STUDIA GEOMORPHOLOGICA CARPATHO-BALCANICA
VOL. XXXIV KRAKÓW 2000 PL ISSN 0081-6434
LANDFORM EVOLUTION IN EUROPEAN MOUNTAINS ISBN 83-86726-96-2

A R T I C L E S

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MORPHOTECTONICS OF THE OUTER EAST CARPATHIANS OF POLAND IN THE LIGHT OF CARTOMETRIC STUDIES

Abstract. Results of geomorphological mapping in the Polish Eastern Carpathians, combined with an analysis of morphometric indices, maps of envelopping surfaces and topolineaments identified on digital elevation models and dense contour maps indicate the presence of long and narrow zones, aligned subparallel to the structural grain of the area and showing alternately uplifting and subsiding tendencies. Localised uplift of frontal thrusts and larger slices is interpreted as resulting from recent relaxation of horizontal stresses accumulated within the overthrust flysch nappes. Such zones started to form during postorogenic collapse of the Outer Carpathian belt, most probably in late Miocene–Pliocene times. The uplift itself is considered to be a byproduct of relaxation of remnant horizontal stresses built up during Late Neogene thrusting.

Key words: neotectonics, morphotectonics, topolineaments, digital elevation models, Outer East Carpathians, Poland

Motto:
"A feature common to many geomorphic systems is that in areas with the highest rate of uplift, not only are the elevations of landforms greater, but the number of episodic events recorded is greater."

E. A. Keller and N. Pinter
(1996, p. 57)

INTRODUCTION

The Outer Carpathians of Poland represent a typical fold-and-thrust belt that was affected by postorogenic uplift coupled with relaxation of some remnant horizontal stresses. Recent studies indicate that the generally modest Bouguer gravity anomalies point to nonisostatic processes causing the postflexural uplift, ranging from 250 m to 550 m (Zoetemeijer et al. 1999). Recent thrust activity causing local uplift has also been documented in the westernmost part of the West Carpathian foredeep (cf. Leichmann and Hejl 1996).

Numerous lines of evidence provided, i.a. by well-bore breakouts, deformation of oil industry well cores, structural data and geomorphic studies, all indicate Late Cenozoic tectonic activity of the Polish Outer Carpathians. The Pliocene–Quaternary ("neotectonic") activity resulted in deformation of geomorphic surfaces of the early Pliocene, late Pliocene and early Quaternary ages, as well as in upwarping, downwarping and/or faulting of straths of Quaternary fluvial terraces (cf. review papers by Zuchiewicz 1995, 1998c). The term "neotectonics" is referred to in this paper according to a definition given by C. M. A. Şengör et al. (1985), stating that neotectonic period is "...the time that elapsed since the last major whole-scale tectonic reorganisation".

The scope of this paper is to review several pieces of cartometric and morphotectonic research on diversified young tectonic activity in the eastern segment of the Polish Outer Carpathians. This approach complements traditional geomorphic study of mapping and landform description.

The study area has a relatively good coverage by detailed geological maps and was the locus of repeated geomorphic and neotectonic investigations by numerous earth scientists. Nevertheless, the neotectonic history of that portion of the Carpathian belt still remains to be reconstructed.

GEOLOGICAL SETTING

The late Palaeogene to Miocene history of the Carpathians is related to the change from collision to strike-slip faulting, surface uplift and sedimentary basin formation (Decker and Peresson 1996). The Outer Carpathian belt was formed as an accretionary prism during the southward-directed subduction of the European plate under Alcapa (Pescatore and Ślączka 1984; Oszczypko and Żytko 1987; Tomek and Hall 1993; Zoetemeijer et al. 1999; and references cited therein), resulting in the NW-directed shortening, followed by major rotation of either the regional stress field (Aleksandrowski 1985; Decker and Peresson 1996; Decker et al. 1997; Zuchiewicz 1998c) or the belt itself (Márton et al. 1999). This rotation gave rise to the NE-directed shortening (Decker et al. 1999), and was postdated in Late Neogene times by regional collapse associated with normal faulting (Decker et al. 1997; Zuchiewicz and Tokarski 2000).

The study area is composed of a number of imbricated thrust sheets (Figs 1, 2), emplaced between the late Oligocene and the end of the Sarmatian (Roca et al. 1995; Oszczypko 1996; and references therein). These sheets are composed of Lower Cretaceous through Miocene flysch strata of variable thickness and competence (Książkiewicz 1977; Ślą-

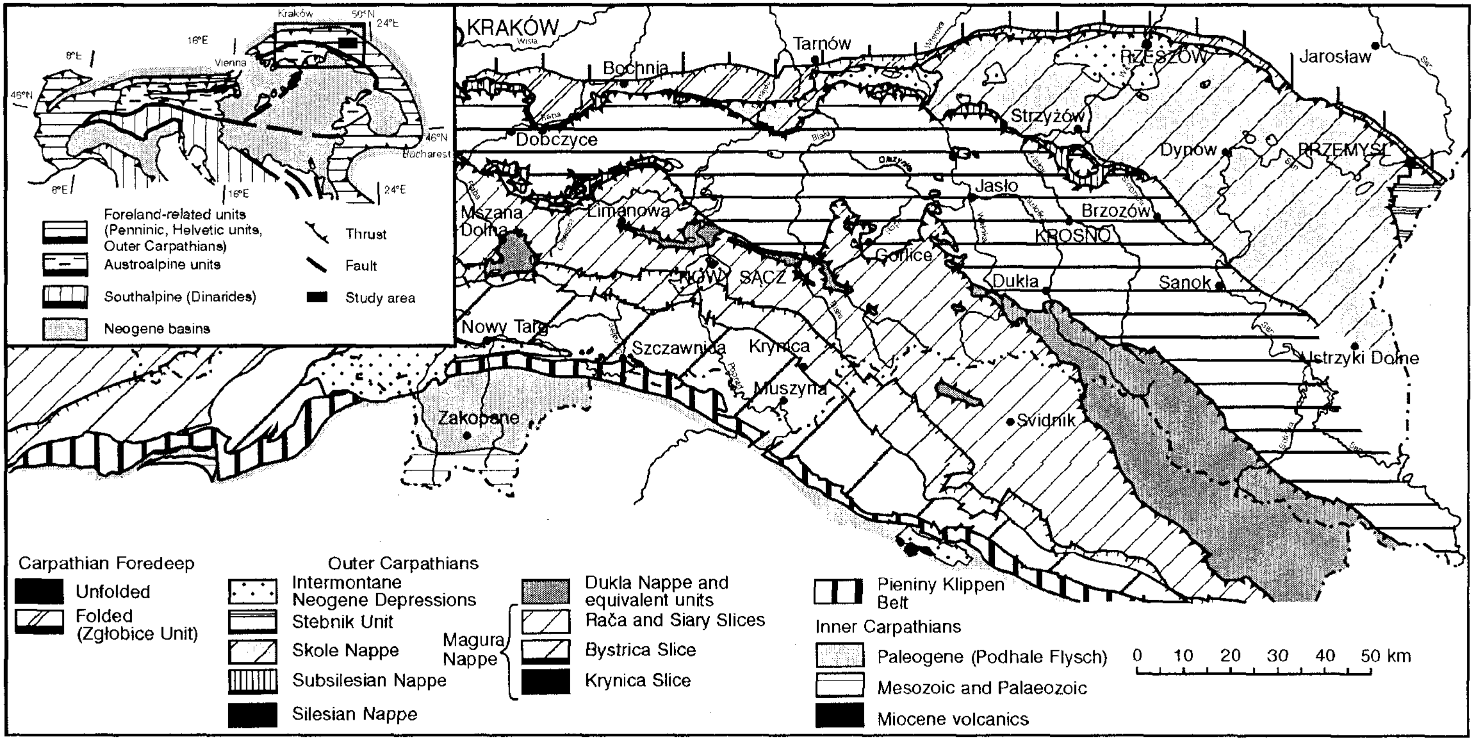

Fig. 1. Geological sketch of the Northern Carpathians showing location of the study area (based on Żytko et al. 1989). Inset map illustrates structural subdivision of the Carpatho-Pannonian region (modified from Neubauer et al. 1997)

