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The dependence of relief on tectonics in the South-West Escarpment Zone of Tomaszowskie Roztocze (SE Poland)

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Abstract: The relatively undeformed South-West escarpment zone (SWEZ) of Roztocze, SE Poland, is marginal to the East European Platform, which is covered by a thick succession of Palaeozoic and Mesozoic rocks. Cainozoic sediments, previously much more widely distributed and largely destroyed by erosion, still fill some valleys and also crop out in the hills of the inner and outer escarpments. The escarpment zone comprises several morphological elements: an outer hill zone, inner inselbergs and a median depression zone of tectonic origin. Transverse to the escarpment, these elements are compartmentalised by transverse valleys, many of which are fault-controlled. Morphometric and geomorphological studies show that the SWEZ of Roztocze was repeatedly tectonically activated. Neotectonic redevelopment has resulted from controls in the underlying basement. Hence there are many young faults, a large number of open fault-fissures and a complex system of joints, all of which have influenced landform development in this area to a considerable degree. The main scarps have been developed along the longitudinal fault zones and, along the transverse fault zones, breach valleys. Joint systems have controlled the development of secondary relief forms. The close association of relief and various elements of the geological structure in the SWEZ of Roztocze mean that cartographic methods can reliably be employed in studies of the landforms in this area.

Key words: geology, geomorphology, tectonics, relief, Roztocze

Introduction

The SWEZ of Roztocze is marginal to the East European Platform and lies within the Radom-Kraśnik Elevation, a structural unit of the Palaeozoic basement (Żelichowski, 1974; 1983). The Palaeozoic rocks are covered by a lithologically-variable succession of Mesozoic sediments. In the Cimmerian and Laramian phases, the sedimentary pile was deformed into gentle tectonic structures which follow pre-existing elements of horst and graben (Ney, 1969; Pożaryski, 1974; Cieśliński *et al.*, 1994). Miocene sediments, once widespread but now largely removed by erosion, are still preserved along the foothills, where they form a zone of narrow, extended periclines (Areń, 1962; 1968).

The escarpment zone comprises three parallel morphological elements: a zone of outer hills and inner inselbergs separated by a zone of tectonic depressions (Fig. 1). The asymmetric outer hills of Tarnowola, Pardysówka and Nowiny (280 m a.s.l.) are delimited by a group of SW-throwing border faults and by antithetic thrust faults to the North-East (Jaroszewski, 1977). These hills have steep southern slopes and gentle northern slopes. According to Jahn (1956), their northern inclination is caused by recent tectonic tilting. Jaroszewski (1977) considered that the antithetic rotation of individual blocks was due to tectonic extension. Padół Józefowa is a second-order tectonic trough developed in a zone of thrusts which accompany the border faults. Between Tereszpol, Górniki Nowe and Narol, the outer inselberg hills (310–320 m a.s.l.) are situated in the zone of the Tereszpol–Majdan Nepryski–Narol border faults. In this respect, they resemble those of the inner edge. These hills, confined to a structural trough to the South-West of Padół Józefowa (270–280 m a.s.l.), are arranged in two parallel chains formed by separate semicircular ridges.

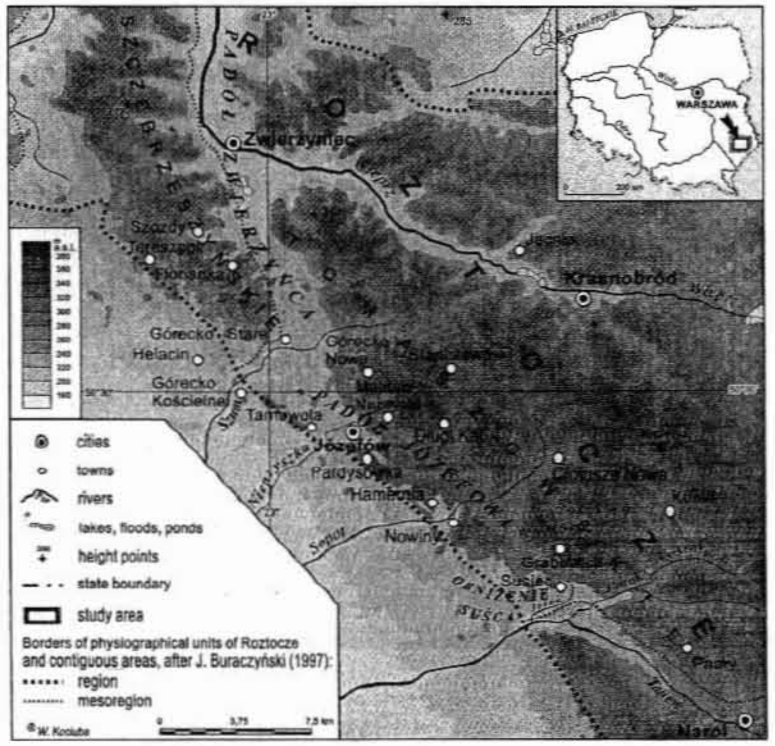

Fig. 1. Location of South-West Escarpment Zone of Tomaszowskie Roztocze

Geological setting

The SWEZ corresponds to an important geological boundary which is often regarded as the edge of the Carpathian Foredeep Basin. According to Ney (1969), Jaroszewski (1974) and Żelichowski (1974) it was formed along the deep-seated thrust zone which marks the south-west edge of the East European Platform (Figs. 1, 2). The most recent geological investigations in the area of the Carpathian Foredeep Basin adjacent to Roztocze (Krzywiec & Pietch, 1996; Oszczypko, 1996; Krzywiec & Jochym, 1997) indicate that the SWEZ was formed in very complex tectonic conditions. Its formation started in the Middle Badenian when a rapid, spatially-differentiated subsidence occurred; this was the result of extension in the Carpathian Foredeep. Several synsedimentary faults were created by these movements. The last stage of the development of the zone was represented by a late Sarmatian (Serravalian) inversion of the normal faults in a compressional regime, which was produced by the latest stage of movements in the Carpathian tectogene.

The SWEZ is built from Lower Campanian and Maestrichtian carbonate rocks in a gaize or marly gaize facies. The sediments are arranged into broad fold structures of small amplitude (Fig. 2) (Cieśliński *et al.*, 1994). Miocene deposits (mainly reef, organo-detrital and algal limestones but which also include sands and sandstones of Upper Badenian age) occur as isolated outcrops in the inner and outer hills. Sarmatian clays and mudstones with sandy bands (Krakowieckie loams) occur below the scarp (i.e. just within the Carpathian Foredeep Basin) (Areń, 1962; Musiał, 1987; Cieśliński *et al.*, 1994).

