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LATE QUATERNARY VALLEY FORMATION AND NEOTECTONIC EVOLUTION OF THE WAŁBRZYCH UPLAND, MIDDLE SUDETEN MTS., SOUTHWESTERN POLAND

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Abstract: The landscape of the Wałbrzych Upland developed for a long time during three main stages: the Oligocene–Early Pliocene, the Late Pliocene–Early Pleistocene and the Middle Pleistocene one. The latter is very complex, and is presented in detail in this paper. The Wałbrzych Upland was covered by continuous ice cover during the Odranian sub-stage (Early Saalian) and, at least in its marginal part, during the Elsterian. The thickness of the ice was *ca.* 150 m during the last glacial stage. The pre-Elsterian fluvial system is poorly documented, although distinct traces of fluvial landscape from before the Odranian glaciation have been found. This fluvial system is documented by terraces with gravels, flattenings covered by tills which are presumably buried terraces, and the abandoned valleys. The pre-Odranian fluvial landscape shows ambiguous evidence of tectonic movements, except valley segments near the Sudetic Marginal Fault. Four stages of the post-Odranian valley development may be recognized, which are documented by four terraces: the Upper Terrace formed during the Wartanian/Eemian, the Middle Terrace formed during the Middle Weichselian, the Lower Terrace formed during the Late Glacial/Early Holocene, and the Lowermost Terrace formed during the historical times. The post-Odranian valleys have been formed due to intensive and short-term uplift of the mountain upland with simultaneous re-activation of fault zones. The main geomorphological effects of this uplift include: formation of abandoned valleys; bottle-like shapes of newly incised valleys; formation of river gorges; highly irregular longitudinal profiles of channels; varying number of terraces and their heights along the valley thalvegs; tilting of terraces, truncation of terraces and formation of fault scarps along the Sudetic Marginal Fault. The main geological effects are: variable thickness of alluvial deposits due to rotation of bedrock blocks; synsedimentary thickness increase of alluvial deposits on some fault lines; and breaking of the continuity of some alluvial surfaces along the Sudetic Marginal Fault. The uplift of the Wałbrzych Upland was induced by isostatic rebound after the Odranian glaciation and localised extentional tectonics, being superimposed on each other. The total uplift during the late Quaternary was about 40–50 m. The uplift rates were at about 1.5 mm/year at the beginning (*ca.* 200,000–150,000 years BP), and much lower during the Late Pleistocene and Holocene (0.15–0.05 mm/year). The uplift, though very slight, continues until now.

Abstrakt: Rzeźba Pogórza Wałbrzyskiego ukształtowała się w trzech etapach: oligoceńsko-wczesnoplioceńskim, późnoplioceńsko-wczesnoplejstoceńskim i środkowoplejstoceńskim. Ten ostatni etap rozwoju rzeźby był najbardziej skomplikowany i jest on przedmiotem szczegółowych rozważań w zaprezentowanym artykule. Pogórze Wałbrzyskie było przykryte lądolodem skandynawskim w czasie ostatniego zlodowacenia tego obszaru, tj. w czasie zlodowacenia Odry (wczesny stadiał zlodowacenia środkowopolskiego) i co najmniej w swoich częściach brzeżnych w czasie zlodowacenia Elstery (południowopolskiego). Grubość lodu dochodziła do 150 m. Rzeźba fluwialna sprzed zlodowacenia Elstery jest słabo udokumentowana, natomiast obserwuje się liczne ślady takiej rzeźby sprzed zlodowacenia Odry. Jest ona udokumentowana przez terasy, spłaszczenia stokowe z pokrywami glin, które reprezentują pogrzebane terasy, oraz przez opuszczone (pogrzebane) doliny rzeczne. Ten przed-odrzański system fluwialny wykazuje bardzo mały związek z tektoniką regionu, z wyjątkiem części dolin w pobliżu Sudeckiego Uskoku Brzeżnego. Po zlodowaceniu Odry, na Pogórzu Wałbrzyskim stwierdzono cztery fazy rozwoju rzeźby fluwialnej, udokumentowane przez terasy: terasę wysoką z okresu Warta/Eem, terasę średnią ze środkowego Vistulianu, terasę niską z późnego glacjału/początku holocenu i terasę najniższą powstałą już w czasach historycznych. Doliny po-odrzańskie były formowane w czasie krótkiego i bardzo intensywnego podnoszenia obszaru górskiego, z jednoczesnym uaktywnianiem stref uskokowych. Główne efekty morfologiczne tego podnoszenia to: butelkowy kształt nowo tworzonych dolin, powstanie odcinków przełomowych dolin, bardzo niewyrównane profile podłużne koryt rzecznych, zmienna liczba teras i ich wysokość wzdłuż dolin, pochylenie teras, obcięcie teras i skarpy uskokowe wzdłuż Sudeckiego Uskoku Brzeżnego. Główne efekty geologiczne to: zróżnicowana miąższość aluwiów w wyniku rotacyjnych ruchów podłoża, synsedymentacyjny wzrost miąższości aluwiów na skrzydłach zrzuconych niektórych uskoków i brak ciągłości niektórych pokryw aluwialnych poza Sudeckim Uskokiem Brzeżnym. Podnoszenie Pogórza Wałbrzyskiego nastąpiło najprawdopodobniej w wyniku odprężenia glaciizostatycznego po zlodowaceniu Odry, na które nałożyły się ruchy tektoniczne wzdłuż reaktywowanych uskoków. Całkowite, czwartorzędowe, tektoniczne podniesienie obszaru wynosi 40–50 m. Prędkość podnoszenia wynosiła początkowo 1,5 mm rocznie (*ca.* 200 000–150 000 lat BP), a potem, w późnym plejstocenie i holocenie, była znacznie mniejsza (0,15–0,05 mm rocznie). Podnoszenie to, choć bardzo małe, trwa do czasów obecnych.

Key words: fluvial landscape, terraces, montaneous glaciation, neotectonics, glacio-isostasy, Wałbrzych Upland, Sudeten Mts., SW Poland.

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INTRODUCTION

The paper presents the Late Quaternary geomorphic evolution of the Wałbrzych Upland, central Sudeten (Fig. 1), with special reference to neotectonically-induced landforms. The landscape of the Sudeten Mts. was formed continuously during the Late Mesozoic and Cainozoic (Migoń, 1994), with the main phase of uplift and formation of montaneous landscape during the Pliocene (Oberc & Dyjor, 1969; Oberc, 1972). The Quaternary geomorphic evolution of the Sudeten Mts. has usually been assumed as a result of climatic factors, especially those connected with the glacial-interglacial cycle (Jahn, 1960; Jahn & Szczepankiewicz, 1967). The tectonic activity was supposed to be rather insignificant at that time. At least two Scandinavian ice-sheets reached the Sudeten (Schwarzbach, 1942; Jahn & Szczepankiewicz, 1967; Badura *et al.*, 1992). In central Sudeten, including the Wałbrzych Upland, which are relatively low, the ice sheet advanced into the montaneous interior, several kilometres away from the mountain margin (Schwarzbach, 1942; Jahn & Szczepankiewicz, 1967). The ice thickness, calculated from the highest positions of Scandinavian erratics on nunatacks, was here about 150 m and the cover of glacial deposits reached a thickness of at least 10–20 m (Dathe, 1892; Schwarzbach, 1942; Szczepankiewicz, 1954).

Zeuner (1928), however, has suggested the neotectonic uplift of the Sudeten Mts., though very low in comparison to the Pliocene one, but significant enough to cause specific geomorphic evolution of some valleys. Also, more recent investigations document neotectonic movements (Dyjor, 1975, 1983; Krzyszkowski, 1990, 1991; Migoń, 1991, 1993; Sroka, 1990, 1992; Krzyszkowski & Pijet, 1993; Mastalerz & Wojewoda, 1993; Krzyszkowski & Migoń, 1995; Krzyszkowski *et al.*, 1995).

The main problem in describing possible tectonic movements in central Sudeten during the Pleistocene is the fact, that the isostatic rebound after individual glaciations might have been superimposed on the uplift caused by endogenic processes. The Wałbrzych Upland exhibits this problem well, and the results are discussed below. Pleistocene deposits of the Wałbrzych Upland have not been investigated extensively. The very early work by Dathe (1892) contains a detail description of glacial deposits of the region. Later, the Pleistocene geology was presented only on geological maps by Berg *et al.* (1910), Dathe and Berg (1925), Zimmerman *et al.* (1925), Zimmermann (1929), Teisseyre and Gawroński (1965), Teisseyre (1969) and Haydukiewicz *et al.* (1982). Explanations to these maps include only limited data on the Pleistocene sequence, which are not enough, with few exceptions, for correlation with the recent works (Dathe & Zimmermann, 1912; Dathe & Berg, 1926; Zimmermann & von zur Mühlen,1933; Zimmermann, 1938; Teisseyre, 1973; Haydukiewicz *et al.*, 1985). Geomorphic evolution of the Wałbrzych Upland and adjacent regions, together with descriptions of Quaternary exposures, has also been presented by Szczepankiewicz (1954, 1963). Teisseyre (1977, 1979) and Jońca (1981) described recent fluvial processes in river valleys of the Wałbrzych Upland, but these results have limited application to this study.

This paper presents materials collected by the senior author in 1988 and 1993–1994, and by both authors during 1989–1992. Additionally, some observations of the senior author come from 1977 (Stare Bogaczowice brickyard) and from 1984 (lower Strzegomka river valley before construction of the water reservoir).

GEOLOGY

The Wałbrzych Upland has a complex bedrock geology, with several tectonic blocks composed of different rocks and characterised by varying tectonic histories (Bederke, 1929; Teisseyre, 1956, 1968; Oberc, 1972). These blocks are separated one from another by faults, including two major dislocations of the Sudeten: the Marginal Sudetic Fault and the Main Sudetic Fault System (Fig. 2).

The Sudetic Marginal Fault separates the Wałbrzych Upland and the entire Sudeten from the Sudetic Foreland, which is geologically a part the Fore-Sudetic Block (Fig. 2). The fault itself is manifested as a 100 m high scarp. The Sudetic Foreland, in the part that lies near the Sudetic Marginal Fault, is occupied by Cainozoic deposits infilling the 400 m deep Roztoka–Mokrzeszów Graben (Dyjor & Kuszell, 1977; Kural 1979).

Four main structural-stratigraphic units are present in the Włabrzych Upland. These are (Fig. 2): the northern part of the Sowie Góry gneiss Block (Proterozoic–Lower Palaeozoic paragneisses); the Świebodzice Synclinorium with Cambrian spilites and greenschists, Upper Devonian and Lower Carboniferous conglomerates, sandstones, mudstones and occasionally limestones; the Kaczawskie Góry Zone with Cambrian spilites, greenshists, cataclasites and mylonites, Upper Devonian/Lower Carboniferous metamorphic schists (Gunia, 1981) and Permian sedimentary rocks; and the Intra-Sudetic Synclinorium with Carboniferous conglomerates, sandstones, mudstones and coal, and Permian volcanites (ryolites and piroclastic rocks). The latter form laccoliths of the Mounts Krąglak, Trójgarb, Chełmiec and Lisi Kamień (Fig. 3), being a part of the Wałbrzych Moun-

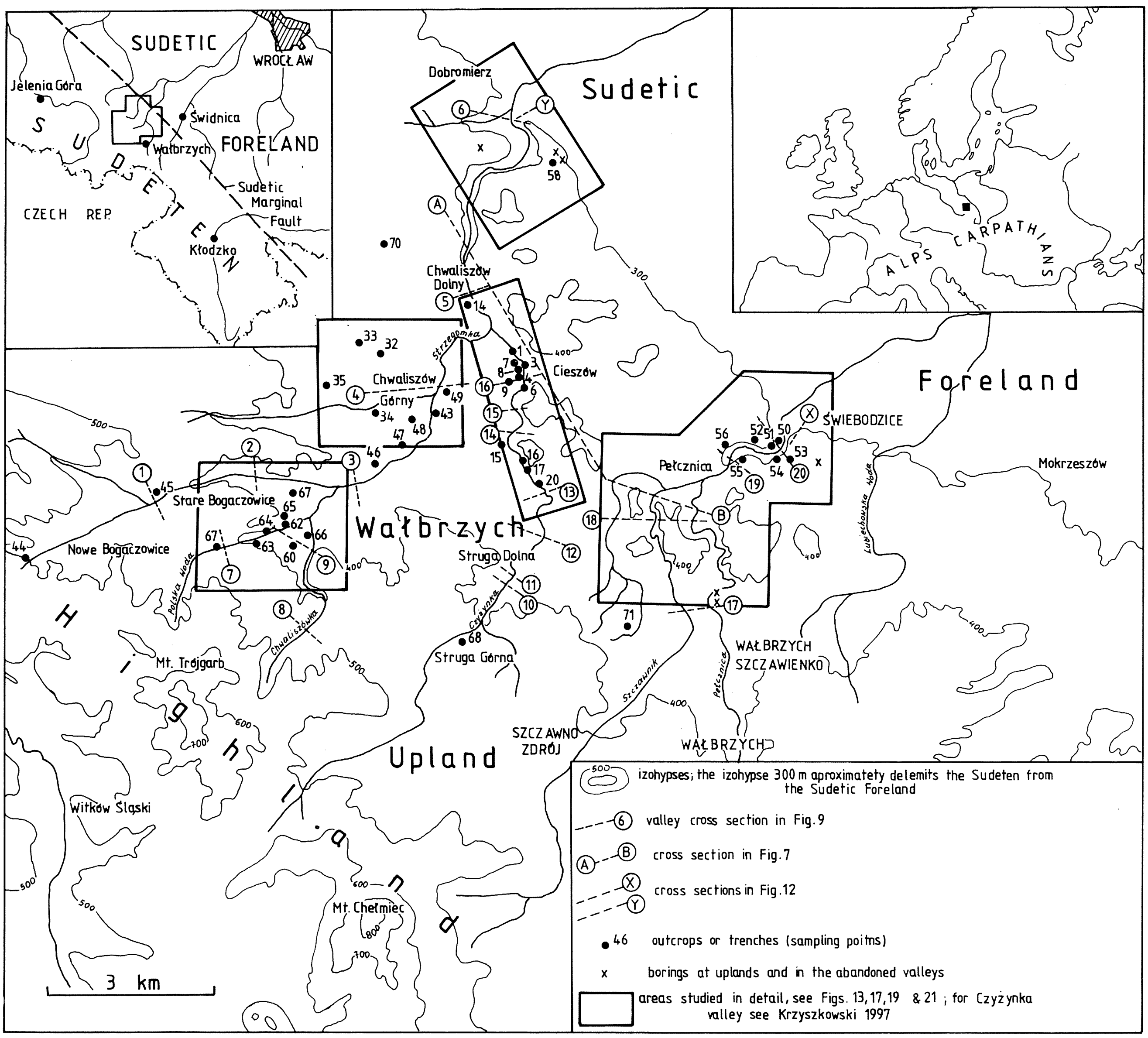


Fig. 1. Location map of the study area

tains (Highland) and forming the southwest boundary of the Wałbrzych Upland.

The bedrock is covered by a discontinuous cover of the Pleistocene deposits. Watershed and plateau areas are covered by a thin mantle of glacial sediments: till, glaciofluvial sands and gravels and, in places, varved clays. Very often, only single large erratics lie on the bedrock. Among them, besides the Scandinavian crystalline rocks, local basalts from the Sudetic Foreland are present. The valleys are infilled both with glacial deposits (up to 10–20 m) and fluvial gravels, as well as with thick mantles of slope (periglacial) deposits and loess-like loam.

GENERAL MORPHOLOGY

Geomorphologically, the region investigated can be subdivided into three parallel and SE–NW trendings zones which are also parallel to the main dislocation zones. The southwestern and southernmost zone is a highland lying at 450–800 m a.s.l. (Fig. 3), which is also characterised by steep slopes (Fig. 4) and high values of relative relief (Fig. 5), and the high values of the relief belt above headstream erosion (Fig. 6). This zone coincides with exposures of resistant Permian volcanites (Fig. 2). The central depression (Fig. 3) is, in turn, only 360–420 m a.s.l. high, and it is characterised by flat watersheds and gentle slopes, except some fragments of river valleys (Fig. 4). This region is characterised by very low relative relief (H_{max}–H_{min} always below 50 m, occasionally below 10 m) (Fig. 5). However, the relief above headstream erosion has the lowest values in the region and generally below 10 m (Fig. 6). This zone is located along the Main Sudetic Fault System (Fig. 2). The northeastern zone, which occurs at the margin of mountain plateau, represents the most complex relief (Fig. 3). It is composed of flat areas (*ca.* 400 m a.s.l.), similar to the central depression, the monadnocks up to 500 m a.s.l., and areas

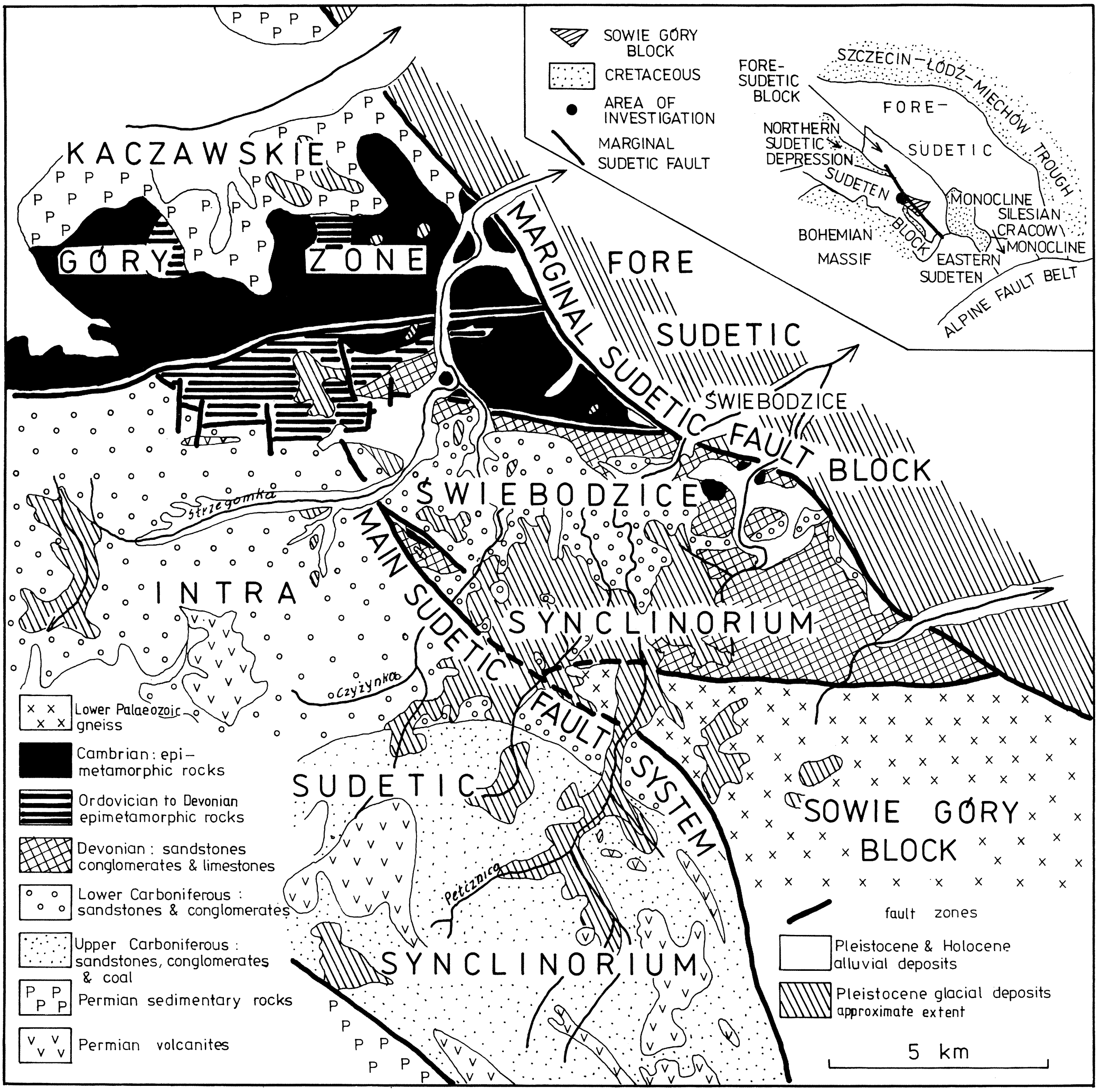


Fig. 2. Simplified geological map of the Wałbrzych Upland (after Haydukiewicz *et al.*, 1982; Teisseyre, 1969; Teisseyre & Gawroński, 1965)

strongly incised by rivers (Fig. 7). The latter zone is characterised by relatively steep slopes (Fig. 4) and increased values of relative relief (Fig. 5). High values of the relief above headstream erosion form narrow zones, which trend along the Sudetic Marginal Fault and the faults separating the Sowie Góry Block from the Świebodzice Depression, and the Świebodzice Depression from the Kaczawskie Góry Zone (Fig. 6), suggesting strong connection of increased erosion with the fault zones.

The flat areas of the northeastern zone form two big plateaus, the Cieszów Plateau and the Lubiechów Plateau (Figs. 3, 7). Together with the central depression they form one synchronous geomorphic surface at about 400 m a.s.l. (Fig. 3), which was originally named the Cieszów horizon (Szczepankiewicz, 1954).

RIVER VALLEYS: ANALYSIS OF CROSS AND LONGITUDINAL PROFILES

Recent valleys are deeply incised, up to 80–100 m in the northeastern zone, near the mountain margin (Fig. 7), and usually 40–50 m in the central depression. The valleys have bottle-shaped morphology, indicating several wide depressions separated by narrow valleys and/or gorges (Fig. 8). The valley width varies from 50–100 m up to 2 km, averag-

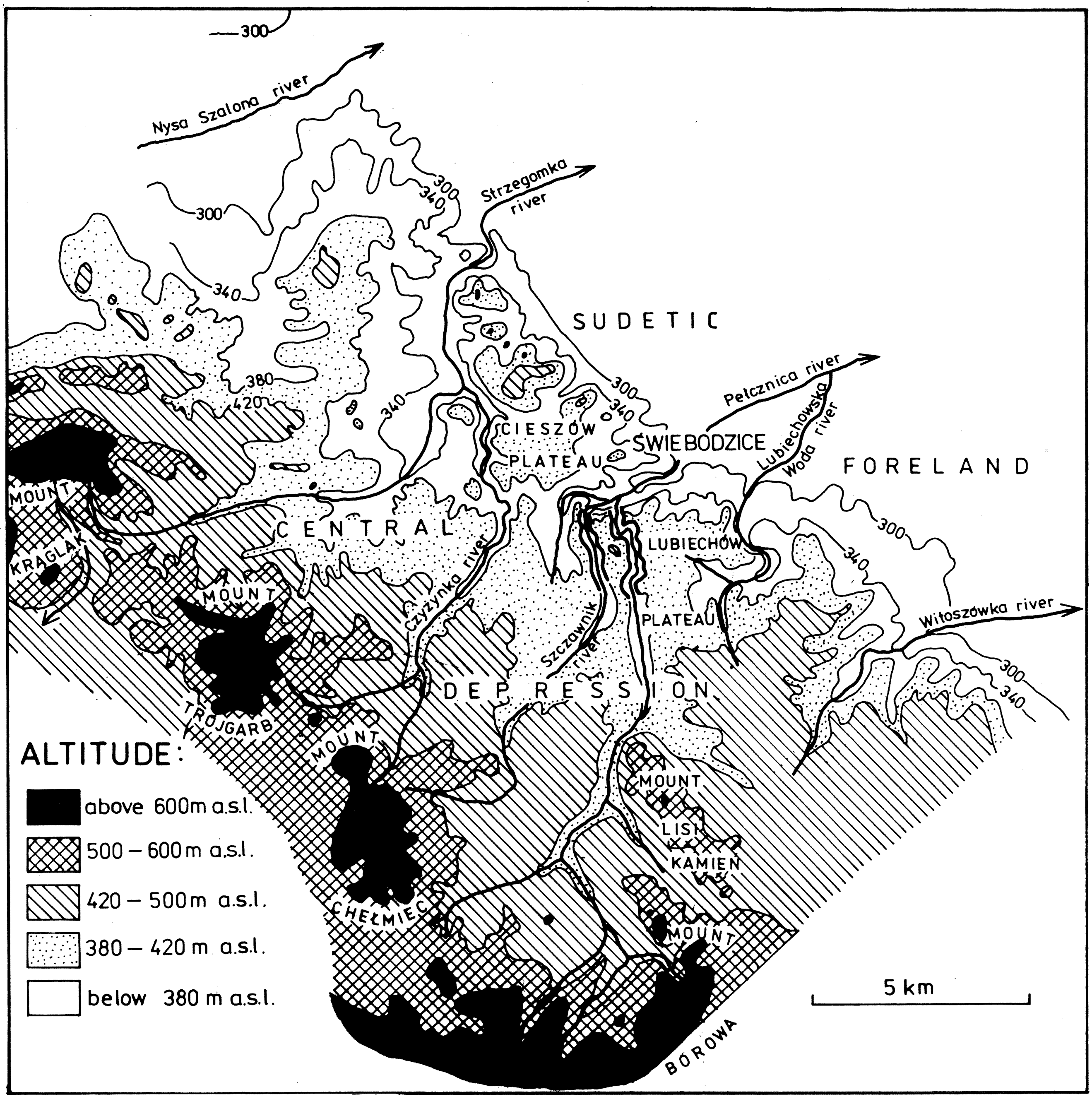


Fig. 3. Hypsometry of the Wałbrzych Upland

ing at 100–300 m in "normal" valleys. The valley cross sections indicate different shapes. The upstream river courses in southwestern highlands are usually V-shaped, with the best examples from Polska Woda and Chwaliszówka rivers. In downstream river reaches, the valleys are usually box-shaped, with flat alluvial bottoms, one or two terraces, and relatively steep slopes (Fig. 9). The river gorges and also some of "narrow" valleys have bedrock channels, very often without alluvial deposits. The valley slopes are represented here by almost vertical bedrock walls, with the best examples in the Pełcznica and Szczawnik river gorges and in Czyżynka river valley (Fig. 9). The valley "depressions", in turn, are at least twice wider than the "normal" valleys, and usually comprise a complex terrace pattern, with two or three, and in places, up to four-five terraces. All depressions are also characterised by relatively gentle slopes, as compared to "normal" valleys and river gorges (Fig. 9).

