Geologia Sudetica, 1998, 31: 307–316.

Geomorphological evidence of neotectonics in the Kaczawa sector of the Sudetic Marginal Fault, southwestern Poland

Piotr Migoń & Janusz Łach

Instytut Geograficzny, Uniwersytet Wrocławski, pl. Uniwersytecki 1, 50-137 Wrocław, Poland

Key words: neotectonics, fluvial morphology, planation surfaces, Quaternary, Sudetes

Abstract The Kaczawa sector of the marginal escarpment of the Sudetes Mts is 80–120 m high and separates upland denudation surfaces, probably Late Miocene in age, and flat foreland surfaces underlain by Cainozoic sediments. Genetically the scarp is related to the course of the Sudetic Marginal Fault. Scarp dissection by short, deeply incised valleys was the response to the Pliocene–Early Quaternary uplift of the Sudetes Mts relative to their foreland. Evidence for tectonic activity during the Late Quaternary is equivocal. Deformations of terrace levels have not been recorded whilst upper valley slope benches apparently cut off at the mountain front do not bear an alluvial cover.

Manuscript received 15 April 1998, accepted 30 October 1998.

INTRODUCTION

The mountain front of the Sudetes Mts, which is genetically related to the course of the Sudetic Marginal Fault, and its immediate vicinity have recently become the focus of geomorphological research aimed at the identification of possible signs of neotectonic activity recorded in landforms and sediment properties. Most of the work carried out so far has been concentrated along the Sowie Mountains sector of the Sudetic Marginal Fault and in the Wałbrzych Upland (Krzyszkowski & Pijet, 1993; Krzyszkowski & Stachura, 1993; Krzyszkowski & Biernat, 1993, 1998; Krzyszkowski *et al.*, 1995). Among the features recognised as indicative of Quaternary tectonic activity have been numerous disturbances in longitudinal profiles of terraces and the truncation of the so-called Upper Terraces at the mountain front in particular. Geomorphological mapping of the upland area adjacent to the mountain front has led to the conclusion that the footwall itself is divided into a number of medium-size morphotectonic units, which were subjected to differential vertical movement. Furthermore, late Middle Pleistocene deformations and the decay of the early Saalian (Odranian) ice-sheet have been shown to coincide in time and it has been argued that glacioisostatic rebound may have played an important part in generating displacement along the Sudetic Marginal Fault.

The Kaczawa sector of the Sudetic Marginal Fault (Fig. 1) and its possible neotectonic activity had not yet been investigated. The few existing studies concerned either the early stages of mountain front development recorded in the remnants of planation surfaces (Kowalski, 1978) or climatically-controlled periglacial landform changes (Piasecki, 1956). The only exception is the detailed study of the Late Tertiary and Quaternary sediments outcropping at the outlet of the Kaczawa valley which, according to the interpretation proposed, show deformational structures indicative of a very high level of tectonic activity and lateral movement along the Sudetic Marginal Fault by as much as 2 km (Mastalerz & Wojewoda, 1990). The limited interest in the Kaczawa sector of the Sudetic mountain front is perhaps a reflection of the relatively weak topographic expression of the scarp,with its only modest height not exceeding 150 m, and the absence of larger valleys which might contain alluvial surfaces suitable for correlation. Moreover, the regional morphometric study of the margin of the Sudetes suggests a very low level of neotectonic activity in this area (Krzyszkowski *et al.*, 1995), a fact further confirmed by only slight deformation of the terrace surfaces in the adjacent Nysa Mala and Nysa Szalona valleys (Migoń *et al.*, 1998). The picture that has emerged from the studies already completed suggests that the level of tectonic activity along the Sudetic Marginal Fault decreases towards the north-west or, alternatively, footwall uplift is of an earlier date than in more southerly located sectors.

This paper provides a more detailed analysis of valley morphology and watershed surfaces in the marginal part of the Kaczawa Upland, also called the Chelmy, contributing in this way to the understanding of patterns of morphotectonic evolution of the Sudetic mountain front. The