The intra-Miocene movements occurred in two stages: Middle Badenian and late Sarmatian. In the Badenian, marine Lithothamnium limestones and sands were deposited along the contemporary inner edge of the SWEZ. Later movements led to the development of regular step faults, the intervening blocks of which were antithetically rotated. Sedimentation of the biogenic limestones took place on the structural benches formed in this way but the sandy and Lithothamnium-detrital sediments accumulated in lagoons and bays. In the Sarmatian, sedimentation was accompanied by tectonic movements. The crustal stress field probably had a large horizontal component at times, which is why the field was reoriented. This led to the development of dip-slip transverse faults. Also, older normal faults became redeveloped as thrusts. Rejuvenation of the fault steps and both longitudinal and transverse troughs gradually led to a relatively large-scale denivelation in the escarpment zone of the Carpathian Foredeep Basin. For some time afterwards, the SWEZ along the present inner scarp of Roztocze was tectonically controlled. A zone of barrier accumulation of products of sediment destruction was situated along the fault scarp of the outer edge. This line represents a marked transition from the movements in the Carpathian Foredeep Basin and those of the Roztocze (Jaroszewski, 1977; Krzywiec & Pietch, 1996). According to Baraniecka (1983), tectonic activity in the Quaternary was particularly intensive at the end of Otwock glaciation (Eburonian, Eopleistocene–Lindner *et al.*, 1998) and the beginning of the Celestynów interglacial (Waalian, Eopleistocene), during the Narew glaciation (Menapian) and the Ferdynandów interglacial (Cromerian complex – interstadial III–IV, Elsterian) as well as at the beginning of the Masovian interglacial (Holsteinian s.s.). According to Rühle (1976), in the Neopleistocene and the Holocene, the Roztocze underwent vertical movements of amplitude from +50 m to +100 m. Wyrzykowski (1971) and Kowalski & Liszkowski (1972) calculated that contemporary vertical movements in the escarpment zone are of the order of 1 mm a year. In this part of Roztocze, young posthumous tectonics are manifest in various hydrological phenomena (Malinowski, 1977; 1993). Deformations of river longitudinal profiles,

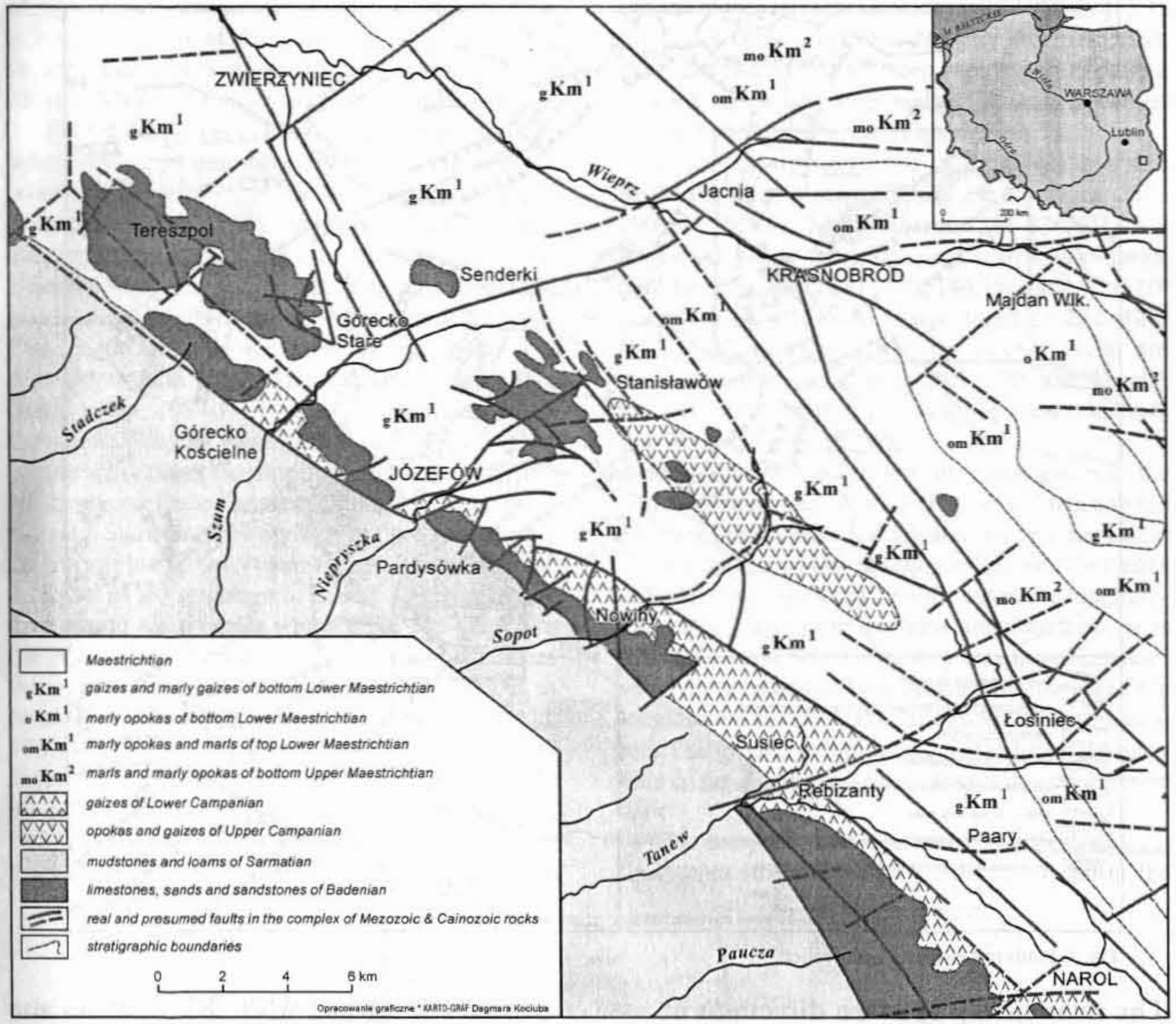

Fig. 2. Geology (without Quaternary deposits) (after Jaroszewski, 1977; Cieśliński, Kubica, Rzechowski, 1994; Kurkowski, 1994; Popielski, 1994)

changes in the development of river beds as well as in their character and the variable thicknesses of alluvia are all clear evidence for contemporary tectonic activity (Buraczyński, 1980/1981; 1984). A distinct differentiation of spatial vertical movements is still evident in this zone (Brzezińska-Wójcik, 1995; 1996; 1997b).