A special case are valley segments near the Sudetic Marginal Fault. Both the Strzegomka and Pełcznica river valleys are bottle-shaped, with at least two wider segments (400–500 m) separated by narrower valleys (100–200 m). However, both wide and narrow parts of the valleys indicate similar morphology (*e.g.* steep slopes) and comprise the same number of terraces (Fig. 9). Another feature is the occurrence of abandoned valleys, infilled with glacial deposits and hanging *ca.* 25–30 m above the recent valleys (Fig. 8). These are box-shaped, with steep slopes and almost flat bottoms. Such valleys are not present significantly in the up-

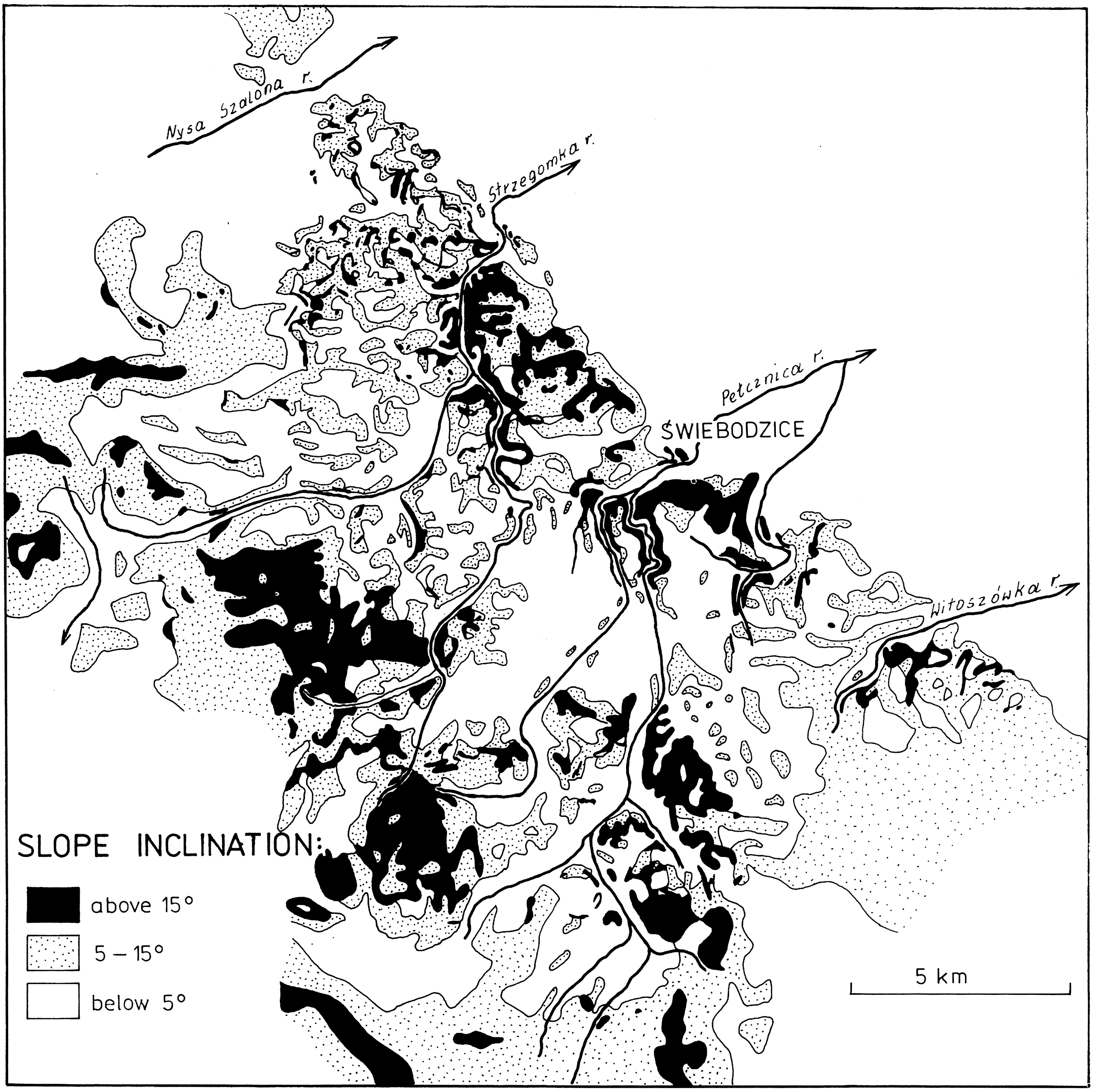


Fig. 4. Map of slope inclination. The map has been compiled on the basis of a topographic map (1:25 000) using the equtiоn $tg\alpha = hd^{-1}$. where α – slope inclination, h – height between contour lines, d – distance between contour lines

stream parts of the valleys. Only two "abandoned valleys", at Chwaliszów Dolny and between the Czyżynka and Polesnica rivers, may potentially exist, except those near the Sudetic Marginal Fault (Fig. 8).

The longitudinal profiles are highly irregular, with channel gradients varying from 0.5% to more than 3% (Figs. 10, 11) (Krzyszkowski & Stachura, 1992, 1993a). The longitudinal profiles can be subdivided into several segments showing different gradients and separated from each other by distinct breaks. The main breaks in longitudinal profiles are about 40–60 m high in the Pełcznica and Szczawnik rivers, and about 15–20 m high in the Czyżynka and Strzegomka rivers. Other breaks are between 1 m to 10 m high (Figs. 10, 11). The breaks in longitudinal profiles occur always in the upper parts of the "narrow" valleys or river gorges. The "normal" valleys indicate gradients between 0.8–1.6%, those of the depressions ranging between 0.4–0.6%. Narrow valleys and especially river gorges indicate increased gradients, from 2% to 2.5% . Moreover, those parts of valleys which contain bedrock channels and rapids, have gradients increased up to 3.5% over short distances.

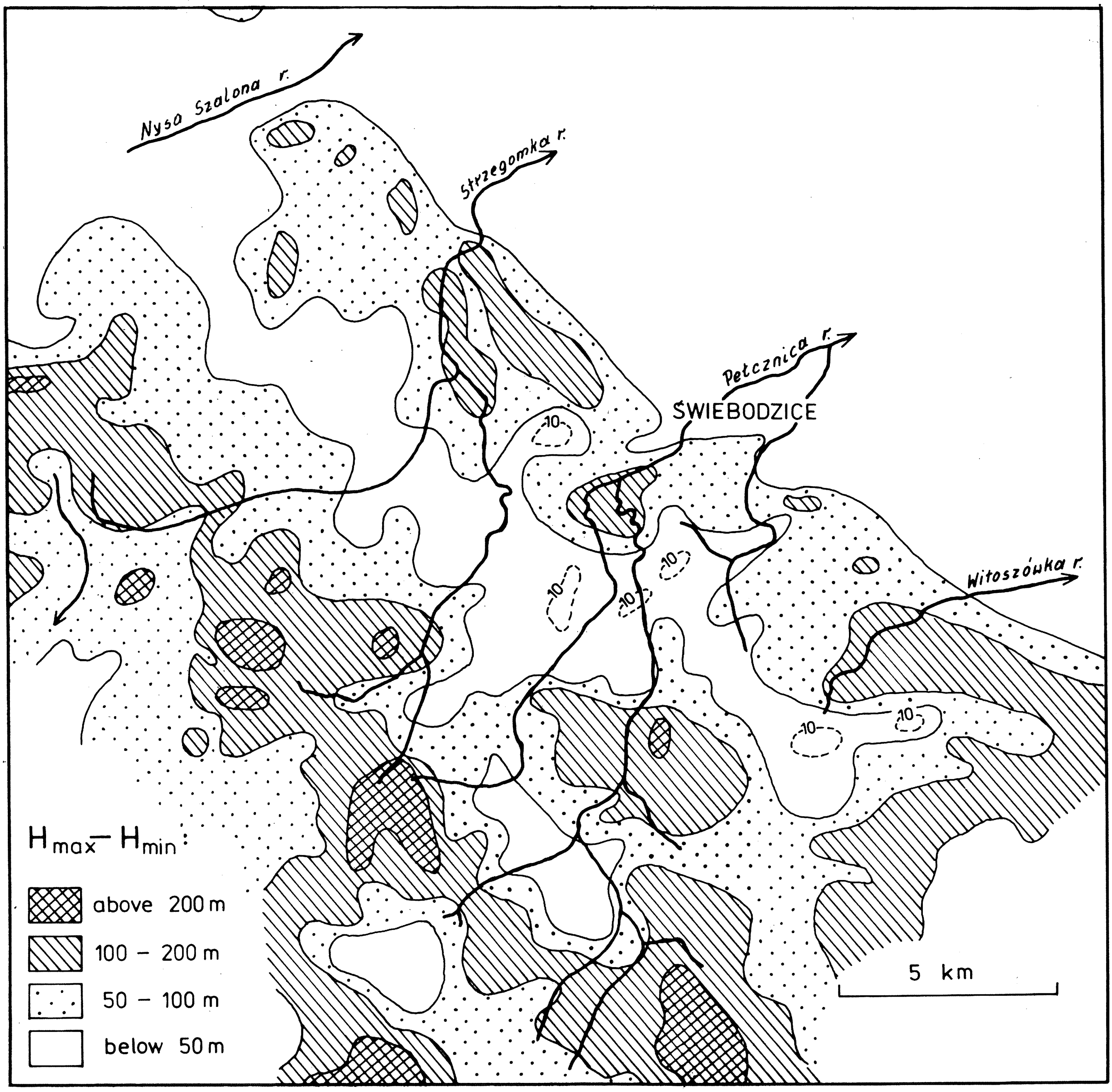


Fig. 5. Map of relief energy (H_{max} – highets elevation in m a.s.l, H_{min} – lowest elevation in m a.s.l.). The map has been interpolated on the basis of a topographic map (1:25 000) with a net of squares (area 1 km^2, distance between centres 0.5 km)

RIVER VALLEYS: TERRACES AND ABANDONED VALLEYS

POSITION AND NUMBER OF TERRACES

Five terraces have been mapped in river valleys of the Wałbrzych Upland (Fig. 8). These are: the Lowermost Terrace, the Lower Terrace, the Middle Terrace, the Upper Terrace and the informal horizon, named the uppermost flattenings, usually covered by till and/or slope deposits. The latter represent, most probably, the equivalents of abandoned valleys in downstream reaches and form small (up to 0.5 km^2) and flat shelves in the upslope position. The uppermost flattenings are very rare (Fig. 8).

The Lowermost Terrace occurs only in the valley segments adjacent to the Sudetic Marginal Fault and in the valley segments of the Sudetic Foreland. This terrace is up to 50 m wide and represents recent alluvial plain. The Middle Terrace occurs only in some "depressions" and in valleys near the Sudetic Marginal Fault, whereas the Lower and Upper terraces occur more or less continuously along all the valleys, except deep river gorges with bedrock channels. The Middle Terrace continues in the Sudetic Foreland in the Strzegomka river valley, whereas it does not continue in the Pełcznica river valley. The Upper Terrace does not continue into the Sudetic Foreland in none of these valleys. The Middle and Upper terraces form elongated, 10–30 m wide, benches along the valley sides, except the Chwaliszów de-

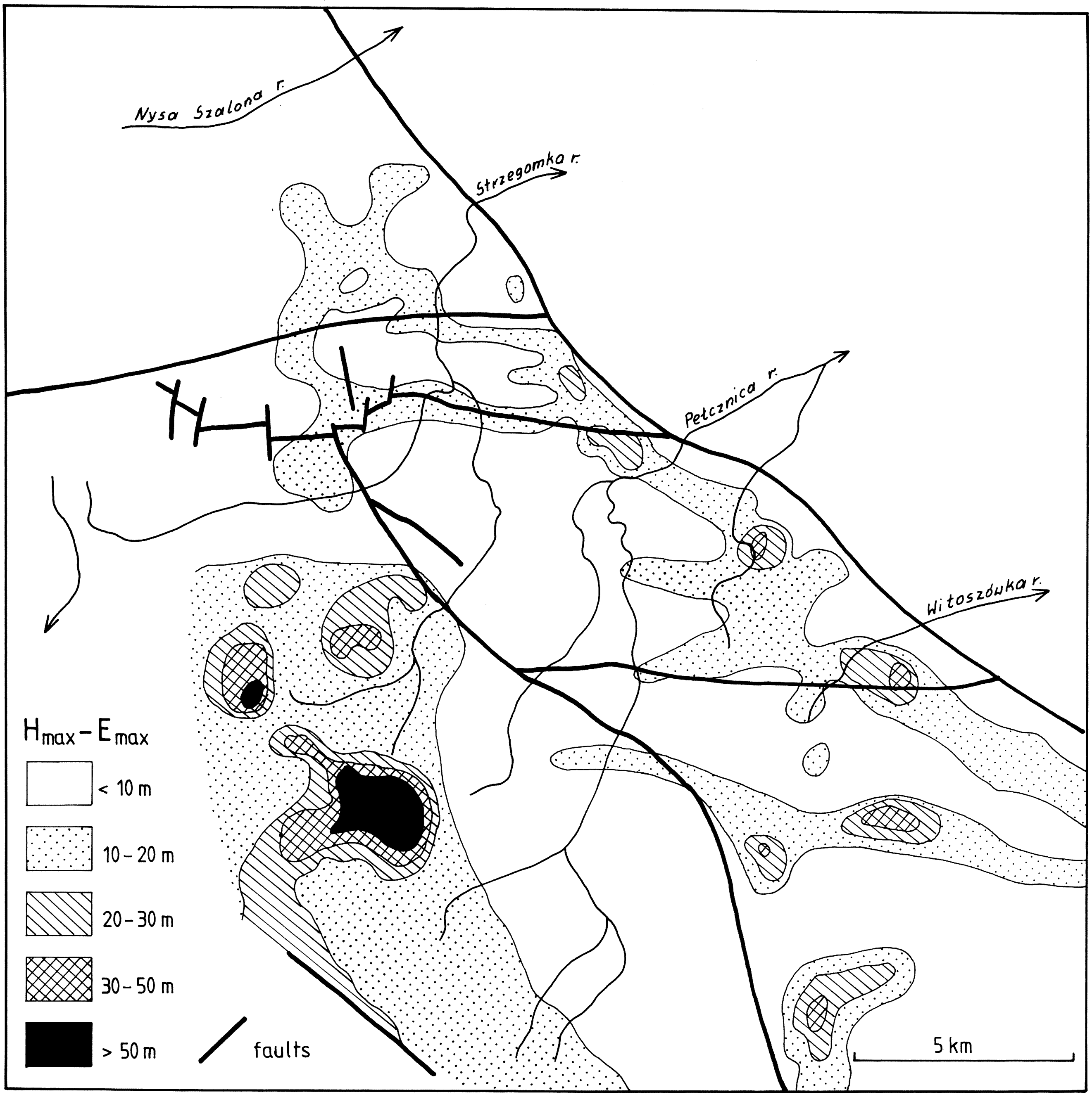


Fig. 6. Map of the relief belt above headstream erosion (Hmax – highest elevation in m a.s.l., Emax – highest position of erosion). The map has been interpolated on the basis of a topographic map (1:25 000) with a net of squares (area 1 km^2, distance between centres 0.5 km)

pression where the Middle Terrace forms an extensive and 3 km wide alluvial plain. The Lower Terrace is usually the most extensive one, infilling the major part of the valley bottom (Figs. 8, 9).

HEIGHT OF TERRACES ALONG THE RIVER COURSES

The uppermost flattenings and abandoned valleys

The abandoned valleys near the Sudetic Marginal Fault and the uppermost flattenings of the lower part of the Pełcznica river valley lie at about 305–310 m a.s.l., *i.e.* 25–30 m above the recent river channel. The possible abandoned valleys in the middle courses of Czyżynka and Strzegomka river valleys lie at 350–360 m a.s.l., *i.e.* 25 m and 23 m above the recent river channels, respectively. The uppermost flattenings in the upper part of the Strzegomka and Polska Woda river valleys lie at 370 m and 390 m a.s.l., *i.e.* 20 m above the recent river channels (Figs. 10, 11). Thus, the heights of abandoned valleys and the uppermost flattenings (terraces) form together a logical sequence, with their lowest positions near the Sudetic Marginal Fault and the highest ones in highland areas. The approximate gradient of

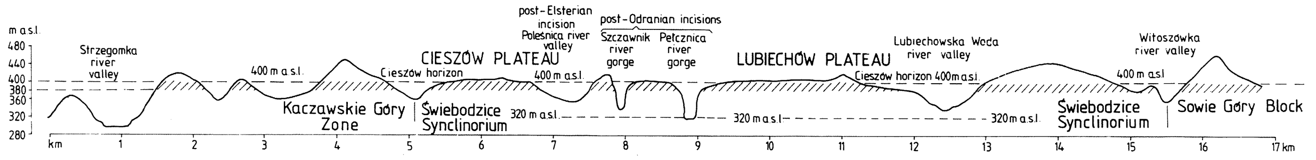


Fig. 7. Morphological cross section along the Cieszów horizon near the Sudetic Marginal Fault zone. Location of the section in Fig. 1

this fluvial system, measured along the Strzegomka river valley, is about 1.6–1.9%, being very similar to recent gradients of the "normal" valleys.

Moreover, a slight divergence of the described surfaces is observed, with 20 m high flattenings at highlands and 30 m high abandoned valleys near the Sudetic Marginal Fault (Fig. 10). It must be stressed out, however, that the height measurements, except two sites with exposed fluvial gravels, were performed on the top of glacial deposits, which mantle the fluvial surfaces with a 5–10 m thick cover. This divergence is not so clear (Strzegomka river valley) or does not occur (Pełcznica river valley) when we take into account

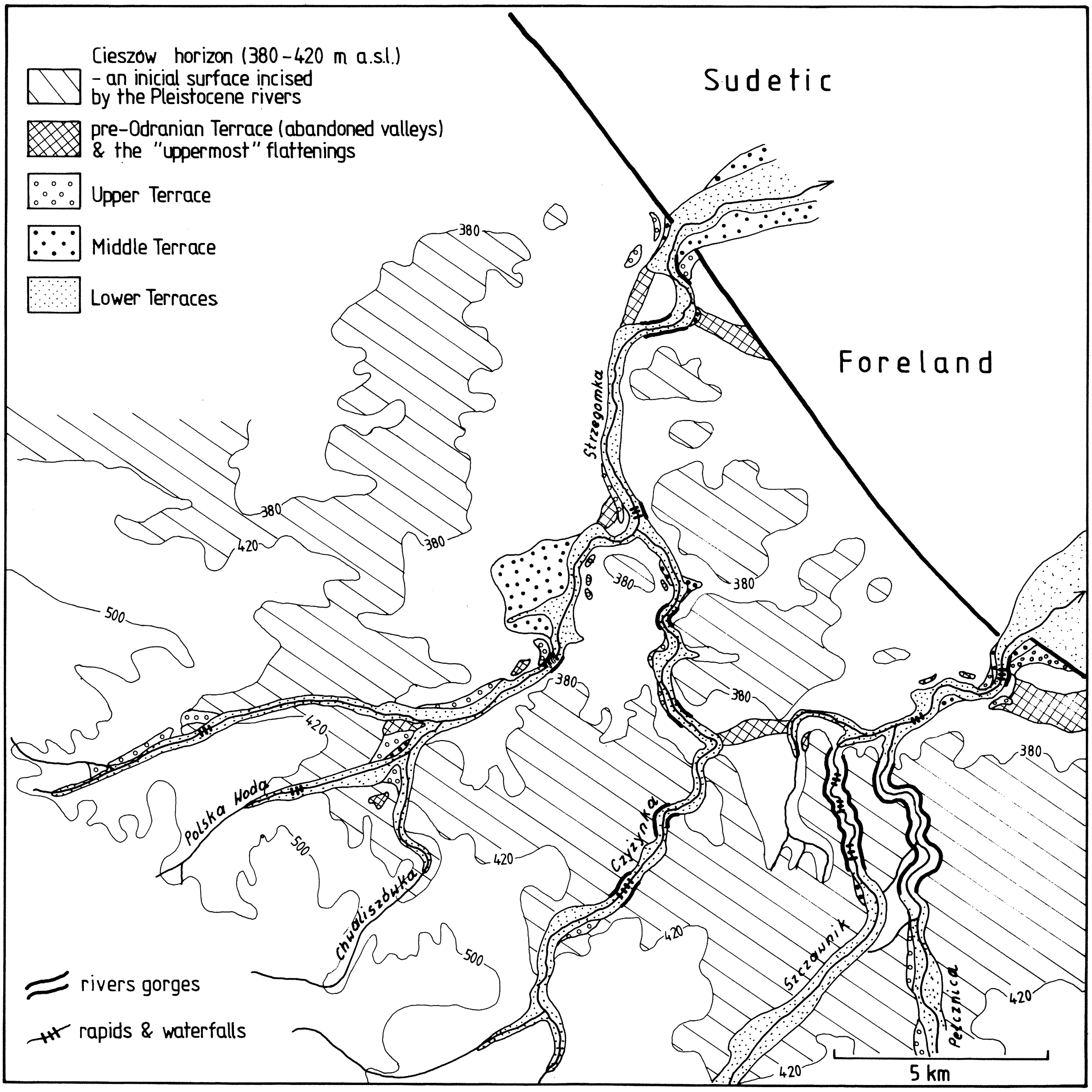


Fig. 8. Map of fluvial morphology of the Walbrzych Upland: terraces, abandoned valleys and river gorges mapped in the field