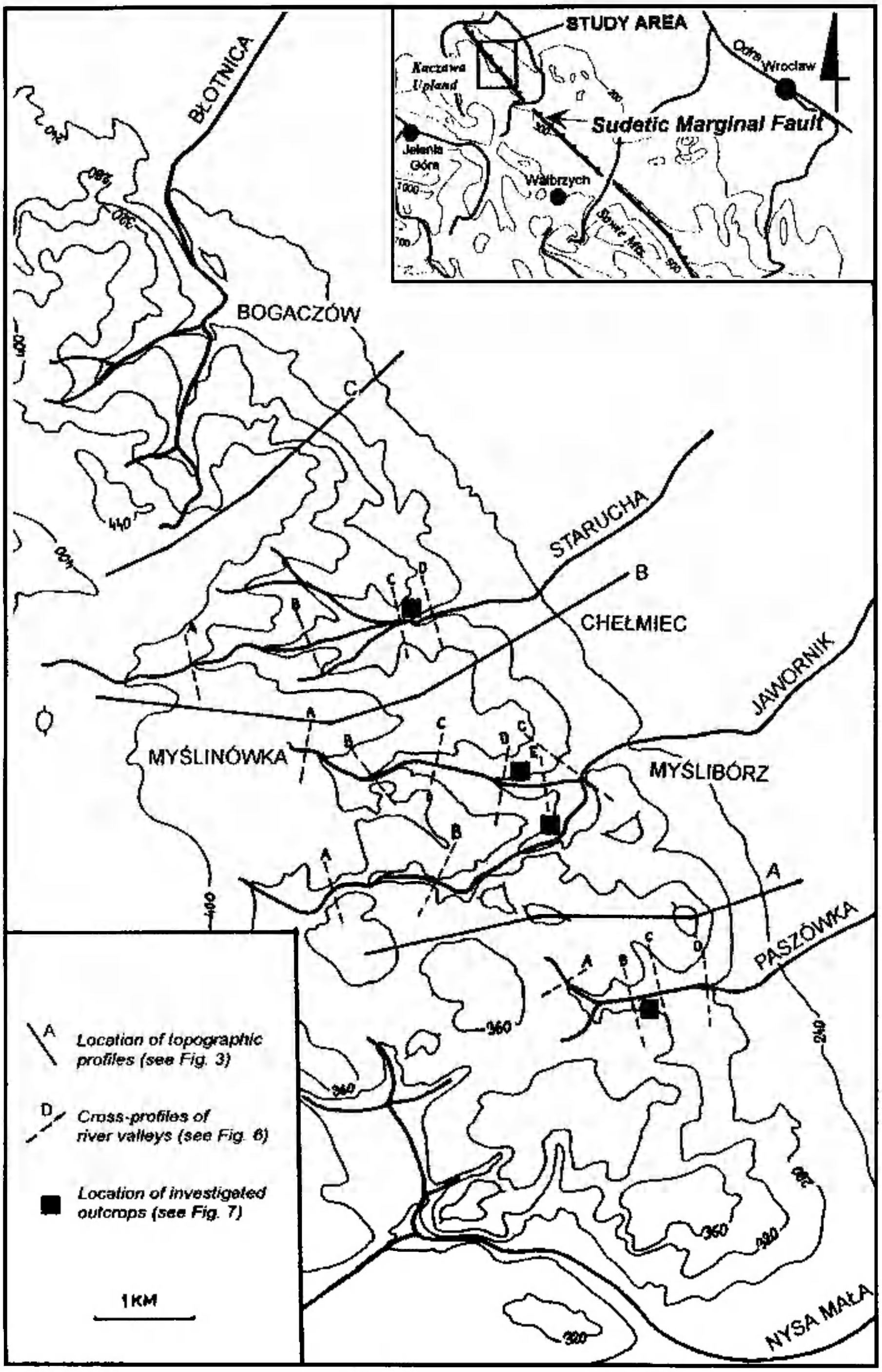

Fig. 1. The eastern part of the Kaczawa Upland (Chełmy) and location of studied area.

scope of investigations was similar to those carried out in other parts of the Sudetic Marginal Fault area. Fieldwork was done in 1996-1997.

GEOLOGICAL STRUCTURE AND THE MAIN GEOMORPHIC FEATURES

The Kaczawa Upland is located within a much larger geological entity, the Kaczawa Metamorphic Unit (Fig. 2), which consists of two structural units, of Variscan and Laramian origin respectively (Baranowski *et al.*, 1982). In the investigated Chełmy area, only rocks belonging to the older Variscan unit outcrop. These are chiefly sedimentary and volcanogenic rock, metamorphosed under greenstone facies conditions, the ages of which cover a protracted time span from the Cambrian up to the Early Carboniferous (Visean).

Ordovician rocks predominate close to the margin of the Kaczawa Upland and these are of either sedimentary, flysch-like origin or of sedimentary to volcanoclastic origin. The former include sericite-quartzose slates, phyllites and quartz schists of cumulative thickness of 1000 m, which are overlain by greenstones, or a spillite–keratophyre association, the thickness of which comes to 1500 m. The greenstones in turn are covered by siliceous slates with graptolite remains of lower Silurian age. Among the volcanic rocks there are massive greenstones, greenschists and pillow lava variants. Early Devonian rocks are represented by slates, quartz-sericite phyllites, quartz schists with a quartzite layer, and alkaline metatuffs and diabase.

From a tectonic point of view, the eastern part of the Kaczawa Upland is divided into two areas, separated by the WNW–ESE trending Myslinów Fault. In the northern Chelmiec Unit phyllite is the dominant rock and greenstones play a rather subordinate part, whilst in the southern Rzeszówek–Jakuszowa Unit greenstones and greenschists occupy most of the area. The only younger solid rocks in the Chełmy area are basalts, tuffs and volcanic breccia, likely to be dated back to the Łate Oligocene/ Early Miocene (Jerzmański, 1965). They perhaps reflect the initial stages of young Alpine tectonic movements. Basalts and associated products of volcanism occur either in isolation as necks and veins or they cover larger areas, if they are remnants of once extensive lava flows. A few of these necks rise immediately at the margin of the Sudetes, including Bazaltowa (368 m a.s.l.), Rataj (350 m a.s.l.) and Górzec (445 m a.s.l.). Unconsolidated Cainozoic sediments are known mainly from the foreland of the Sudetes. In the marginal part of the Kaczawa Upland only fluvial and colluvial sediments of Late Pleistocene age occur. The latter are periglacial solifluction