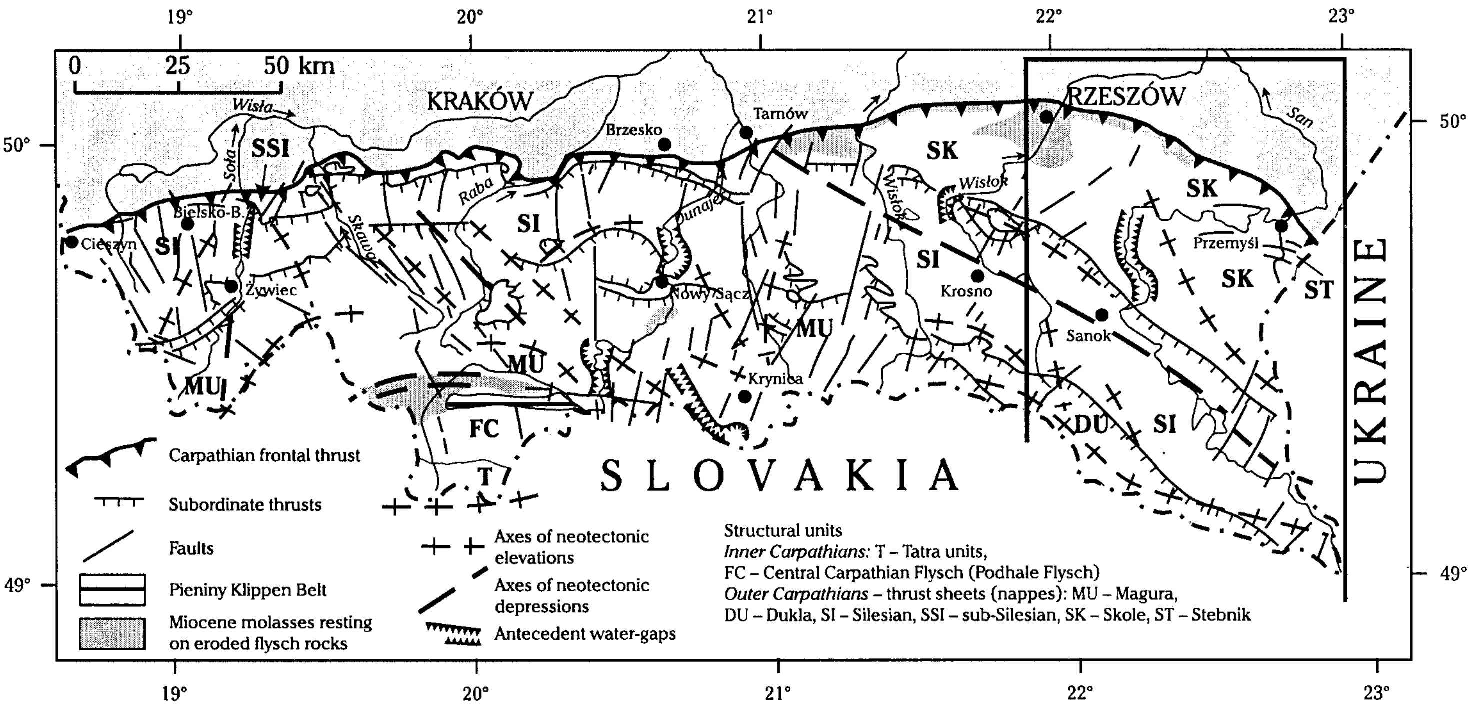

Fig. 2. Neotectonic sketch of the Polish Carpathians (based on Książkiewicz 1977, and Zuchiewicz 1995). The study area is boxed

czkaand Żytko 1979; Gucik et al. 1980; Ślączka and Kaminski 1998). Thin-bedded turbidites are strongly deformed by tight folds and are included into a number of imbricated slices locally forming antiformal stacks, whereas thick-bedded turbidites are less deformed and are accreted in slightly imbricated thrust sheets (Roca et al. 1995). The most extensive is the Silesian Nappe, overthrust by the Dukla Nappe from the SW, and thrust itself upon the Skole Nappe in the NE. The latter is thrust over the Stebnik Nappe in the NE and the Zgłobice Unit (composed of folded Miocene molasses) in the north. Both thrust faults and map-scale folds within all these units trend predominantly NW–SE and are cut by strike-slip faults orientated NE–SW to NNE–SSW, subordinately WNW–ESE and N–S (Figs 1, 3).

GEOMORPHIC SETTING

Different types of relief in the study area are portrayed in Fig. 4. The southern part, located upon flysch sequences of the Dukla Nappe and Fore-Dukla Zone, is dominated by middle mountain massifs, surrounded by low mountains and high to middle foothills with traces of early and late Pliocene planation surfaces. Middle to high foothills and low mountains prevail also in the Skole Nappe area, whereas the Central Carpathian Depression located within the Silesian Nappe is a vast, relatively low area, occupied by low foothills and high intramontane basins with early Quaternary planation surfaces.

The Carpathian frontal thrust is not expressed in the topography. In contrast, the well-marked escarpment is located farther north, on the northern periphery of recently uplifted plateaux which are built up of Miocene molasses covered by Elsterian sediments and upper Pleistocene loesses (Starkel 1972, 1980; Laskowska-Wysoczańska 1995).

It is important to note that the NW-orientated array of depressions associated with the Central Carpathian Depression is largely composed of thick-bedded flysch sandstones (Figs 3, 4) which, farther south, build highly elevated mountain ranges of the High Bieszczady Mts. On the other hand, the southern part of the Skole Nappe, composed of moderately to poorly resistant flysch strata (Fig. 3), is a topographically well expressed low mountain terrain, rising upon the Central Carpathian Depression. These gross features of topography do not appear to be lithologically controlled, probably due to post-orogenic uplift. Smaller-scale landforms, in turn, are largely influenced by lithological properties of the bedrock. This is why a number of earth scientists considered this area particularly suitable for mapping neotectonic structures, which are usually arranged subparallel to the structural grain of the region (Klimaszewski 1965; Starkel 1965, 1972, 1980; Henkiel 1977, 1978; Zuchiewicz 1987, 1995, 1998a, 1998c; and references therein).