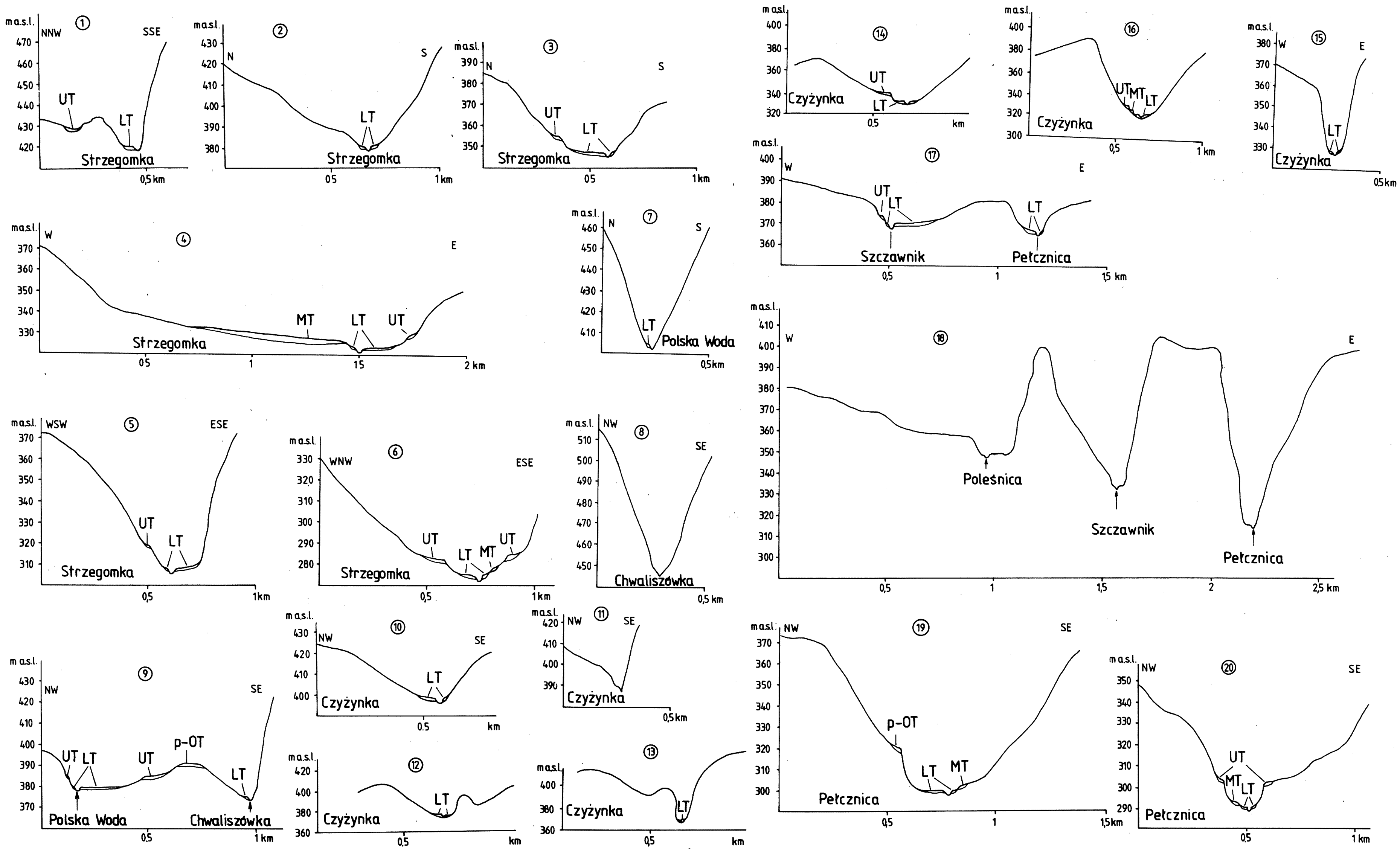


Fig. 9. Valley cross-profiles trough river valleys of the Wałbrzych Upland (LT – Lower Terrace, MT – Middle Terrace, UP – Upper Terrace, p-OT – pre-Odranian Terrace)

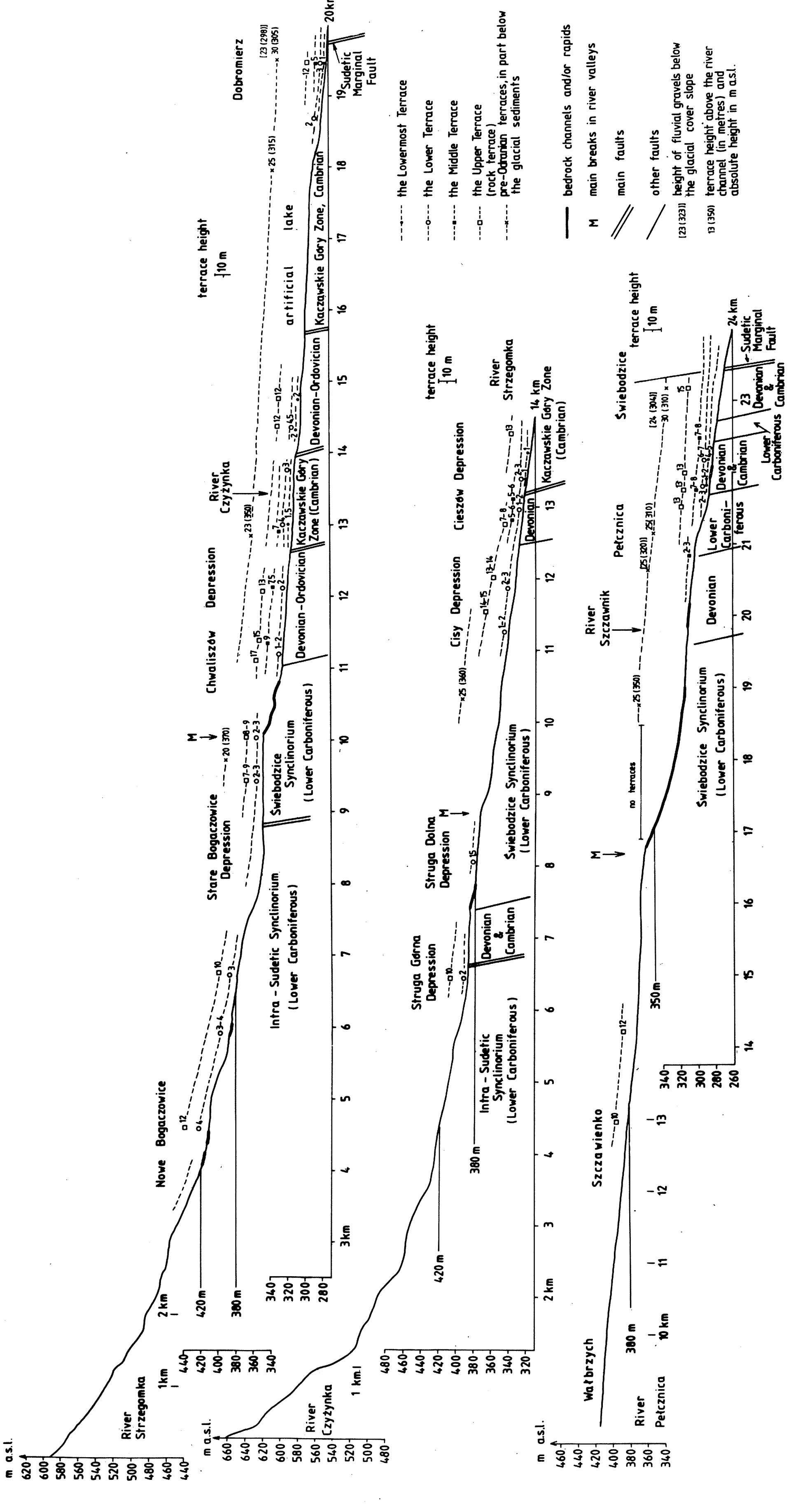


Fig. 10. Longitudinal profiles and terrace heights along the Strzegomka, Czyżynka and Pełcznica rivers of the Wałbrzych Upland

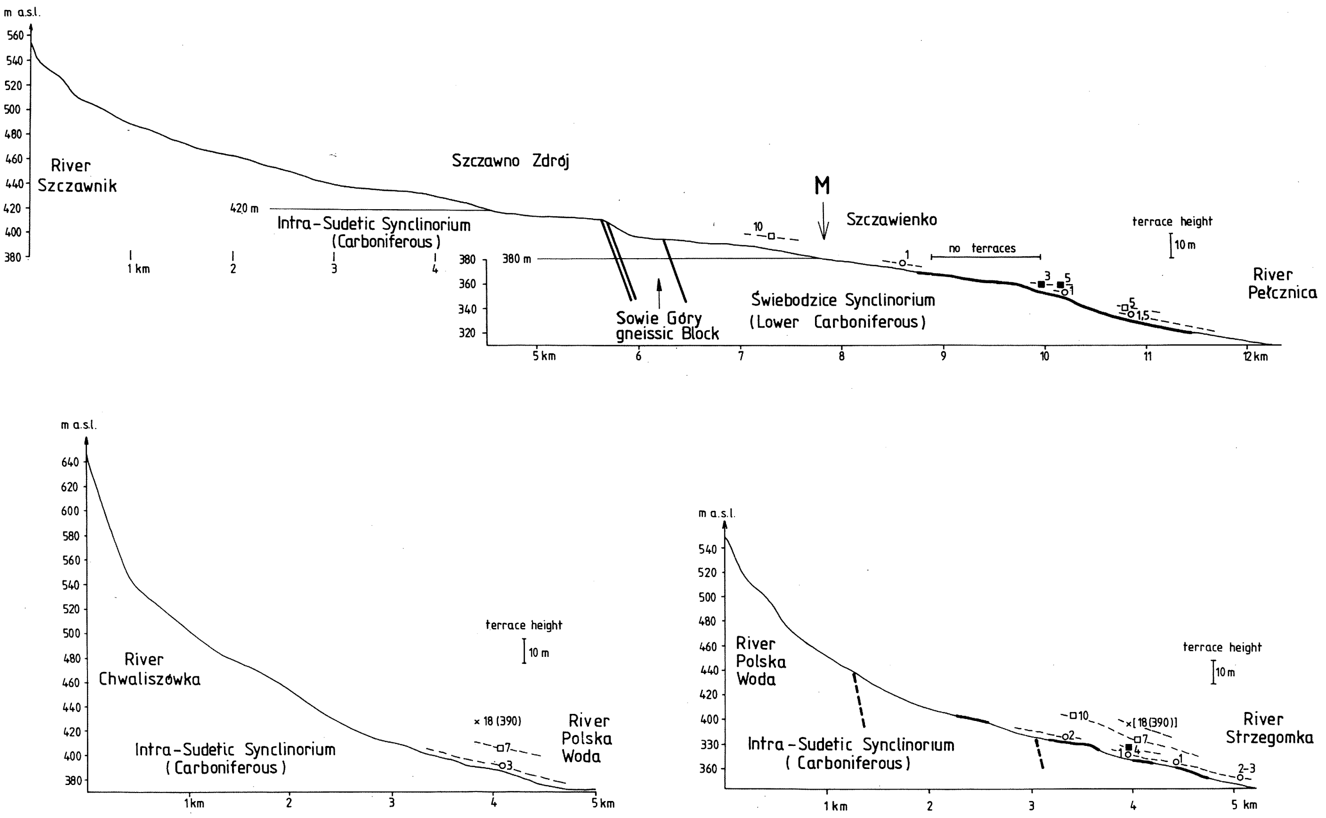


Fig. 11. Longitudinal profiles and terrace heights along the Szczawnik, Polska Woda and Chwaliszówka rivers of the Wałbrzych Upland. Explanations are in Fig. 10

the height of the top surface of fluvial gravels (Fig. 10).

Younger terraces

The younger terraces have very variable heights, both along the entire valleys and along their smaller segments. The height of the Upper Terrace varies from 7 to 17 m, that of the Middle Terrace from 5 to 9 m, the Lower Terrace from 1.5 to 6.5 m, and the Lowermost Terrace from 0.5–1.0 to 4.5 m (Figs. 10, 11) (Krzyszkowski & Stachura, 1992, 1993a). A very characteristic feature is the convergence of terraces within depressions (wide valleys). This is especially well visible in the Upper Terrace level of the Strzegomka river valley, but it is also present in other valleys (Fig. 10). The Middle and Lower terraces are characterised by smaller height differences, although they also indicate minor convergence. The increase of terrace heights is sudden, and usually occurs directly downsream of the river gorges and/or breaks in the longitudinal profiles. Surely, it is connected with deeper erosion downstream the breaks, in the "narrow" valleys and/or gorges. In turn, the convergent lowering of terrace heights is visible downstream, suggesting a continuous decrease of the erosional power.

All terraces indicate divergence in valley fragments adjacent to the Sudetic Marginal Fault, especially those of the Pełcznica river valley (Fig. 10). The heights of some terraces increase twice at a distance of 2–3 km, *e.g.* from 2–3 m to 7–8 m for the Middle Terrace, and 2–3 m to 6–7 m for the Lower Terrace. The presence of divergence of all the terraces show results from a downstream increase of erosional power which was continuous through a long time.

Moreover, the continuity of some terraces has been broken down at the Sudetic Marginal Fault (Fig. 8). Both in the Strzegomka and Pełcznica river valleys, the Upper Terrace is truncated on this tectonic line and forms distinct, *ca.* 10–15 m high scarps (Fig. 12). These scarps represent, most probably, the fault scarps. A similar feature is expected for the Middle Terrace of the Pełcznica river valley, although the scarp is probably much smaller and recently not visible in the field due to human activity (the possible scarp occurs in the city of Świebodzice) (Fig. 7).

DEPOSITS OF TERRACES AND ABANDONED VALLEYS

Five key regions have been studied in detail (Fig. 1). They are located near the margin of the mountains and/or within wide valleys (depressions), both having well developed terrace sequences and numerous outcrops of fluvial deposits. The other parts of valleys have been surficially mapped, with only some 0.5–1.0 m deep trenches. The latter were sampled only for petrological studies; sedimentological description was impossible. Four key regions are described in this paper; the lower Czyżynka river valley is described separately (Krzyszkowski, *in press*).

Strzegomka river valley near Dobromierz

Recently, this area is not available lying at the bottom of an artificial lake. Detailed geological map (Fig. 13) was constructed using the rough observations of the senior author in 1984, as well as the hitherto published geological maps, topographic maps and archival well-log data.

The Strzegomka river valley near Dobromierz is 100–400 m wide and comprises four terraces: Upper Terrace (10–15 m), Middle Terrace (3–6 m), Lower Terrace (1–3 m) and the Lowermost Terrace (0.5–1.5 m). Moreover, two abandoned valleys have been recognized, which are hanging *ca.* 20–30 m above the recent river channel (Szczepankiewicz, 1954; Krzyszkowski, 1991) (Fig. 13). All the terraces are composed of alluvial gravels and/or gravels and sands, partly interbedded with silty or clayey layers. The thickness of alluvial deposits varies from 2–3 m to 5–8 m. In many places, terraces are covered by 1–2 m thick slope coluvium, diamictons and/or angular debris, and occasionally slope deposits are interlayered with alluvial sequences (Krzyszkowski & Stachura, 1993b) (Fig. 14). The thickness of alluvial deposits is also variable along the river course, especially well when analysing deposits of the Lower Terrace only (Fig. 15). The sediment thickness of this terrace cover varies from 3 up to 8 m. Moreover, a rapid increase in thickness of alluvial sediments has been noticed directly downstream of the fault lines (and breaks in longitudinal profile), on the downthrown blocks (Figs. 13, 15).

Two abandoned valleys have good geological documentation by deep boreholes and exposures. The S–N trending valley (Fig. 13) comprises till and glaciofluvial deposits exposed on the ground surface (Teisseyre, 1969). Boreholes in the middle part of this valley have indicated a sequence with two tills separated by glaciofluvial sand and glaciolacustrine silt and clay, but without fluvial gravels (Fig. 16). The W–E trending valley (Fig. 13), in turn, is filled with till and colluvium at the ground surface (Teisseyre, 1969). Borings indicated here only one till bed. Below the till, there are fluvial gravels up to 9 m thick, composed of predominantly local rocks (*i.e.* greenschists and quartz) and about 10% of Scandinavian rocks. Jahn (*vide* Stachura, 1993a) has described more detailed stratigraphy from the outcrop of thick fluvial gravels covered by glaciolacustrine silts, till and, in the uppermost part of the section, with loess, peat and slope debris (Fig. 16).

The fluvial gravels of the W–E oriented abandoned valley near Dobromierz were deposited before the last glaciation in the area discussed, being presumably correlative with deposits of the uppermost flattenings (terraces) on the highlands. The possible occurrence of two tills in the S–N oriented valley may suggest two glaciations of the Strzegomka river valley.

Strzegomka river valley at Chwaliszów depression

The Strzegomka river valley in the Chwaliszów depression is up to 2 km wide and comprises three terraces: the Upper Terrace (13–17 m), the Middle Terrace (7–9 m) and the Lower Terrace (1–2 m) (Fig. 17). Moreover, at the southern margin of the Chwaliszów depression, the uppermost flattening occurs. It occurs at about 370 m a.s.l., *i.e. ca.* 20 m above the recent river channel. The 1 m deep trench (site 47; Fig. 17) indicated only silty diamicton with limited number of large clasts (10–35 mm). Among them, angular sandstones and conglomerates predominate (90%). This may

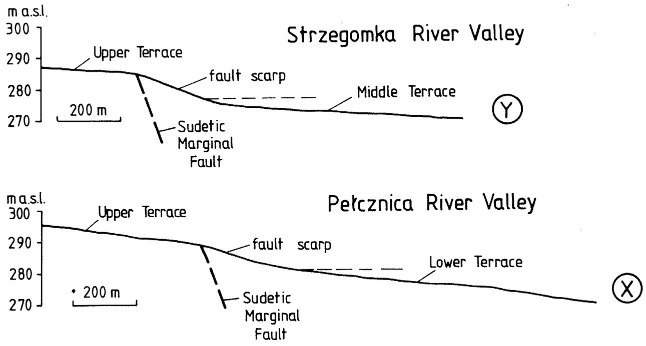


Fig. 12. Cross-profiles along the possible fault scarps formed in Upper Terraces along the Sudetic Marginal Fault. Note that the Upper Terrace alluvial horizons do not continue in the mountain foreland being cut off on the fault line. Detailed location of profiles in Fig. 1

suggest that the diamicton represents slope coluvium, probably mixed loess and coarse-grained slope covers. Nevertheless, the till has been mapped on the surrounding slopes and hills (Teisseyre, 1969) and it is also documented in the outcrop at site 35 (Fig. 17).

The Upper Terrace gravels lie in two positions: in the southern part of the depression they occur on top of the till, forming a 100–200 m wide shelf (site 48; Fig. 17), and on the eastern margin of the depression, forming several, 20–50 m wide and not more than 100 m long, shelves cut in the bedrock (rock terraces) (Fig. 17). These rock terraces are covered by thick slope debris (site 49; Fig. 18). The total thickness of Upper Terrace gravels in unknown.

The Middle Terrace forms an extensive alluvial plain which covers about a half of the depression, mainly in its western part (Fig. 17). Two sites were examined (32, 34; Fig. 17), at which alluvial gravels of the Middle Terrace are 0.5–2.0 m thick and overlie the till bed (Fig. 18). Clast imbrication in fluvial deposits does not show any consistent palaeoflow direction, probably due to the location of the sites at the margin of the main valley (Figs. 17, 18).

The deposits of the Lower Terrace are documented at a large exposure in the southern part of the depression (site 43; Fig. 17). There are two main lithofacies: the alternating beds of strongly imbricated gravels and massive sands and gravels (with clasts up to 25 cm), and a large-scale trough cross-bedded gravels. Clast imbrication shows palaeoflow from SE to NW, which is consistent with the course of the recent river channel. The large trough indicates similar orientation (Fig. 18). Moreover, the boring located near the section 43 (Fig. 17) indicated at least 8 m thick alluvial sequence of the Lower Terrace.

Strzegomka, Polska Woda and Chwaliszówka river valleys in the Stare Bogaczowice depression

The Stare Bogaczowice depression is about 1–1.5 km wide and comprises all terraces, except the Lowermost one (Fig. 19). The uppermost flattening occupies a 100–200 m wide shelf at 390 m a.s.l., on the interfluve between rivers Chwaliszówka and Polska Woda (site 60; Fig. 19). It is formed of coarse gravels. Dathe and Zimmermann (1912)

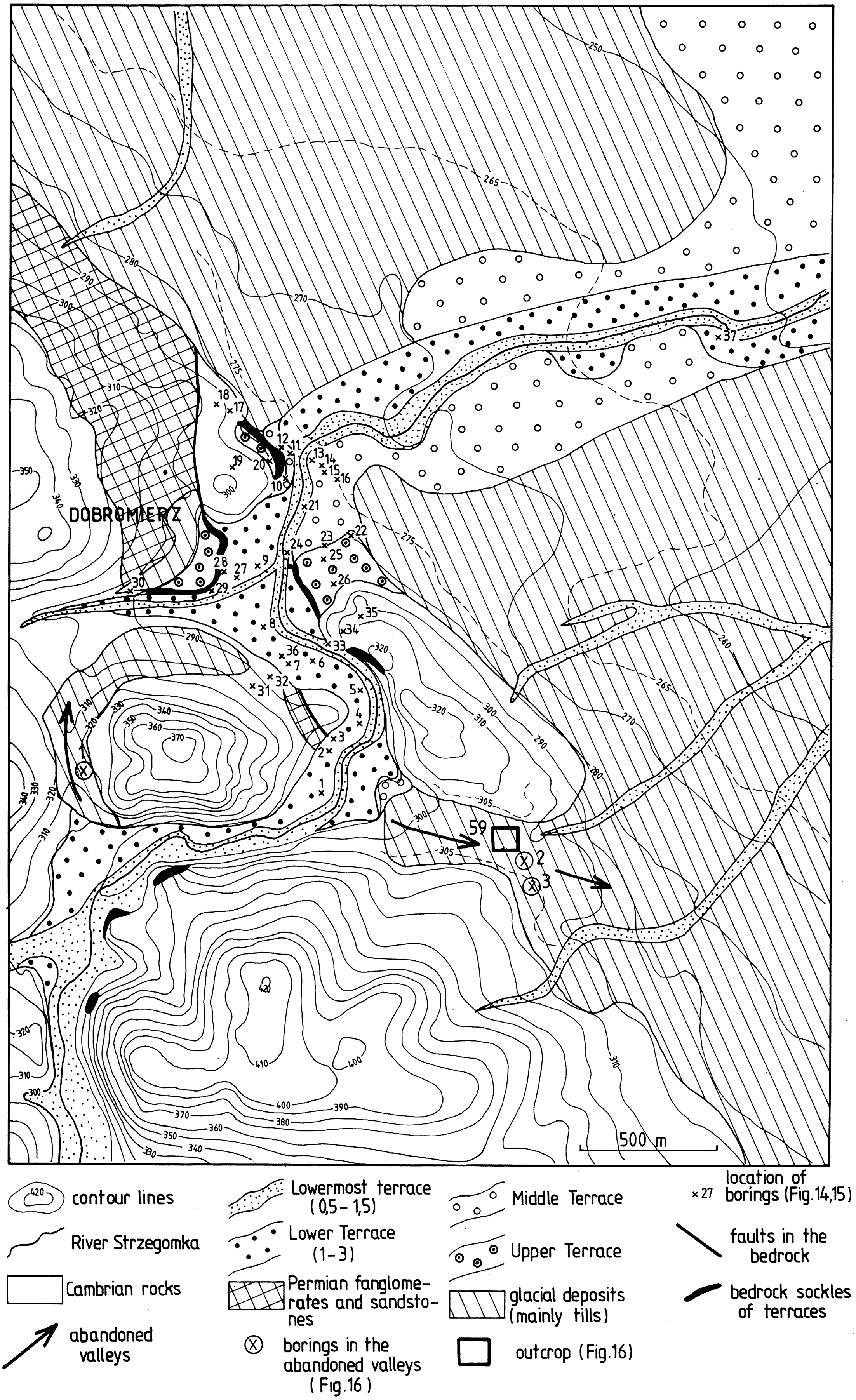


Fig. 13. Quaternary geology and position of alluvial terraces and abandoned valleys in the lower Strzegomka river valley near Dobromierz (after Zimmermann *et al.*, 1925; Teisseyre & Gawroński, 1965; modified in river valleys). Location map in Fig. 1