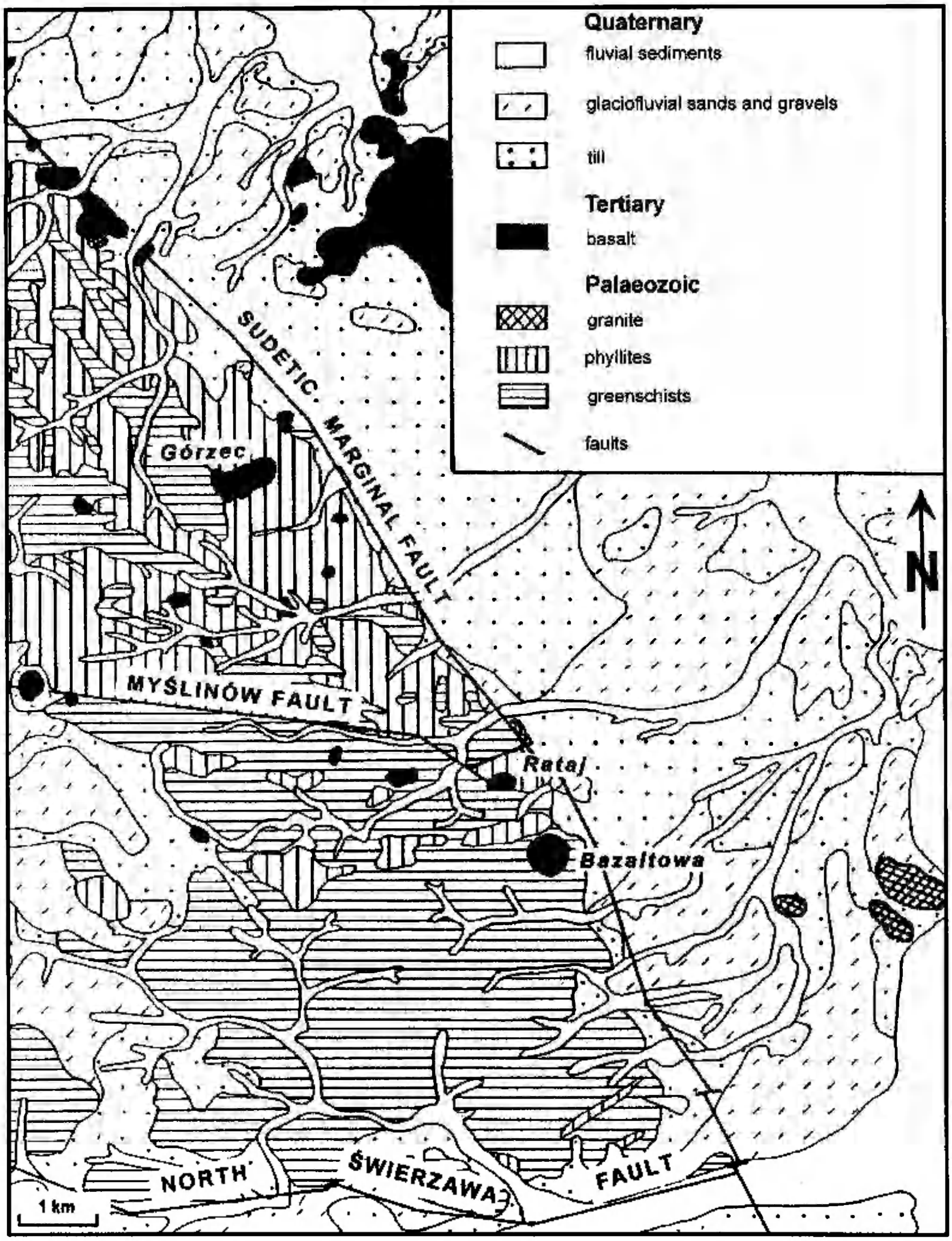

Fig. 2. Geology of the eastern part of the Kaczawa Upland. Based on "Mapa geologiczna Parku Krajobrazowego Chełmy", 1:50 000, Państwowy Instytut Geologiczny, Warszawa 1995.

and deluvial loams (Piasecki, 1956). On the upland surface patches of till and glacifluvial deposits are locally present; they were probably laid down during the early Saalian (Odranian) glaciation.

The landforms of the eastern part of the Kaczawa Upland are poorly known, and the only general work available is that by Kowalski (1978). He distinguished three horizons of denudation surfaces, which were supposed to reflect the intermittent character of the tectonic movements along the Sudetic Marginal Fault and cyclic planation (pediplanation) during the Tertiary. The highest horizon, 380–400 m a.s.l., includes flat watershed surfaces between Pomocne and Myślibórz and would date back to the Early Miocene. The next horizon would be of Late Miocene age; its remnants are now located at the altitude of 300–360 m a.s.l. The lowest horizon would be mid-Pliocene slope benches along the margin of the Sudetes, at an elevation of 260–300 m a.s.l.

It has to emphasised, however, that both the above identification of these palaeosurfaces and the ages ascribed to them should not be accepted uncritically. Hence, the implications for morphotectonic development are not necessarily correct. Firstly, the altitude of these watershed surfaces is higher in the northern part of Chełmy (420–450 m a.s.l.) than in to the southern part (360–380 m a.s.l.), and this difference corresponds to the tectonic division of the

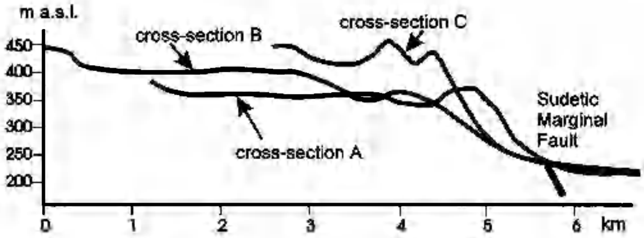

Fig. 3. Topographic profiles across the escarpment of the Kaczawa Upland; for location see Fig. 1.

study area. Secondly, the step-like arrangement of these watershed surfaces is difficult to identify on longitudinal profiles of the watershed ridges (Fig. 3). The absence of clear breaks of slope is also evident on the densed contour map (Fig. 4); this kind of map has been found very useful in the identification of similar forms in other areas (Badura & Przybylski, 1995; Migoń, 1996). The accuracy of dating the surfaces can also be questioned, as it seems to lack firm ground. In particular, an Early Miocene age for the 400 m a.s.l. surface seems to be contradicted by the occurrence of basaltic plugs up to 40 m high within this surface. They point to a post-Early Miocene depth of denudation of the order of at least a few tens of meters.

An interesting feature of the Chełmy marginal zone is the spatial variability in the degree of its erosional dissection, clearly seen on the densed contour map (Fig. 4). In the northern part, a dense network of deeply incised valleys occurs, some of them dry at present, and the total width of the dissected zone comes up to 4 km. As a result, the watershed flat surfaces have a very limited extent as

