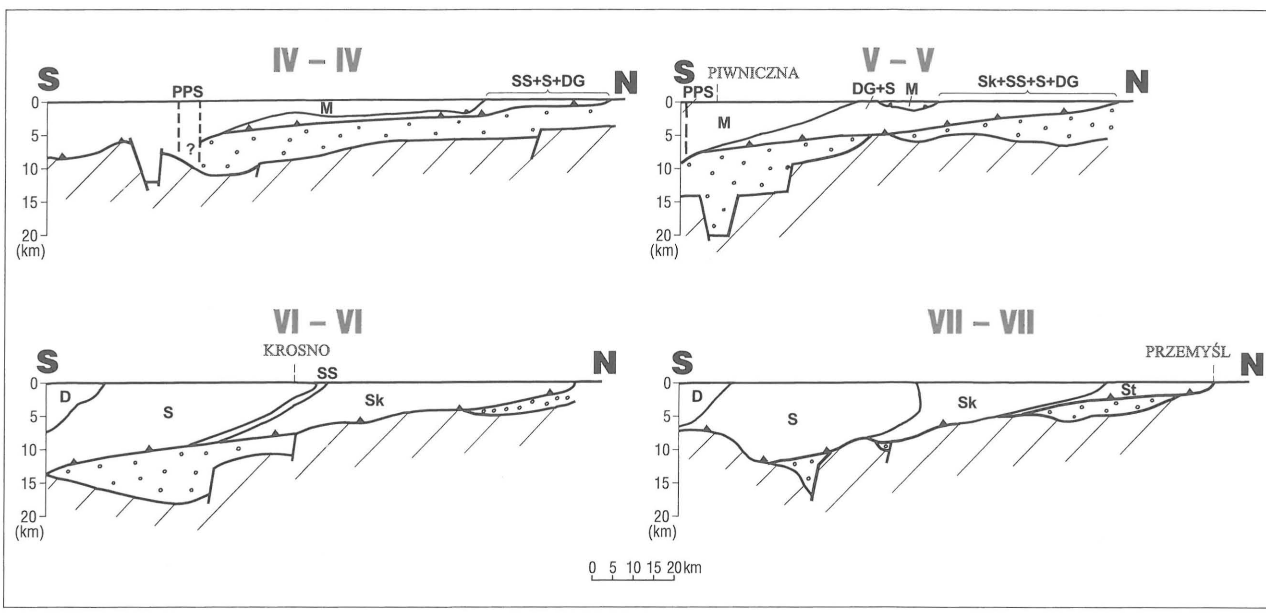

Fig. 3b. Geological cross-sections

basement of the Polish Flysch Carpathians (Fig. 2) and a number of longitudinal profiles and cross-sections (Fig. 3a, b) have been drawn. The sketch as well as the sections allowed for developing a concept about major tectonic pattern of the consolidated basement in this part of the Carpathians.

The morphology of the consolidated basement surface of the Carpathians is very diversified (Fig. 1). Depth to the top of the basement varies from several hundred meters in the western part of the Carpathians to around 20 km in the south-eastern part. Generally, the surface drops from the north-west toward the south-east. The drop is not uniform, and it has a discontinuous character. As it can be seen on the map of the depth of the horizon of high specific resistivity (Fig. 1), the most visible, eye-catching feature of the consolidated basement is the sharp drop in the south-eastern and central parts of the Polish Carpathians. This zone runs from the region of Ustrzyki Górne through the vicinity of Lesko to the region of Jasło. Then, along the Jasło–Wysowa line, it is shifted about 40 km to the south. From the region of Wysowa, the drop zone can be traced as far as Mszana Dolna. It is likely to continue farther westward and southward in Slovakia (Ibrmajer & Suk, 1989), outside the area covered by magnetotelluric coverage. The described zone is the most important discontinuity element in the area of the consolidated Carpathian basement. From now on it will be called the „regional basement slope".

The surface of the consolidated basement is also characterized by a series of local drops and rises. The greatest drop extends along the southern Polish boundary from Wetlina through Baligród to the vicinity of Wysowa. It is as much as

20 km deep and is about 12 km lower than the more northern area. An interesting point is that the magnitude of the basement drop corresponds to the magnitude of a drop in the Moho surface from profile III GSS (Guterch, 1977) located not far to the east in the Ukrainian Carpathians. The described drop is two-fold, separated by the Rymanów elevation, with four distinct local hollows. The first two (in the south-eastern part) are located in the region of Wetlina and Bukowsko, and the remaining two (in the western part) are located north-east of Wysowa in the region of Świątkowa and Dukla. To the south, the drop described earlier (along the southern state boundary) is bounded by an elevation of 6 to 8 km below the surface. Further to the west, a series of local depressions along the Krynica–Jabłonka line can be seen. In the northern, elevated part of the basement, only one significant depression can be seen at the meridian of Tarnów in the region of Gorlice. Its relative depression is 4 km, and in its centre the consolidated basement surface drops to a depth of 10 km below the Earth's surface.