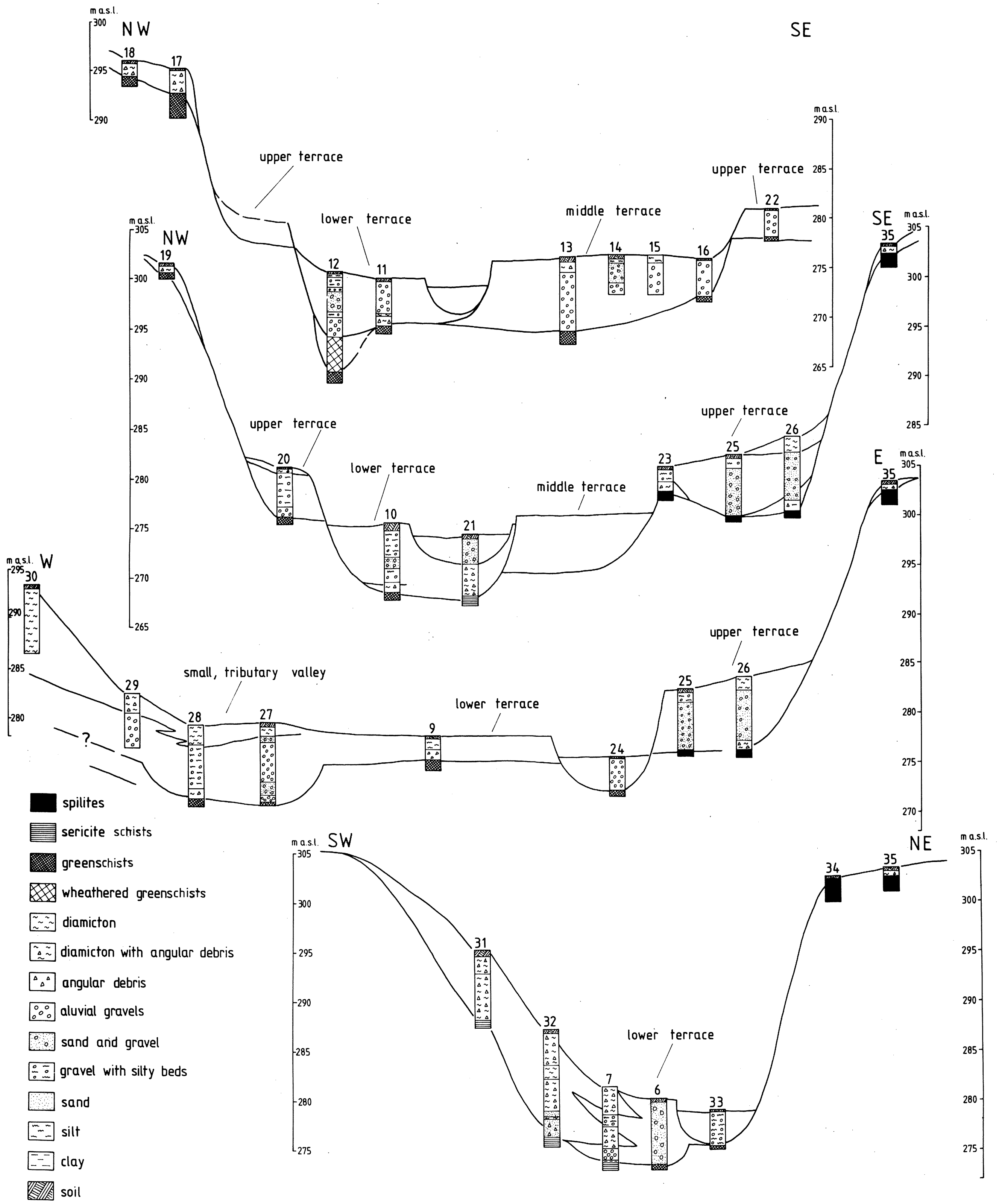


Fig. 14. Valley cross-sections and geology of terraces (boring profiles) in the Strzegomka river valley near Dobromierz. Location of borings in Fig. 13

have interpreted these gravels as fluvial deposits and regarded the shelf as the "pre-glacial" terrace, *i.e.* terrace formed before the Saalian (= Odranian) glaciation. Teisseyre (1969) incorporated these gravels into the Upper Terrace, together with other gravels, lying 10 m below (site 66; Fig. 19). This, however, makes no sense and we prefer the first interpretation. The uppermost flattening of the Polska Woda river valley appears as typical fluvial, rock terrace and it is only one example of the real "pre-Odranian" fluvial terrace in the Strzegomka river drainage basin. The other

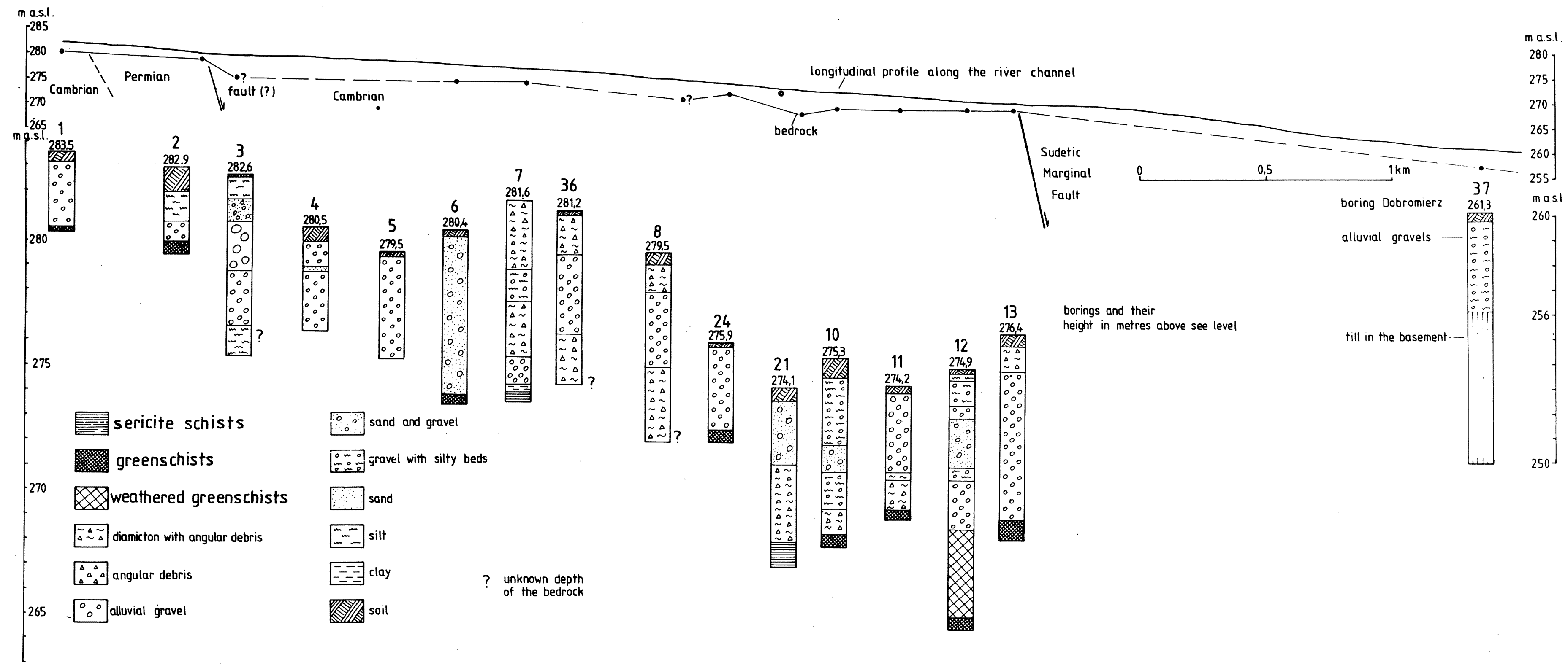


Fig. 15. Longitudinal profile along the Lower Terrace of the Strzegomka river valley near Dobromierz and thickness of alluvial deposits (location of borings in Fig. 13)

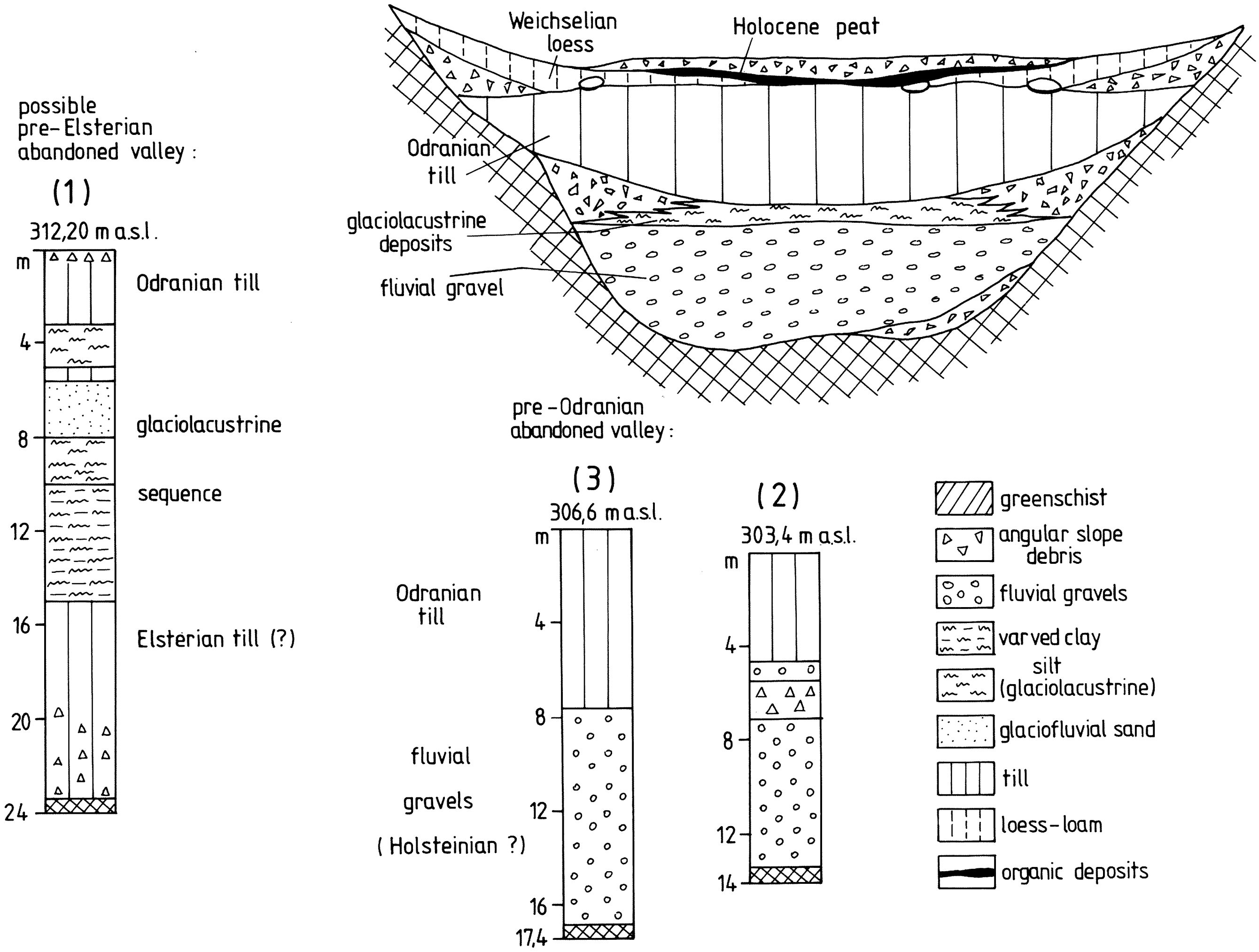


Fig. 16. Geological profiles (boring-logs) of the abandoned valleys near Dobromierz. The section in upper right is based on the data from the outcrop described by A. Jahn (*vide* Stachura, 1993a) (location of borings and the outcrop is in Fig. 13)

"terraces" are covered by a thick till layer and only can be named as the "flattenings". Such a flattening is also documented in the Stare Bogaczowice depression. Site 67 (brickyard) is located within a thick glacial cover, with *ca.* 2–3 m of till on the ground surface and varved clay (0.5 m) mixed with the sand (*ca.* 1 m) at the bottom. Fluvial gravels have not been recognised unambiguously at this site, although it seems that they may occur below the described above sands. The supposed position of gravels is at about 375 m a.s.l. (Fig. 20).

The Upper Terrace occurs in three patches on both sides of the Polska Woda and Chwaliszówka river valleys, as well as in the Strzegomka river valley. It is about 7–10 m high and represents the rock terrace. In part, it is cut into a glacial cover (Fig. 20). The Upper Terrace gravels are medium to coarse-grained and presumably up to 5 m thick.

The Middle Terrace forms a 20–50 m wide shelf in the lower course of the Polska Woda river valley. The terrace is 4 m high, and its top surface lies only 2–3 m lower than that of the Upper Terrace. The thickness of fluvial gravels of the Middle Terrace is 4 m. The Middle Terrace was examined in detail at site 62 (Fig. 20). The Middle Terrace gravels are coarse, massive, matrix-supported and imbricated. Clast imbrication shows the palaeotransport from NW to SE. The topmost unit of the Middle Terrace is composed of alluvial diamicton, containing numerous sub-rounded clasts (Fig. 20).

The Lower Terrace sequence is very similar to that of the Middle Terrace. It was examined at sites 63 and 61 (Figs 19, 20). The thickness of alluvial deposits varies from 1 m to 3–4 m. At both sites fluvial gravels are medium to coarse-grained, massive and imbricated. The palaeoflow at site 61 was from SW to NE, which is consistent with the orientation of the recent channel.

Czyżynka river valley

A detailed description of fluvial deposits and terraces is presented elsewhere (Krzyszkowski, *in press*). Here, it must be pointed out that the Czyżynka river valley comprises the Upper, Middle and Lower terraces. However, the two first terraces have limited occurrence. The Upper Terrace occurs only in depressions, at Struga Górna (site 68), Cisy (site 15) and Cieszów (site 9). The Middle Terrace occurs only near Cieszów (sites 4, 7, 8) (Figs. 1, 8). The Lower Terrace, in

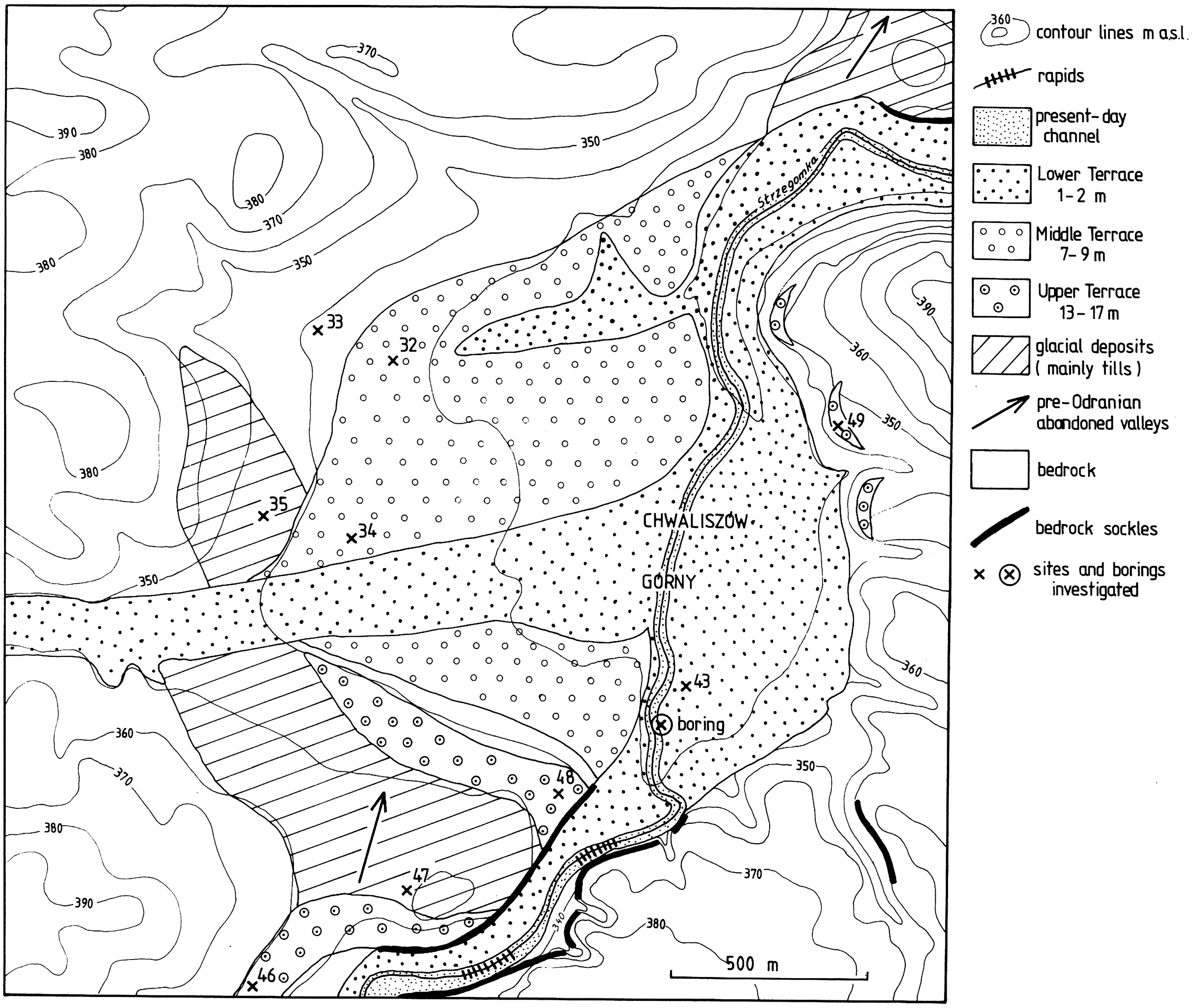


Fig. 17. Quaternary geology and position of alluvial terraces and abandonend valleys in the Chwaliszów Depression of the Strzegomka river valley. Location map in Fig. 1

turn, is present uninterruptedly along the river valley (Fig. 8), with several sites investigated in detail and numbered: 20, 17, 16, 6, 3 and 1 (Fig. 1).

The loess cover is observed on some slopes, as well as on the top of the Upper and Middle Terraces of the Czyżynka river valley (Krzyszkowski, *in press*). Its age may be assumed in relation to the youngest terrace covered by loess. It is the Middle Terrace and, thus, the loess must have been deposited in the time-span between the formation of the Middle and Lower terraces. The latter has no loess cover at all (Krzyszkowski, *in press*).

Pełcznica river valley between Szczawienko and Świebodzice

The lower course of the Pełcznica river valley is 100–500 m wide and it contains all the 5 terrace systems recognised in the region (Fig. 7). The uppermost fluvial surfaces are represented by distinct terraces (flattenings with alluvial gravels), by shelves with slope and/or glacial cover, and by abandoned valleys. The uppermost terrace is documented at site 56 (Fig. 21). Fluvial gravels are here about 1–2 m thick. These gravels are underlain by the bedrock socle and angular debris (colluvium?), and they are overlain by slope diamicton (colluvium) with angular debris (clasts up to 0.4 m). In comparison to slope debris, the fluvial gravels are generally smaller and well- to sub-rounded (Fig. 22). Another flattening was found farther eastwards (site 52), at 310 m a.s.l., although there only slope (angular) debris was documented on the bedrock socle (Fig. 23). In turn, the W–E oriented abandoned valley is infilled with a till (*e.g.*, site 53). The till is about 3 m thick and it is underlain by varved clay and sands with gravels (Fig. 23). Thick varved clays have also been reported from deep exposures (Dathe, 1892) and borings (Fig. 23). Below glacial deposits, there is a gravel bed which may represent fluvial series. However, this is not confirmed unambiguously, due to complete lack of petrological data (archival borings were available only). If these gravels represent the "pre-Odranian" fluvial deposit, it

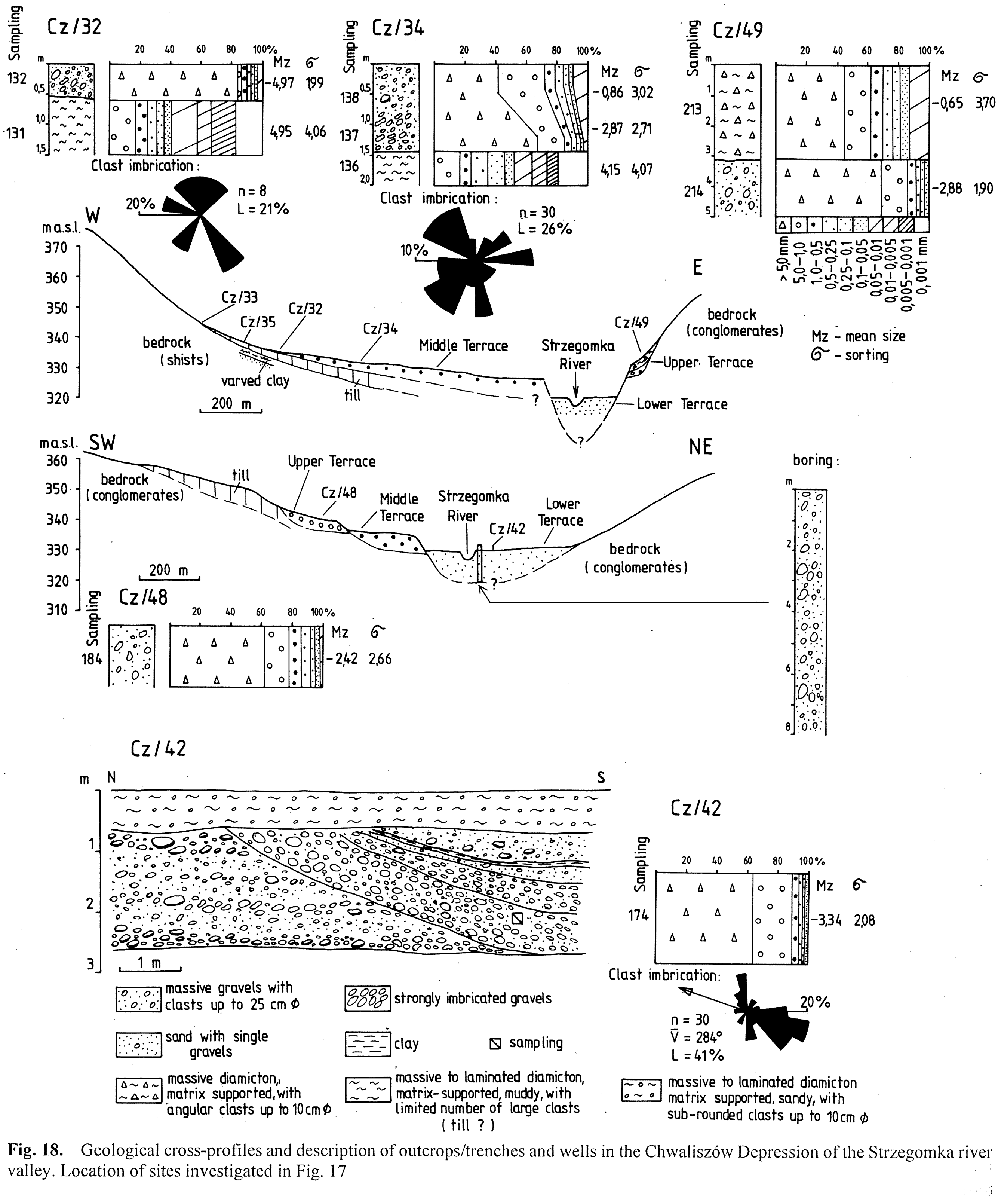


Fig. 18. Geological cross-profiles and description of outcrops/trenches and wells in the Chwaliszów Depression of the Strzegomka river valley. Location of sites investigated in Fig. 17

is possible to calculate former river gradient. It would be about 1.3% between sites 56 and 53, which is comparable with the recent channel gradients in the region investigated.

There are some other shelves in the Pełcznica river valley and its tributaries, which have the till at the ground surface (Fig. 21). However, they lie at very different heights. Well-logs (*e.g.*, those in Fig. 22) have shown that the till and/or glaciofluvial and glaciolacustrine deposits lie usually directly on the bedrock and that they are from 3–4 m (Pełcznica river valley) to 10–12 m thick (Polesnica river valley). These shelves could have originated due to either fluvial or glacial erosion.