The escarpment zone is compartmentalised by transverse valleys which have been hollowed out along transverse and longitudinal faults, in tectonic troughs (Figs. 2, 3). The outer hills of Pardysówka and Nowiny, Padół Józefowa and the inner hills near Górniki Nowe, Górecko Stare and Majdan Nepryski are those areas where tectonic control of relief is most evident. The variable relief and inselberg-like character of the hills are associated with an uneven elevation of escarpment zone blocks and a variable erosional resistance of the Miocene rocks (Jaroszewski, 1977; 1994; Buraczyński, 1980/1981). Padół Józefowa was formed in the Badenian as a secondary tectonic unit in the antithetical thrust fault zone, which follows the main border fault of the Carpathian Foredeep Basin. In the Sarmatian, this trough was cut by transverse faults during a phase of East Carpathian movements. The Józefów and Górniki Nowe faults are two examples of this. The wide gap in the zone of the outer hills near Pardysówka is a result of this transverse fault activity (Jaroszewski, 1977) (Fig. 3).

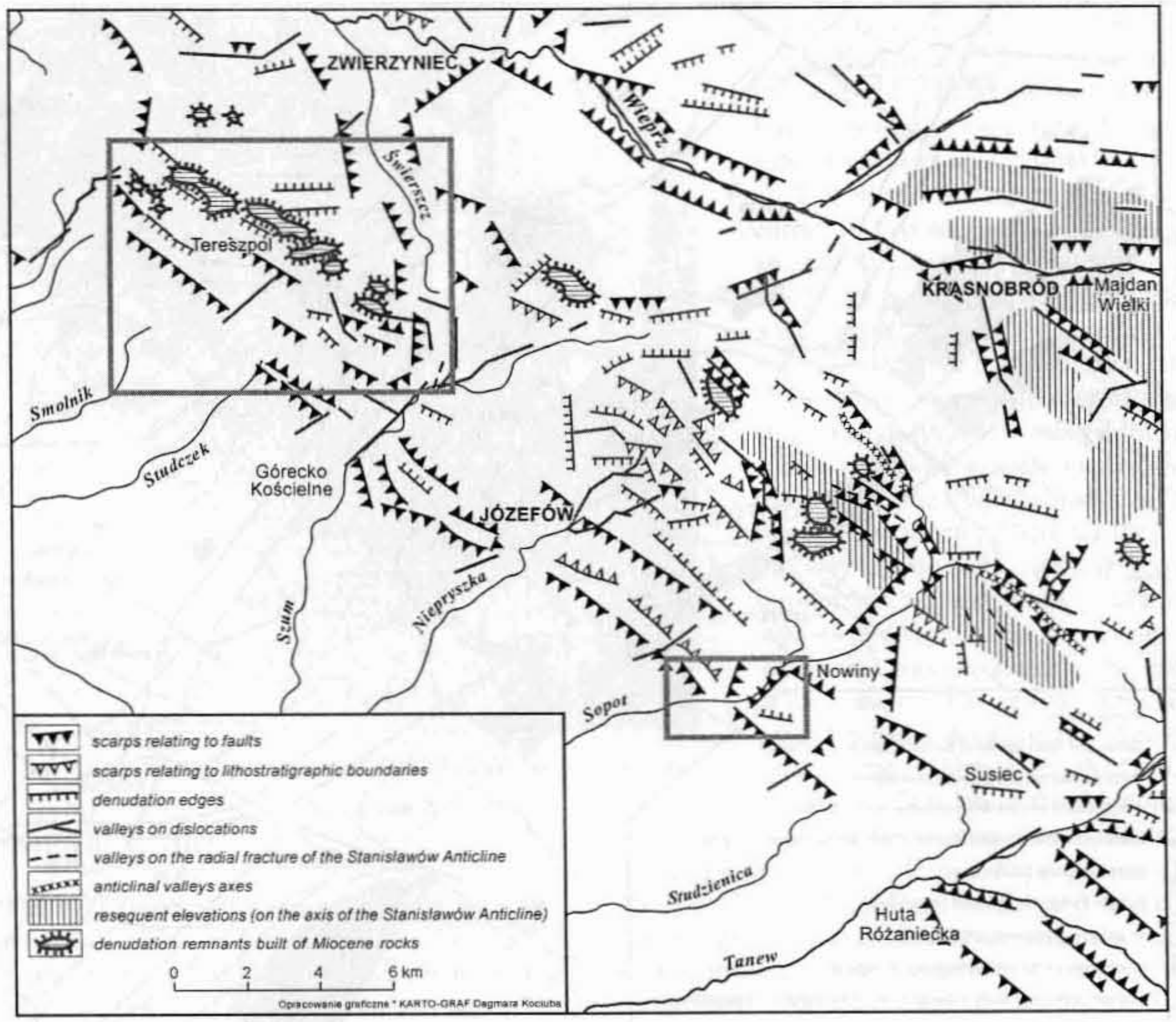

Fig. 3. Structural elements in the relief

The relationship between directions of valleys and scarps and tectonics of the Mesozoic complex

Polish geomorphological and geological textbooks have not devoted much attention to the influence of structural and tectonic elements of the basement on the first-order relief forms and only a few regional papers have discussed this problem (e.g. Kosmowska-Suffczyńska, 1998). However, in respect of the Roztocze, this inter-dependence has been the subject of geological and geomorphological study for many years (Łomnicki, 1898; Czyżewski, 1929; Pawłowski, 1938; Jahn, 1956; Maruszczak & Wilgat, 1956; Buraczyński, 1974; 1980/1981; Jaroszewski & Piątkowska, 1988; Harasimiuk, 1980; Brzezińska-Wójcik, 1996; 1997a).

The problem of the extent to which valley and scarp trends in the Roztocze relate to joint systems was first studied by Łomnicki (1898). He concluded that valleys and scarps of NW–SE trend were dominant. This was supported by Czyżewski (1929). Jahn (1956) demonstrated the presence of two fissure systems: NW–SE and WNW–ESE, patterns also evident in scarps and valley courses. He emphasised that, whereas the NW–SE trend is evident in the course of Tomaszowskie Roztocze southern scarp, some valleys, scarps and periclines have a WNW–ESE orientation. The steep rapids of the Tanew, Jeleń and Sopot also have a similar orientation (Chałubińska *et al.*, 1954). In similar studies by Buraczyński (1980/1981; 1984), three sets of joint fissures were identified, which were also identified in the trends of the morphological forms: 340° – close to the course of the south-west scarp; 70° – characteristic of the valleys which intersect this scarp and oblique to SWEZ – present in the courses of numerous valleys. According to Harasimiuk (1980), valleys of ENE orientation constitute over 30% of the total length of valleys in Roztocze and this is one of the principal geomorphological features of the region. In Tomaszowskie Roztocze, the number of valleys which trend 285–315° is greater; this is probably due to a small change of tectonic stress on the line of transverse faults in the vicinity of the Gorajec valley. According to Jaroszewski & Piątkowska (1988), the expression

of morphotectonic elements in the escarpment zone is a direct result of the presence of active linear structures, to which morphotectonic scarps of NW–SE and WNW–ESE orientation are related.