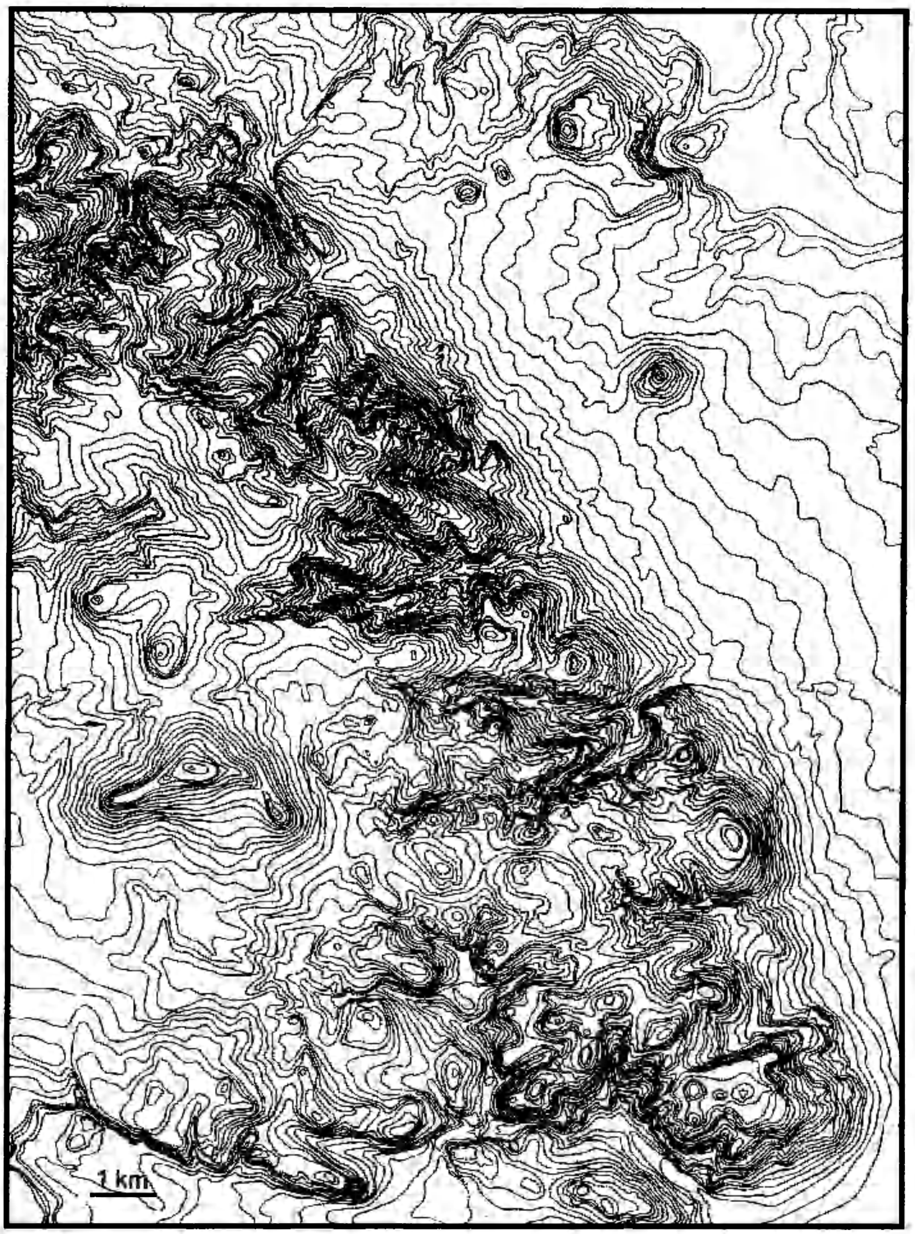

Fig. 4. Densed contour map of the eastern part of the Kaczawa Upland, based on the topographic map from edition: Topographische Karte 1:25,000, Königlich Preussische Landesaufnahme.