The Upper Terrace has been found on both sides of the valley (Figs. 21, 23, 24). Both sites, investigated in detail

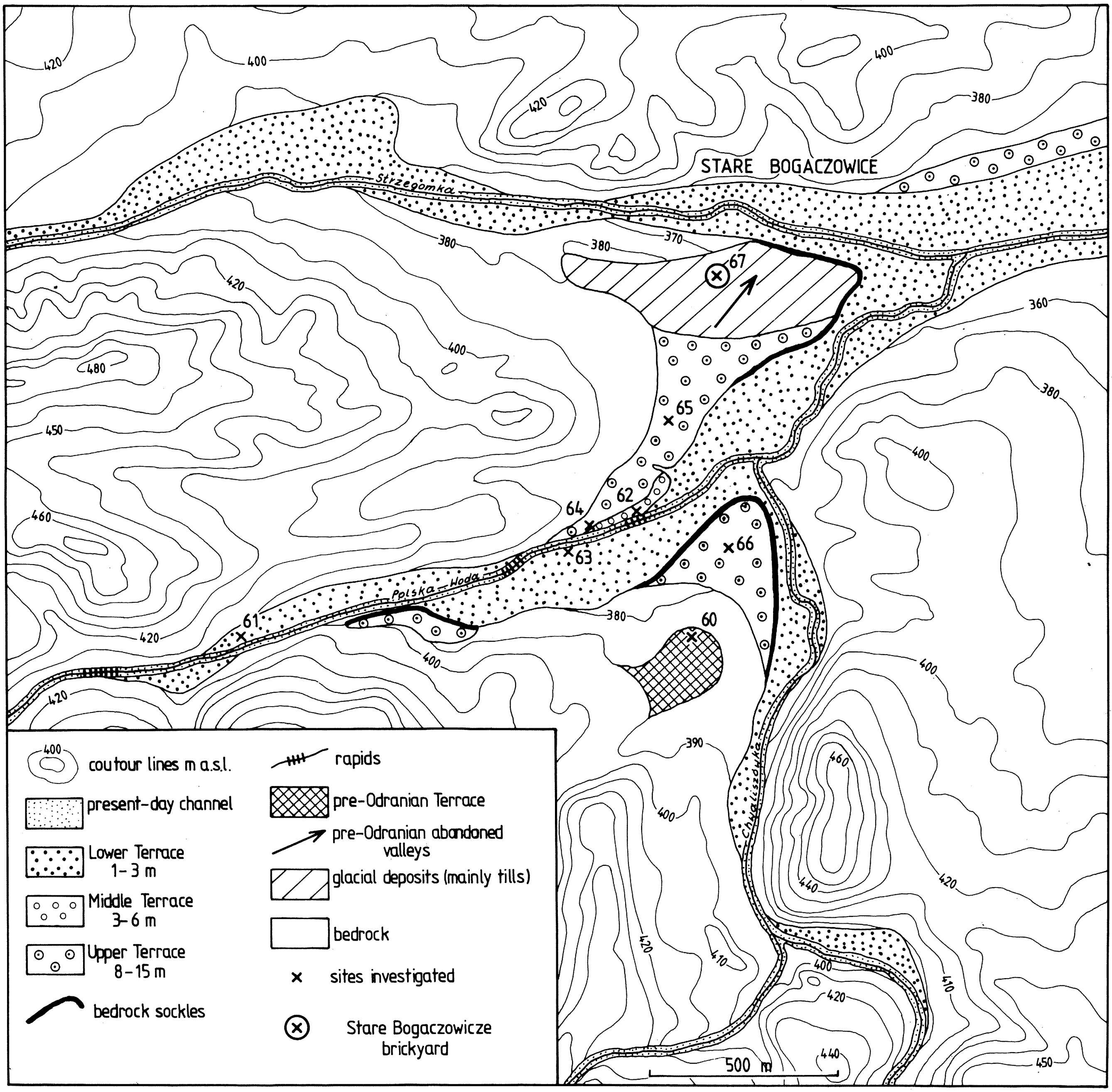
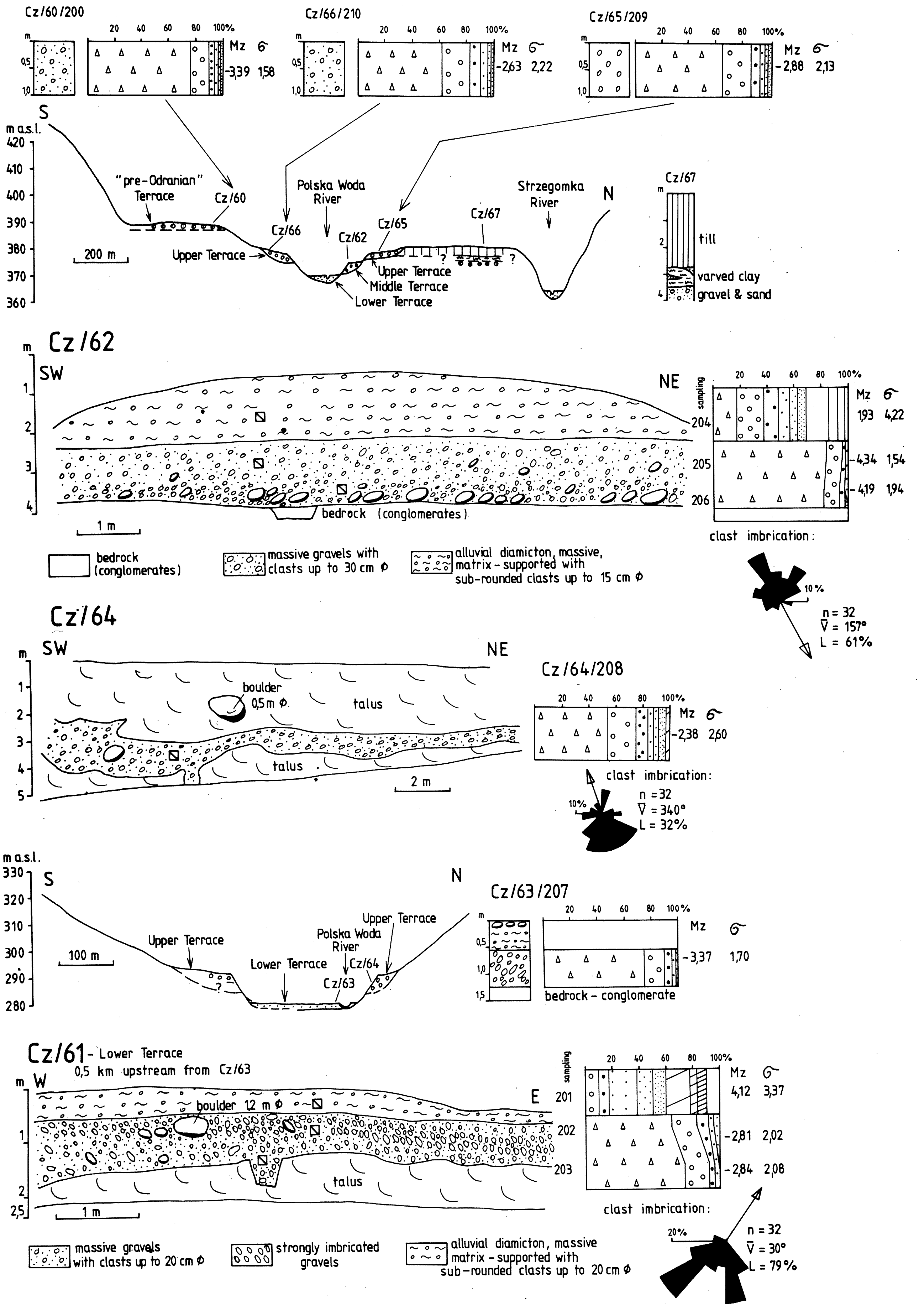


Fig. 19. Quaternary geology and position of alluvial terraces in the Stare Bogaczowice Depression (Strzegomka, Polska Woda and Chwaliszówka river valleys). Location map in Fig. 1

(51, 54), contain slope (angular) debris both below and above fluvial gravels. The thickness of fluvial gravels varies between 1.5 and 2.5 m. The Middle Terrace has also been found on both sides of the valley (Fig. 21). Its internal structure was examined in two small trenches (sites 55, 50). In both cases, alluvial gravels of unknown thickness are covered by the alluvial diamicton with sub-rounded clasts (Figs. 22, 24). The Lower Terrace continues uninterruptedly along the valley, although no exposures are available. Some borings are located upon the Lower Terrace. They indicate very variable thickness of alluvial deposits, from 2–3 m in the upland near Szczawienko, through 0 in the Pełcznica and Szczawnik river gorges (no Lower Terrace), and again from 2–3 m to 12 m in the downstream zone (Fig. 22). Changes in sediment thickness are quite rapid (Fig. 25). The increase in thickness is connected with the downthrown blocks of the bedrock (Stachura, 1993b).

Figure 26 presents main stages of the evolution of the

Fig. 20. Geological cross-profiles and description of outcrops and trenches in the Polska Woda and Chwaliszówka river valleys. Location of sites studied in Fig. 19. Grain size ranges are explained in Fig. 18


Cz/60/200
Cz/66/210
Cz/65/209
20 40 60 80 100%
Mz σ
-3,39 1,58
-2,63 2,22
-2,88 2,13
S
m a.s.l.
420
410
400
390
380
370
360
"pre-Odranian" Terrace
Cz/60
Polska Woda River
Strzegomka River
N
Cz/66
Cz/62
Cz/65
Cz/67
200 m
Upper Terrace
Upper Terrace
Middle Terrace
Lower Terrace
till
varved clay
gravel & sand
Cz/62
SW
NE
sampling
204
205
206
1,93 4,22
-4,34 1,54
-4,19 1,94
bedrock (conglomerates)
1 m
clast imbrication:
bedrock (conglomerates)
massive gravels with clasts up to 30 cm Φ
alluvial diamicton, massive, matrix-supported with sub-rounded clasts up to 15 cm Φ
10%
n = 32
V̄ = 157°
L = 61%
Cz/64
SW
NE
boulder 0,5m Φ
talus
talus
2 m
Cz/64/208
-2,38 2,60
clast imbrication:
n = 32
V̄ = 340°
L = 32%
m a.s.l.
330
320
310
300
290
280
S
N
100 m
Upper Terrace
Upper Terrace
Polska Woda River
Lower Terrace
Cz/64
Cz/63
Cz/63/207
-3,37 1,70
bedrock - conglomerate
Cz/61 - Lower Terrace
0,5 km upstream from Cz/63
W
E
boulder 1,2 m Φ
201
202
203
talus
1 m
4,12 3,37
-2,81 2,02
-2,84 2,08
clast imbrication:
20%
n = 32
V̄ = 30°
L = 79%
massive gravels with clasts up to 20 cm Φ
strongly imbricated gravels
alluvial diamicton, massive matrix-supported with sub-rounded clasts up to 20 cm Φ

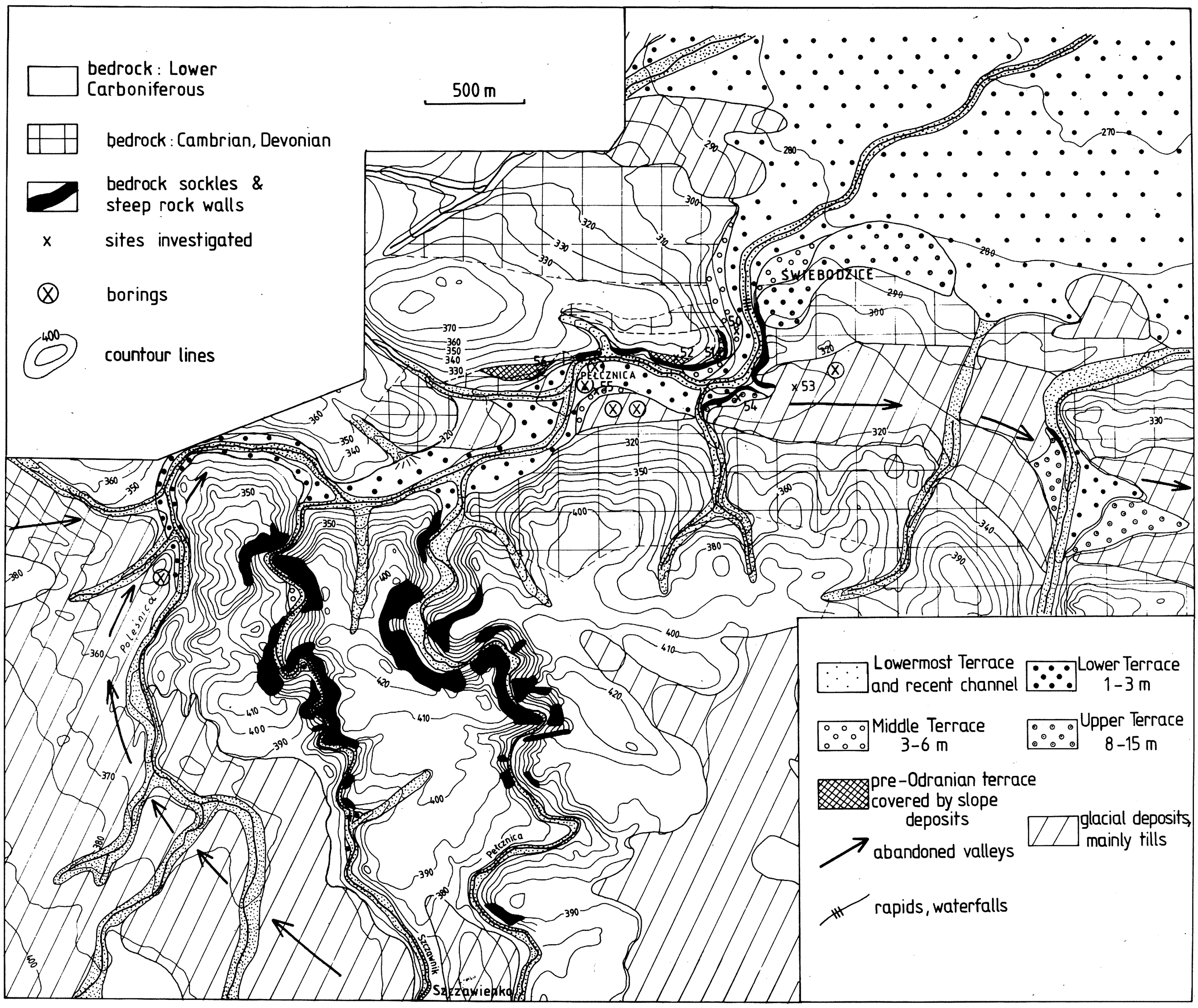


Fig. 21. Quaternary geology and position of alluvial terraces and abandoned valleys in the lower Pełcznica river valley near Świebodzice. Location map in Fig. 1

Pełcznica river valley during the Late Quaternary. The valley formation was not only due to fluvial activity but – presumably – also due to glacial erosion. The pre-Odranian fluvial valley was most probably widen principally due to glacial processes. The post-glacial fluvial activity started from this new, initial (glacial) surface, leaving shelves with glacial deposits on both banks of the recent valley.

THE AGE OF FLUVIAL DEPOSITS AND TERRACES

Tills are the main index stratigraphic horizons in the region discussed. The latest glaciation in southwestern Poland occurred during the early Saalian (Odranian). Thus, it seems likely that the till lying commonly on the ground surface, both on the Cieszów horizon and in abandoned valleys, may be considered as the Odranian till. The lower till in the S–N oriented abandoned valley near Dobromierz may have originated during the Elsterian stage. Two ice advances during the Elsterian, separated by an interstadial stage, have been documented in southwestern Poland (Czerwonka & Krzyszkowski, 1992; Badura *et al.*, 1992; Krzyszkowski & Czech, 1995). Thus, it is not certain which Elsterian ice sheet advanced into the Wałbrzych Upland. Consequently, the old valley incision may have occurred during the pre-Elsterian times (Cromerian) or during the intra-Elsterian interstadial (Fig. 27).

The pre-Odranian fluvial gravels have been documented in two abandoned valleys, near Dobromierz (W–E oriented valley) and near Świebodzice. In both cases, there are no lower till, most probably due to fluvial erosion. Moreover, two pre-Odranian terraces, in the Polska Woda and the Pełcznica river valleys, and all other "uppermost flattenings" come, most probably, from this stage, too. Very roughly, this fluvial surface may be correlated with the Holsteinian (Fig. 27).

All the other terraces are younger than the Odranian till. None of the terraces contained organic material available for

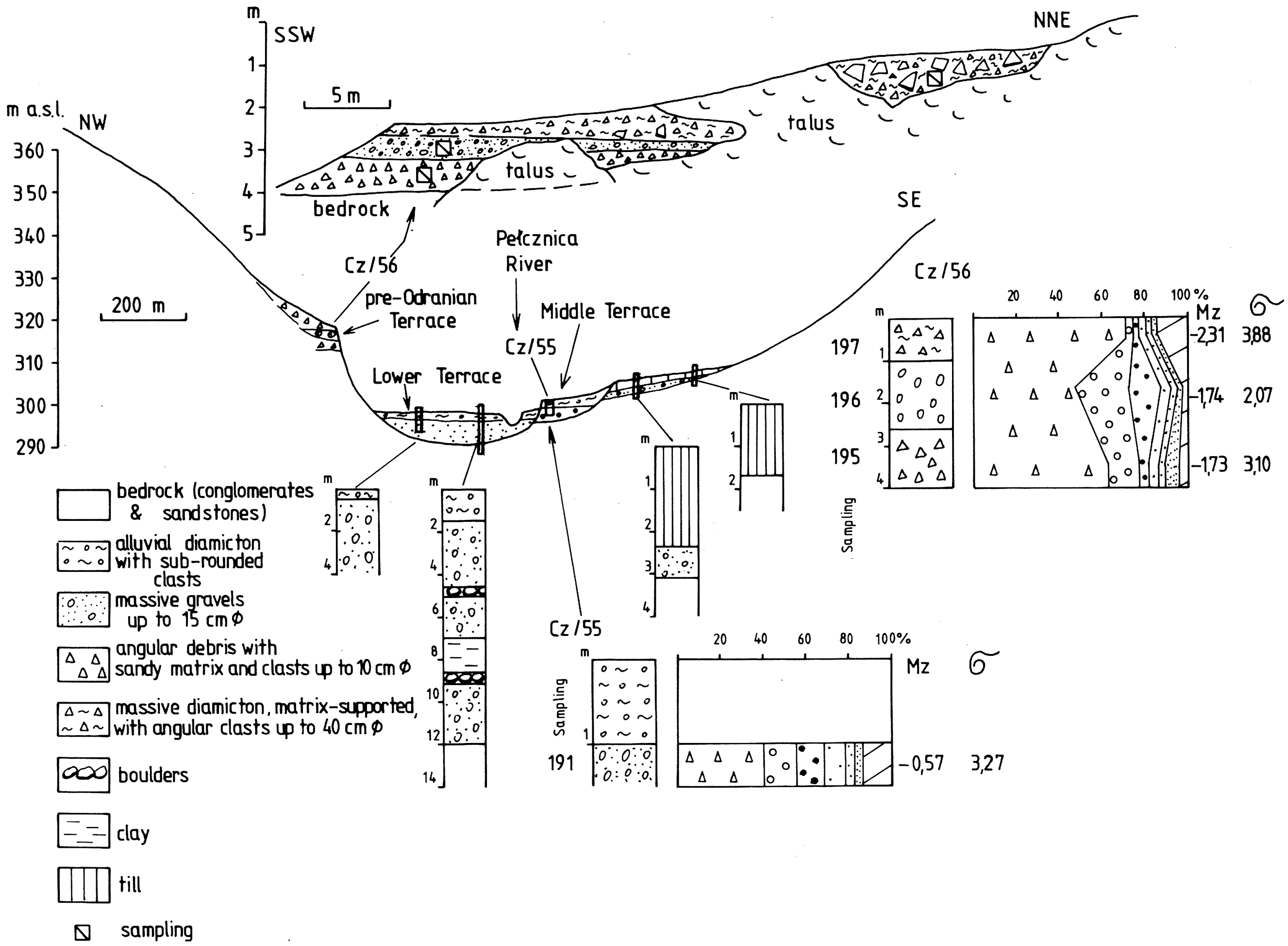


Fig. 22. Geological cross-profiles and description of outcrops/trenches and wells in the Pełcznica river valley. Location of sites studied in Fig. 21. Grain size ranges are explained in Fig. 18

dating. Hence, only superposition of terraces, their relation to slope and loess deposits and correlation with general palaeoclimatic events can be a basis for their dating. It seems likely that the Upper Terrace originated during the Wartanian stage, or even during both the Wartanian and Eemian stages. The Middle Terrace was formed, most probably, during the Middle Pleniglacial of the Weichselian stage. This is the youngest terrace covered by thick slope covers and loess. Deposition of loess and slope debris could have been connected with the coolest conditions during the Upper Pleniglacial of the Weichselian stage (Fig. 27). The Lower Terrace was formed during the Late Weichselian and continued throughout the Early Holocene. The Lowermost Terrace is in part human induced, and formed during the medieval times up to the recent. Deposits of this terrace contain charcoal and Mediaeval to recent artifacts (Teisseyre, 1977). The possible ages and correlation of terraces with other deposits is presented in Fig. 27.

PETROLOGICAL CHARACTERISTICS OF FLUVIAL DEPOSITS

Gravel petrography

Gravel petrography has been investigated in fraction 10–35 mm for all the terraces. Two main groups of rocks have been found in fluvial gravels. These are local rocks and northern rocks. The latter group contains Scandinavian red crystalline rocks and red quartzites, as well as Mesozoic flint and white sandstones, which may have come from the southern Baltic area or the Polish Lowland. White sandstones could also have been derived from the Cretaceous sandstone series of western Sudeten. Limestones have not been found at all, except one grain in the Upper Terrace (diamicton) of the Czyżynka river valley near Cieszów (site 9). This limestone represents the local, Devonian rock (Krzyszkowski, *in press*).The dominat group in the samples studied are local rocks: Carboniferous or Devonian conglomerates, sanstones and mudstones; quartz, lydite, quartzite, siliceous and crystalline rocks, all representing components of the Carboniferous and Devonian conglomerates; the Sowie Góry gneiss; Permian volcanites (porphyries = ryolites and tuffites); metamorphic schists of the Kaczawskie Góry Zone; greenschists and spilites of the

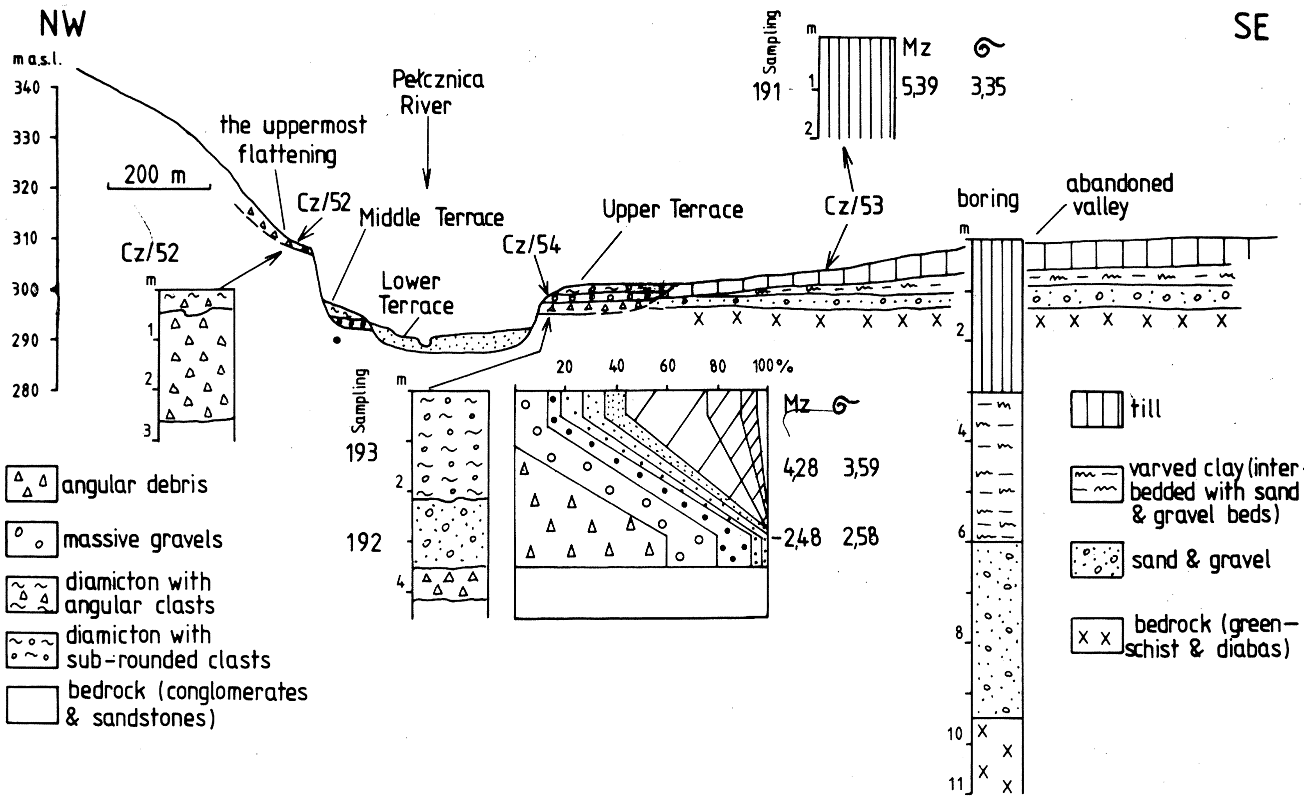


Fig. 23. Geological cross-profiles and description of trenches and borings in the Pełcznica river valley. Location of sites studied in Fig. 21. Grain size ranges are explained in Fig. 18

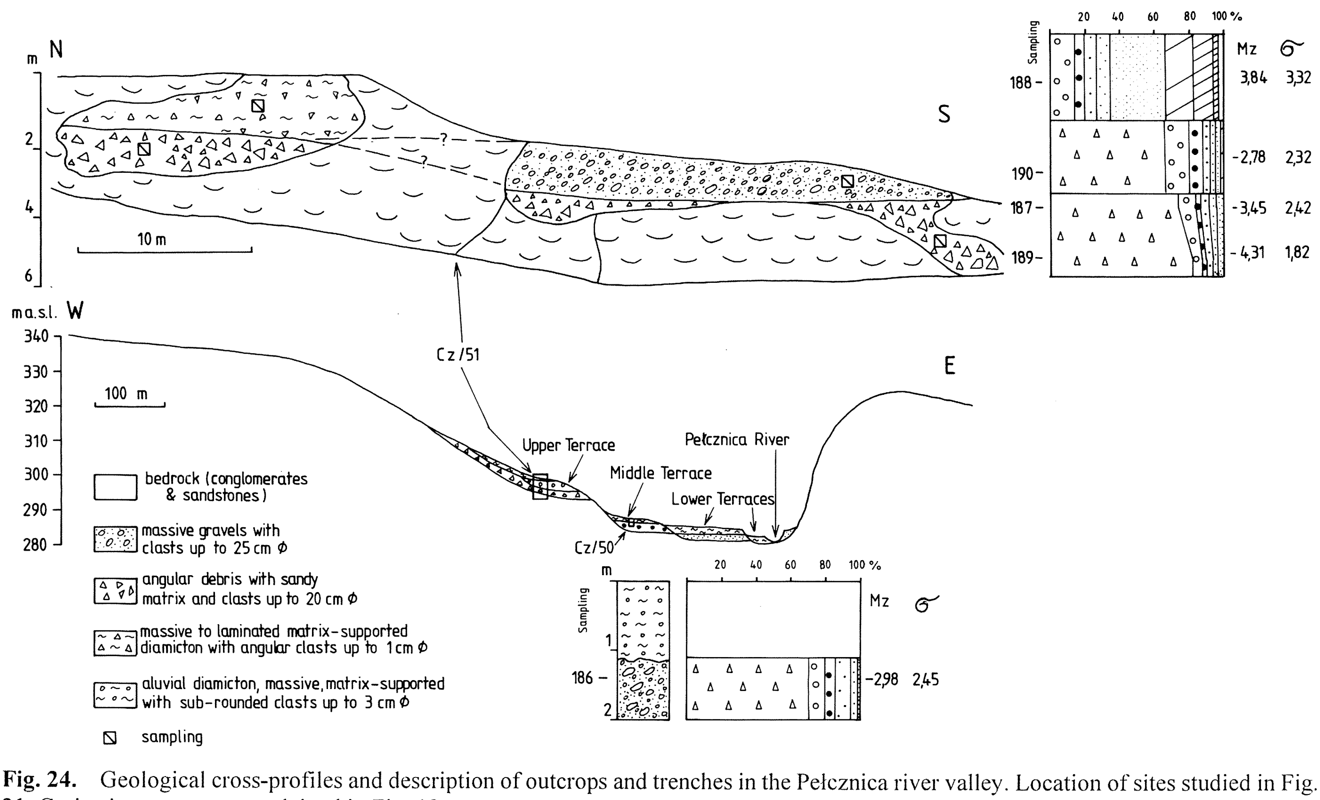


Fig. 24. Geological cross-profiles and description of outcrops and trenches in the Pełcznica river valley. Location of sites studied in Fig. 21. Grain size ranges are explained in Fig. 18

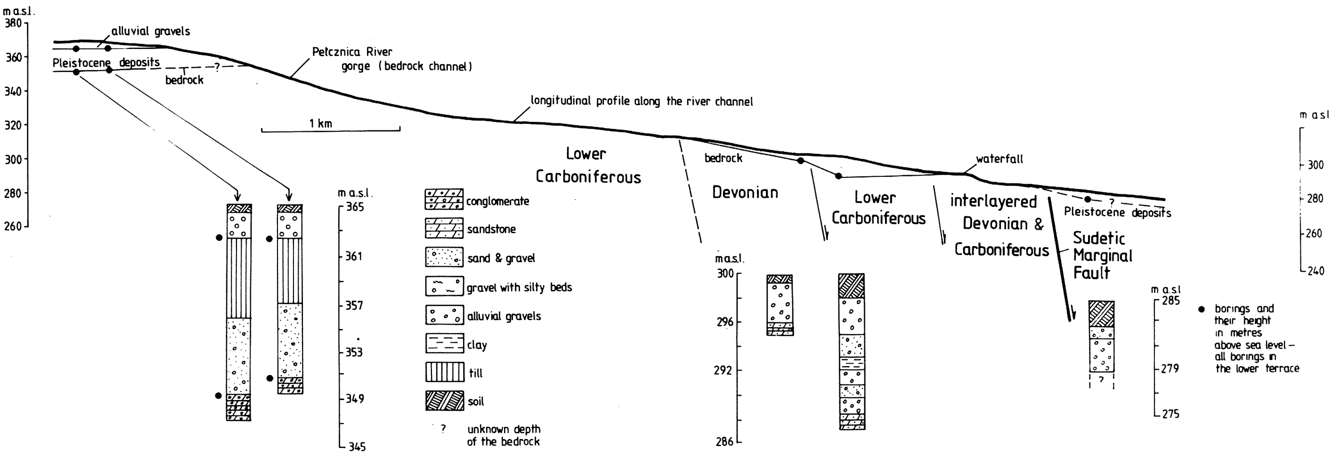


Fig. 25. Longitudinal profile along the Pełcznica river near Świebodzice and thickness of alluvial deposits (Lower Terrace). Location of borings in Fig. 21

Kaczawskie Góry Zone and Świebodzice Synclinorium (Fig. 2).

All terraces, including the pre-Odranian one, contain northern rocks (Fig. 28) which however, rarely reach 1–4.5%, often below 1%. The frequency of northern rocks is not stratigraphically controlled. The pre-Odranian terraces in the Polska Woda and Pełcznica river valleys contain *ca.* 1% of red granitoids (6 and 4 grains, respectively). Although the Carboniferous conglomerates may contain a small admixture of red crystalline rocks (Teisseyre, 1975), it seems probable that those which have been found are rather glacially-derived. Hence, this suggests the presence of the glacial cover before the formation of the pre-Odranian terrace. Consequently, we must assume at least two ice-sheet advances in the region discussed; one during the Odranian and another one during the Elsterian.

The content of local rocks is also variable (Fig. 28), and depends on the available exposures within the valleys, rather than on stratigraphic position. Usually, two groups are dominating ones: conglomerates (+ sandstones and mudstones) and quartz (+ lydite). The first group varies from 15% to 70%, the second one from 8% to 44%. Occasionally, quartzites are very frequent (up to 30%). Metamorphic schists are common only in the Middle Terrace in the Chwaliszów depression (35–57%), which is situated directly below slopes composed of these schists (Fig. 2). Porphyries are most common in the Polska Woda river valley, reaching 14–24%, where that is porphyre exposures occur (Mt. Trójgarb, Fig. 2). Greenschists and spitiltes, in turn, occur in all the valleys, except the uppermost part of the Strzegomka river valley and the lower part of the Pełcznica river valley. Theirs occurrence in the Polska Woda river valley, where there are no greenshists and spilites outcrops at all, is especially important. This fact suggests, that greenschists and spilites must have been included into fluvial sequences from glacial deposits, since their outcrops lie 6 km northwards and northeastwards in the lower part of Strzegomka and Czyżynka river valleys.

In conclusion, we must assume that also a part of local rocks of the fluvial sequences is glacially-derived. This is

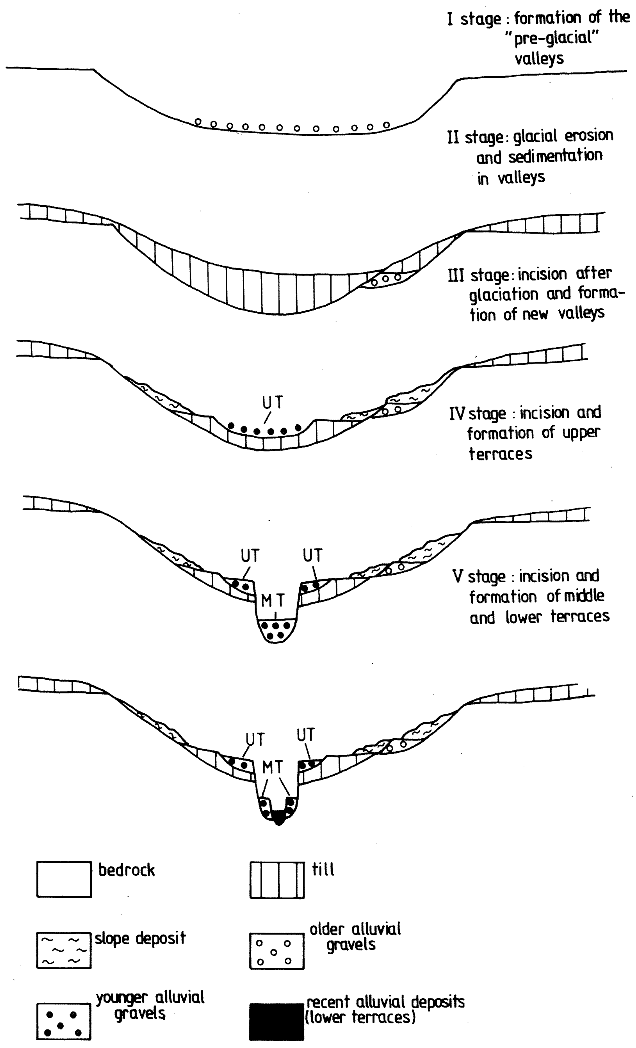


Fig. 26. Stages of the Pełcznica river valley development through Late Quaternary

Stratigraphy			Strzegomka river & tributaries	Czyżynka river	Pełcznica river & tributaries	Erosion events	Age in Ma
Holocene			Lowermost Terrace *		Lowermost Terrace*		
			incision		incision	⇐ca 1–4 m	
			Lower Terrace	Lower Terrace	Lower Terrace		
Upper Pleistocene	Weichselian	Late	incision	incision	incision	⇐ca 5 m	0,01
		Middle	slope debris + loess	slope debris + loess	slope debris		
			Middle Terrace	Middle Terrace	Middle Terrace		0,06
		Early	incision	incision	incision	⇐ca 10–15 m	
	Eemian						0,13
Middle Pleistocene	Saalian	Younger Saalian (Wartanian)	Upper Terrace	Upper Terrace	Upper Terrace		
		interstadial	incision	incision	incision	⇐ca 70–80 m	
		Older Saalian (Odranian)	till, varved clay & glaciofluvial sand in the abandoned valleys and at flattenings	?	till, varved clay & glaciofluvial sand in the abandoned valleys		0,20
	cold stages & interglacials (Holsteinian)		fluvial gravels in the abandoned valleys and in the "pre-Odranian" Terrace	?	fluvial gravels in the abandoned valleys and in the "pre-Odranian" Terrace		
			incision		incision	⇐ca 40–50 m	0,44
	Elsterian	Younger Elsterian	till in the N-S abandoned valley near Dobromierz	?	?		
		interstadial	incision ?				
		Older Elsterian	?		?		0,47
	Cromerian interglacials		formation of the Cieszów horizon				0,85
Lower Pleistocene							2,5
Pliocene						⇐ Main uplift of the Sudeten	5,5

Fig. 27. Fluvial and glacial Quaternary stratigraphy of the Wałbrzych Upland, Middle Sudeten. Stars indicate units which were formed in part due to artificial activity. Detailed event stratigraphy of the Czyżynka river valley is in Krzyszkowski (*in press*)

certain for almost all greenschists and spilites in the uppermost parts of the valleys and also possible for some of metamorphic schists, quartzites and crystalline rocks.

Heavy minerals

Heavy minerals have been investigated in fraction 0.1–0.25 mm for the same samples as those examined for petrographic composition (Fig. 29). The frequency of minerals is generally low, from single grains in samples collected from the uppermost parts of valleys, through 10–100 in the middle, to 150–250 in the lowermost parts of the valleys (Czyżynka river valley near Cieszów, and Pełcznica river valley between Pełcznica and Świebodzice). Thus, only data from the latest zones are discuttable. However,

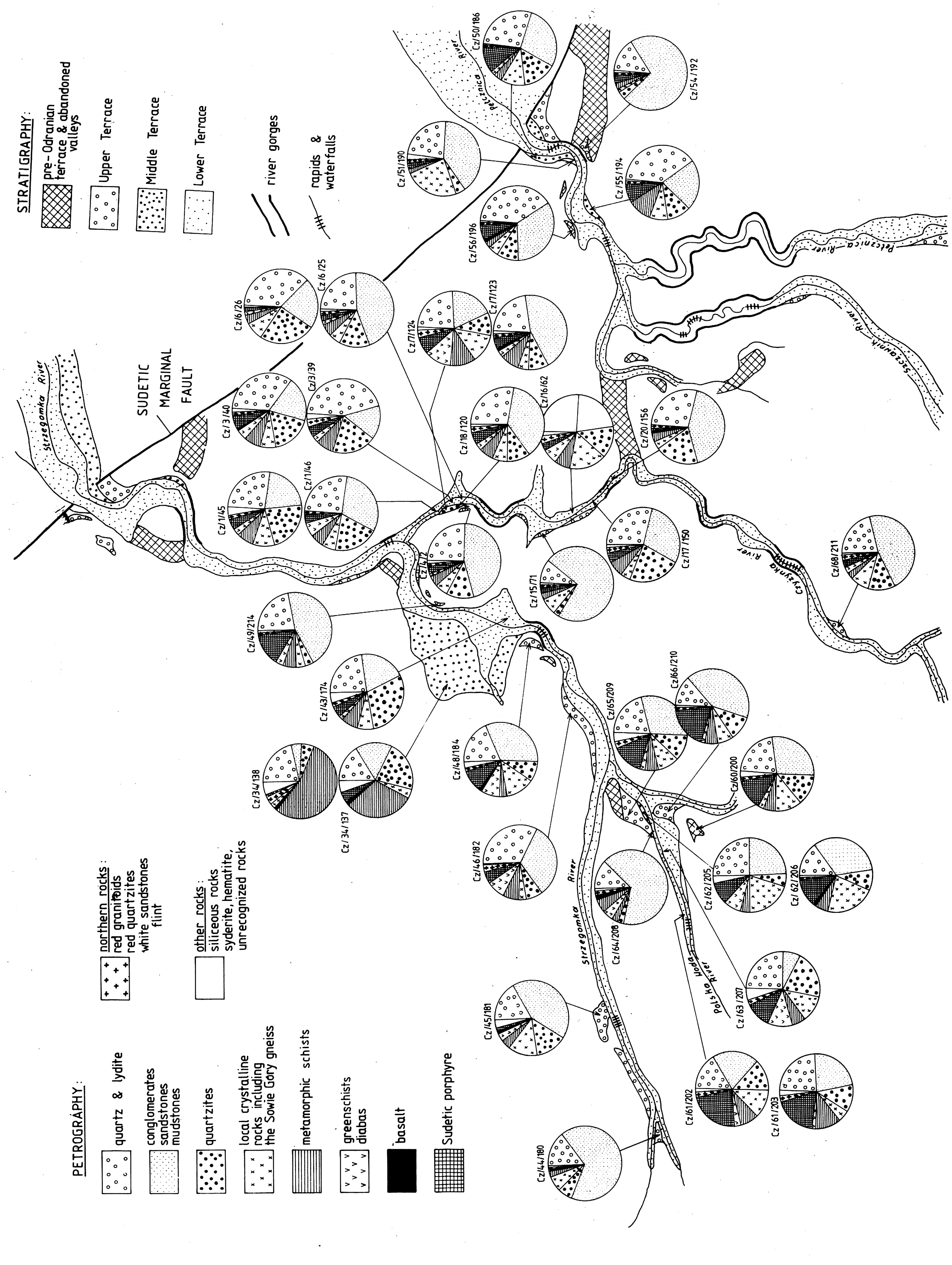


Fig. 28. Petrographic composition of alluvial deposits of the Wałbrzych Upland and their distribution along the river valleys

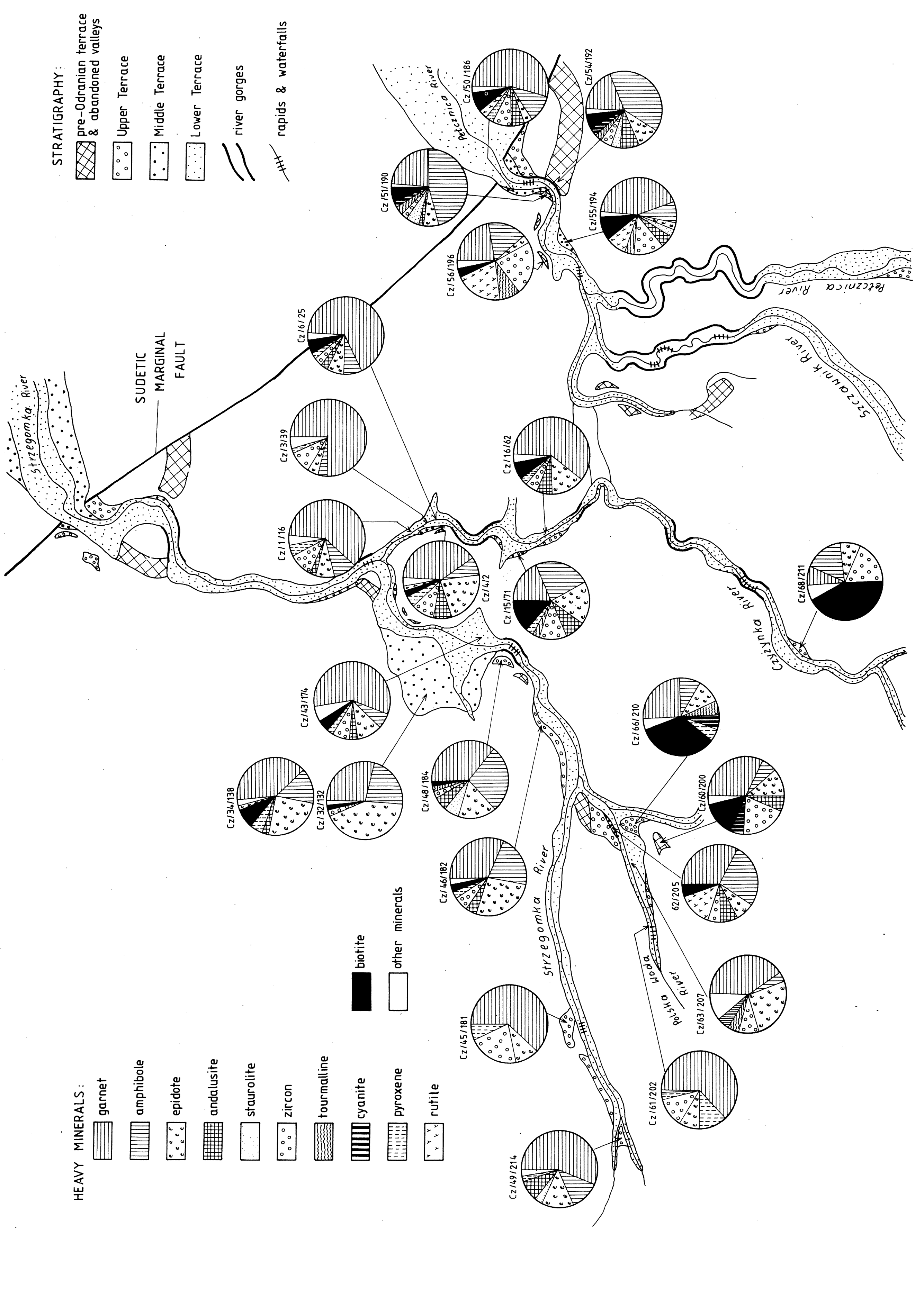


Fig. 29. Heavy mineral content of alluvial deposits of the Walbrzych Upland and its distribution along the river valleys

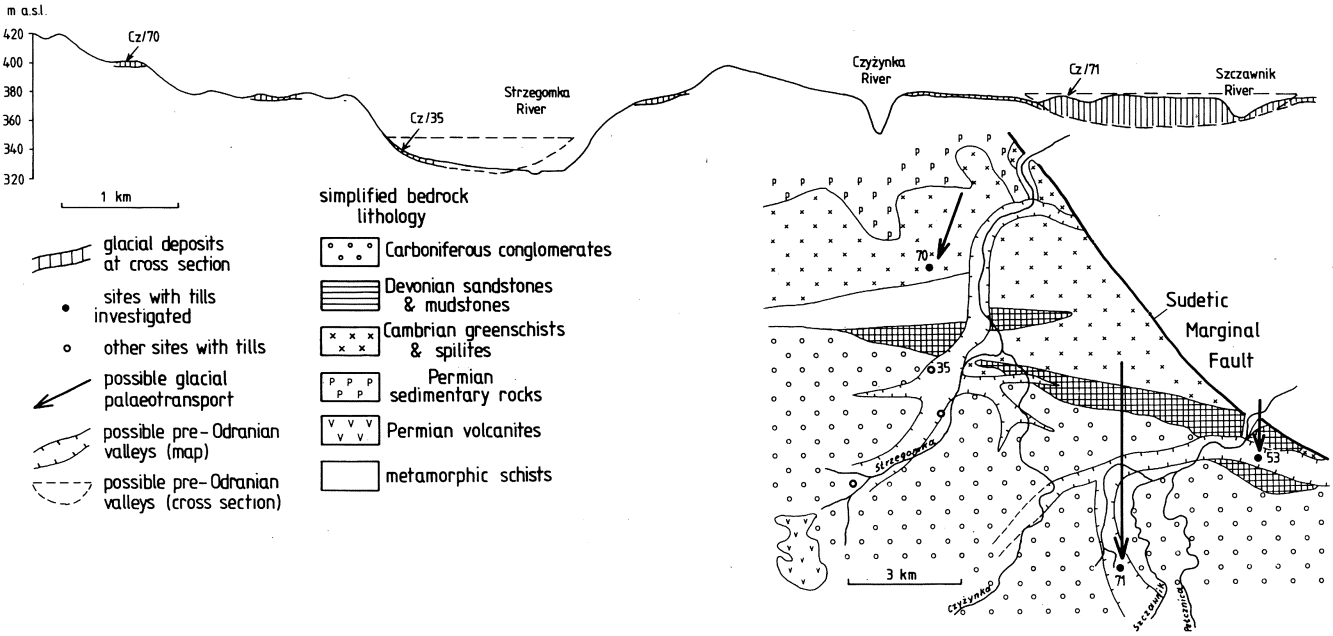


Fig. 30. Position of tills at the Wałbrzych Upland (upper section) and possible glacial palaeotransport directions in relation to the bedrock (map). Bedrock geology after Teisseyre & Gawroński (1965), Teisseyre (1969) and Haydukiewicz *et al.*, (1982)

samples with low frequency of minerals contain assemblages more or less similar to those with high frequency (Fig. 29). Main minerals are garnet and amphibole (together 40–60%), which are accompanied by epidote, zircon, andalusite, staurolite, tourmaline, cyanite, pyroxene, biotite (each *ca.* 2–10%) and, occasionally, rutile. A very characteristic feature is the absence of syllimanite, a mineral common in the Sowie Góry gneiss and gneissic conglomerates.

The analysed mineral assemblages of fluvial deposits show a mixed composition. Local minerals come both from crystalline and metamorphic rocks, but it seems likely that the majority of garnets, amphiboles and epidotes are glacially-derived (Czerwonka & Krzyszkowski, 1992).

GLACIAL DEPOSITS

Glacial deposits in the valleys has been described together with alluvial terraces (Figs. 16, 18, 20, 22, 23). In the upland areas, two sites with glacial deposits were available during the study period: at Chwaliszów Dolny (site 70) and Szczawienko (site 71). Another one was present in the abandoned valley near Pełcznica (site 53) (Fig. 30). The tills of the two latter sites are weathered and contain only resistant rock components. The till at Pełcznica (site 53) contains mainly Devonian sandstones (56–58%) and quartz (20–24%). Northern rocks constitute about 5–10% and other local rocks are also 5–10% of the total. The latter group comprises 3–5% of porphyry, which occurs only in mountain highlands, 15 km to southwest of the area (Fig. 30). Local glacial palaeotransport was most probably from the north, since the exposures of Devonian rocks lie 0.5 km northwards from the site. Quartz, other local rocks and especially, the porphyry must have come from an alluvial fan at the mountain foreland (Fig. 30). The till at Szczawienko (site 71) contains mainly quartz (23–42%) and Carboniferous conglomerates (13–20%). Northern rocks are about 10–15% and other local rocks are about 30–36%, including porphyry (2–7%), greenschists and spilites (4–8%), and quartzite (8–10%). Conglomerates, greenschists and spilites may have been derived directly from the outcrops of these rocks northwards of the site studied (Fig. 30). Local palaeotransport from north is thus assumed.

The section at site 70 contains both the till and glaciofluvial sands and gravels, as well as fine grained deposits of apparently glaciolacustrine origin (Fig. 31). All these deposits are deformed. A distinct thrust plane of NWW–SEE orientation can be observed in the section. This suggests glacial push from NEE (the thrust plane mean orientation is 80/30°). The stereonet diagram of all deformations, including folds, shows glacial push from NNE (35°). Thus, it seems that the glacial palaeoflow was generally from the NE, from the lower Strzegomka river valley (Fig. 30). The till is partly weathered, with only 0.1–1% of limestones (1–4 grains). Dominating rock groups are quartz (24–51%) and northern rocks (28–38%). Local rocks are together about 22–32%. Among them, the most common one are porphyries (3–6%), quartzites (2–18%), crystalline rocks (4–9%) and Sowie Góry gneisses (3–5%). Carboniferous conglomerates do not occur at all. Greenschists, which are the main rocks in the substratum (Fig. 30), are very rare or absent (Fig. 32). This suggests, that the ice-sheet eroded mainly the former alluvial covers, presumably advancing up-valley, which is consistent with the palaeoflow inferred from deformation structures (from NNE to NE). The glaciofluvial deposits lying below the till indicate an originally glacial petrographic composition of gravels, with limestones (18–35%) being ubiquitous. Other rocks are similar to those in the till (Fig. 32).

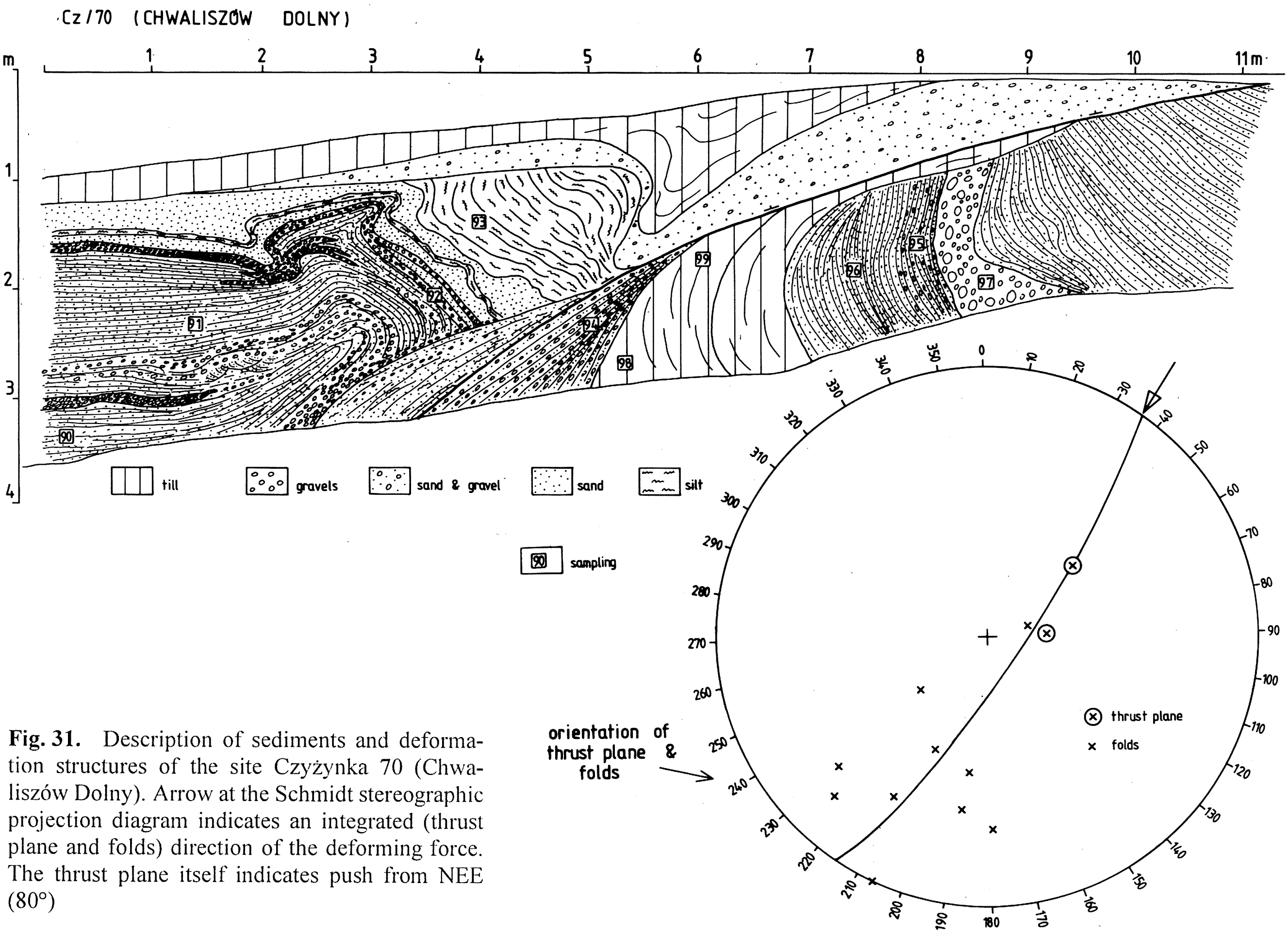


Fig. 31. Description of sediments and deformation structures of the site Czyżynka 70 (Chwaliszów Dolny). Arrow at the Schmidt stereographic projection diagram indicates an integrated (thrust plane and folds) direction of the deforming force. The thrust plane itself indicates push from NEE (80°)

INTERPRETATION AND DISCUSSION

EVOLUTION OF THE LANDSCAPE

Three principal stages of the relief evolution can be deduced from the geomorphological evidence (Fig. 33). The central depression was formed as a consequent alluvial surface during the Oligocene–Early Pliocene times and due to the removal of thick, Mesozoic–Lower Tertiary weathering mantles (Fig. 33A). Final removal of the weathering mantles was during the Pliocene, *i.e.* during the main uplift of the Sudeten (Oberc & Dyjor, 1969; Oberc, 1972; Dyjor, 1986). At that time, the outflow was probably stopped to the north, due to the presence of more resistant rocks of the Kaczawskie Góry Zone, as well as owing to relatively larger uplift of the latter zone and the Sowie Góry Block. As a result, the subsequent palaeoflow through the Świebodzice Synclinorium was initiated (Fig. 33B). The flat and extensive surface, the Cieszów horizon, was shaped between the Late Pliocene up to, most probably, the beginning of the Middle Pleistocene (Fig. 27).

The Middle and Late Pleistocene development of the relief was very complex and only the latest stages can be recognised unambiguously. Generally, it was characterised by deep and repeated incision of river valleys into the Cieszów horizon (Fig. 33C), which was interrupted at least twice by the advances of the Scandinavian ice-sheet. Late Quaternary evolution of fluvial landscape may be interpreted at two time horizons: the pre-Odranian and the post-Odranian times, with the last glaciation as a boundary event.

Figure 34 presents the map of the lowest position of the top of glacial cover (mainly till), measured in 1 km^2 quadrangles. The data have been collected from geological maps, literature (Dathe, 1892; Szczepankiewicz, 1954) and our own observations. This map is believed to show a very rough pattern of the valleys before the last (Odranian) ice-sheet advance. It comes from a general assumptions, that the glacial cover mantled uniformly the former landscape. The differences in thickness of glacial deposits in the uplands (5–10 m) and in valleys (10–20 m) may be omitted, the more so, as the altitudinal differences between these two zones may reach in places more than 100 m. The map shows some very fine regularities. First of all, the positions of the uppermost parts of old valleys are similar to recent valleys. In turn, the middle and lower parts of old valleys are somewhat different. Among them, the most stable is the Strzegomka river valley. The present-day valley is located almost entirely in the middle of a large depression cut into glacial deposits (Fig. 34). The abandoned valleys, the pre-Odranian Terrace as well as the uppermost flattenings are located along this depression, too (Fig. 34). Data from the Czyżynka, Szczawnik and Pełcznica river valleys indicate, in turn, quite big hydrographic changes (Fig. 34). The Czyżynka river was flowing originally to the east, to the Poleśnica river valley, what is also documented by the abandoned valley (Figs. 8, 34). The Szczawnik and Pełcznica rivers formed one valley, which was located along the recent

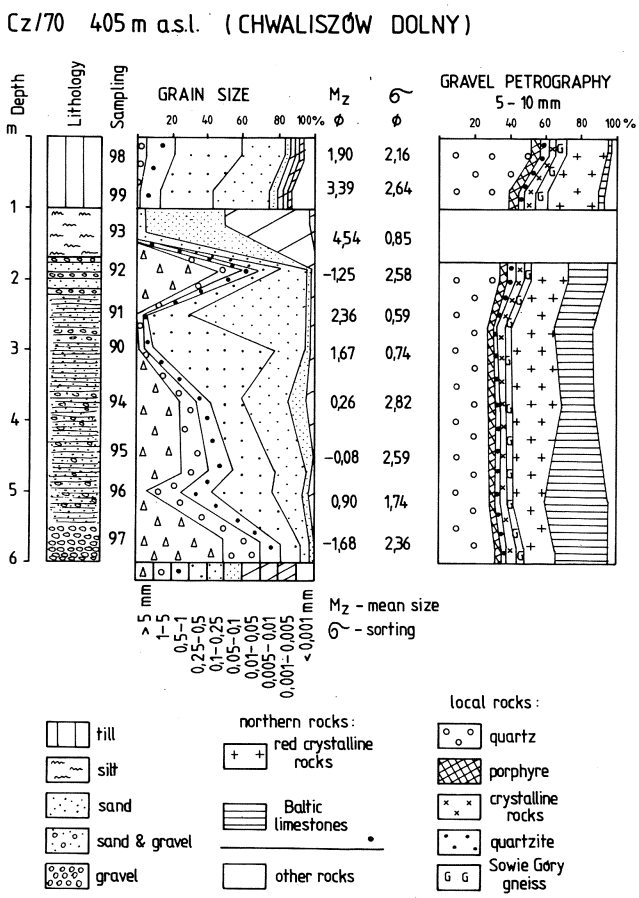


Fig. 32. Sediment stratigraphy and lithological and petrographical properties of deposits at site Czyżynka 70

Poleśnica river valley, too.

From the above, we may conclude that the evidence of pre-Odranian fluvial landscape, *i.e.* terraces with gravels, uppermost flattenings, abandoned valleys and depressions of the top-surface of glacial deposits, have a consistent pattern, which may be interpreted as a valley pattern (Fig. 34). Another evidence of the pre-Odranian river valleys is a large admixture of local porphyre and some other rocks in the studied tills. They were incorporated into the tills from the pre-existing fluvial sequences.

The pre-Odranian valley system may come from the Holsteinian, although there is no datable evidence (Fig. 27). At least at one location in the region investigated, near Dobromierz (Fig. 8), there is evidence for the river valley older than the Holsteinian. This valley is infilled with two tills, the lower one of which representing, most probably, the Elsterian ice-sheet advance. Thus, the deep valley must have formed before the Elsterian or during the interstadial between two Elsterian stadials. However, no fluvial gravels have been found to confirm this hypothesis. Dathe (1892) and Szczepankiewicz (1954) have described some other sections bearing two tills near Walbrzych. None of them contained fluvial gravels. In fact, all the sections with two tills come from archival well-log data, and it is not certain whether they really contain two stratigraphically separate glacial horizons, or only the lithologically variable proglacial sequence. Thus, at this stage of investigation, the problem of possible occurrence of pre-Elsterian valleys remains open.

The surficially lying glacial deposits have been interpreted as belonging to the last glacial event in SW Poland, *i.e.* the Odranian glaciation. The sediments of the Odranian glaciation represent a regional, stratigraphic correlation bed, as well as the chronostratigraphic bench-mark. These sediments are easily recognizable in the field, first because of specific, northern, glacially-derived gravel assemblages and because of specific lithology (till, varved clay). The ice-sheet advanced into the Wałbrzych Upland from NE or N, which is roughly consistent with the regional advance of this ice-sheet in SW Poland (Krzyszkowski & Czech, 1995). The thickness of ice reached up to 150 m, as the highest position of glacial deposits at Mount Chełmiec and Trójgarb (Fig. 3) is at 520–550 m a.s.l. (Dathe, 1892; Schwarzbach, 1942; Szczepankiewicz, 1954).

The glacial cover and the bedrock were consecutively dissected during the postglacial (post-Odranian) times. The main features of the post-Odranian valleys are as follows (Fig. 35): (1) the valleys are deeply (up to 80–100 m) incised, reaching in many cases the bedrock and with the glacial cover on slopes and at uplands; some valley fragments are cut only in the bedrock (Fig. 21); (2) longitutinal profiles of river channels are highly irregular; (3) valleys are bottle-shaped, with wide depressions characterised by low gradi-

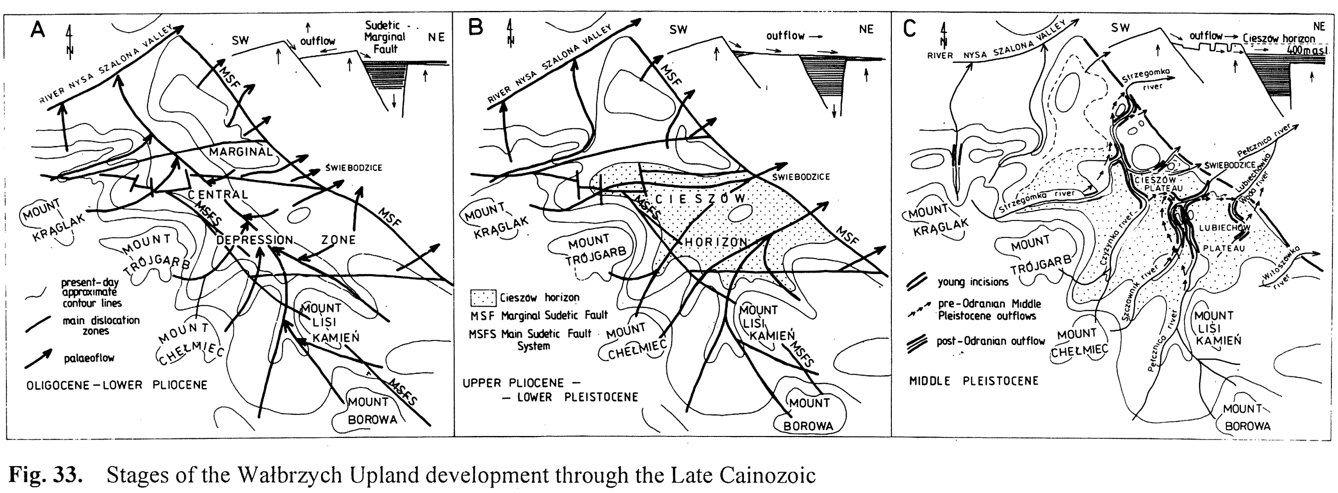


Fig. 33. Stages of the Wałbrzych Upland development through the Late Cainozoic

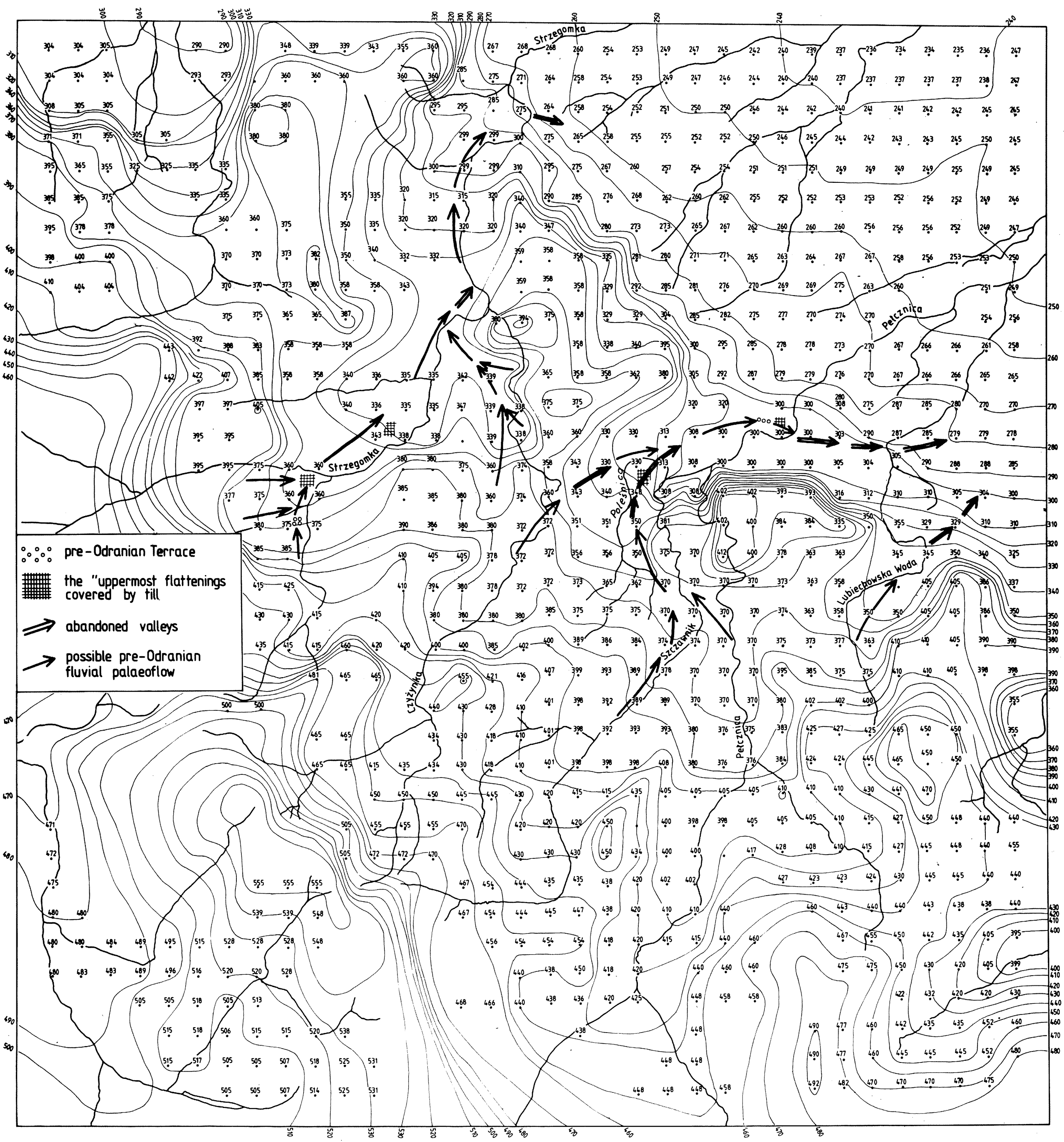


Fig. 34. Map of the lowest position of glacial deposits in the Wałbrzych Upland (presumably indicating the pre-glacial fluvial morphology, compare with Fig. 30). The map has been interpolated on the basis of geological maps 1:25,000 with a net squares (area 1 km^2, distance beween centres 0.5 km). Numbers indicate the lowest position of glacial deposits in the observed square in metres above sea level

ents, and the narrow valleys and/or river gorges show steep gradients with rapids and waterfalls; (4) all the valleys contain four terraces; the Upper Terrace is a rock terrace and other terraces are cut and fill terraces; (5) the terraces have different heights, with distinct downstream convergence within depressions and with distinct divergence at the margin of the mountain highland; (6) some terraces have restricted occurrence; the Middle Terrace occurs only in some depressions, and the Lowermost Terrace occurs only near the mountain margin. The Upper Terrace in the Strzegomka river valley and the Upper and Middle terraces in the Pełcznica river valley are cut by the Sudetic Marginal Fault and they do not continue into the mountain foreland; (7) the thickness of alluvial deposits is variable along the valley being, generally the thinnest in the upstream part of depressions, with gradual increase in sediment thickness down-

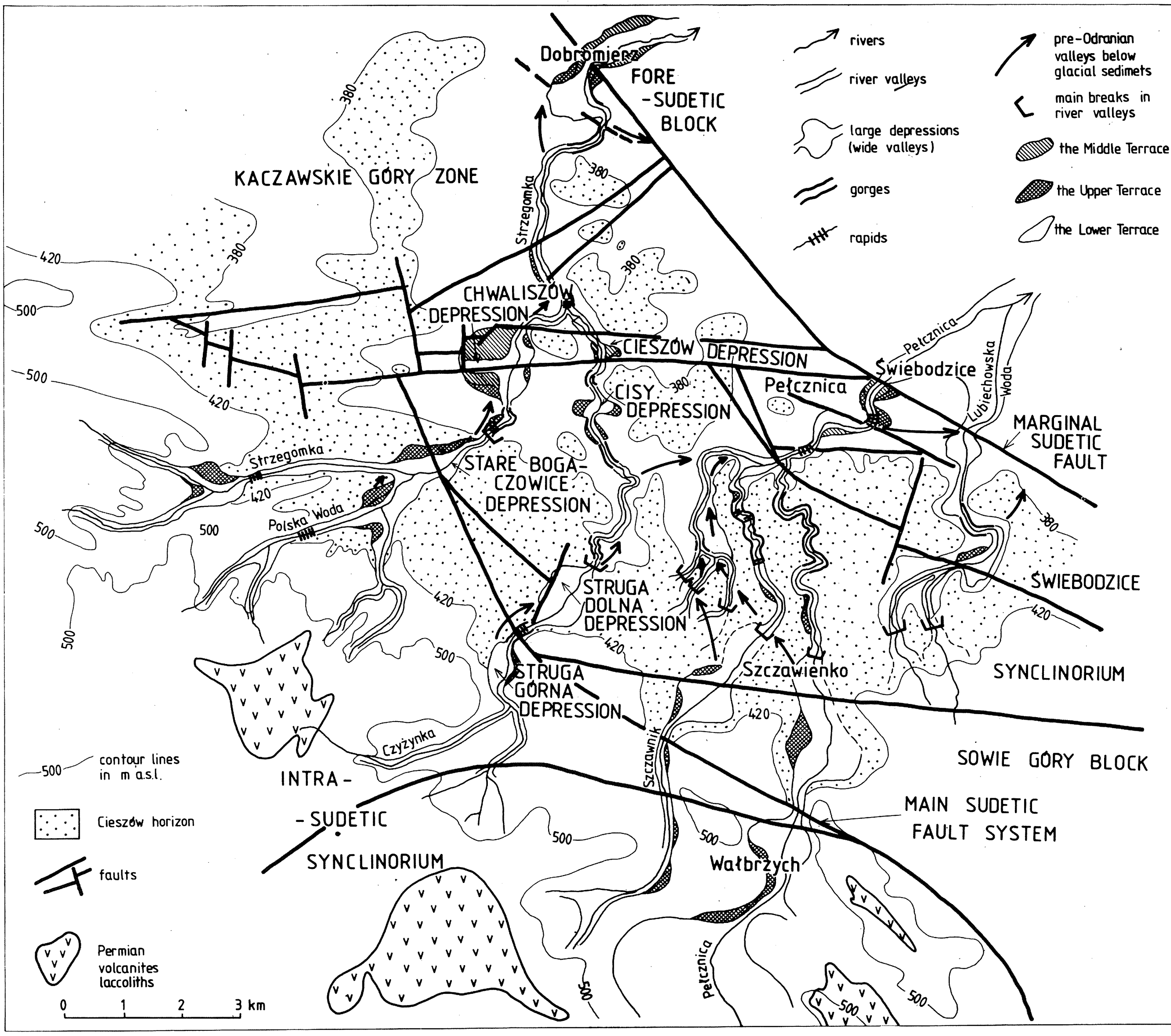


Fig. 35. Morphotectonic map of the Wałbrzych Upland (terraces are marked roughly)

stream. Moreover, in places, there are rapid changes in sediment thickness, distinctly connected with fault lines in the bedrock.

Some of these features may be easily connected with differential uplift of the basement. The most indicative are irregular longitudinal profiles, tilting of terraces and rapid changes in sediment thickness. The convergence of terraces shows local subsidence and the divergence indicates local uplift. Hence, in the region investigated, the valley "depressions" represent the subsided zones. This corresponds well with the increased sediment thickness within the depressions, including the increased number of terraces (Fig. 36A). It seems likely, that valley "depressions" are located within separate tectonic blocks of the bedrock, which are also characterised by different geological history, as they differ in size, the number of terraces and sediment thickness. Generally, rotation of individual blocks may be assumed (Fig. 36A). This causes an increased uplift in the upstream zone of the block and, hence, formation of deep and narrow valleys with irregular longitudinal profiles, and the increased subsidence, with thick alluvial sequences and wide valleys (depressions) in the downstream zones. A connection of some of narrow valleys/river gorges with the faults in the basement is unequivocal (Fig. 35), although some other have more ambiguous documentation.

A special case are valley fragments near the Sudetic Marginal Fault. Here, all terraces indicate divergence, some of the terraces being truncated by the fault plane. Both these facts suggest permanent uplift along the Sudetic Marginal Fault and strong differences in tectonic regimes in the montaneous region (uplift) and its foreland (subsidence, tectonic graben formation, Fig. 36). However, rapid changes in thickness of alluvial deposits are documented best in this zone (Figs. 15, 25). This suggests strong activity not only

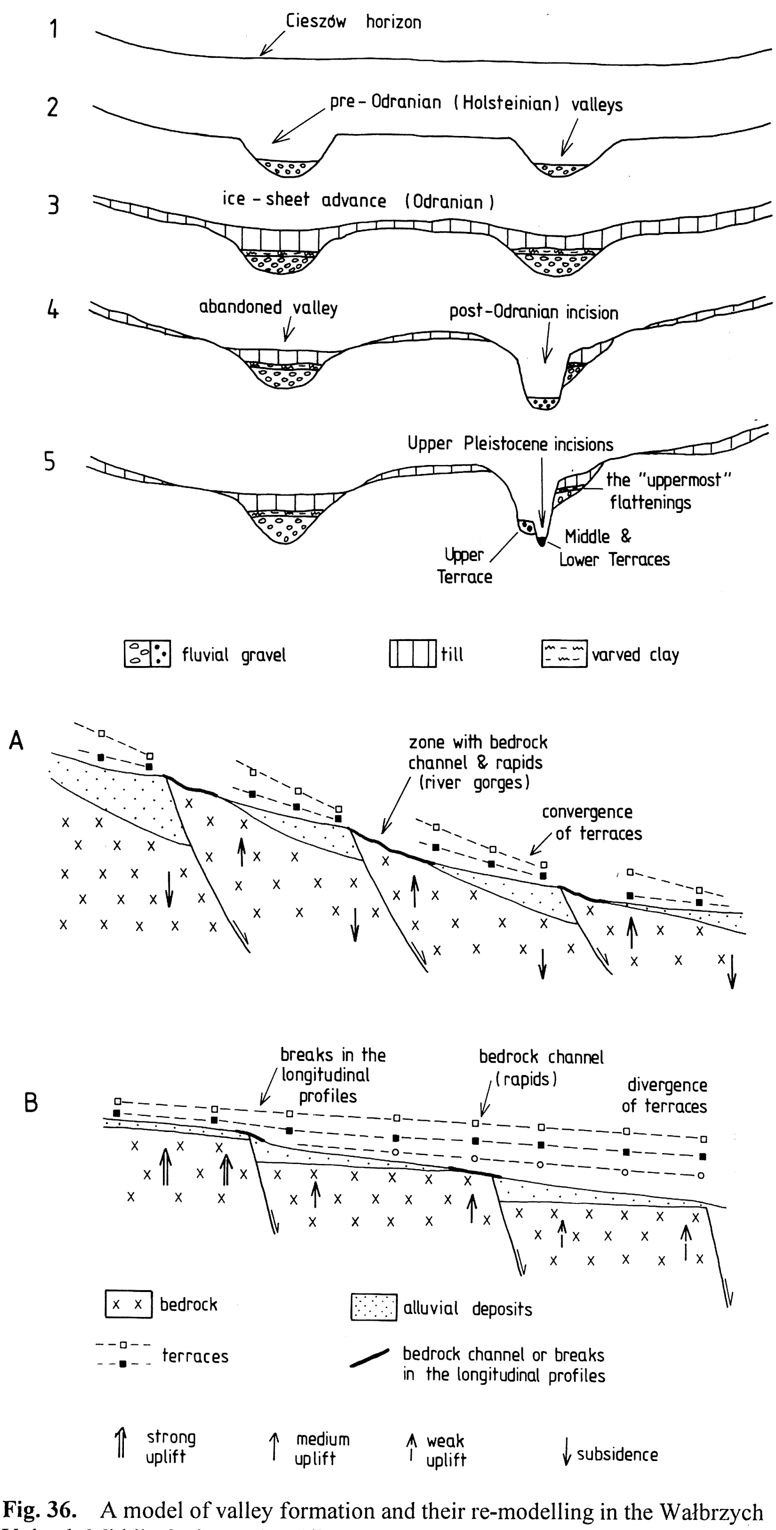


Fig. 36. A model of valley formation and their re-modelling in the Wałbrzych Upland, Middle Sudeten: 1 – Pliocene–Early Pleistocene, 2 – Middle Pleistocene, 3 – Older Saalian (Odranian) glaciation, 4 – Younger Saalian (Wartanian) stage, 5 – Late Pleistocene (simplified): A – fluvial sedimentation and erosion in the mountain interior; rotation of tectonic blocks with simultaneous downstream increase in alluvial sediment thickness and terrace convergence; B – fluvial sedimentation and erosion on the mountain margin (*en block* uplift); sediment thickness increase in downfaulted blocks and terrace divergence

along the main fault, but also along minor faults.

The differential uplift and rotation of blocks is permament, as even recent channels have highly irregular profiles and rapids, although some of them have receded 0.5–2 km upstream from fault lines due to headward erosion. The permanent uplift along some faults, including the Sudetic Marginal Fault, is also well visible in the map of relief above headstream erosion (Fig. 6).

CAUSES, TIMING AND RATES OF UPLIFT

The tectonic activity during the Late Pliocene or the Pliocene/Pleistocene transition might be regarded as prolongation of the Neogene tectonics (Oberc & Dyjor, 1969; Oberc, 1972; Grocholski, 1977; Dyjor, 1986). Evidence for increasing tectonic activity in the same period is also available from adjacent regions (Lewandowski, 1988; Zuchiewicz, 1990). In turn, the younger uplift clearly coincides with the decay of the Odranian ice-sheet. The deeply-incised till-covered plateau of the Wałbrzych Upland suggests a phase of rapid uplift due to isostatic rebound of the bedrock, which followed the ice decay. The original ice thickness of 150 m in the Wałbrzych Upland should have resulted in 40–50 m of the "postglacial" uplift, if isostatic rebound models are adopted (Mörner, 1979).

In fact, the total post-Odranian erosion is twice as large, being up to 80–100 m (Fig. 7). On the other hand, the pre-Odranian (Holsteinian) valleys, which are nowadays abandoned and dry, are only 40–50 m deep (Figs. 7, 8). They do not show clear evidence of tectonic movement, such as divergence of alluvial surfaces. This may lead to the conclusion that the Elsterian ice-sheet was much thinner in the Wałbrzych Upland or did not advance into the mountain interior. In this case, isostatic rebound might have been very small, and the valleys were formed only due to climatic reasons and changes in the base level. On the other hand, the (abandoned) valley fragments near the Sudetic Marginal Fault show distinct dextral deflection and possible occurrence of transverse ridges (Figs. 8, 30, 34). This may lead into conclusion, that at least the Sudetic Marginal Fault was tectonically active even during the post-Elsterian time, when the old valleys were formed. The deflections might have been caused by the activity of splintering faults. Such forms have been documented in the Sudeten from the post-Odranian neotectonic stages (Sroka, 1991; Migoń, 1993).

The post-Odranian incision occurred in two positions: at the Cieszów horizon (*ca.* 400 m a.s.l.), where rivers cut completely new, 80–100 m deep river gorges, and along the old valleys, filled with glacial deposits. In the latter case,

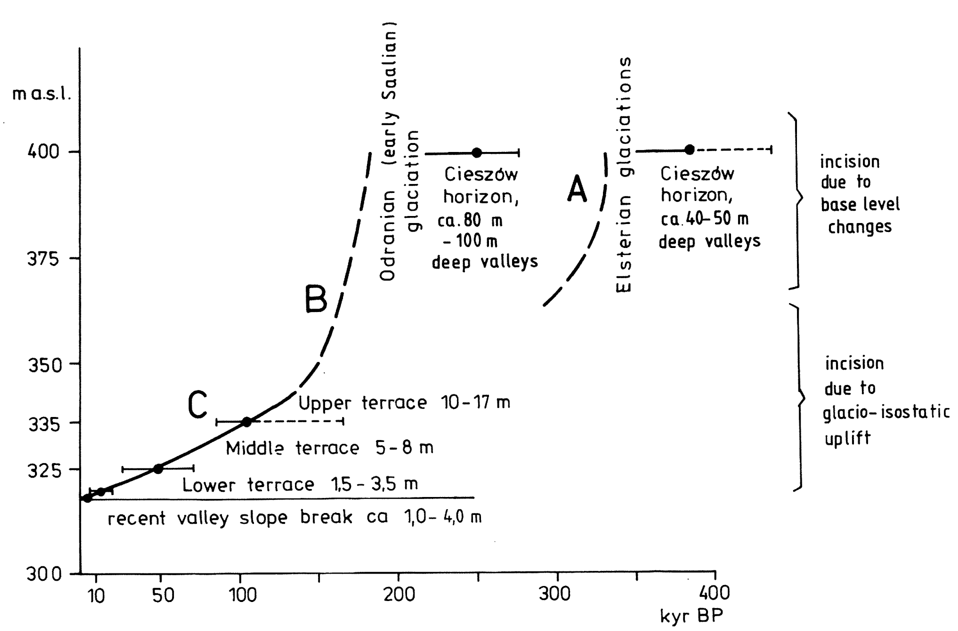


Fig. 37. Erosion rates during the Late Quaternary in the Wałbrzych Upland: A – periods of tectonic stability, B – periods of rapid and deep river incisions (regional uplift due to isostatic rebound), C – periods of small, though continuous incisions

only a part of the total valley depth comes from the post-early Saalian time, as rivers at first must have exhumed the Holsteinian valleys. Thus, the original post-early Saalian incision represents only a half of the total valley depth in the Wałbrzych Upland, *i.e. ca.* 40–50 m (Fig. 7). This additional incision may be related to the regional uplift, when the incision of the first 40–50 m is controlled by post-glacial change of the base level, similarly to the post-Elsterian times. Thus, the value of presumably post-early Saalian uplift corresponds well with the theoretical isostatic rebound.

It is proposed that two components played a role in the late Quaternary, "postglacial", tectonic movements, being superimposed on each other. These are glacioisostatic rebound after the ice-sheet decay and the localised extensional tectonics along the bedrock faults in the region. The regional isostatic uplift probably induced short-term reactivation of permanently unstable faults zones, although the actual relationship between these two components are not established, yet. The post-Odranian reactivation of the faults have also been noticed in other parts of the Sudeten (Krzyszkowski *et al.*, 1995) and in the central-European Lowlands (Krzyszkowski, 1992).

The begining of the Saalian stage, when correlated with the Oxygene Isotope Stage 6, is *ca.* 200,000 years BP (Shackleton & Opdyke, 1976). The Odranian sub-stage represents the first ice advance during this glacial stage. Therefore, we have assumed a simplified age boundary at 200,000 years BP for all calculations of the post-Odranian uplift rates, taking into account the fact that ice-sheet advances into central Europe were relatively short.

Three phases of the post-Odranian uplift can be recognised, and they are documented by the formation of alluvial levels of the Upper, Middle and Lower terraces and their incision (Fig. 36). The first phase was characterised by rapid uplift, with an incision of valleys down to about 70 m (the height difference between the Cieszów horizon and the Upper Terrace). As the Upper Terrace started to be formed, most probably during the Wartanian sub-stage, the first uplift period was not longer than 50,000 years. It gives the erosion rate of at least 1.5 mm/year. The heigth differences between the Upper and Middle terraces and between the Middle and Lower terraces are much lower, although the total timing of these phases is *ca.* 150,000 years. The possible erosion rates are 0.15 mm/year and 0.05–0.1 mm/year, respectively (Fig. 37). The present-day longitudinal profiles of rivers are irregular and the height of waterfalls varies from 1 to 4 m. This may indicate that the Late Holocene movements along the faults, although not extensive, still exist and they are sufficient to preserve irregular profiles, in spite of large headward erosion.

CONCLUSIONS

1. The landscape of the Wałbrzych Upland developed during three main stages. The Oligocene–Early Pliocene stage was characterised by consequent fluvial valleys formed in thick weathering mantles with outflow to the northwest. During the Late Pliocene–Early Pleistocene stage there was a complete change of hydrographic system with new, subsequent rivers flowing to the northeast. The flat landscape of the Cieszów horizon – a main geomorphic element of the region – was formed during that time. The Middle Pleistocene development of the landsape is very complex, and described below.

2. The Wałbrzych Upland was covered by continuous ice cover during the Odranian sub-stage (Older Saalian). The Scandinavian ice sheet advanced from the NE and N and reached the interior of the Sudeten Mts. up to a distance of several kilometres from the mountain margin. The thick-

ness of ice was *ca.* 150 m. During the Elsterian, at least a marginal part of the Wałbrzych Upland, was once covered by ice.

3. The possible pre-Elsterian fluvial system is documented in one, deeply incised (abandoned) valley, filled with two tills, although no fluvial gravels have been documented from that time.

4. The Wałbrzych Upland bears distinct traces of fluvial landscape from before the last glaciation of the region (pre-Odranian stage). This fluvial system is documented by terraces with gravels, flattenings covered by tills (which are presumably buried terraces), and the abandoned valleys. The latter are nowadays infilled with glacial deposits, although in two of them fluvial gravels have been documented from below the glacial cover. The pre-Odranian fluvial landscape shows an ambiguous evidence of tectonic movements, although they are possible.

5. The post-Odranian rivers dissected the glacial cover and in part, especially in their middle and lower courses, formed valleys in quite new places, incising the bedrock. Four stages of valley development may be recognised, which are documented by four terraces: the Upper Terrace formed during the Wartanian/Eemian, the Middle Terrace formed during the Middle Weichselian, the Lower Terrace formed during the Late Glacial/Early Holocene, and the Lowermost Terrace formed during the historical times.

6. The post-Odranian valleys have been formed due to intensive and short-term uplift of the mountain upland with simultaneous re-activation of fault lines. The main geomorphological effects of this uplift are: the formation of abandoned valleys, bottle-like shapes of newly incised valleys, with alternating wide valleys (depressions) and narrow valleys or river gorges; highly irregular longitudinal profiles of channels with many breaks and even rapids and waterfalls; varying number of terraces and their heights along the valleys; tilting of terraces, with several convergent systems in the mountain interior and terrace divergence near the Sudetic Marginal Fault; truncation of terraces and formation of fault scarps along the Sudetic Marginal Fault. The main geological effects are: variable thickness of alluvial deposits, the synsedimentary thickness increase of alluvial deposits along some fault lines, and breaking of the continuity of some alluvial surfaces at the Sudetic Marginal Fault.

7. The uplift of the Wałbrzych Upland was induced by isostatic rebound after the Odranian glaciation, although it was supported much by another, most probably, a localised extensional endogenic component. Both together have given a total uplift during the Late Quaternary of about 40–50 m. Erosion rates during the uplift were at about 1.5 mm/year at the beginning (*ca.* 200,000–150,000 years BP), and much lower during the Late Pleistocene and Holocene (0.15–0.05 mm/year). The uplift, though very slight, continues until now.

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Streszczenie

PÓŹNOCZWARTORZĘDOWY ROZWÓJ DOLIN RZECZNYCH I EWOLUCJA NEOTEKTONICZNA POGÓRZA WAŁBRZYSKIEGO, SUDETY ŚRODKOWE, POLSKA POŁUDNIOWO-ZACHODNIA

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W artykule przedstawiono rozwój rzeźby fluwialnej Pogórza Wałbrzyskiego (Fig. 1), ze szczególnym uwzględnieniem środkowego i górnego plejstocenu. Pogórze Wałbrzyskie położone jest w części brzeżnej Sudetów, wzdłuż Sudeckiego Uskoku Brzeżnego (Fig. 2, 3), pomiędzy rzekami Strzegomką na północy i Pełcznicą na południu. Do interpretacji cech geomorfologicznych terenu zastosowano mapy morfometryczne (Fig. 4–6), przekroje przez doliny i działy wodne (Fig. 7, 9, 12), profile podłużne rzek (Fig. 10, 11) oraz wykonano terenowe kartowanie geomorfologiczne i geologiczne dolin rzecznych (Fig. 8). W wyniku kartowania terenowego ustalono występowanie czterech poziomów terasowych, nazwanych odpowiednio od najstarszej: terasą wysoką, średnią, niską i najniższą. Ponadto zaobserwowano wysoko położone spłaszczenia stokowe przykryte glinami lodowcowymi, w dwu przypadkach także z udokumentowanymi żwirami rzecznymi oraz opuszczone doliny rzeczne (Fig. 27). W artykule opisano także osady rzeczne wszystkich teras z wybranych (typowych) odcinków rzek: Strzegomki i jej dopływów koło Dobromierza (Fig. 13–16), Chwaliszowa (Fig. 17, 18) i Starych Bogaczowic (Fig. 19, 20) oraz Pełcznicy pomiędzy Szczawienkiem a Świebodzicami (Fig. 21–26). Przedstawiono skład petrograficzny żwirów rzecznych i skład minerałów ciężkich oraz przedyskutowano ich zmienność regionalną i stratygraficzną (Fig. 28–29). Oprócz osadów rzecznych udokumentowano, zarówno w dolinach jak i na wysoczyznach, osady glacjalne, w tym gliny lodowcowe. Ustalono dla nich kierunki transportu lokalnego na podstawie cech składu petrograficznego glin oraz orientacji zaburzeń glacitektonicznych (Fig. 30–32).

Rzeźba Pogórza Wałbrzyskiego ukształtowała się w trzech etapach: oligoceńsko-wczesnoplioceńskim, późnoplioceńsko-wczesnoplejstoceńskim i środkowoplejstoceńskim (Fig. 33). Ten ostatni etap rozwoju rzeźby, najbardziej skomplikowany, jest przedmiotem szczegółowych rozważań w zaprezentowanym artykule. Pogórze Wałbrzyskie było przykryte lądolodem Skandynawskim w czasie ostatniego zlodowacenia tego obszaru, tj. zlodowacenia Odry (wczesny stadiał zlodowacenia środkowopolskiego), oraz co najmniej w swoich częściach brzeżnych w czasie zlodowacenia Elstery (południowopolskiego). Grubość lodu dochodziła do 150 m. Rzeźba fluwialna sprzed zlodowacenia Elstery jest słabo udokumentowana (jedna opuszczona dolina wypełniona osadami glacjalnymi). Zaobserwowano natomiast liczne ślady rzeźby fluwialnej sprzed zlodowacenia Odry (interglacjał mazowiecki?). Jest ona udokumentowana przez terasy, spłaszczenia stokowe z pokrywami glin, które reprezentują pogrzebane terasy, oraz przez liczne opuszczone (pogrzebane) doliny ze żwirami rzecznymi i osadami glacjalnymi (Fig. 30, 34). Ten przed-odrzański system fluwialny wykazuje bardzo mały związek z tektoniką regionu, z wyjątkiem części dolin w pobliżu Sudeckiego Uskoku Brzeżnego. Na Pogórzu Wałbrzyskim zrekonstruowano (po zlodowaceniu Odry) cztery fazy rozwoju rzeźby fluwialnej, udokumentowane przez terasy. Terasa wysoka pochodzi prawdopodobnie z okresu Warta/Eem, terasa średnia ze środkowego Vistulianu, terasa niska z późnego glacjału/początku holocenu a terasa najniższa powstała w czasach historycznych (Fig. 27). Datowanie osadów rzecznych ma charakter konwencjonalny, ze względu na całkowity brak osadów organicznych czy szczątków paleontologicznych w badanych profilach. Występowanie lessów na niekórych terasach pozwoliło na względne odniesienie ich wieku w stosunku do górnego pleniglacjału zlodowacenia Wisły.

Doliny po-odrzańskie były formowane w czasie krótkiego i bardzo intensywnego podnoszenia obszaru górskiego, z jednoczesnym uaktywnianiem stref uskokowych. Główne efekty morfologiczne tego podnoszenia to (Fig. 35): butelkowy kształt nowo tworzonych dolin, powstanie odcinków przełomowych dolin, niewyrównane profile podłużne koryt rzecznych, zmienna liczba teras i ich wysokość wzdłuż dolin, pochylenie teras, obcięcie teras i powstanie skarp uskokowych wzdłuż Sudeckiego Uskoku Brzeżnego. Główne efekty geologiczne to (Fig. 36): zróżnicowana miąższość aluwiów w wyniku rotacyjnych ruchów podłoża, synsedymentacyjny wzrost miąższości aluwiów na skrzydłach zrzuconych niektórych uskoków i brak ciągłości niektórych pokryw aluwialnych położonych poza Sudeckim Uskokiem Brzeżnym. Podnoszenie Pogórza Wałbrzyskiego nastąpiło najprawdopodobniej w wyniku odprężenia glaciizostatycznego po zlodowaceniu Odranian, na które nałożyły się ruchy tektoniczne wzdłuż reaktywowanych uskoków. Całkowite, czwartorzędowe, tektoniczne podniesienie obszaru wynosi 40–50 m. Prędkość podnoszenia wynosiła początkowo 1.5 mm rocznie (ca 200 000–150 000 lat BP), a potem, w górnym plejstocenie i holocenie, była znacznie mniejsza (0,15–0,05 mm rocznie) (Fig. 37). Podnoszenie to, choć bardzo małe trwa do czasów obecnych.