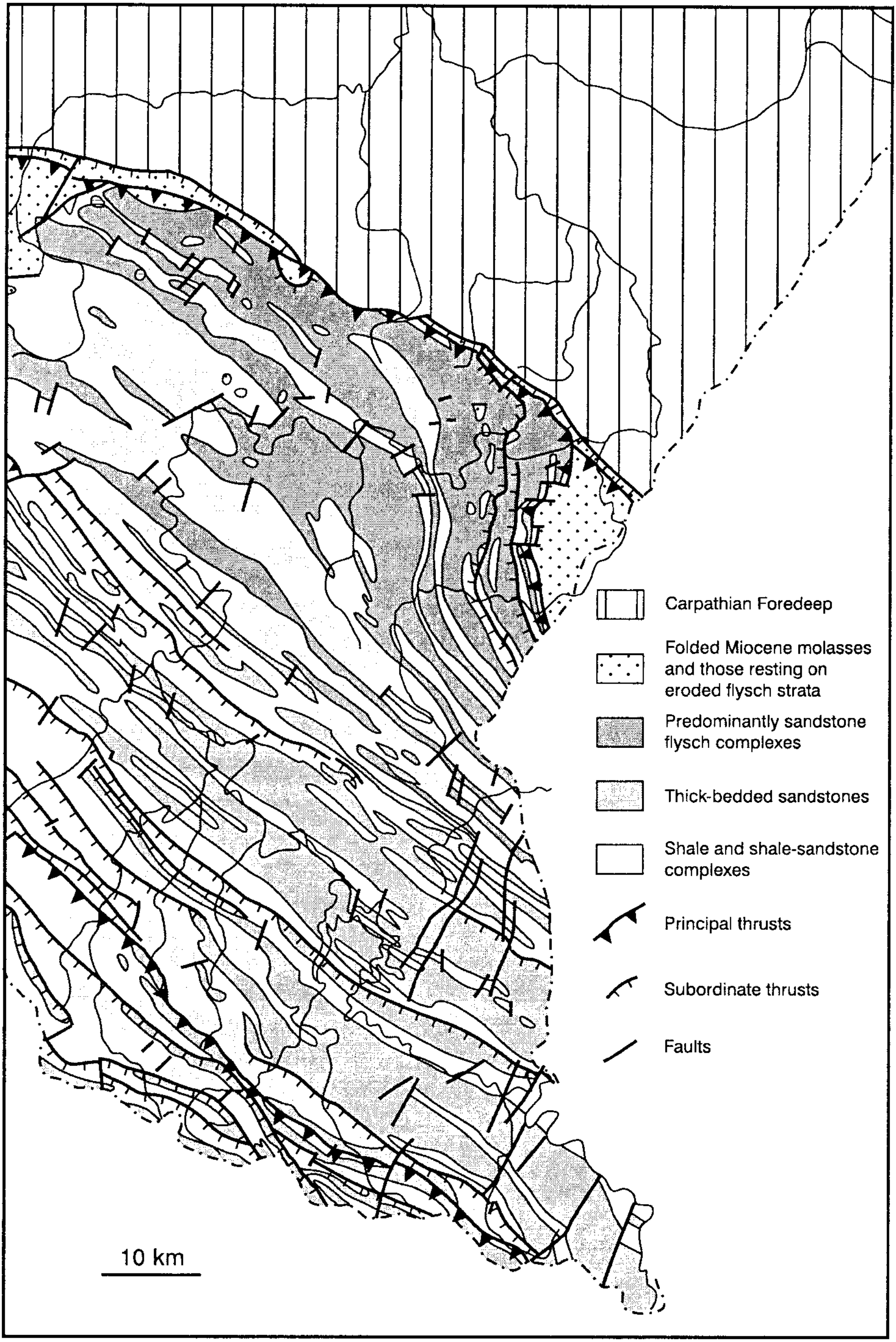

Fig. 3. Geological map of the eastern segment of the Polish Carpathians showing rock complexes of contrasting resistance to erosion (based on Żytko et al. 1989)

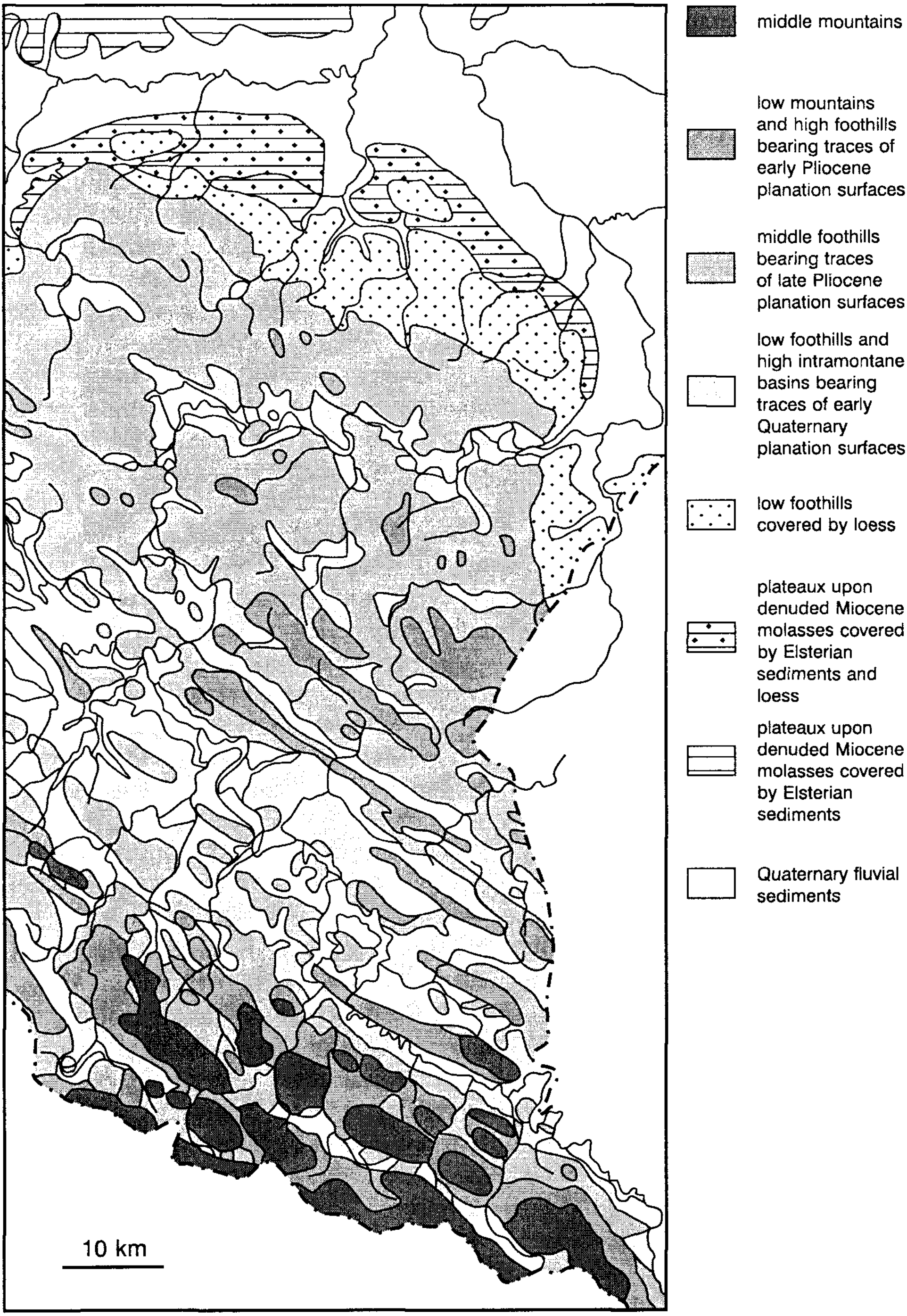

Fig. 4. Types of relief *in* the eastern segment of the Polish Carpathians (based on Starkel 1980; simplified)

GEOMORPHIC EVIDENCE OF YOUNG TECTONIC ACTIVITY

Traditional geomorphological and structural-geomorphological studies in the Carpathians were aimed at the reconstruction of long-term landform development, by means of mapping the ridge and valley patterns, planation surfaces and fluvial terraces. These reconstructions are recently becoming more and more supplemented by palaeoclimatic, palaeohydrological, palaeontological, palaeoecological, archaeological, minero-petrographic and geophysical techniques.