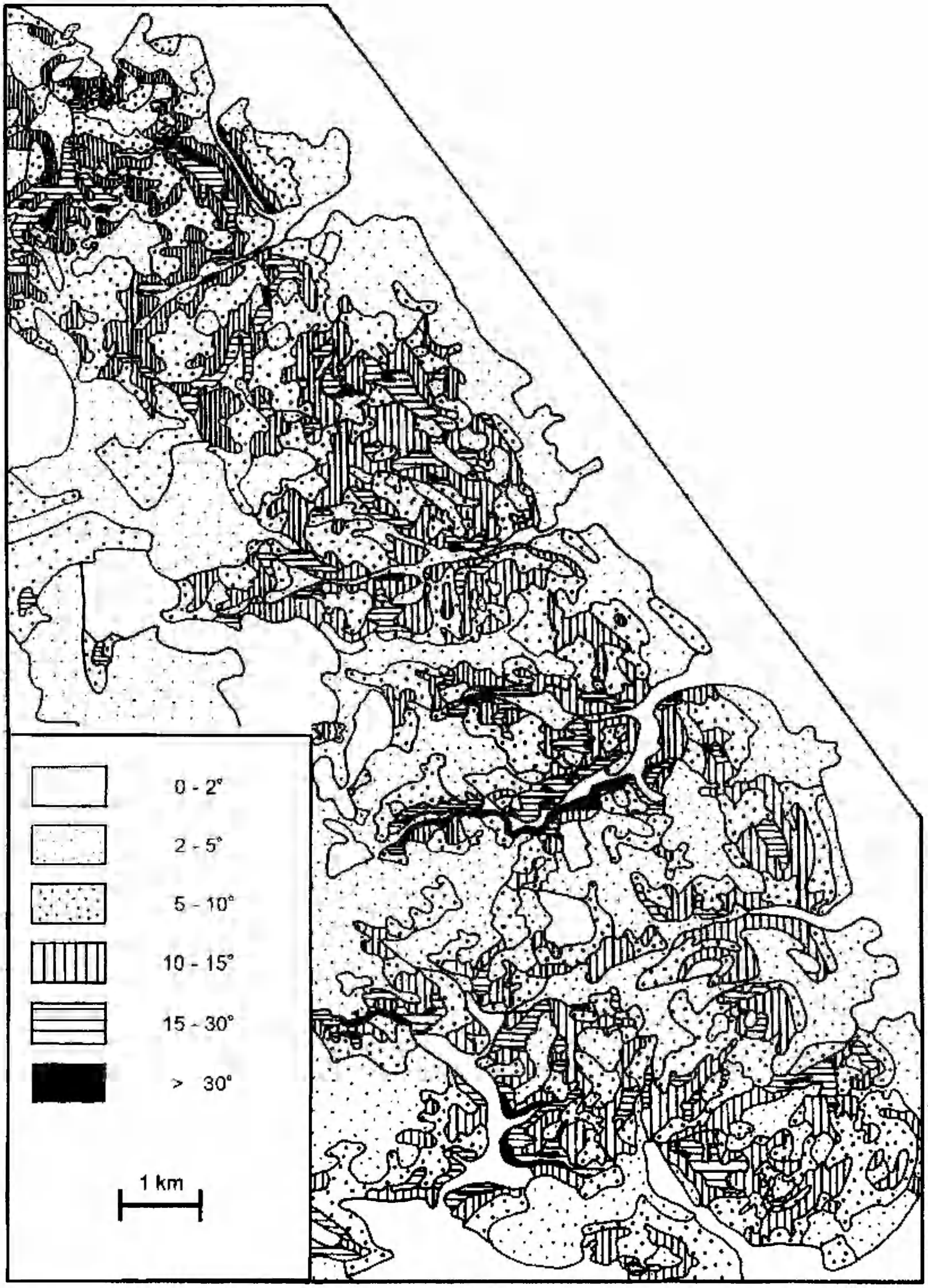

Fig. 5. Slope inclination map of the eastern part of the Kaczawa Upland.

evidenced by the slope inclination map (Fig. 5). By contrast, in the southern part, southwards of the Jawornik valley, the valleys are shorter and more widely spaced, whilst the planation surfaces remnants can be traced much farther towards the mountain front. They disappear only 1.2–1.5 km away from the mountain front footslope. The degree of erosional dissection increases with increase of altitude, yet it is not reflected in the sinuosity of the mountain front. The front retains its straightness all along the Chełmy, the sinuosity index being 1.5–1.6 (Sroka, 1992).

VALLEY MORPHOLOGY AND TERRACE SYSTEM

The mountain front of the Sudetes in the Kaczawa sector is dissected by three main valleys, those of the Paszówka, the Jawornik with its tributary the Myślinówka, and the Starucha respectively (Fig. 1). In addition, there are a few smaller valleys which lack perennial streams at present. The common feature of the larger valleys in the Chełmy is their oblique orientation with respect to the course of the mountain front; they generally run W–E, whilst the front trends NW–SE. This latitudinal direction is close to the direction of the main tectonic structures in the Kaczawa Metamorphic Unit (the Myslinów Fault, the North Świerzawa Fault) and indicates significant structural control exerted on drainage pattern development. Most of the valleys are deeply incised all along their courses, although the upper sections of Jawornik and Starucha valleys have not yet been rejuvenated (Fig. 6).

The longitudinal profiles are not very differentiated and short reaches of increasing slope play a subordinate part. At the margin of the Sudetes, it is only the Paszówka that displays an increase in valley slope from 2.1% to 5.2%. In the Jawornik valley a break of slope is observed in its upper part and the longitudinal profile is evened out below the break. The Myślinówka profile is the most complex and consists of alternating reaches of higher and lower slope, but even there, differences between the reaches are small.

In spite of the little differentiation of the longitudinal profiles, the valley cross-sections show a variety of shapes (Fig. 6). The Jawornik valley is particularly specific in this context as it is very narrow and deeply incised, up to 70 m, in its middle course. This reach is known as the Myslibórz Ravine and is 2.5 km long, and includes a 0.5 km long gorge-like section, with vertical rock walls up to 30 m high and a bedrock channel. Going downstream, the width of the valley floor increases and cut-and-fill terraces start to form, yet the slopes retain their considerable inclination exceeding 30°. The cross-section of the Myślibórz Ravine is asymmetric, with the north-facing slopes being steeper. This is not the rule, however, as evidenced by the Paszówka and Starucha valleys; in both cases consecutive valley sections show alternating asymmetry. In other valleys in the marginal part of the Chełmy area gorges do not occur, but they are present in the south-western part, in the Nysa Mala catchment, outside the limit of this study.

The terrace systems of the streams dissecting the margin of the Kaczawa Upland are poorly developed and consist of only two terrace levels, namely recent floodplain along channels and higher cut-and-fill terrace. The structure of the upper terrace is similar in all the major valleys and consists of three units (Fig. 7). The lower unit is at least 0.5–0.6 m thick and is made up of densely packed, angular and strongly weathered clasts of local rocks, 15–20 cm in diameter. A grain-size analysis of its matrix indicates that it mostly consists of silt and sand. Above the lower unit sands and silts occur with single large clasts of local rock, up to 30 cm long, some of them showing initial rounding. The thickness of the middle unit is 0.3–0.7 m. In the Jawornik and Starucha valley its bottom part is composed of a thin layer (10–20 cm) of fine, well rounded gravels impregnated by iron to form an iron pan. The upper unit is 0.3–0.6 m thick and is formed of angular debris up to 10 cm long, in a loamy matrix.

The three units differ in terms of their petrographic composition (Fig. 8). The lower unit has the most varied composition, although rocks present in particular drainage basins clearly dominate. Exotic rocks, lydite and flint, have only been found in the sediments of the Jawornik valley. The sediments of the middle unit consist entirely of local rocks and the quantitative proportions between different lithologies reflect the relative resistance of the bedrock. Therefore, in the Starucha valley the percentage of rather rare basalt increases at the expense of weak metamorphic slates. Debris pieces in the upper unit are derived from the slope outcrops immediately above the sections; this unit is the least differentiated.

The likely interpretation of the threefold division of sediments is the following. The lower unit is the result of the reworking of slope deposits constantly subjected to downslope movement. The mixed composition and traces of exotic rocks suggest that glacial deposits were also incorporated into the slope colluvium. The middle unit is of fluvial origin, whilst the upper one is a footslope deposit which overlies the terrace surface rather than being part of the terrace structure. No data is available to date the sedimentary complex of the upper terrace. From regional stratigraphy it can only be inferred that its origin goes back to the Last Glacial period, and thus it is correlative with so called Middle Terrace of other river valleys in the Sudetes Mts (Krzyszkowski *et al.*, 1995; Krzyszkowski & Stachura, 1993; Krzyszkowski & Biernat, 1998; Migoń *et al.*, 1998).