Recent detailed geological investigations in Roztocze have produced radically new interpretations concerning the relationship between relief and structural elements. The main relief forms of the SWEZ express the tectonic fragmentation of the Mesozoic and Cainozoic rock foundation. The tectonic activity took place intermittently from the Miocene to the Early Pleistocene and was accompanied by erosion and denudation (Jahn, 1956; Maruszczak & Wilgat, 1956; Buraczyński, 1980/1981; 1984; Harasimiuk, 1980; Brzezińska-Wójcik, 1996; 1997a).

Breach valleys developed in the zones of SW–NE transverse faults. Between Górecko Kościelne and Górecko Stare the narrow valley of the Szum forms a deep gorge in the escarpment zone of Roztocze (Figs. 2, 3). In its floor, gaizes of Lower Campanian age give rise to steep rapids which trend 305–325°. On the NW side of Brzezińska Góra, where it reaches the greatest gradient (12,5‰), the river has cut as much as 10 m into the outer hill zone (Buraczyński, 1980/1981). The Niepryszka valley intersects Padół Józefowa obliquely and crosses the outer edge of the SWEZ in the transverse fault zone (Jaroszewski, 1977). In the escarpment zone, the valley reveals the fracture in the profile of both the present floodplain and the higher terraces (Buraczyński, 1980/1981). In the Sopot Gorge, between Nowiny and Hamernia, there are two series of steep rapids: the higher in Lower Campanian gaizes and the lower in Badenian organodetrital limestones (Figs. 2, 3, 4, 5).

In the escarpment zone of the Tomaszowskie Roztocze, three topolineaments are dominant: 281–290° (24,7%), 51–70° (19,2%) and 311–330° (11,2%). In respect of the morphological scarps, two trends may be identified: 301–330° (44,7%) and 71–110° (33,9%). The tectonic scarps trend at 291–320° (61,2%). The azimuths of the known faults are concentrated in two ranges: 301–320° and 51–60°; the 341–360° trend is poorly developed (Brzezińska-Wójcik, 1996; 1997a).

The joints in the Lower Campanian gaizes in the Sopot channel near Nowiny (Fig. 4) and those in the Lower Maestrichtian gaizes and marly gaizes near Tereszpol (Fig. 6) are closely parallel with the trends of faults and main scarps. As the extensive longitudinal, orthogonal joint systems are dominant, it is reasonable to conclude that they may have been activated quite recently; these parallel the courses of the longitudinal faults. A similar system of longitudinal joint fissures has determined the orientation the inner hills of the Roztocze Szczebrzeszyńskie escarpment zone.

The comparison of joint trends in Lithothamnium limestones in the Tereszpol Hills and those in the

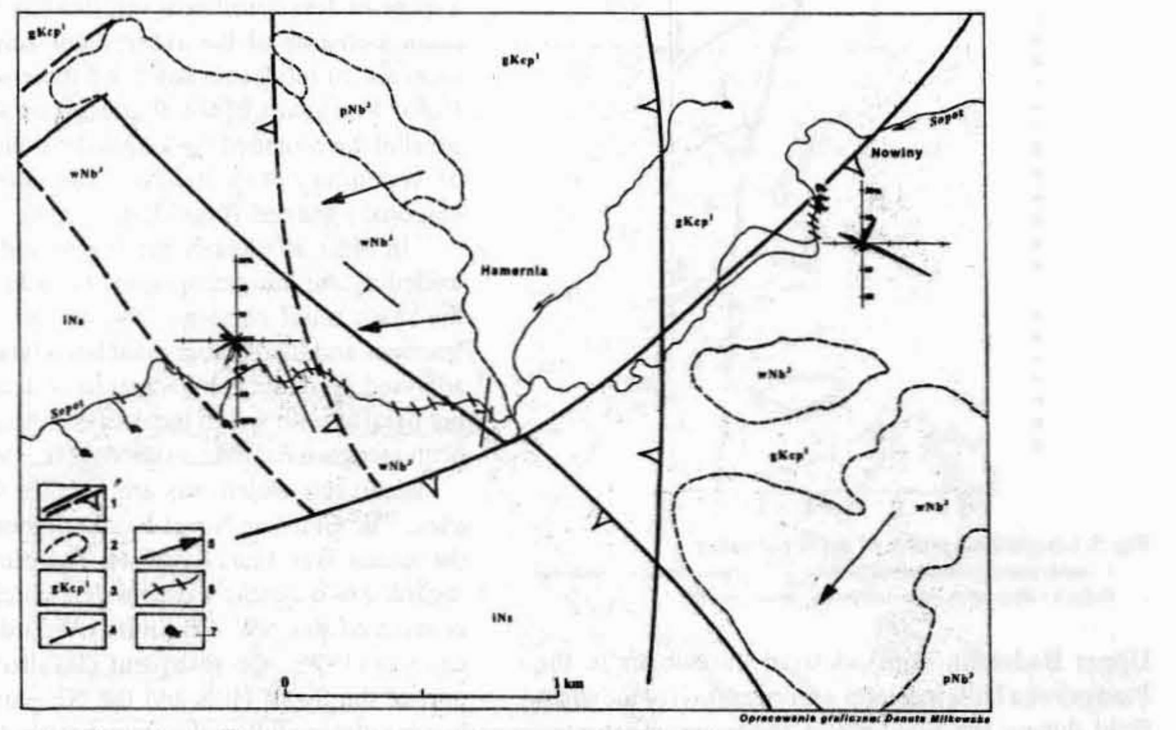

Fig. 4. The geology of the Sopot breach valley (after Jaroszewski, 1977; Cieśliński, Kubica, Rzechowski, 1994; Kurkowski, 1994; Popielski, 1994)

1 – real and presumed faults; 2 – stratigraphic boundaries; 3 – $gKcp^1$ – gaizes of Lower Campanian, pNb^3 – sands of Upper Badenian, wNb^3 – reef, detritic and algal limestones and sandstones of Upper Badenian, iNs – clays and mudstones with sandy bands (Krakowieckie loams) of the Sarmatian; 4 – strike and dip of beds; 5 – direction of sediment transport interpreted from cross bedding; 6 – steep rapids in the river bed; 7 – major springs

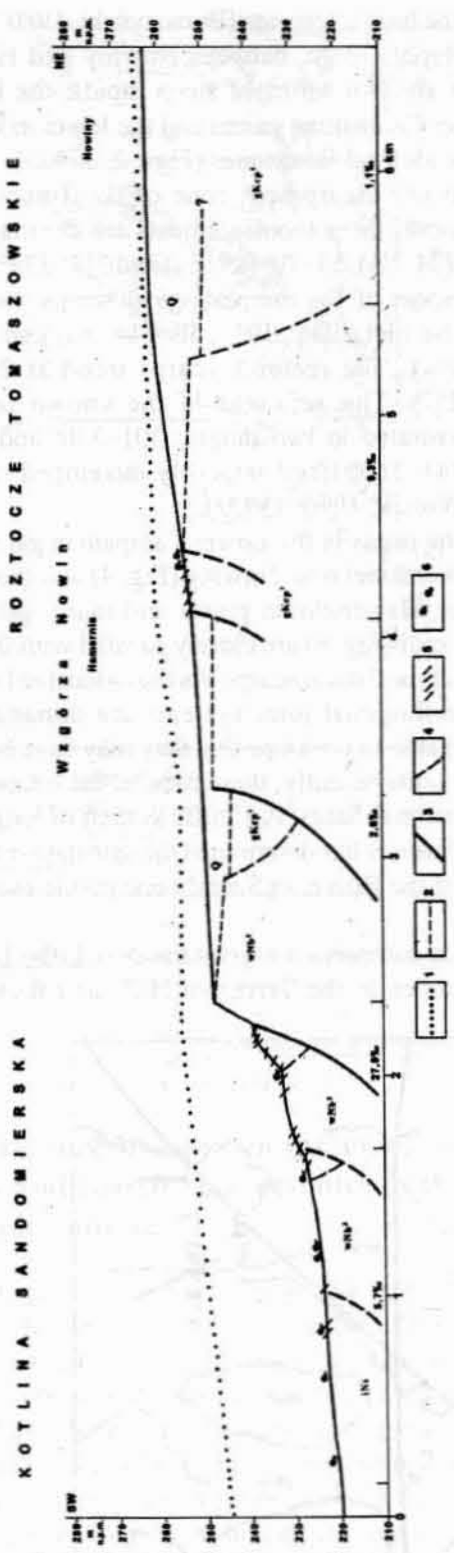

Fig. 5. Longitudinal profile of the Sopot valley
1 – sandy plain; 2 – stratigraphic boundaries; 3 – known faults; 4 – presumed faults; 5 – steep rapids in the river bed; 6 – major springs

Upper Badenian organodetrital limestones in the Pardysówka Hills indicates a reorientation of the stress field during the Miocene in the escarpment zone between Nowiny and Tereszpol (Figs. 3, 4, 6). The orthogonal system is predominant in the whole of this zone. The longitudinal joint fissures parallel the fractures in the Lower Maestrichtian gaizes but the transverse fissures of the Badenian Lithothamnium limestones are not parallel with those in the Maestrichtian rocks. The longitudinal and transverse orthogonal fractures in the Badenian rocks are equally represented in field surveys. Therefore, no particular trend in the fracture system is evident. The orthogonal system of joints in the Badenian limestones has determined the form of inner inselberg hills in the Tereszpol region.

In the Upper Badenian organodetrital limestones of the Pardysówka Hills, the orthogonal fracture system is accompanied by an oblique set, in which the transverse trend (61–90°) is dominant; this is also present in the Lithothamnium limestones of the Tereszpol region. The existence of two overlapping joint systems in the Upper Badenian organodetrital limestones accounts for the irregularity of the lower steep rapids in the Sopot channel and the great variation in the height of the rapids is attributed to the generally massive form of the limestones. Diagonal, transverse joints are significantly responsible for many of the features of the Sopot Gorge area.

There is a clear correlation of changes between the trends of the major relief elements and those of joint sets. In the southern part of the escarpment zone (the Pardysówka Hills) NNE–SSW joints are dominant and these are parallel with the scarps, whereas to the NW of Tereszpol they are replaced by a more-or-less meridional set; this has fashioned the main elements of the escarpment zone. The main elements of relief (the outer and inner scarps and the Padół Józefowa) of the Roztocze escarpment zone parallel the course of the longitudinal faults and those of secondary importance – the orthogonal and diagonal joint sets (Figs. 3, 4, 6, 7, 8).

In order to identify the scarps and valleys controlled by the lithostratigraphic boundaries, trends of the main relief elements, the course of faults and fractures and lithostratigraphic boundaries, have been analysed. Numerous short denudation scarps which are not parallel with any of the dominant trends have also been recognised (Brzezińska-Wójcik, 1997a) (Fig. 3).

Some relief elements are parallel with the fold axes. The Ciotusza Nowa-Kunki depression follows the Jacnia-Werchrata Syncline. Therefore, it may be regarded as a synclinal depression which follows the courses of the NW–SE faults. According to Buraczyński (1995), the resequent elevations in the NE part of the Sopot Hills and the NE part of the Grabowica Plateau follow the Stanisławów Anticline. The valleys between Ciotusza Nowa and Grabowica and Długi Kąt and Ciotusza Nowa follow the radial joint fissures of Stanisławów Anticline (Brzezińska-Wójcik, 1997a) (Figs. 2, 3).

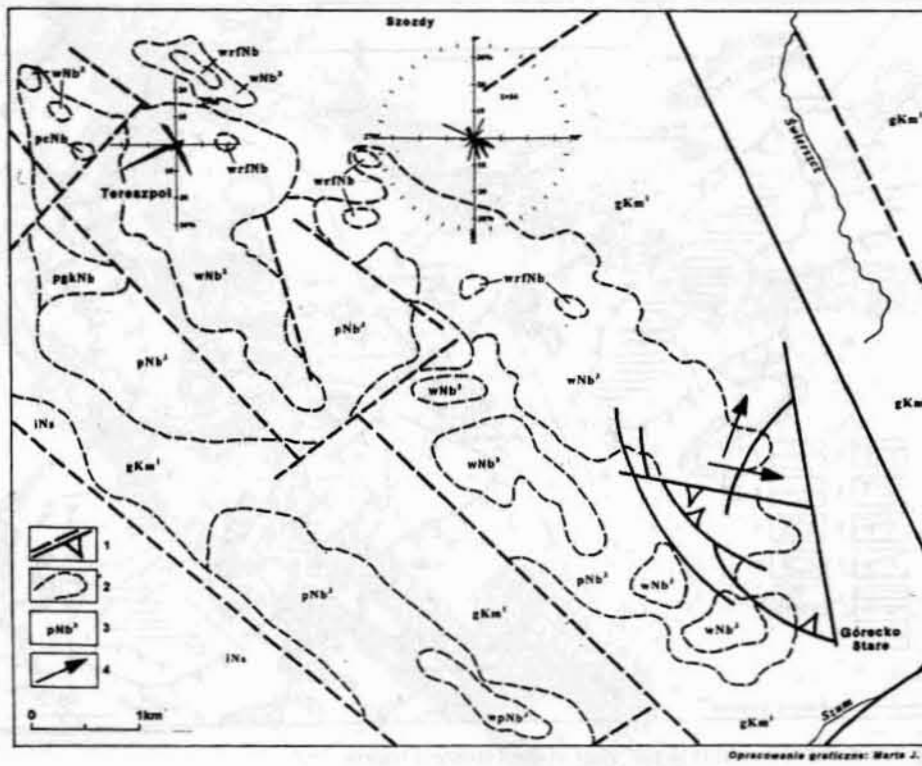

Fig. 6. The geology of the Tereszpol region (after Jaroszewski, 1977; Cieśliński, Kubica, Rzechowski, 1994; Kurkowski, 1994; Popielski, 1994)
1 – known and presumed faults; 2 – stratigraphic boundaries; 3 – gKm^1 – gaizes and marly gaizes of Lower Maestrichtian, pgkNb – glauconitic sands of the Badenian, pcNb – sandstones of the Badenian, wrfNb – reef limestones of the Badenian, $wpNb^2$ – organodetrital limestones of the border zone of the Badenian, pNb^2 – quartzic and glauconitic sands of Upper Badenian, wNb^2 – Lithothamnium limestones of Upper Badenian, iNs – clays and mudstones with sandy bands (Krakowieckie loams) of the Sarmatian; 4 – direction of sediment transport interpreted from cross bedding

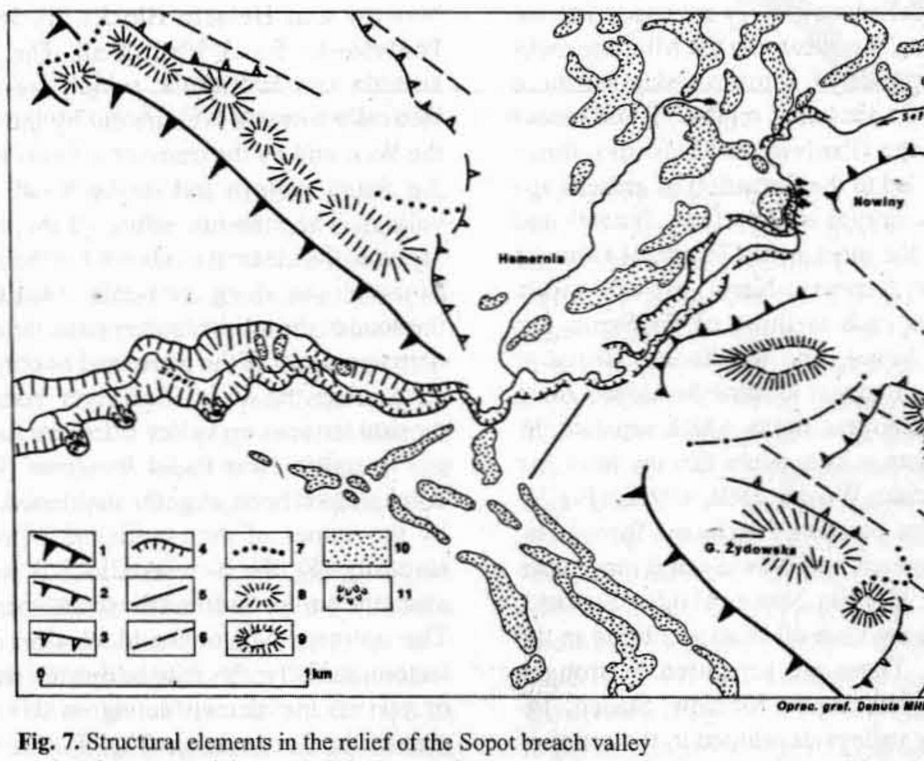

Fig. 7. Structural elements in the relief of the Sopot breach valley
1 – primary scarps relating to main faults; 2 – secondary scarps relating to faults; 3 – scarps relating to lithostratigraphic boundaries; 4 – denudation scarps; 5 – valleys according to faults; 6 – valleys relating to lithostratigraphic boundaries; 7 – denudation valleys; 8 – residual hills relating to joint fissures; 9 – residual hills relating to joint fissures and lithostratigraphic boundaries; 10 – dunes; 11 – landslides

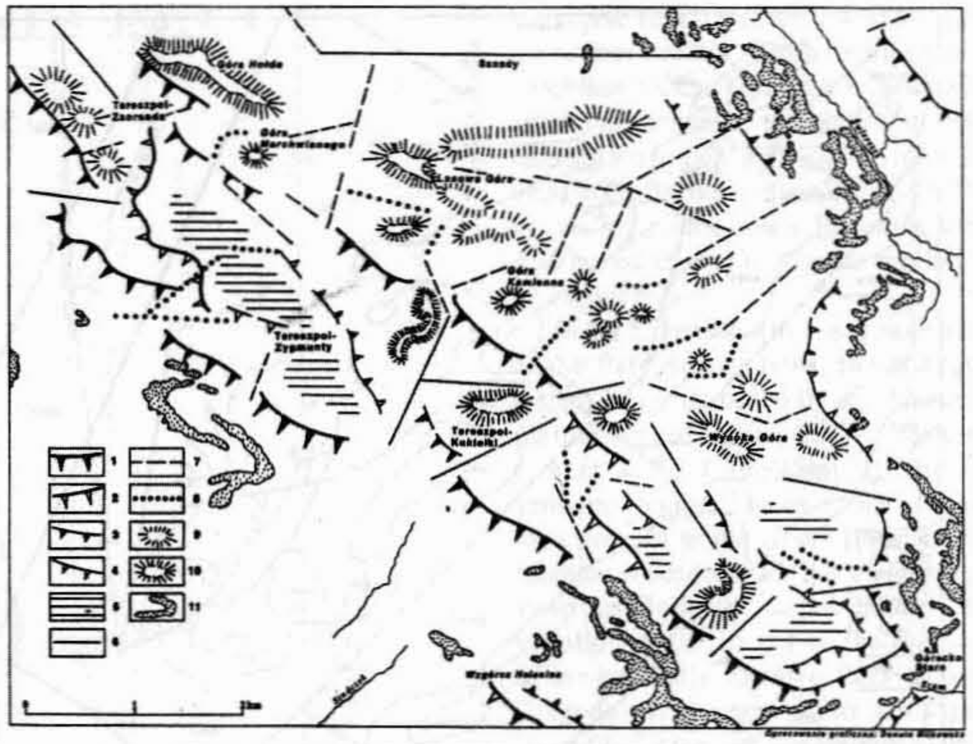

Fig. 8. Structural elements in the relief of the Tereszpol region
1 – primary scarps relating to main faults; 2 – secondary scarps relating to faults; 3 – scarps relating to lithostratigraphic boundaries; 4 – denudation scarps; 5 – structural surface; 6 – valleys relating to faults; 7 – valleys relating to lithostratigraphic boundaries; 8 – denudation valleys; 9 – residual hills relating to joint fissures; 10 – residual hills relating to joint fissures and lithostratigraphic boundaries; 11 – dunes

Morphotectonics of the escarpment zone

When the morphometric coefficients of drainage basin shape (R_e) and of the mountain-front sinuosity (S) of Bull and McFadden (1977) are applied to the new geological data, it is clear that the Miocene rocks of the escarpment zone of Tomaszowskie Roztocze display features of a tensional regime. Tilted blocks along the outer edge (Pardysówka, Nowiny), thrust faults which have led to the formation of grabens and half-grabens (Zwierzyniec, Józefów, Tanew) and uplifted blocks in the inner zone (Tereszpol-Górecko Stare and Majdan Nepryski-Narol) are all readily identified. Valleys such as those of the Szum, the Niepryszka, the Sopot, and the Tanew Gorge at Łosiniecki Potok all appear to have developed along the lines of the transverse faults which separate the blocks. Further, there is little doubt that the faults are still active (Brzezińska-Wójcik, 1996; 1997b) (Fig. 9).

Antithetic outer blocks of Helacin, Tarnowola, Pardysówka, Hamernia and Nowiny and inner ones of Górecko Stare, Górniki Nowe, Majdan Sopocki, Grabowica and Paary have all been identified in the escarpment zone. These are separated by troughs which trend NW–SE (Sopot, Józefów, Susiec, Tanew) as well as by valleys developed in the zones of the SW–NE faults (Szozdy-Tereszpol Zygmunty, Florianka, Szum, Niepryszka, Sopot, Tanew with Jeleń and Łosiniecki Potok) (Figs. 2, 9). These blocks partially follow the morphological ones which were first described by Harasimiuk (1980).

In the outer hills zone, the Tarnowola and Hamernia Blocks are the most strongly uplifted. The Nowiny and Helacin Blocks are less so and the Pardysówka Block least of all. The blocks of Tarnowola and Hamernia, which are inclined antithetically towards NE, are cut by the border fault in the West and by the transverse faults in the North (in the Szum valley) and in the South (in the Sopot valley). The sinuous nature of the outer scarp represents the clearest evidence for the intensive uplift of the blocks along the border fault (311–320°). In the zone of the border fault system, the deeply incised, narrow valleys of the Szum and Sopot, both of which have steep rapids in their river beds, and narrow erosion terraces on valley sides, are further evidence of this uplift. Near Padół Józefowa (Figs. 2, 9), the blocks have been slightly depressed. As indicated by the values of the coefficient of mountain-front sinuosity (*S*), the Nowiny Block is weakly uplifted along the border fault and the transverse fault of Sopot. The northern part of the block does not show any tectonic activity; this may be due to a superimposition of various movements acting on this block and the area of the Sopot Gorge (Fig. 9). The steep gradient of the river channel (up to 27,9‰) (Fig. 5) and three systems of erosion terraces represent firm evidence for uplift of the Sopot breach valley (Buraczyński,

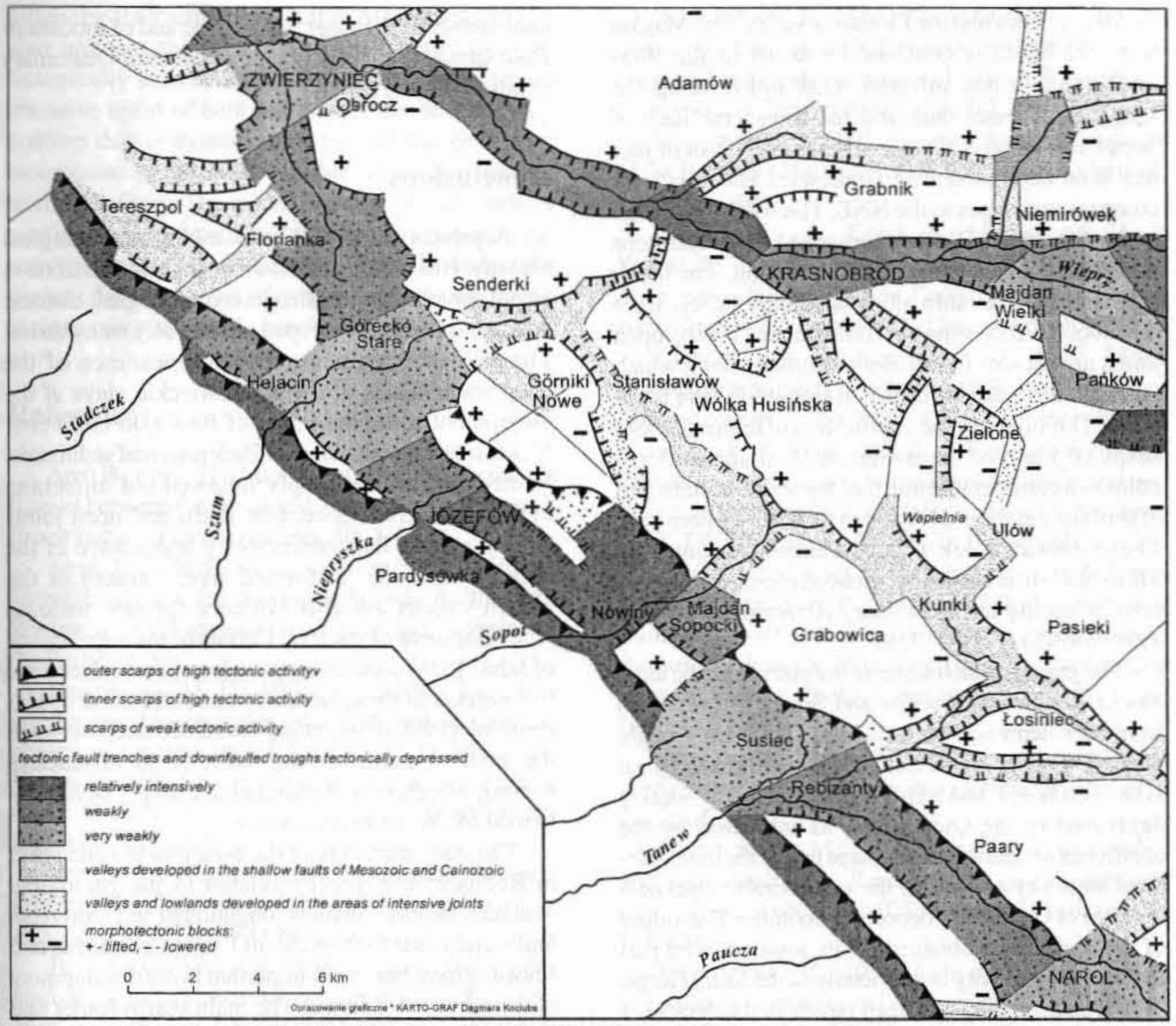

Fig. 9. Morphotectonics of the SWEZ (after: Brzezińska-Wójcik, 1996, modified)

1980/1981). The Pardysówka Block, which is a composite of several smaller blocks, has undergone only limited uplift. The smaller blocks have been rotated antithetically and translocated along transverse faults. The Niepryszka valley divides this block into an inactive northern part and a southern, where there has been intense activity. The coefficient of the mountain-front sinuosity (*S*) suggests considerable activity in the border dislocation and uneven and limited uplift of the blocks (Brzezińska-Wójcik, 1996; 1997b) (Figs. 2, 3, 9).

In the inner blocks zone, that of Górniki Nowe is the most strongly uplifted whereas the Górecko Stare, Majdan Sopocki and Grabowica Blocks have undergone only limited uplift. The Górniki Nowe Block is one of the better understood structures, both in terms of its geological foundation and its tectonic history. In the North it is intersected by the Szum SW–NE transverse fault and also by the antithetic NW–SE oriented faults (Jaroszewski, 1977). The complex geological structure of the block is reflected in its relief. Valleys have developed along the faults there; the faults separate the block into western and eastern structural units. The coefficients of drainage basin shape (R_e) and of mountain-front sinuosity (*S*) indicate that different parts of the block have been affected by movements of different intensity and direction. The valleys which divide the block are depressed whereas the northern edge of the western part of the block, on the transverse fault line, is strongly uplifted. The Szum valley has evidently suffered tectonic depression in the Quaternary. The eastern edge of the block exhibits little evidence of tectonic uplift. The complicated geological structure of the Górniki Nowe Block appears to reflect a variable tectonic activity in the Quaternary (Figs. 2, 3, 9). The Górecko Stare Block is cut by a system of faults (Jaroszewski, 1977) and exhibits only limited tectonic activity. The coefficient of the mountain-front sinuosity (*S*) indicates only weak uplift along the fault which separates it from

Padół Józefowa and the Florianka valley. The Majdan Sopocki Block is confined by faults in the West and South. It has suffered weak uplift along the longitudinal inner fault and the transverse fault of Sopot and Długi Kąt whereas the north-eastern part has been depressed. The Grabowica Block is very compact and slopes to the NNE. The south-west edge of the Grabowica Block is composed of several steps which descend to the Susiec Depression. The block is cut by NW–SE faults along which dry valleys have developed. According to Harasimiuk (1980), open joints are present in the chalk bedrock, along which vertical translocations of 5–7 m amplitude have taken place. The values of the coefficients of drainage basin shape (R_e) and of the mountain-front sinuosity (S) point to a considerable uplift of the south-eastern part of the block and a depression in its north-eastern part. The Grabowica Block suffered antithetic rotation from SE to NW, as is shown by measurements of tectonic activity during the Quaternary (Brzezińska-Wójcik, 1996; 1997b) (Figs. 2, 3, 9).

The grabens which separate the outer from the inner blocks (the Szum, Józefów and Susiec Depressions) have been depressed only slightly. The Szum Trough, which is founded on the tectonic lines of the orthogonal system (NW–SE and NE–SW), was generally weakly depressed in the Quaternary, as indicated by the coefficient of drainage basin shape and of the mountain-front sinuosity as well as the considerable thickness (>50 m) of Quaternary deposits it contains. The values of the coefficients obtained for its southern-west part indicate great activity in the vicinity of the Szum Gorge. This is indicated by the steep rapids in its channel, a deep incision (up to 10 m), a steep gradient (13,3 ‰) and a convex profile of the raised terrace which contrasts to a concave profile in the floodplain terrace (Buraczyński, 1980/1981). The Susiec Depression is also founded on the faults of the orthogonal system; these took place in the Sarmatian and relate to a phase of the East Carpathian movements. They created an hiatus in the Miocene succession. The coefficient of mountain-front sinuosity (S) indicates a considerable activity along the northern and eastern scarps as well as pronounced depression below these scarps. Padół Józefowa is an example of a second-order fault trough which was developed in the zone of reverse faults and associated antithetic step faults. An antithetic rotation is manifested by the depression of the trough towards the NE and an increase in the thickness of Quaternary deposits in this direction. The western part of Padół Józefowa has suffered only limited depression; this is presumably due to the antithetic uplift of the outer hills. The Majdan Nepryski Block in the eastern part of Padół Józefowa has suffered weak antithetic uplift along its western edge; this is shown by the values of the coefficients of drainage basin shape and of mountain-front sinuosity as well as the thin cover of Quaternary deposits (Figs. 2, 3, 9).

Conclusions

At present, the SWEZ has a striking morphological identity. But there is much evidence that this zone is an old geological and paleogeomorphological element which has been redeveloped tectonically many times. The evidence includes: the disappearance of the deep water facies of the Krakowieckie clays at the escarpment zone; the traces of Badenian cliffs near Józefów and a wide range of Badenian reef sediments. Neotectonic effects simply followed old influences in the basement. Hence, new faults and open joints largely control the contemporary appearance of the escarpment zone. Deformed river terraces in the breach valleys are also evidence for new tectonic redevelopment of the area. Certainly, the conclusions of Jahn (1956) concerning postglacial vertical tectonic movements in the escarpment zone and those of Harasimiuk (1980) concerning the relationship between the relief elements and the nature of the disjunctive tectonic structure in Roztocze have amply been confirmed by recent investigations.

The main elements of the escarpment zone relief in Roztocze are directly related to the geological structure. Normal, shallow longitudinal and transverse faults and joints in the rocks of Upper Cretaceous and Miocene have been very important in the development of the main relief forms. The main scarps (outer and inner), the valleys (e.g. the Tanew valley) and the depressions (Józefów, Stanisławów–Kunki) have been developed in the zones of longitudinal faults or Tertiary fault troughs. The valleys of the Szum, Niepryszka, Sopot and Potok Łosiniecki and certain scarps appear to follow transverse faults. In the escarpment zone, an orthogonal joint system is predominant. Joints of the diagonal system are of considerable importance in the development of secondary forms of the border zone relief, particularly in the Tereszpol region of the escarpment zone.

The distribution and trends of topolineaments are a function of differentiated neotectonic movements on a regional scale: this supports earlier conclusions based on hydrological data (Liszkowski, 1975; Malinowski, 1977).

The very clear correlations between relief and various elements of geological structure in Roztocze, particularly in its south-west escarpment zone, imply that this area is particularly suitable for analysing these relationships by cartometric methods (Brzezińska-Wójcik, 1996; 1997b). Morphometric calculations, following the methods of Bull & McFadden (1977), also indicate that the border fault system is still tectonically active; also that there has been recent intensive uplift of both inner and outer scarps. They confirm that, in Roztocze, the zone of the south-west escarpment is the most variable in terms of recent tectonic activity. The values of morphometric indices confirm earlier views about the contemporary tectonic activity of this part of Roztocze. They also indicate a distinct differentiation of tectonic activity within the various morphotectonic blocks.

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