The slope of the basement is tilted toward the south at an average angle of 35 to 50° (Ryłko & Tomaś, 1995). Considering the dip, it is possible to believe that its intersection with the Moho surface in the region east of Krynica occurs along a line coinciding with the trend of the pre-Pieninian Dislocation. To the west of the meridian of Krynica, regularity of this sort can no longer be observed, and the intersection with the Moho is presumably along the Krompachy (Slovakia)–Nowy Targ.

In the tectonics plan of the consolidated basement of the Carpathians (Fig. 1), in the territory of Poland, three major elements are distinguished. These are two transverse, generally SW–NE oriented fault zones (A–A and B–B), where the basement is dipping eastward. The third element is a longitudinal zone of the basement slope dipping southward — „regional basement slope" (Ryłko & Tomaś, 1995).

The first of these large fault zones, the transverse and western-most one (A–A), runs from Babia Góra to the region of Rzeszotary. The dislocated area lying to south-east of the fault zone is lowered by about 8.5 km in its southern part and about 2 km in its northern part. This fault zone, if extended south-west encounters a fault zone near Zazriva in the Pieniny Klippen Belt (Zazriva–Revuca–Sahy dislocation — Mahel, 1974) and the Danube dislocation line. In the region of Sahy it joins with a deep fracture Bielsko–Żywiec–Banska Bystrica as suggested Sikora (1976). If one presumes that the referred fault zone is a north-eastern extension of the Zazriva–Revuca–Sahy dislocation, then its age might be documented by the age of magma intrusions in the region of Banska Bystrica. Thus, the age might be Middle and Upper Miocene (Styrian phase). In the northern part of the Carpathian Foredeep, in the extension of the described dislocation, in the Middle Miocene an active fault appears in the Miocene deposits (Hamor, 1988). Obviously, this zone might have been active much earlier, in the pre-Alpine period and its current state is only an alpine remodelling of an older stage. In the light of the discussion presented above, this is the Rzeszotary–Maków Podhalański–Babia Góra–Sahy zone of the Middle(?) Miocene. The A–A fault zone divides the consolidated Carpathian basement into two tectonic environments: an uplifted, relatively calm western element (western block) and a lowered, two-fold (central and eastern) eastern element possessing a distinct block structure.

The second, transverse B–B fault zone follows the Wysowa–Sędziszów Małopolski line.

The dislocated area lying to the east of this fault zone is lowered by several kilometers to maximum of 12 km in the southern part. The entire eastern block is moved along the fault 40 km to the north. The B–B zone separates the central block from the eastern one. The southern part of the dislocation zone in the region of Wysowa is probably joined with the Cigla–Kyjov fault system (Slovakia) and further to the north it turns into the Murań dislocation zone (Lesko *vide* Mahel, 1974) which then runs to the south-west toward Sahy. The B–B zone in its northern part, in the segment between Gorlice and Jasło, reaches a deep seated fault zone Preszów–Gorlice that was distinguished by Sikora (1976). Even more to the north it may be linked with the Jasło–Połaniec fissure that has been distinguished by Żytko (1985). When looking at the Moho plan, the B–B zone might have its equivalent in the D–D deep-seated fault zone distinguished by Bojdys & Lemberger, (1986). In the Moho plan sketched by these authors, the south-western continuation of the D–D fissure from the region of Bardejov to the region of Poprad–Bańska Bystrica shows up as the B–B fissure. The authors of the paper suggests the western part of the fissure, starting from Poprad, runs towards Sahy not to Bańska Bystrica. Because of that our zone B–B is a part of a large fissure running from Połaniec through Jasło, Bardejov towards Sahy.

The third major tectonic element is the described earlier zone of the regional basement slope (Fig. 2). It is a longitudinal element which remodels the consolidated basement of the Carpathians in the southern direction. Along this zone, there is an abrupt block-wise lowering of the consolidated basement to the south. To the south of the regional basement slope there is a series of deep declines. Between the eastern state boundary and the B–B zone, the regional basement slope runs along the line Ustrzyki Dolne–Sanok–Jasło. Here, the dislocated area is lowered southward by about 12 km. Between the fault zones B–B and A–A the regional basement slope runs along Wysowa–Mszana Dolna. In this region, the dislocated area is also lowered to the south by ca 5–7 km. To the west of the A–A zone the regional basement slope is beyond the magnetotelluric coverage, in the Slovakian territory. In the structural sketch of the top of the crystalline complex (Ibrmajer & Suk, 1989) draw a deep fissure running along the Rabcice–Mutne line. Because of that the dislocated area is lowered to the south by about 3 km. This is probably the most western part of the regional basement slope.