The existence of higher strath terraces, correlative to the Upper Terrace in other valleys, is uncertain. Benches parallel to the valley courses do occur in all three major valleys and they terminate at the margin of the Sudetes, but in no case have sediments indicative of fluvial origin been found on these benches. In the Paszówka valley the bench is located *c.* 10 m above the floodplain and is 300 m long. On its surface local greenstone debris derived from the slope above occurs; the thickness of the debris cover is at least 1 m. In the Jawornik valley an extensive bench occurs, ca 8 m high and 100 m wide, on the northern slope. Its surface is dissected by the Myślinówka valley. Again, the sediments on the bench are of colluvial origin and contain strongly weathered clasts of greenstones and phyllites; their thickness is at least 3.1 m. A well developed mid-slope bench also occurs in the Starucha valley and is ca. 300 m long and 100 m wide. A pit cut in this surface revealed a 1.2 m thick layer of densely packed debris containing phyllites, greenstones and quartz, and greenstone bedrock below.

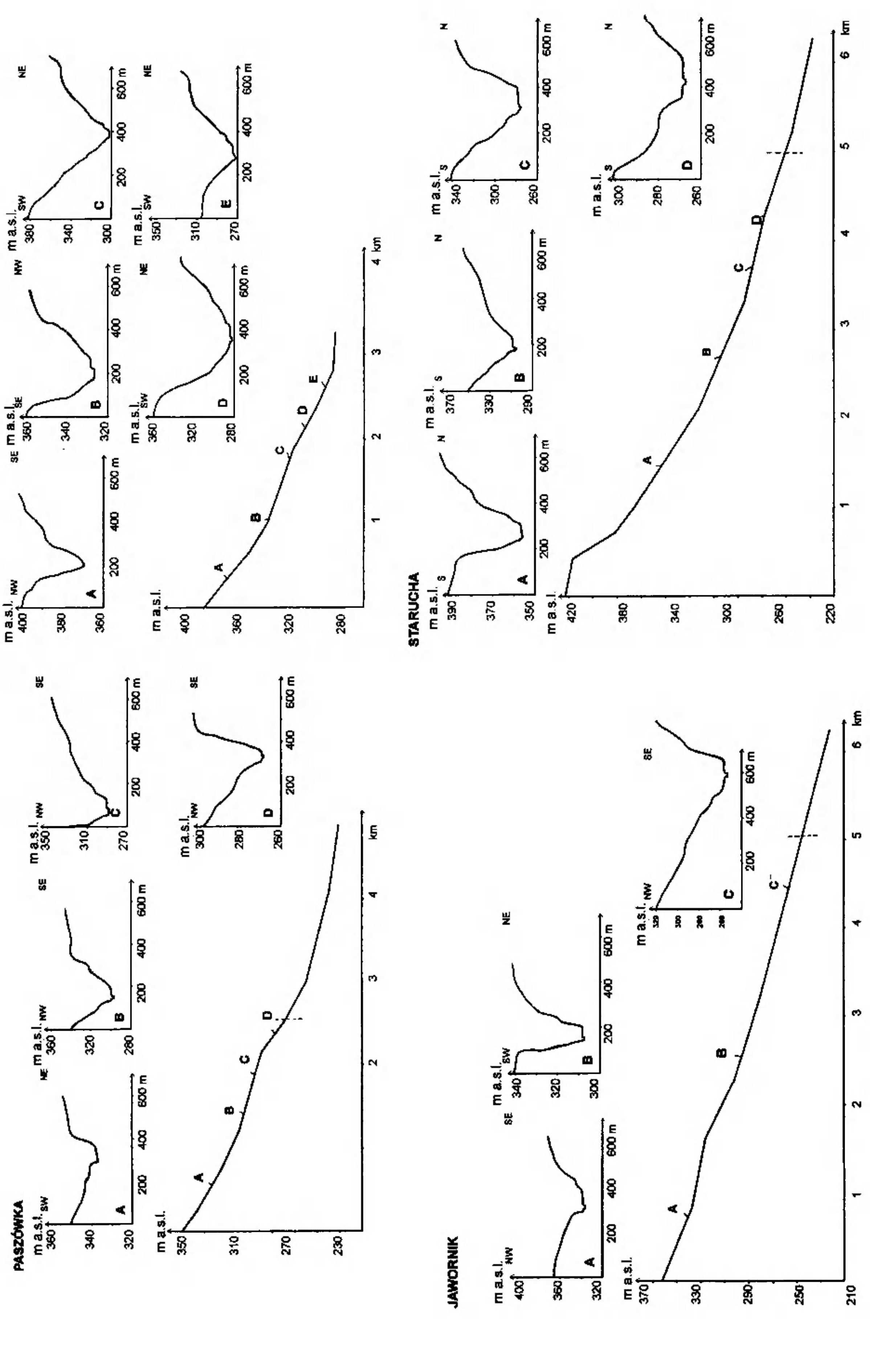

Fig. 6. Longitudinal and cross profiles of large valleys of the eastern part of the Kaczawa Upland. Vertical broken line indicates position of the Sudetic Marginal Fault.

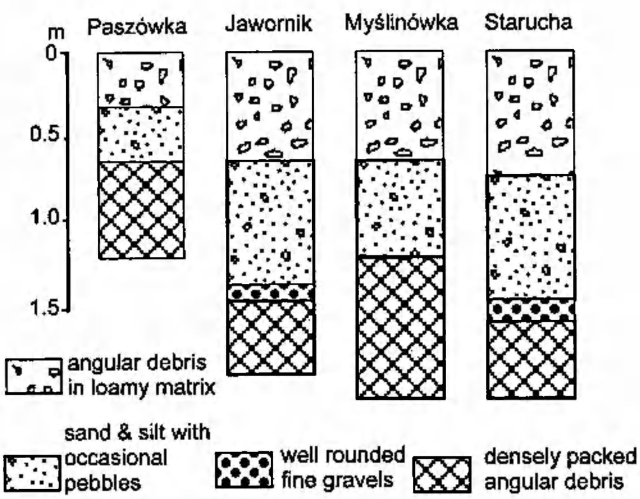

Fig. 7. Sedimentary sequences in higher terrace levels (Middle Terrace ?) in river valleys of the eastern part of the Kaczawa Upland.