The studies focusing on deformations of planation surfaces and fluvial terraces make it possible to distinguish a number of elevated and subsided structures, of relatively small widths (15–20 km) and subparallel arrangement with respect to the strike of principal thrusts and imbricated folds, which suggests that they originated due to Pliocene–Quaternary relaxation of remnant horizontal movements within the flysch nappes (Zuchiewicz 1995, 1998c).

RATES OF EROSION: A PROXY FOR YOUNG UPLIFT?

Analysis of rates of fluvial downcutting helps to understand landscape evolution which is controlled by both climatic and tectonic factors. Differentiation in downcutting of a river along its long profile enables one to reconstruct the spatial distribution of young uplifted structures. Fluvial erosion depends principally on climatic changes in successive glacial/interglacial cycles, river hydraulics and geometry, sea-level changes and other factors, although its spatial variability is also controlled by tectonic tendencies (cf. discussion in Bull 1990; Starkel 1991; Burbank et al. 1996; Blum and Törnqvist 2000).

Main valleys of the Outer Carpathians in Poland bear remnants of 5 to 9 Quaternary terrace steps (Zuchiewicz 1995, 1998b, 1998c). Most of Pleistocene terraces are strath or complex-response terraces, whereas the last glacial and Holocene ones are cut-and-fill terraces, except for those that are located in axial zones of young uplifted areas. Longitudinal profiles of individual straths frequently show convergence, divergence or tilting, pointing to tectonic control. Moreover, both the amount and rate of downcutting of straths of comparable age are different for different morphotectonic units, despite regionally consistent Quaternary climatic conditions throughout the Outer Carpathians and more or less uniform bedrock resistance to erosion. Holocene terraces contain straths only in axial zones of neotectonically uplifted structures, and the highest rates of their incision are to be observed in some areas only. Increased rates of fluvial downcutting are characteristic for those segments of the Outer Carpathian rivers which dissect structures elevated in Plio–Quaternary times. These include, in the western segment of the Polish Carpathians, river gorges of Soła in the Beskid Mały Mts, Skawa and Raba in the Beskid Żywiecki Mts, Dunajec and Poprad in the Beskid Sądecki Mts, Biała Dunajcowa in the Ciężkowice Foothills, and — in the eastern portion of the Outer Carpathians of Poland — Wisłoka in the Strzyżów Foothills, Wisłok in the northern Beskid Niski Mts, as well as of San in the Low Bieszczady Mts (Zuchiewicz 1998a; cf. also Fig. 2).

Long-term rates of fluvial downcutting of successive Quaternary straths tended to increase in the periods of 800–472 ka, 130–90 ka, and 15–0 ka, ranging from 0.18 to 0.40 mm/yr (Zuchiewicz 1995, 1998c). Rates calculated for individual Quaternary stages have varied from 0.04 to 2.00 mm/yr, being different for neighbouring morphotectonic units (Zuchiewicz 1998b). The late Pleistocene increased rates of fluvial incision into solid bedrock are particularly well noticeable in frontal parts of some nappes and slices, both in the western (Rača slice of the Magura nappe, Silesian nappe), and eastern segments of the Polish Carpathians (Dukla Nappe). Rates of incision in mountaineous regions are, of course, driven by both climatic and tectonic factors. The former are particularly well documented for the Vistulian Late Glacial and Holocene times.

Nevertheless, average rates of fluvial downcutting for the whole of Quaternary (0.06 to 0.22 mm/yr) are compatible with those of isostatic uplift of that area during the last 10 million years, which has been from 0.03 to 0.11 mm/yr, or from ca 200 to nearly 1000 m in the Carpathian Foredeep and the Outer Carpathians, respectively (Oszczypko 1996; Zuchiewicz 1998b; Poprawa et al. 1999). Such estimates, based on comparative analysis of compaction curves across the basin and on extrapolation of erosionally truncated seismic horizons, have been made for several tens of wells which pierce through Miocene molasses, either underlying the overthrust flysch nappes or filling the Carpathian Foredeep. Unfortunately, the eastern segment of the Outer Carpathians of Poland does not have such proxies yet.

MORPHOTECTONIC INDICATORS

Differentiated values of morphometric parametres characterising the present-day topography provide indirect evidence in favour of diversified neotectonic tendencies. Analysis of river-bed gradients, Hortonian indices, hypsometric curves and hypsometric integrals, drainage basin asymmetry, valley floor width to valley height ratios, mountain front sinuosity and other parametres proved helpful in identification of uplifted/subsided zones in the Polish segment of the Outer Carpathians (cf. Zuchiewicz 1987, 1995, 1999; and references therein).

Another cartometric approach to morphological manifestations of young tectonic activity is represented by construction of envelope and subenvelope maps (Rączkowski et al. 1984; Keller and Pinter 1996; and references therein). The former portray the highest elevations of a terrain, the latter reconstruct the level to which the streams have eroded by connecting points of equal elevation between the streams. A series of such maps produced for drainage networks, classified according to the Horton–Strahler hierarchy, and called base-level surface maps, makes it possible to compute maps of residuals between individual surfaces of different orders and to hypothesize about either uplift or subsidence tendencies, indicated by dense/sparse pattern of isobases and increased/decreased relief portrayed on residual maps (cf. Rączkowski et al. 1984; Zuchiewicz and Oaks 1993). Reliable interpretation of such maps, however, is impossible without knowledge about the number and age of geomorphic cycles that affected the study area. Therefore, both envelope and subenvelope maps should complement traditional geomorphic mapping (see, for instance, arguments listed by Starkel 1985).

The hitherto-published geomorphological maps of the Polish Carpathians feature a few longitudinal elevated areas, including the Beskid Śląski, Beskid Żywiecki and Beskid Sądecki Mts, Rożnów Foothills–Grybów Mts–Beskid Niski–High Bieszczady Mts, Low Bieszczady Mts, and Wańkowa Highland areas (Starkel 1980; Rączkowski et al. 1984; Zuchiewicz 1995; cf. also Fig. 2). More prominent subsided structures are to be located along the Soła river course, in the Orava–Nowy Targ Basin, in the Jasło–Sanok Depression and following the lower course of the San river valley in the Przemyśl Carpathians.

Fig. 5 shows a series of three subenvelope maps constructed for valleys of the 5th, 6th and 7th order, classified on 1:100,000 topographic maps. Both the 5th and 6th-order subenvelope maps reveal a few elevated areas that are orientated NW–SE in the medial and northern parts of the study region, as well as NNW–SSE in the southern part, their strike obliquely cutting under small angle the overall trend of imbricated slices and map-scale folds. Elevations of the 5th-order isobases range 250–750 m a.s.l., those of the 6th-order ones change from 200 to 500 m a.s.l. Residuals between these two subenvelope surfaces do not exceed 100 m, a figure taken by W. Rączkowski et al. (1984) as a proxy for Quaternary uplift of this region. Analysis of geomorphological maps, showing the size of erosional dissection of early Pleistocene planation surfaces, gives comparable results (cf. Starkel 1972; Henkiel 1977). We shall come back to this issue in the next chapters.