The two transverse dislocation zone A–A and B–B, discussed earlier, divide the consolidated basement of the Polish Carpathians into three regions. The western region located to the west of the A–A zone, the central region between the A–A and B–B zones, and eastern region located to the east of the last zone (B–B).

The consolidated basement of the western region is relatively shallow, at the depth from one to four kilometers. This region is technically calm. Here, dislocations with amplitudes varying from one kilometer to a several hundreds meters are observed. The most important is the fault zone extending from the junction of the state boundaries of Poland, Czech and Slovakia to the region located north-west of Sucha Beskidzka. It is SW–NE oriented. There is also an outstanding complex of faults oriented NNW–SSE (Paul et al., 1996).

The central and eastern blocks are two-fold, separated by the regional basement slope into the elevated northern part and lowered southern part (Fig. 2).

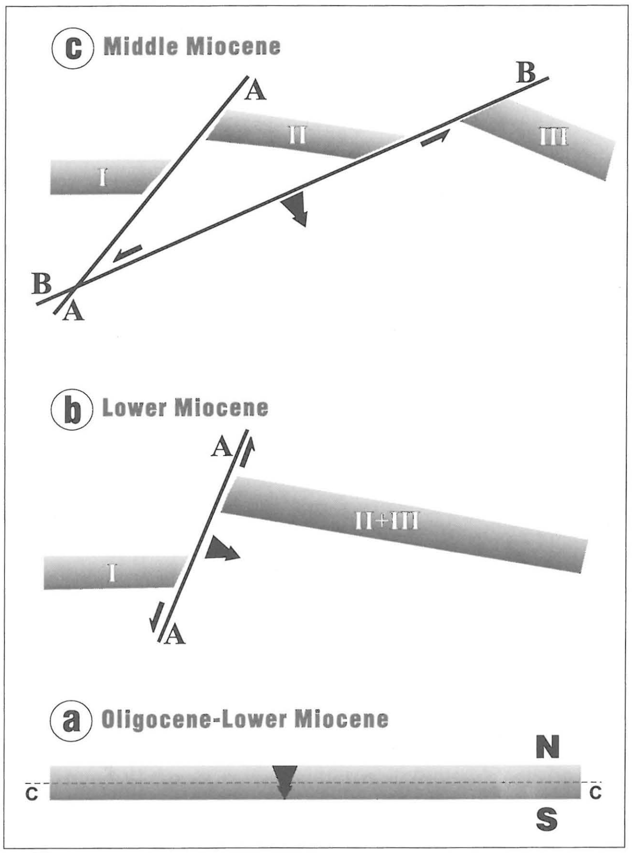

Fig. 4. Scheme of Neogene remodelling of the consolidated basement

In the central region, in its northern part, the consolidated basement occurs at the depth of 5–8 km. In the southern part, south of the Wysowa–Mszana Dolna line, it is lowered to the depth of several kilometers. Two directions of dislocations are observed here; NW–SE direction is related to the regional basement slope, and N–S direction being transverse to it. In the western part of this region, the transverse dislocations depart from the N–S direction towards NNW–SSE direction. In the eastern region, the situation is analogous to that in the central region. The consolidated basement in the northern part of the region is at the depth of a few kilometers. Two principal directions of dislocations are observed here: NW–SE and NNE–SSW. The zone of southern depressions is divide in two parts by a distinct horst of Rymanów. In the region of this horst the basement rises to the depth of 8 km.

The authors of the paper have presented a general framework of the tectonics of the consolidated basement of the Polish Carpathians. This is a present-day representation, yet it was finally formed in the Neogene. We can assume that in the Early Neogene (probably at the turn of the Oligocene and Miocene) the northern plate collided with the Carpathian block (Cicha et al., 1989).

In the Oligocene/Lower Miocene, along the border between the northern plate and the Carpathian block, the latter was dropped from a few kilometres in the west to several kilometers in the east (Fig. 4a). Thus, the regional basement slope, dipping irregularly, was formed (Ryłko & Tomaś, 1995).

In the Lower Miocene, probably at the Middle Miocene interface the Carpathian block started to disjoin. It was fractured along the A–A zone and rotationally shifted by about 40 km to the north-east in its eastern part (Fig. 4). In the west the western block formed. The eastern part, apart from being shifted and rotated, was additionally lowered by a few kilometers towards the south.

In the Middle/Upper/ Miocene (Fig. 4) fracture along the B–B zone occurred, and as in the previous stage, the rotational transfer by ca 40 km to the north-east took place in its eastern part. Thus, the net shift, along the A–A and B–B line, was about 80 km. The eastern part was divided along the B–B line into the central and eastern blocks. The eastern block, moreover, was lowered by a few kilometers to the south.

This process is accompanied by a development of a set of oblique slip faults (fig. 2) of various directions. Among the secondary dislocations in the western block, the NW–SE directions dominate in the western block, while directions close to the N–S in the central block and NE–SW directions in the eastern block.

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