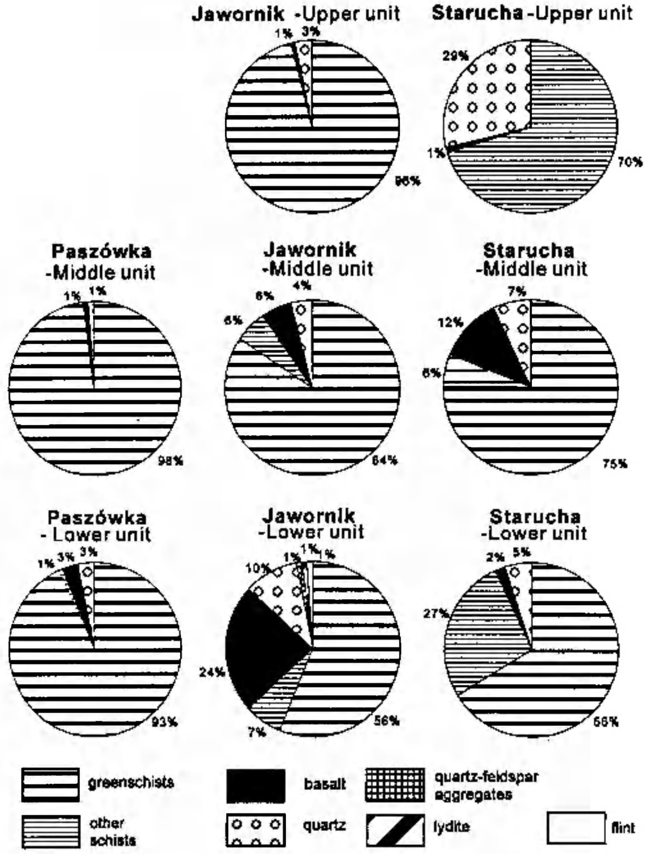

Fig. 8. Petrographic composition of sediments of the higher terrace levels (Middle Terrace ?) in river valleys of the eastern part of the Kaczawa Upland.

DISCUSSION

The neotectonic component in the landscape development of the marginal part of the Kaczawa Upland is difficult to unequivocally identify, particularly with respect to the timing of morphotectonic events. This seems to be in accordance with the general picture emerging from morphometric (Krzyszkowski *et al.*, 1995) and surveying data (Gierwielaniec & Woźniak, 1983), and from regional analysis of the geology and relief of the Sudetic Marginal Fault zone (Oberc & Dyjor, 1969; Migoń *et al.*, 1998), which all suggest decreasing tectonic activity towards the north-west and less clear tectonic control on landform development.

Evident signs of Late Quaternary tectonic activity, such as terrace truncation and divergence towards the mountain front and the occurrence of knick points at the scarp base, all common in other sectors of the Sudetic Marginal Fault (Pijet, 1991; Krzyszkowki & Pijet, 1993; Krzyszkowski & Stachura, 1993, 1998; Krzyszkowski & Biernat 1998; Krzyszkowski *et al.*, 1998), have not been found in the Kaczawa Upland. Other features, potentially indicative of Late Pleistocene to recent tectonic activity, such as stream deflections, overlapping alluvial fans and rapids in channels, have not been found either.

However, some influence of Quaternary tectonics should not be totally dismissed. It has also to be borne in mind that the area is predominantly underlain by erodible, highly tectonised metamorphic slates, whose potential to preserve small-scale tectonic features is very limited. The considerable dissection of the margin of the Kaczawa Upland indicates high dynamics of landform changes and points to an active part played by incision and headward erosion, likely to reflect rejuvenation of the mountain front in a not very distant past. Since the extensive watershed surfaces are of Late Miocene rather than of Early Miocene age (see the chapter about the main landscape features), a Pliocene to Quaternary age for the major dissection is very probable. It would reflect major uplift along the Sudetic Marginal Fault at that time. Landscape rejuvenation has not yet been completed as evidenced by the occurrence of shallow trough valleys in the headward sections of the Jawornik and Starucha valleys. The scarcity of sedimentary cover and the absence of a stepped arrangement of terrace levels also point to a dominance of erosion over deposition. Finally, the interpretation of mid-slope benches as truncated older terraces cannot be ruled out. In two cases the bottom of the slope deposits has not been reached and the occurrence of fluvial gravels below them might be possible.

CONCLUSIONS

The results of landscape analysis in the marginal part of the Kaczawa Upland show that this sector of the Sudetic Marginal Fault was characterised by a lower degree of tectonic activity during the Cainozoic than the areas located further towards south-east. The scarcity of sediments and the ambiguous significance of some landforms do not allow us to put forward any complete reconstruction of morphotectonic history, yet its main components may be outlined.

The tectonic uplift of the Sudetes relative to the foreland took place, in principle, during the Pliocene and Quaternary, and postdates the origin of Late Miocene denudation surface with residual basaltic plugs on the Kaczawa Upland. The northern and southern tectonic blocks of the Chełmy, separated by the Myślinów Fault, were subjected to differential movement, the former being uplifted slightly higher than the latter. No signs of stepped topography of tectonic origin are present. The origin of the mountain front induced the rejuvenation of fluvial relief, much more advanced in the northern part.

The neotectonic reactivation of the Sudetic Marginal Fault in the Late Quaternary, well expressed in landforms and sediments in more southerly sectors of the fault, cannot be unequivocally confirmed. The longitudinal profiles of streams and lower terrace levels do not show any conspicuous disturbance at the mountain front, whilst higher mid-slope benches apparently truncated at the margin of the Sudetes do not bear an alluvial cover, but colluvium instead; therefore their interpretation as truncated terraces is at present without support.