TOPOLINEAMENTS VERSUS PHOTOLINEAMENTS

It has become fashionable during the past two decades to analyse photolineaments interpreted from satellite images and air photographs, with a view to identify potentially active fault zones (e.g., Bażyński et al. 1984; Doktór et al. 1988). Since this approach is highly subjective (cf. discussion in Karnkowski and Ozimkowski 1998), particularly in areas with dense vegetation cover, special attention is given to radar images and digital elevation models. Fig. 6 shows principal and subordinate photolineaments interpreted in the eastern segment of the Polish Carpathians. Some of them coincide with known faults or rectilinear valley reaches, clustering around

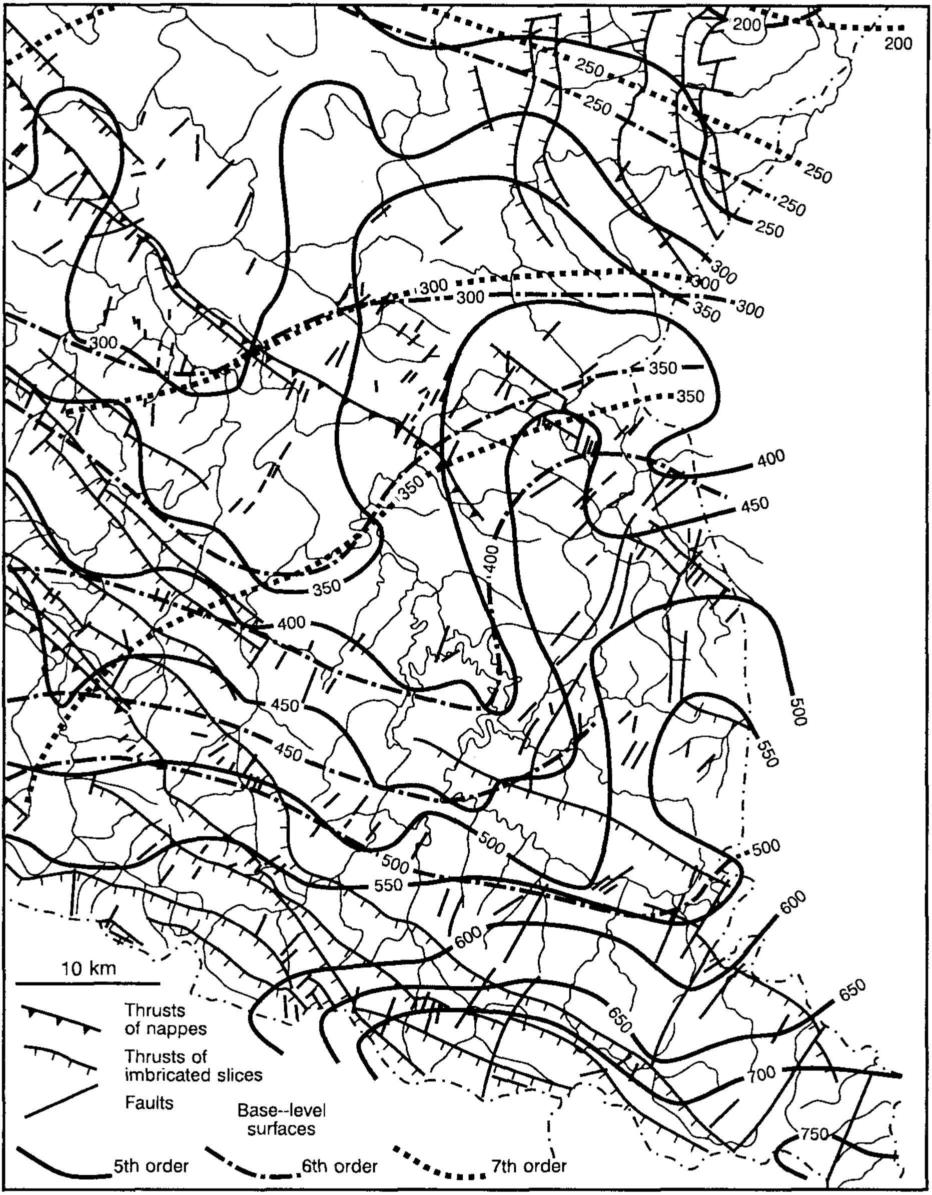

Fig. 5. Map of base-level surfaces of different orders of the Outer East Carpathians of Poland (partly based on Rączkowski et al. 1984; modified)

NNE to NE orientation, whereas the others appear to follow zones of increased joint density (Zuchiewicz and Henkiel 1995) or have no association with any structural features at all. No significant correlation with radar lineaments is to be observed, for instance in the area located in the San river valley between Zagórz and Solina (cf. Mastella and Szynkaruk

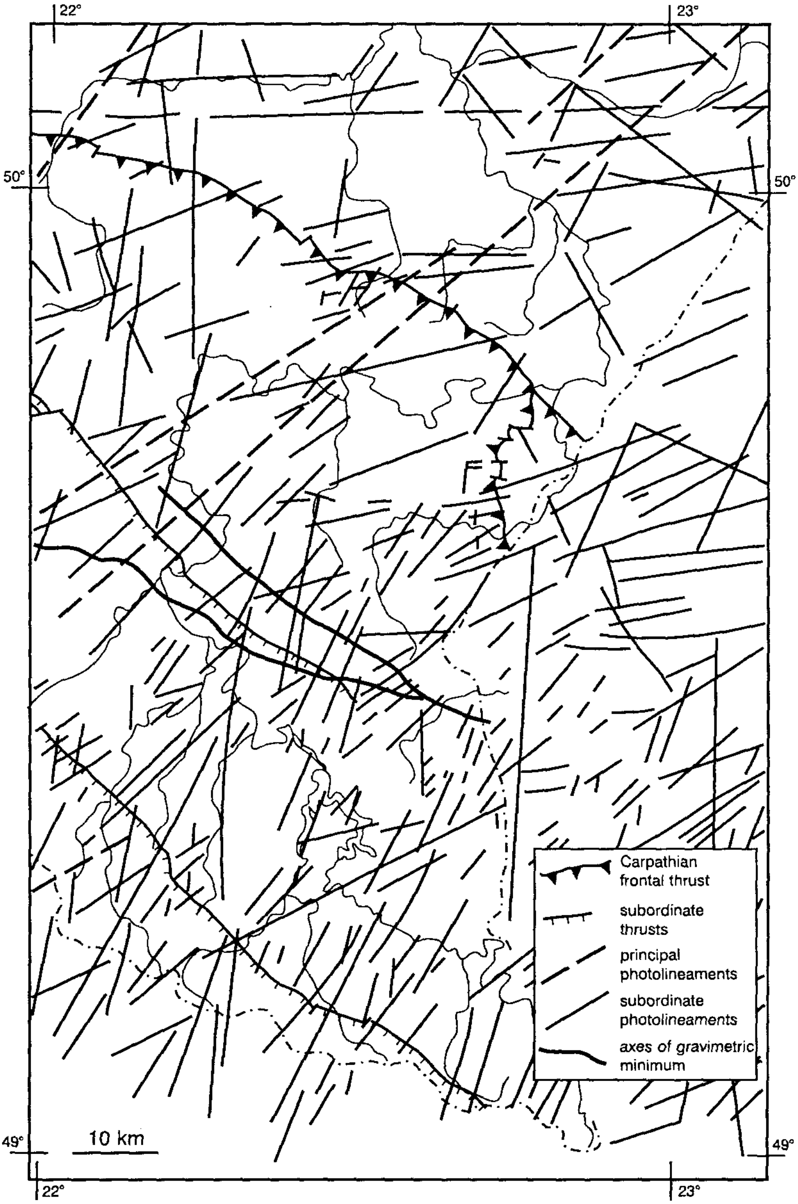

Fig. 6. Photolineament pattern in the eastern segment of the Polish Carpathians (based on Bażyński et al. 1984; Doktór et al. 1988; and Królikowski and Petecki 1995; simplified)

1998), where N15°E trend appears to dominate, being accompanied by less clearly marked N65°E orientation.

The photolineament pattern (Fig. 6) shows some resemblance to that of topolineaments (Fig. 7), interpreted from shaded-relief topographic maps produced by Wybraniec (1999, 2000). This applies particularly to the

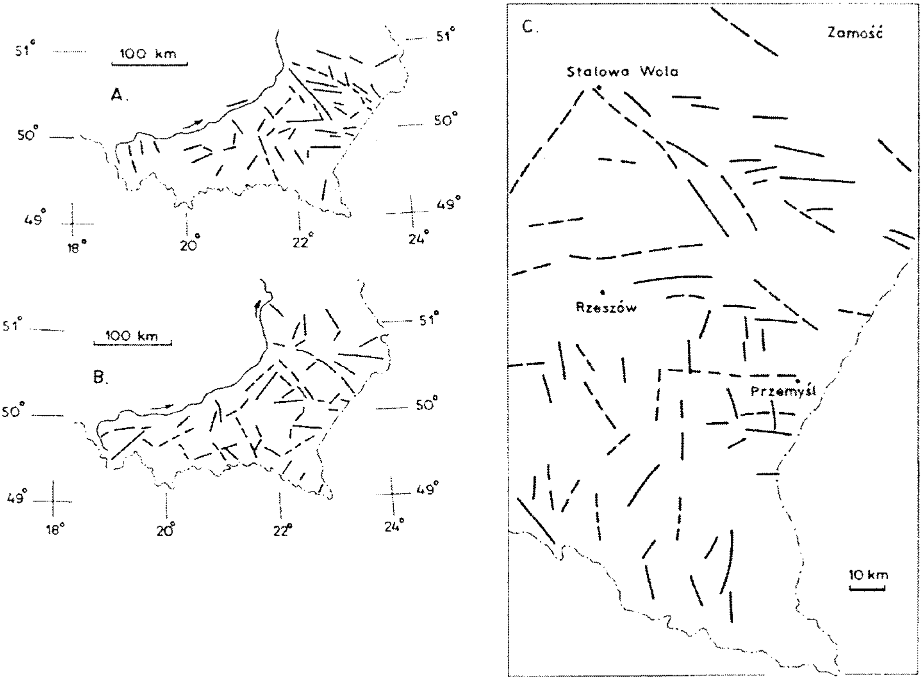

Fig. 7. Topolineaments identified on DEM's of Poland (author's interpretation of maps constructed by Wybraniec 1999, 2000): A — topolineaments in SE Poland, interpreted from digital hypsographic, non-transformed full-hue colour scale map illuminated from the north (Wybraniec 1999); B — topolineaments in SE Poland, interpreted from horizontal-vectorial image of local anomaly of hypsography (basic wavelength 1–30 km; transformation: sum of 4 directional components obtained by digital filtering with Hilbert bi-transformer of 61x61 dimensions), exposing the gradient of relief (Wybraniec 1999); C — topolineaments in the eastern segment of the Polish Carpathians, interpreted from 1 : 500,000 shaded relief topographic map of the Northern Carpathians (Wybraniec 2000)

Carpathian Foredeep and Roztocze areas, whereas in the Outer Carpathians such coincidence is barely recognizable (Fig. 7). In the latter case, topolineaments visible on digital elevation models appear to follow some rectilinear river bed stretches and, in the southern part, zones of increased density of joints. Therefore, any "neotectonic" significance of such a picture is difficult to assess, since the sole coincidence of the existent zone of weakness (increased fracture density) with a topolineament does not necessarily mean its young tectonic reactivation. North of the Carpathian frontal thrust, however, well-pronounced topolineaments coincide very well with the escarpment zone of Roztocze, as well as with the trace of the Subcarpathian furrow and linear zones that bound on the NE and NW the uplifted Kolbuszowa Plateau (Laskowska-Wysoczańska 1995; Zuchiewicz 1998a, 1998c). One of the most prominent E–W trending linear features visible on digital elevation

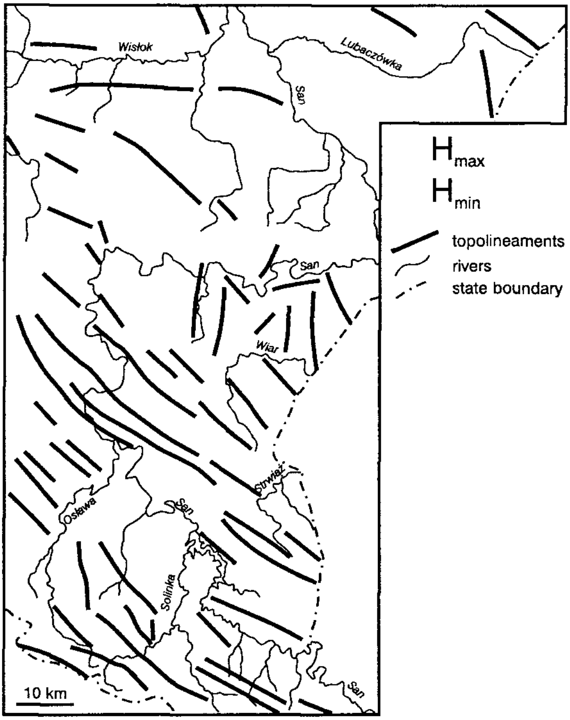

Fig. 8. Principal topolineaments interpreted from dense-contour envelopping surface maps

models, air photographs and MSS (Landsat Multi Spectral Scanner) images is that following the Subcarpathian furrow in the autochthonous foredeep basin, and called sometimes the Wisłok fault line (cf. also Chorowicz et al. 1999).

Still another picture can be obtained from analysis of envelope maps portraying the highest and lowest elevations, measured for 1 km^2 grid on 1 : 50,000 topographic maps, interpolated with the help of the SURFER programme, and then reduced in scale to obtain dense-isoline pattern. Both these maps, further called Hmax and Hmin maps (Fig. 8), clearly feature elongated, NW–SE to WNW–ESE orientated structures coinciding with the overall strike of map-scale folds and imbricated slices. This coincidence is disturbed in the southern and northern parts of the studied portion of the Carpathians, wherein N–S to NNW–SSE topolineaments are to be recognized. In the Skole Nappe, the N–S trend is associated with similar orientation of fold axes in the Przemyśl sigmoid, whereas in the Dukla Nappe and Fore-Dukla Zone the NNW–SSE orientations are oblique to the structural grain of the area and coincide with similarly arranged, long and narrow zones of localised uplift (Henkiel 1977; Zuchiewicz 1995, 1998c). North of the Carpathian front, such topolineaments tend to be aligned E–W, i.e. parallel to the Subcarpathian furrow.

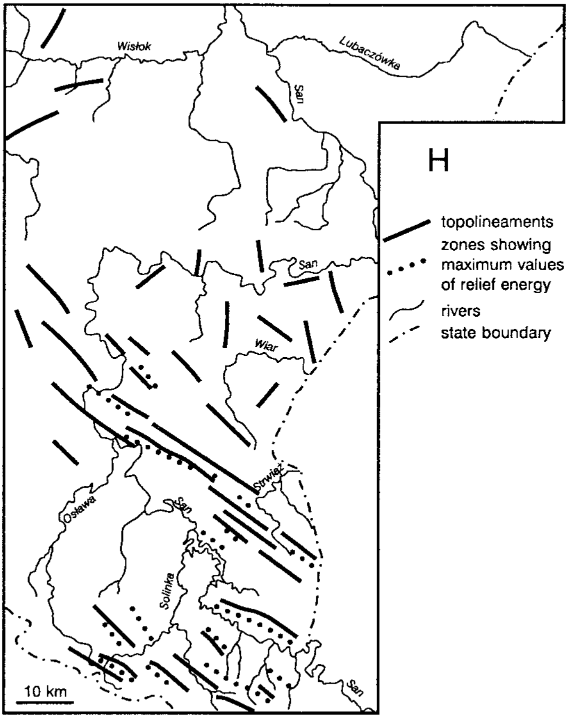

Fig. 9. Principal topolineaments and zones of maximum relief energy interpreted from dense-contour relief energy map

Residual maps portraying the relief energy (Hmax – Hmin) show a slightly different picture (Fig. 9), exposing several, not very long zones of increased relief energy (200–400 m in the south, 75 to 100 m in the north of that part of the Carpathians), the orientation of which in the Central Carpathian Depression approximates that of principal folds, and in the Dukla Nappe and Fore-Dukla Zones strikes at low angles to the fold axes. Such a pattern, resulting from both lithological control and uplifting tendencies of some WNW–ESE orientated structures, is fairly similar to that obtained by A. Henkiel (1977, 1978) due to reconstruction of topography of the early and late Pliocene planation surfaces (initiated by Starkel 1965 and continued by Henkiel 1977), upwarped by subsequent motions within the flysch cover (Fig. 10).

STRUCTURAL DATA

Fold-parallel joints are ubiquitous features throughout the study area, together with cross-fold joints (cf. Zuchiewicz and Henkiel 1995; Zuchiewicz and Tokarski 1999). These joints form two sets (L and L') intersecting one another under small angles. Set L is roughly parallel to bedding, whereas set L' is aligned independently of the strike of map-scale folds and probably postdates set L. Both these sets are devoid of properties

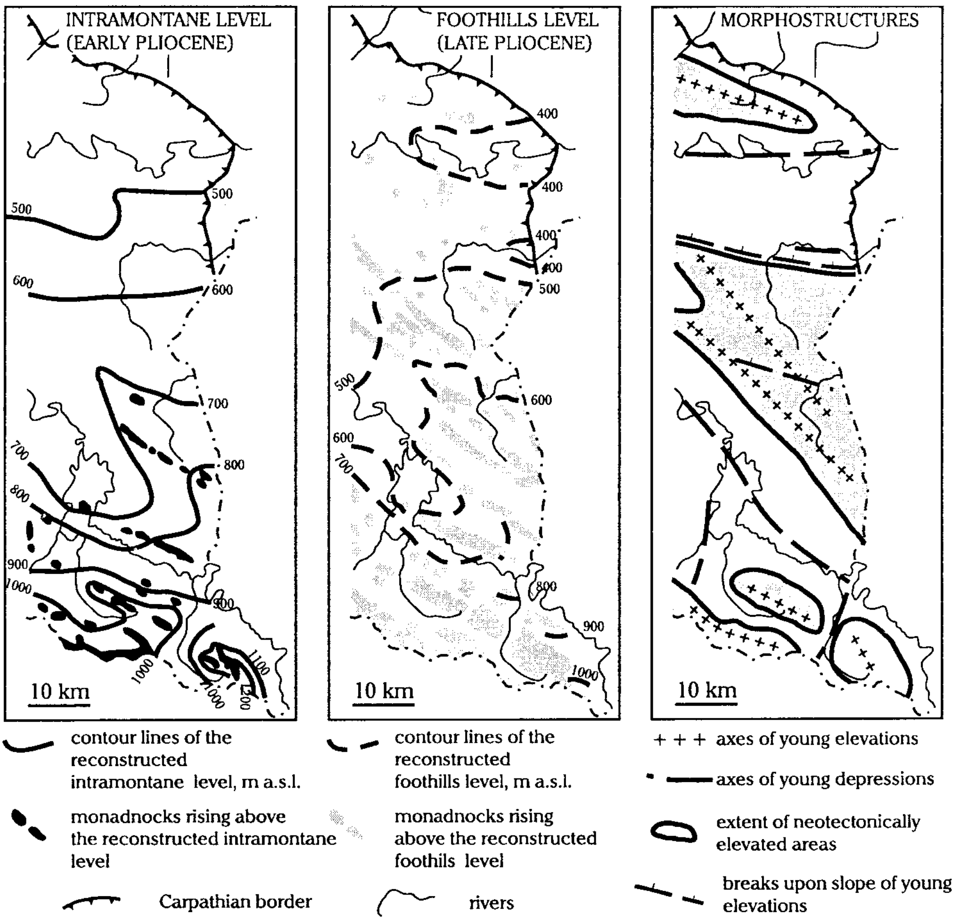

Fig. 10. Topography of Pliocene planation surfaces and morphotectonic units in the eastern segment of the Polish Carpathians (after Henkiel 1977)

that would point to their shear origin. Instead, their morphological characteristics, like common occurrence of plumose structures or discontinuous, nonlinear traces of intersection with bedding planes, appear to indicate extensional and extensional-relaxation origin. Cross-cutting relationships indicate that the formation of fold-parallel L' joints is related to postorogenic uplift of the already folded structures.

Dominant strikes of the L and L' extensional joints in the Dukla Nappe (Fig. 11), indicating N35°–55°E orientation of joint-related σ_3 (cf. Zuchiewicz and Henkiel 1995; Mastella and Zuchiewicz, in prep.), are roughly parallel to those of topolineaments and linear zones of increased relief energy which have been identified on maps of envelopping surfaces and relief energy dense-isoline maps (Zuchiewicz 1999). They are also subparallel to the

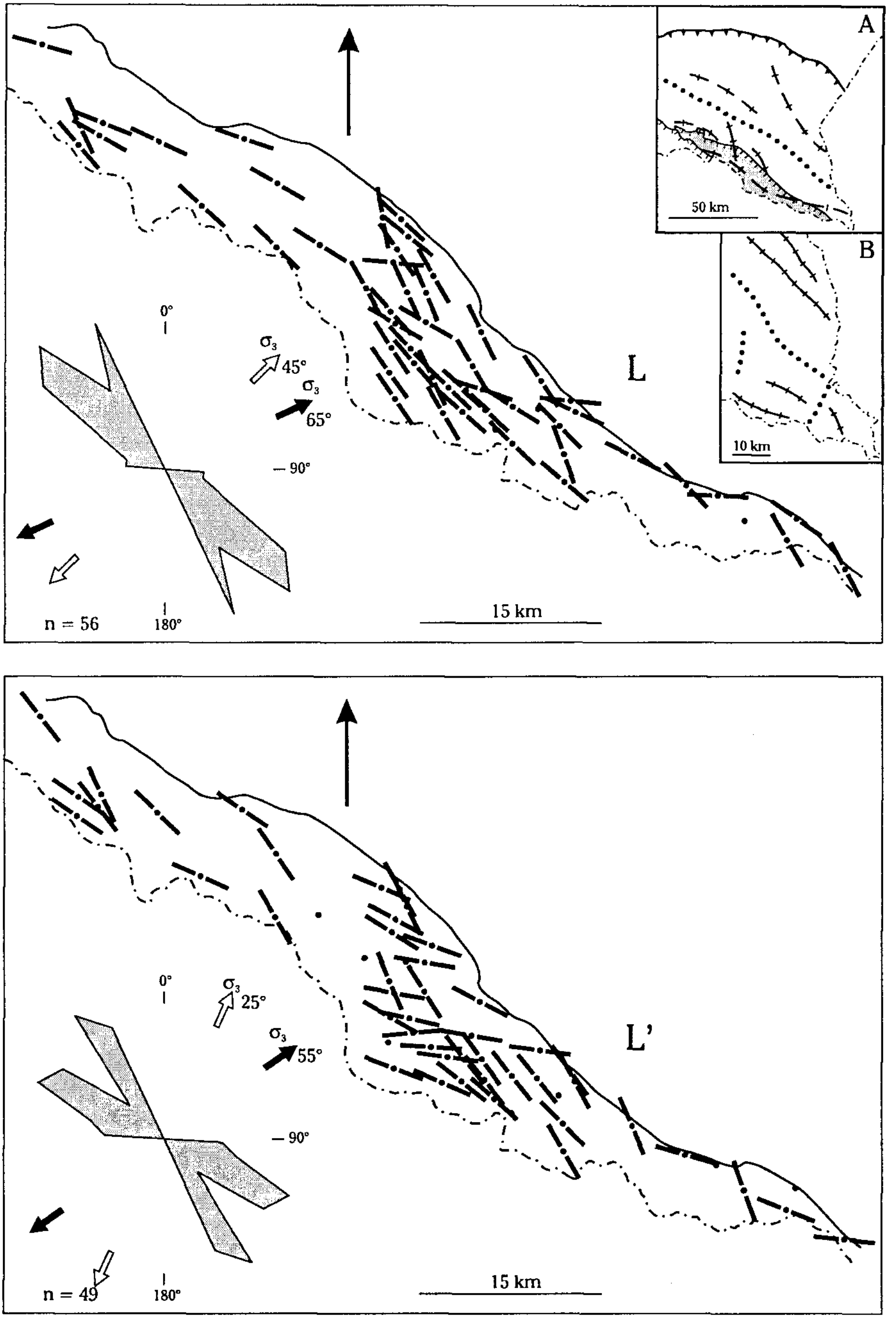

Fig. 11. Spatial distribution of fold-parallel joints related to postorogenic uplift (a — older, joint set L; b — younger, joint set L') in the Dukla Nappe. Arrows indicate the orientation of joint-related σ_3. Inset maps portray location of Pliocene-early Quaternary zones of localized uplift (fence lines) and subsidence (dotted lines) in the Polish Eastern Carpathians, mapped by W. Zuchiewicz (1995) — A, and A. Henkiel (1977) — B

linear zones of localised Plio–Quaternary uplift (Figs 10, 11 A, B), reconstructed in this area by A. Henkiel (1977) and W. Zuchiewicz (1995). Such a relationship indicates that the opening of fold-parallel joints, and particularly those which belong to L' set, orientated NW–SE and WNW–ESE, could have been coeval with that of Pliocene–early Quaternary extension in the eastern segment of the Polish Carpathians.

DISCUSSION AND CONCLUSIONS

The pattern of different types of relief, together with spatial distribution of topolineaments and some photolineaments in the eastern portion of the Polish Outer Carpathians has been shaped due to mutual interactions between climatic, lithological and tectonic factors. Lithology is important as far as small-scale landforms are concerned and controls the state of preservation of individual planation surfaces, particularly in higher elevated regions (cf. Starkel 1969), but appears to have reduced influence upon the orientation of zones of deformed planation surfaces, distribution of zones of abnormally increased river bed gradients or some morphometric parametres, like those portraying relationship between valley floor width and relief energy. A notable example is the Central Carpathian Depression where NW-arranged array of morphological depressions are located upon exposures of relatively resistant, thick-bedded sandstone complexes. On the other hand, differences in the amount and rate of fluvial incision observed throughout relatively small area, i.e. developing under comparable, regionally consistent climatic conditions, point to young tectonic control. Well-pronounced topolineaments either follow fault-related zones of weakness, provided one side of the fault is composed of strongly resistant rocks, are associated with dense network of extensional cross-fold joints, or indicate recent reactivation of some faults and/or joint sets.

The presence of long and narrow zones that show alternately uplifting and subsiding tendencies in the eastern segment of the Outer Carpathians of Poland and are aligned subparallel to or crossing under small angles the structural grain of the region, appears to exclude their purely isostatic origin. Localised uplift of frontal thrusts and larger slices could have resulted from recent relaxation of horizontal stresses accumulated within the overthrust nappes. Such a mechanism explains: (a) manifestations of localised young uplift occurring along frontal thrusts of some imbricated slices, (b) the present-day configuration of S_{hmax} recorded by breakouts in wells that pierce through the flysch nappes and their substratum (cf. Jarosiński 1998), and revealed by focal mechanisms of the 1992–1993 Krynica earthquakes (Wiejacz 1994; Dębski et al. 1997), as well as (c) the orientation of maximal compressive stress interpreted from joint pattern in late Neogene molasses that rest unconformably upon eroded flysch units (Zuchiewicz 1998d; Tokarski and Zuchiewicz 1998).

Sublongitudinal zones of localised uplift started to form during postorogenic collapse of the Outer Carpathian belt, most probably in late Miocene–Pliocene times. This uplift is considered to be a byproduct of relaxation of remnant horizontal stresses accumulated during Late Neogene thrusting.

ACKNOWLEDGEMENTS

I would like to thank Dr. Stanisław Wybraniec (Polish Geological Institute) for providing his unpublished 1 : 1,000,000 shaded relief map of the Northern Carpathians. Comments by an anonymous reviewer have been very helpful. Financial support for this research from the National Committee for Scientific Research of Poland (KBN), allocated to Statutory Research Fund of the Institute of Geological Sciences, Jagiellonian University, through grant No. DS/V/ING/5/99-00 is gratefully acknowledged.

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STRESZCZENIE

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MORFOTEKTONIKA WSCHODNIEJ CZĘŚCI POLSKICH KARPAT ZEWNĘTRZNYCH W ŚWIETLE BADAŃ KARTOMETRYCZNYCH

Zróżnicowane typy rzeźby, a także układ topolineamentów i niektórych fotolineamentów w polskim segmencie Karpat Wschodnich, były kształtowane dzięki współdziałaniu czynników litologicznych, klimatycznych i tektonicznych. Rola odporności podłoża wydaje się być istotną w odniesieniu do form małoskalowych oraz stopnia zachowania powierzchni zrównania. Natomiast jej wpływ na orientację stref o anomalnie wysokich spadkach koryt, czy też grupujących skrajne wartości niektórych parametrów morfometrycznych, a także deformacji rekonstruowanych powierzchni zrównań w wyżej wzniesionych partiach Karpat Zewnętrznych, jest ograniczony. Różnice w rozmiarach i tempie rozcięcia erozyjnego obserwowane na stosunkowo niewielkim obszarze, a zatem podlegającym podobnym wahaniom klimatycznym w młodszym kenozoiku, są w niniejszej pracy interpretowane jako efekt młodej mobilności tektonicznej.

Wyniki kartowania geomorfologicznego, w połączeniu z analizą parametrów morfometrycznych, map powierzchni oblekających oraz topolineamentów widocznych na numerycznych modelach terenu i mapach zagęszczonych poziomic sugerują obecność we wschodniej części polskich Karpat zewnętrznych szeregu długich i stosunkowo wąskich struktur o tendencjach na przemian podnoszących i obniżających, a układających się pod niewielkim kątem względem rozciągłości fałdów regionalnych. W obrębie płaszczowiny dukielskiej orientacja tych struktur jest zbieżna z przebiegiem ekstensyjno-odprężeniowych spękań podłużnych, sugerując NE orientację młodej ekstensji.

Strefy zlokalizowanego wypiętrzania są ograniczone do postramianych w pliocenie i czwartorzędzie czół nasunięć i większych złuskowanych fałdów, a ich powstanie było najprawdopodobniej efektem relaksacji resztkowych naprężeń poziomych w obrębie płaszczowin Karpat zewnętrznych.