It may be speculated that after the Pliocene–Early Quaternary phase of considerable tectonic activity all along the Sudetic Marginal Zone (Oberc & Dyjor, 1969; Krzyszkowski *et al.*, 1995), subsequent movements varied in intensity along different sectors of the fault. In the Kaczawa sector, endogenic factor was then of minor importance, therefore the present-day relief is mostly of fluvial and denudational character, and the mountain front itself is residual.

REFERENCES

BADURA, J. & PRZYBYLSKI, B., 1995. Neotektoniczne aspekty rzeźby przedpola Sudetów Wschodnich [Neotectonic aspects of the East Sudeten foreland relief]. *Przegląd Geologiczny*, 43: 762–766.

BARANOWSKI, Z., HAYDUKIEWICZ, A. & URBANEK, Z., 1982. Aktualne kierunku badań stratygraficznych, sedymentologicznych i tektonicznych metamorfiku Gór Kaczawskich [Present directions of stratigraphic, sedimentologic and tectonic studies over the metamorphic zone of the Góry Kaczawskie (Mts.)]. *Biuletyn Instytutu Geologicznego*, 341: 141–161.

GIERWIELANIEC, J. & WOźNIAK, J., 1983. Ocena współczesnej aktywności tektonicznej uskoku sudeckiego brzeżnego w świetle archiwalnych materiałów niwelacyjnych [Estimation of recent tectonic activity of the Sudetic Marginal Fault in the light of archival levelling data]. In: *Współczesne i neotektoniczne ruchy skorupy ziemskiej w Polsce, 4.* Ossolineum, Wroclaw, pp. 109–123.

JERZMAŃSKI, J., 1965. Budowa geologiczna północno-wschodniej części Gór Kaczawskich i ich wschodniego przedłużenia [Geology of the north-eastern part of the Kaczawa Mts. and of their eastern extension]. *Biuletyn Instytutu Geologicznego*, 185: 109–193.

KOWALSKI, B., 1978. Osady cykliczne na przedpolu kaledonidów kaczawskich a rozwój powierzchni zrównania i sudeckiego uskoku brzeznego na odcinku ich wschodniej części. *Prace Geograficzne WSP w Kielcach*, 1: 34–50.

KRZYSZKOWSKI, D. & BIERNAT, J., 1993. Terraces of the River Bystrzyca valley, Middle Sudeten, Southwestern Poland, and their deformation by Sudetic Marginal Fault. *Bulletin of the INQUA Neotectonic Commission*, 16: 29–31.

KRZYSZKOWSKI, D. & BIERNAT, J., 1998. Terraces of the Bystrzyca river valley and their deformation along the Sudetic Marginal Fault. *Geologia Sudetica*, 31: 241–258.

KRZYSZKOWSKI, D. & PIJET, E., 1993. Morphological effects of Pleistocene fault activity in the Sowie Mts., southwestern Poland. *Zeitschrift für Geomorphologie N.F., Supplement-Band*, 94: 243–259.

KRZYSZKOWSKI, D. & STACHURA, R., 1993. Morfologiczne efekty ruchów neotektonicznych na Pogórzu Wałbrzyskim w Sudetach Środkowych. [Morphologic effects of neotectonic movements in the Wałbrzych Foothills, Middle Sudety Mountains, SW Poland]. *Folia Quaternaria*, 64: 71–82.

KRZYSZKOWSKI, D. & STACHURA, R., 1998. Neotectonically controlled fluvial features, Walbrzych Upland, Middle Sudeten Mts, southwestern Poland. *Geomorphology*, 22: 73–91.

KRZYSZKOWSKI, D., MIGOŃ, P. & SROKA, W., 1995. Neotectonic Quaternary history of the Sudetic Marginal Fault, SW Poland. *Folia Quaternaria*, 66: 73–98.

KRZYSZKOWSKI, D., PRZYBYLSKI, B. & BADURA, J., 1998. Late Cainozoic evolution of the Nysa Klodzka river system between Kłodzko and Kamieniec Ząbkowicki, Sudetes Mts, Southwestern Poland. *Geologia Sudetica*, 31: 133–155.

MASTALERZ, K. & WOJEWODA, J., 1990. Stożek aluwialny pra-Kaczawy - przyklad sedymentacji w czynnej strefie przesuwczej, plio-plejstocen, Sudety [The Pre-Kaczawa alluvial fan - an example of sedimentation in an active wrench zone, Plio-Pleistocene age, Sudetic Mountains]. *Przegląd Geologiczny*, 38: 363–370.

MIGOŃ, P., 1996. Struktura morfotektoniczna centralnej części Sudetów Zachodnich w świetle mapy zagęszczonych poziomic [Morphotectonic structure of the central part of the Western Sudetes in the light of densed contour map]. *Czasopismo Geograficzne*, 67: 233–244.

MIGOŃ, P., KRZYSZKOWSKI, D. & GOGÓł, K., 1998. Geomorphic evolution of the mountain front of the Sudetes Mts between Dobromierz and Paszowice and adjacent areas, with particular reference to the fluvial systems. *Geologia Sudetica*, 31: 289–305.

OBERC, J. & DYJOR, S., 1969. Uskok sudecki brzeżny [Marginal Sudetic Fault]. *Biuletyn Instytutu Geologicznego*, 236: 41–142.

PIASECKI, H., 1956. Morphologie périglaciaire du bord des Sudetes aux environs de Jawor. *Biuletyn Peryglacjalny*, 4: 277–283.

PIJET, E., 1991. Pleistocene activity of the Sudetic Marginal Fault in the sector of the Sowie Mountains, SW Poland. *Bulletin of the INQUA Neotectonic Commission*, 14: 55–56.

SROKA, W., 1992. Czwartorzędowa aktywność sudeckiego uskoku brzeżnego w świetle analizy morfometrycznej. In: