Geologia Sudetica, 1998, 31: 317–328.

The pre-Elsterian valley system in the Western Sudetes, southwestern Poland, and its later transformation

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Key words: buried valleys, fluvial pattern, glacial deposits, Elsterian glaciation

Abstract This paper presents a reconstruction of the pre-Elsterian fluvial pattern in the Western Sudetes Mts using borehole and geophysical data. These valleys were blocked by the advancing Elsterian ice sheet, enabling the proglacial lakes to be formed, and most of them were later covered by the ice sheet which entered into the mountain interior. The valleys are now filled with 5–15 m of 'pre-glacial' fluvial gravels and a generally thick glacial series. The latter comprises a till and glaciofluvial and glaciolacustrine sediments, including varved clay. The former valleys occur along the axes of the present-day valleys or at their margins, or occur in watershed areas which have been recently abandoned. Post-Elsterian changes in valley pattern is due to the filling of old valleys and epigenetic incision of new valleys along the tributary valleys. The valley fragments which preserved their former position were deeply incised, with the almost complete removal of older deposits. Some fault activity has been documented for that time in the marginal zone of the Sudetes Mts. The Saalian ice sheet only entered the marginal part of the Sudetes Mts, and hydrographic changes from that time are smaller.

Manuscript received 15 April 1998, accepted 30 October 1998.

INTRODUCTION

The analysis of borehole and geophysical prospecting data indicated that buried valleys in the Western Sudetes (Fig. 1) contain sediments from only one glaciation, including one till, glaciolacustrine clay, silt and fine sand, which is usually underlain by fluvial gravel and coarse-grained sand. Only at the mountain margin, in the northernmost part of the studied region, are there more till beds which suggest more than once ice sheet advance (Michniewicz *et al.*, 1995, 1996). A similar situation has been described in the adjacent part of Germany (Eissmann, 1975, 1994), where fluvial deposits at the base of buried valleys are interpreted as representing the Cromerian–early Elsterian stage. Besides the buried valleys, there are some very deep troughs in the marginal part of the mountainous region, which may be interpreted as glacial tunnel valleys. Similar deep troughs are interpreted in Germany as having formed during the Elsterian ice sheet advance (Kupetz *et al.*, 1989).

The age of the buried valleys and their sediments in the western Sudetes has not been precisely established, mainly due to the complete lack of organic deposits or palaeontological findings. The crucial fact is, that all the valleys are covered by one till, and thus the age of the till gives the upper age boundary for the formation and the filling of the buried valleys. There are several views on the age and the number of Scandinavian glaciations in the Sudetes Mts.; the most important are:

1. The Sudetes Mts were glaciated once during the Elsterian stage (Genieser, 1936; Schwarzbach, 1942; Dyjor, 1991)
2. The Sudetes Mts were glaciated once during the early Saalian stage (Wilczyński, 1991)
3. The Sudetes Mts were glaciated twice and the extents of ice sheets during both advances were more or less the same, although the field data are very ambiguous (Jahn, 1960; Jahn & Szczepankiewicz, 1969)
4. The Sudetes Mts were glaciated twice, but the ice sheets from different stages indicated various extents (Macoun & Kralik, 1995; Badura & Przybylski, 1998; Krzyszkowski & Stachura, 1998; Krzyszkowski & Biernat, 1998; Krzyszkowski *et al.*, 1998).

This problem has not yet been solved satisfactorily (Jahn, 1995; Badura & Przybylski, 1998). It seems that the glacial sediments of the interior of the western Sudetes represent the Elsterian stage. This interpretation takes into account the great similarity of the studied sequences to those of southeast Germany, and the fact that the ice sheet from the Elsterian glaciation indicated a more southern

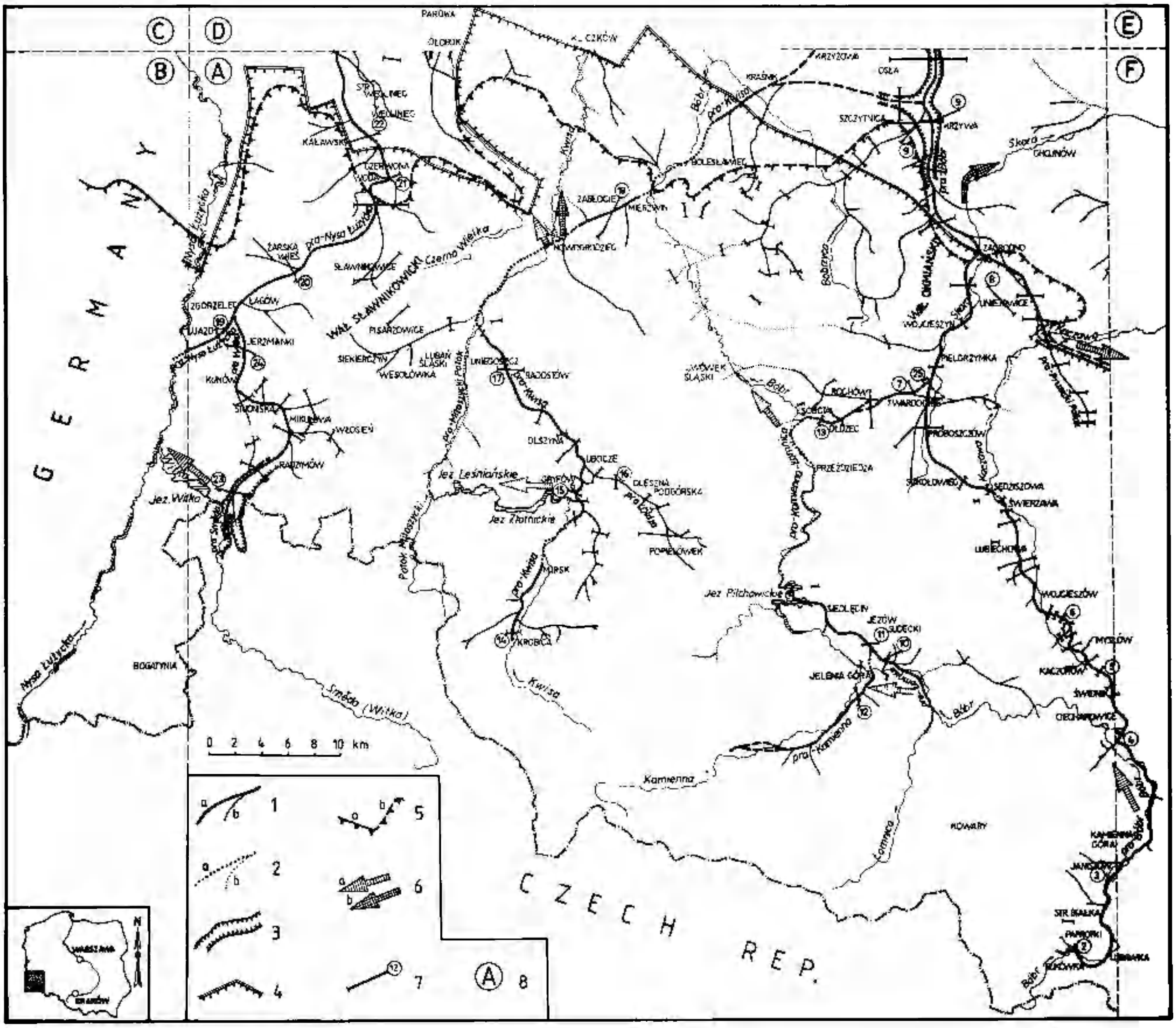

Fig. 1. The valley pattern of the western Sudetes and its foreland: *1* - pre-Elsterian valleys: a - main valleys, b - tributary valleys; *2* - pre-Elsterian valleys incised deeply during the Middle and Late Pleistocene: *a* - main valleys, *b* - tributary valleys; *3* - glacial tunnel valleys; *4* - faults zone of the margin of the Sudetes Mts; *5* - maximum extent of the Saalian glaciation: *a* - in Germany (after Kupetz *et al.*, 1989), *b* - in western Sudetes (after Michniewicz *et al.*, 1995, 1996); *6* - post-Elsterian (*a*) and post-Saalian (*b*) hydrographic changes in western Sudetes; *7* - anayled geological and geophysical cross sections, numbers indicate sections discussed in the paper; *8* - sheets of the 1:200,000 geological map: sheets Jelenia Góra (A), Bogatynia (B), Gubin (C), Zielona Góra (D), Leszno (E) and Wałbrzych (F).

extent than the Saalian ice sheet in the wide region from Leipzig to the Polish/German border (Eissmann, 1975, 1994; Kupetz *et al.*, 1989; Macoun & Kralik, 1995). The glacial sediments of the Saalian stage probably occur only at the margin of the Western Sudetes (Fig. 1). Thus the fluvial deposits under discussion are most probably of pre-Elsterian age, and may roughly correlate with the Cromerian–early Elsterian fluvial series of Eissmann (1975, 1994). However, some other authors, on the basis of data from adjacent regions such as the northern part of the Czech Republic (Macoun & Kralik, 1995) or the Middle Sudetes (Krzyszkowski & Stachura, 1998; Krzyszkowski & Biernat, 1998) suggest that the early Saalian ice sheet had a much wider extent.

Distribution and stratigraphy of the buried valleys in the Western Sudetes were recently presented in detail by Michniewicz *et al.* (1995, 1996) and Michniewicz (1997). This paper only presents the general results of this study and its main aim is to reconstruct the fluvial pattern in the Western Sudetes before the first Scandinavian glaciation in this region (Fig. 1, 2). The results presented are based on the analysis of geophysical prospecting and 2649 boreholes which were done over the last few decades (Michniewicz *et al.*, 1995), as well as of the analysis of new geoelectrical profiles, which were performed during this project (Mżyk, 1995). There are 1234 measuring points along the new geoelectrical profiles, each located from 50 to 200 m apart. The profiles lie perpendicularly to the valleys, and have

AB line spacing from 250 m at the margins to up to 1000 m in the axes of the valleys. These parameters gave depth penetration down to 50–150 m.

A RECONSTRUCTION OF THE PRE-ELSTERIAN VALLEY SYSTEM

THE PRE-BÓBR VALLEY SYSTEM

The upper course of the present-day Bóbr river valley is located along the pre-Bóbr valley system. In the southernmost, non-glaciated region, the young fluvial deposits are superimposed on the older fluvial gravels, forming a 15 m thick sequence near Bukówka (Fig. 3). More to the north, near Janiszów, these young and old fluvial sequences are separated by glaciolacustrine clay and silt (Fig. 4). The latter was deposited in the proglacial lake formed at the front of the Scandinavian ice sheet. Geophysical prospecting beyond the present-day valley between Paprotek and Stara Białka (Fig. 1) documented only bedrock, indicating a very stable position for the Bóbr valley in this region. In contrast, north of Kamienna Góra, the present-day and buried valleys have quite different locations. The former runs west, whereas the latter is present between Ciechanowice and Kaczorów (Fig. 1). The buried valley near Ciechanowice is filled with 10–15 m of fluvial gravels

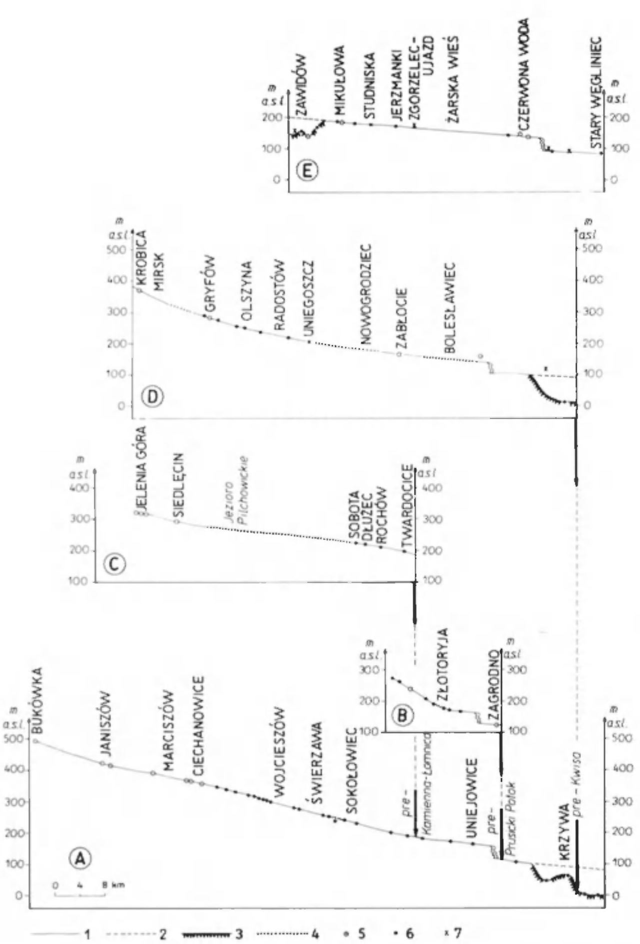

Fig. 2. Longitudinal profiles along the buried valleys of the western Sudetes: pre-Bóbr (A), pre-Prusicki Potok (C), pre-Kamienna and pre-Lomnica, pre-Kwisa (D) and pre-Nysa and pre-Witka (E). *1* – the bottom surface of the valley axes, *2* – valley fragments glacially incised during the Elsterian glaciation, *3* – the base of Quaternary deposits in tunnel valleys, *4* – valley fragments incised during the post-Elsterian time, *5* – position of the base of Quaternary deposits in boreholes, *6* – interpreted position of the base of Quaternary deposits in geophysical profiles, *7* – other boreholes.

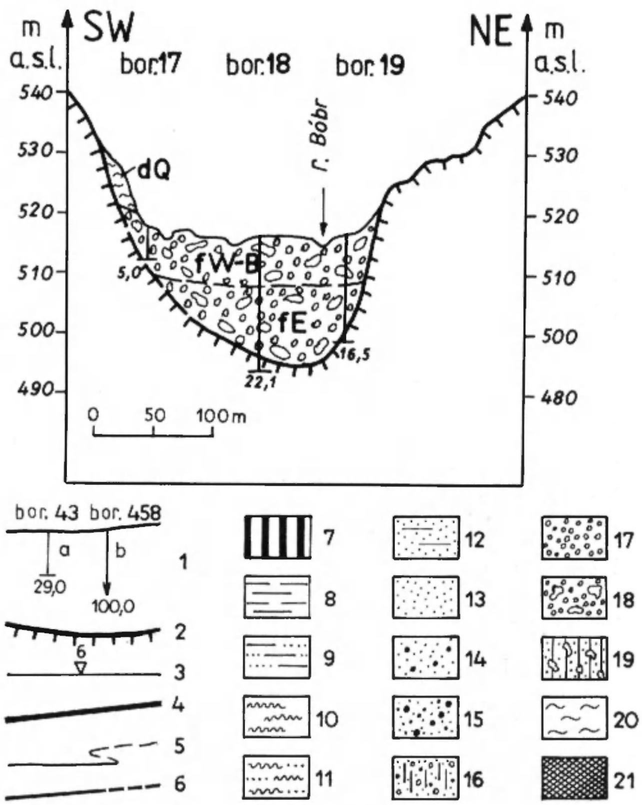

Fig. 3. Geological cross section (no. *2*) through the Bóbr valley near Bukówka. Location in Fig. 1. *1* – location of the boreholes, *2* – the base of Quaternary deposits, *3* – location of the geophysical measuring points, *4* – faults, *5* – lithological boundaries, *6* – lithostratigraphic boundaries. Lithology: *7* – brown coal, *8* – varved clay, *9* – varved silt, *10* – silt, *11* – sandy silt, *12* – fine-grained sand and silt, *13* – fine-grained sand, *14* – medium- and coarse-grained sand, *15* – mixed, fine- to coarse-grained sand, *16* – pebble sand, *17* – pebble gravel, *18* – cobble gravel, *19* – till or glaciolacustrine diamictons, *20* – slope deposits, mainly diamictons, *21* – artificial deposits. Stratigraphy: Q – Quaternary, H – Holocene, B – Weichselian, W – late Saalian (Wartanian), O – early Saalian (Odranian), M – Holsteinian, E – Elsterian; Lithological indexes on cross sections: d – fine-grained colluvium, r – coarse-grained colluvium, l – loess, li – lacustrine deposits, b – glaciolacustrine deposits (b_d – lower, b_g – upper), fg – glaciofluvial deposits (fg_d – lower, fg_g – upper), g – glacial deposits (till), f – fluvial deposits.

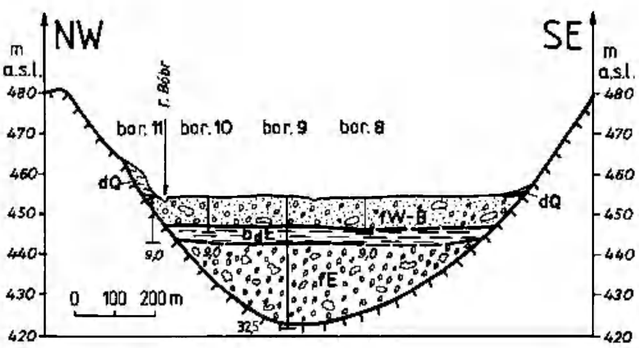

Fig. 4. Geological cross section (no 3) through the pre-Bóbr valley near Janiszów. Location in Fig. 1, explanations in Fig. 3.

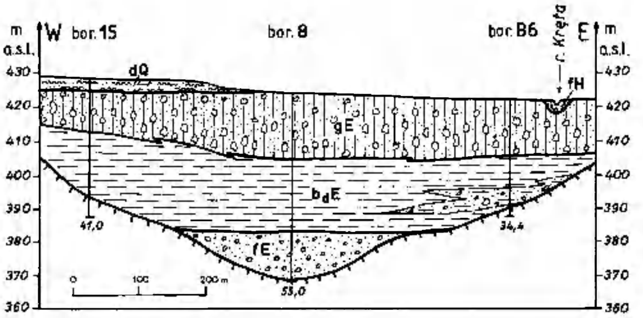

Fig. 5. Geological cross section (no 4) through the pre-Bóbr valley near Ciechanowice. Location in Fig. 1, explanations in Fig. 3.

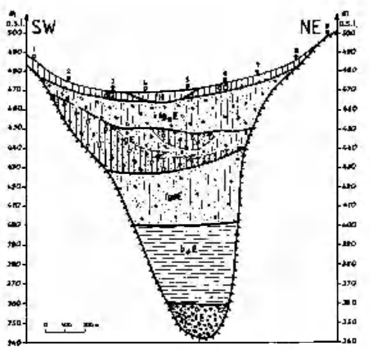

Fig. 6. Interpretation of the geological structure (section no 5) of the pre-Bóbr valley near Świdnik based on geophysical data. Location in Fig. 1, explanations in Fig. 3.

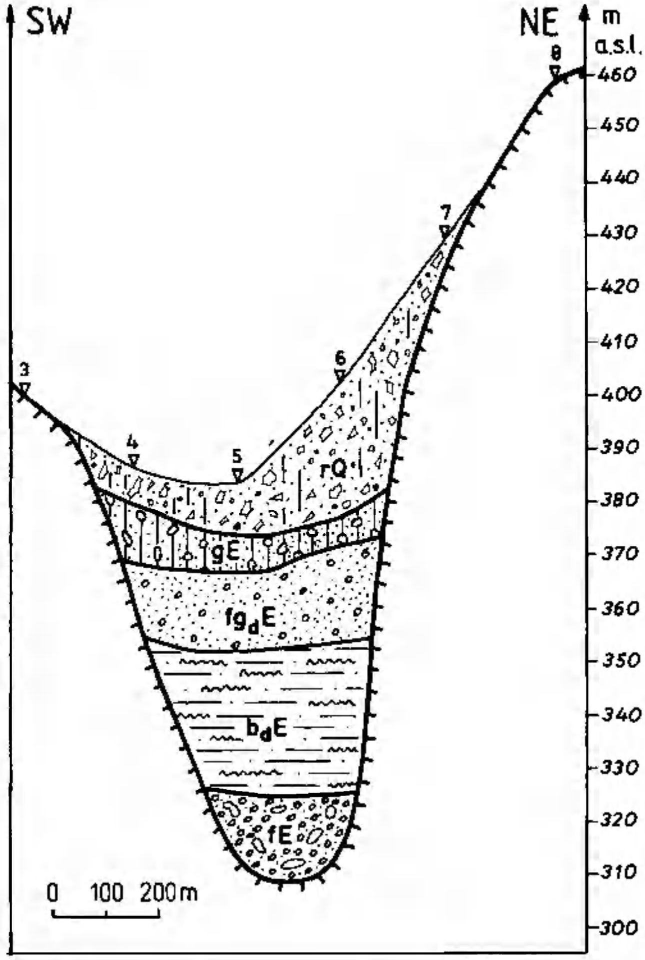

Fig. 7. Interpretation of the geological structure (section no 6) of the pre-Bóbr valley near Wojcieszów based on geophysical data. Location in Fig. 1, explanations in Fig. 3.

and about 40 m of glacial deposits, glaciolacustrine clay and silt and a till (Fig. 5). The till bed was found at the surface of the abandoned valley.

The middle course of the pre-Bóbr valley is located along the present-day Kaczawa river valley from Kaczorów to Wojcieszów, where it was documented during several geophysical profiles (Fig. 1). Cross sections interpreted from this geophysical data show that the buried valley contains similar sequences to Ciechanowice, *i.e.* about 10 m of fluvial gravels at the bottom and 50–100 m of glacial deposits at the top (Fig. 6, 7). The fluvial gravels do not contain Scandinavian material, and were named the 'preglacial' series by Genieser (1936). North of Wojcieszów, the pre-Bóbr valley is parallel to the present-day Kaczawa valley, with the probable exception of a short fragment near Świerzawa, and then turns west, to the present-day Skora valley (Fig. 1). Boreholes were done very rarely in this region and the cross sections (Fig. 8) are based practically only on geophysical data. Nevertheless, it seems that between Sokolowiec and Pielgrzymka the valley contains a similar sediment sequence to its upper courses, with lower fluvial gravels and an upper glacial series, although there are no glaciolacustrine deposists (Fig. 8). Further north, at the margin of the mountainous region, the glacial deposits are highly reduced, having been completely eroded in the valley and only occurring beyond it (Fig. 8) (Michniewicz *et al.*, 1995, 1996). One borehole, at Zagrodno (Fig. 1), is probably in a tributary-valley of the pre-Prusicki Potok (Fig. 2).

The pre-Bóbr valley is glacially re-modelled beyond the mountaineous region, as documented at Krzywa (Fig. 9). The boreholes there indicate a deep (bottom at about 60 m a.s.l.) and up to 2 km wide trough filled with glacial deposits. In contrast with the mountainous region, the sequence contains glacial deposits from at least two, and probably from three glaciations, with two or three tills (Sztromwasser, 1997). The lower part of this sequence is very like the sequences of the tunnel valleys described by Kupetz *et al.* (1989) in east Germany. The valley course

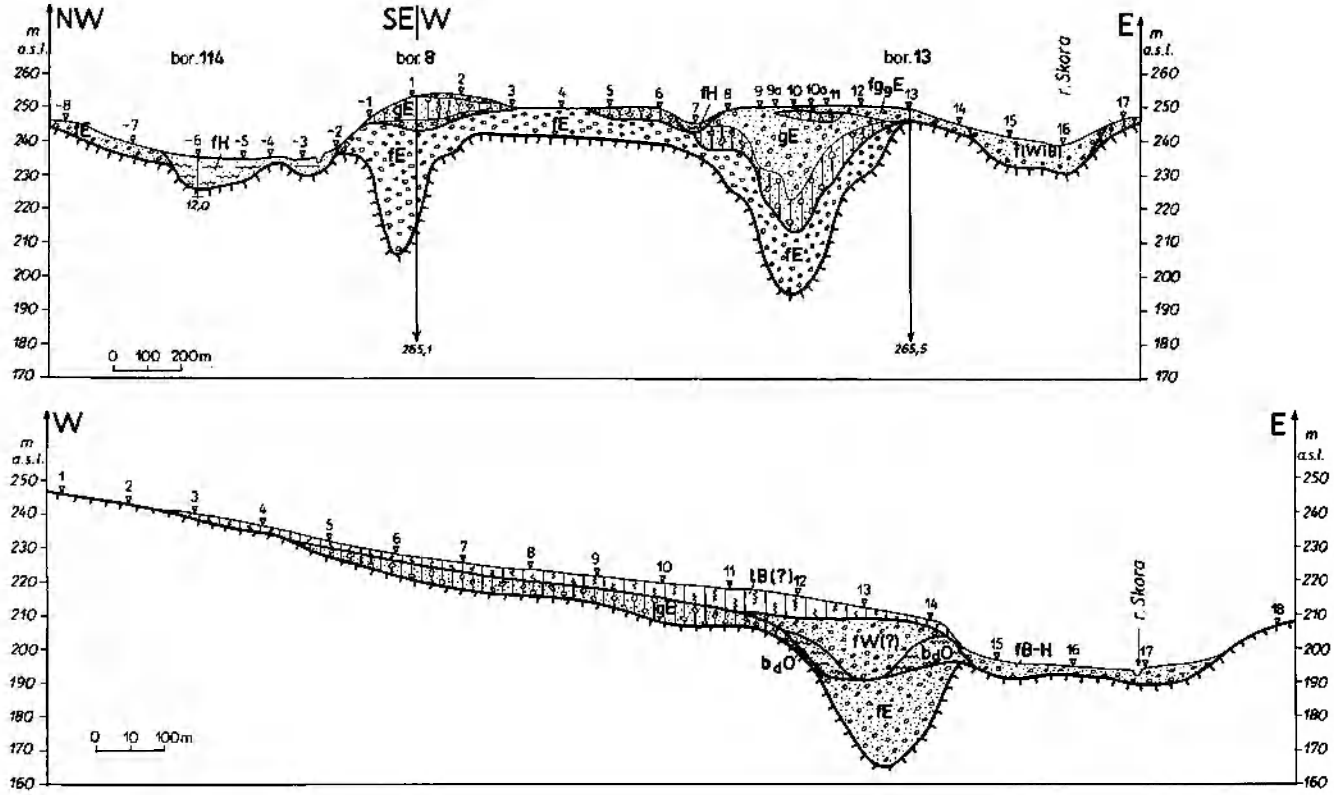

Fig. 8. Interpretation of the geological structure of the pre-Bóbr and pre-Kamienna valleys near Twardocice (upper section – no 7) and near Uniejowice (lower section – no 8) based on geophysical data. Location in Fig. 1, explanations in Fig. 3.

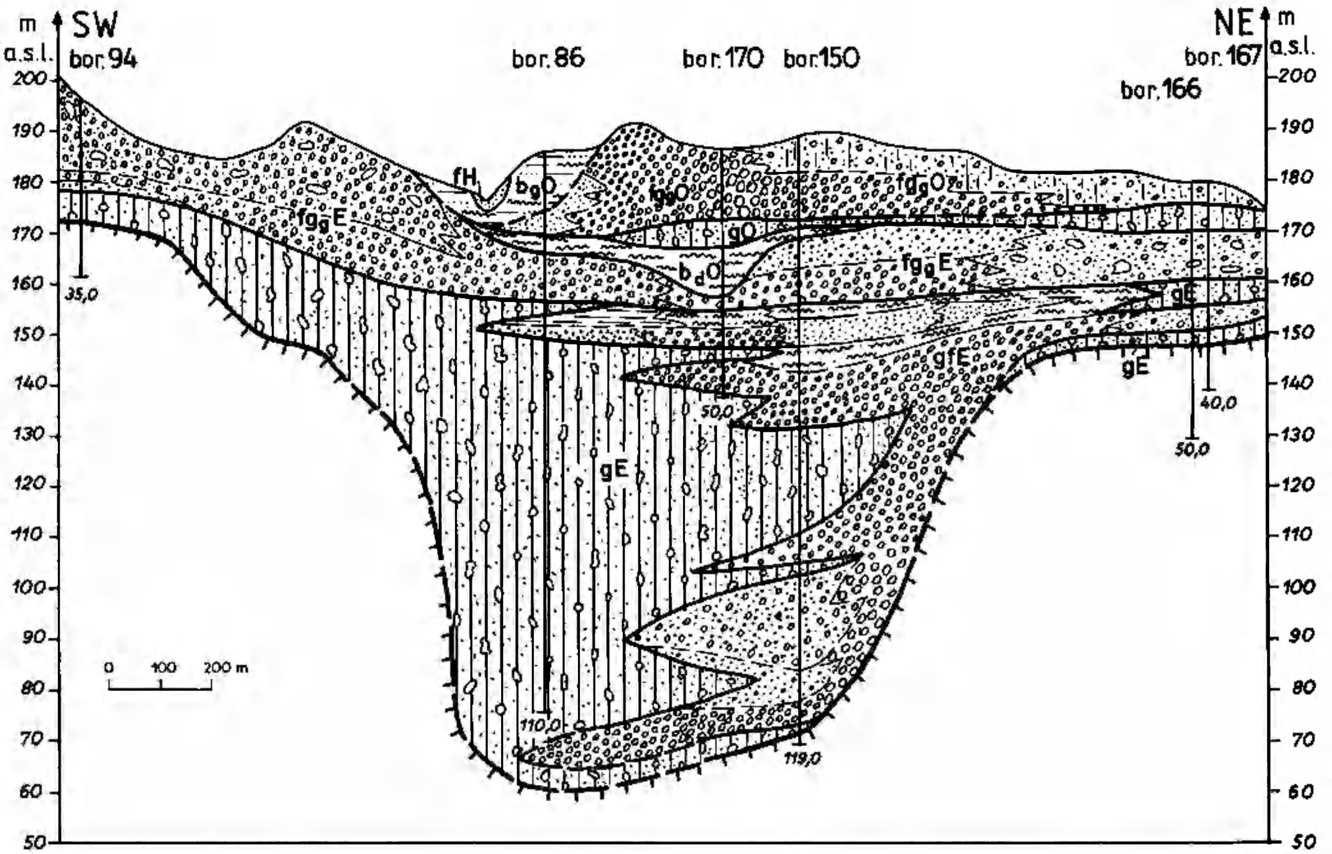

Fig. 9. Geological cross section through the tunnel valley near Krzywa (section no 9). Location in Fig. 1, explanations in Fig. 3.

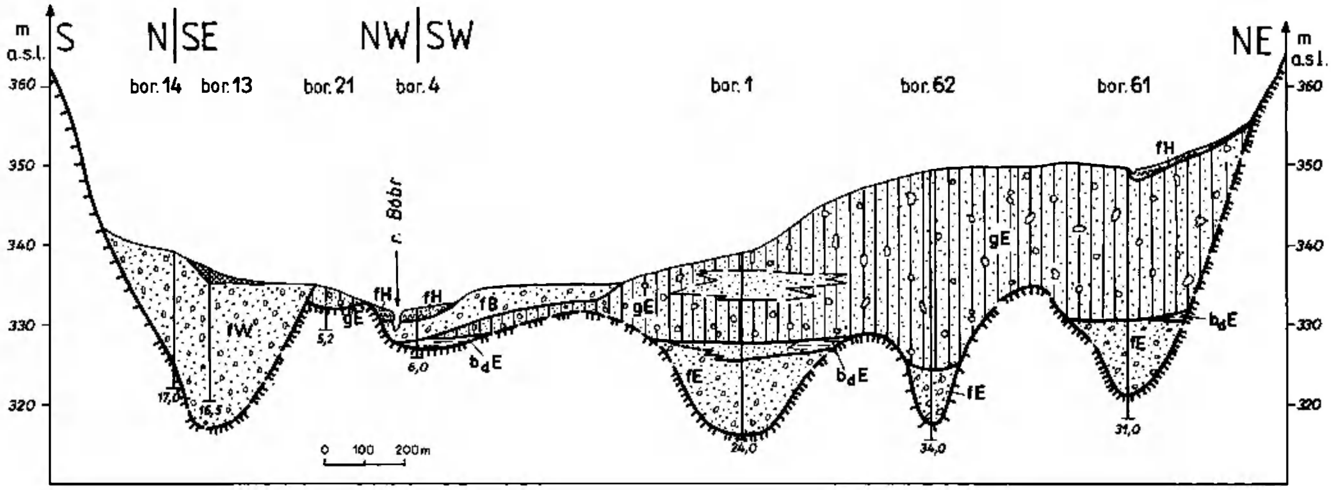

Fig. 10. Geological cross section (no 10) through the pre-Lomnica valley near Jelenia Góra Location in Fig. 1, explanations in Fig. 3.

northwards is poorly documented; the geophysical profiles and geological data presented by Szałajdewicz (1985) suggest the a N–S trend, although the trough must be very sinuous as there are numerous outcrops of Pliocene sediments at the surface (Sztromwasser, 1997).

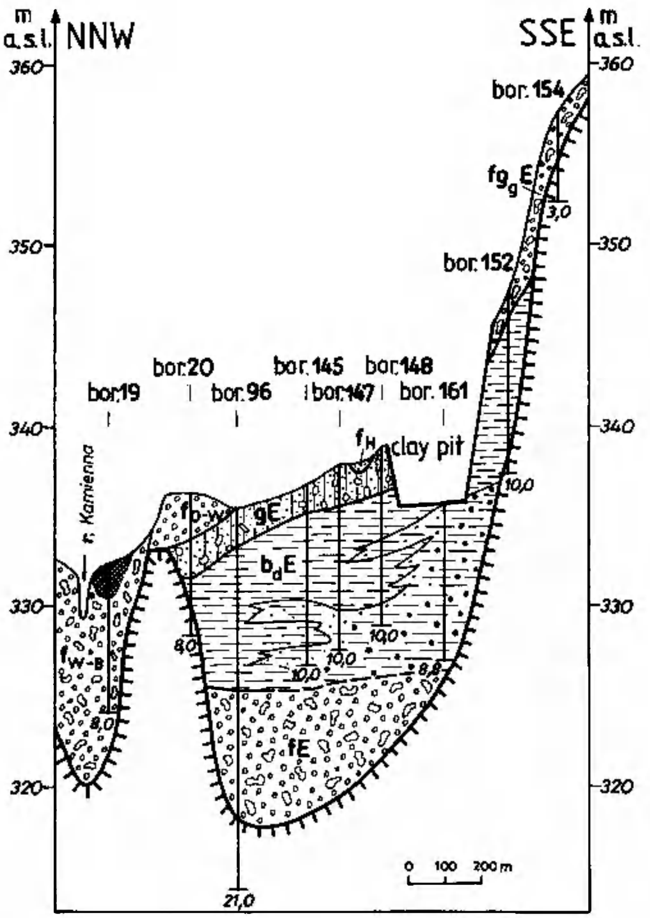

Fig. 11. Geological cross section (no 12) through the pre-Kamienna valley near Jelenia Góra. Location in Fig. 1, explanations in Fig. 3.

THE PRE-KAMIENNA-LOMNICA VALLEY SYSTEM

Before the Elsterian glaciation, the Jelenia Góra Basin was drained by two rivers: the pre-Łomnica and the pre-Kamienna. The buried valley of the former was documented near Jezów Sudecki (Fig. 10) and of the latter near Jelenia Góra (Fig. 11). In both cases, the buried valleys occur beyond the present-day valleys of Łomnica and Kamienna, and both of them contain 'preglacial' fluvial gravels and thick glaciolacustrine series and with a till bed at the surface (Michniewicz, 1993). The till is locally overlain by glaciofluvial sediments. The original borehole description suggested that the glaciolacustrine clay and silt was from 1 to 2 m thick. However, data from the Jelenia Góra brickyard (Fig. 11) suggest that these deposits may be up to several metres thick and that they may contain other types of sediments, including diamicton beds, besides the laminated clay and silt (varved clay). It is possible that the boreholes, instead of a thick till with lenses of fine-grained material, contain a strongly lithologically variable glaciolacustrine series (Fig. 10, 12). A similar thick glaciolacustrine series was described by Genieser (1936) near Siedlęcin.

West of Jeżów Sudecki, the pre-Łomnica and pre-Kamienna valleys join into one valley (Fig. 12), which trends parallel to the present-day Bóbr valley in the northern part of the Jelenia Góra Basin between Jeżów Sudecki and Siedlęcin (Fig. 1). Jahn (1995) suggested that this valley trends from Siedlęcin directly to the north. However, geophysical research did not confirm such a position for the buried valley, which must have joined the present-day Bóbr valley before Pilichowice. There is no trace of any buried valley in the present-day Bóbr valley or on its margin between Pilichowice and Sobota. The young valley incised down to a depth of 30 m, and the sediments of the old valley were probably completely eroded in this region. Milewicz (1985) found some older fluvial deposits at surrounding uplands only near Przeździerza and Sobota. These deposits occur at about 240 m a.s.l. The geophysical profile near Sobota (Fig. 13) indicated a shallow valley

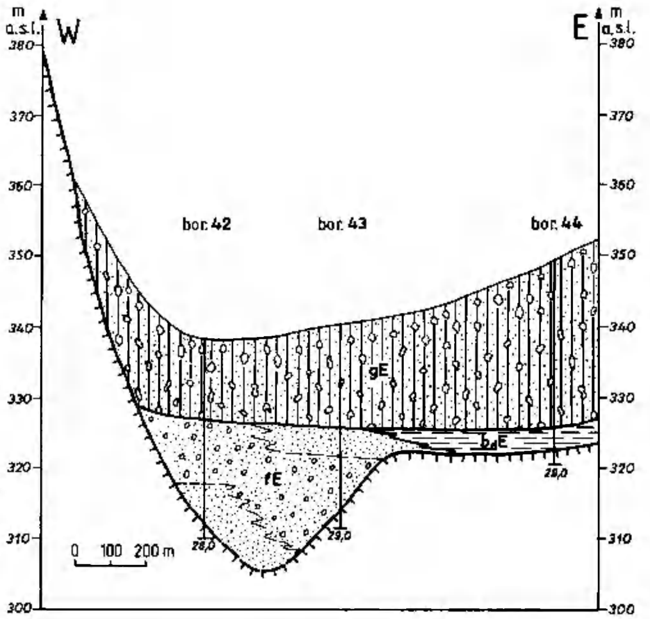

Fig. 12. Geological cross section (no 11) through the pre-Kamienna–Łomnica valley near Jezów Sudecki. Location in Fig. 1, explanations in Fig. 3.

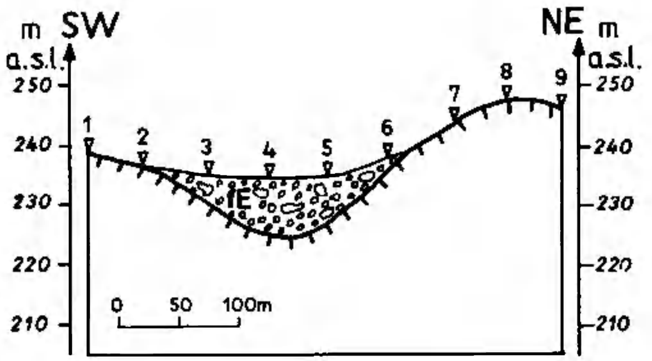

Fig. 13. Interpretation of the geological structure (section no 13) of the pre-Kamienna valley near Sobota based on geophysical data. Location in Fig. 1, explanations in Fig. 3.

filled with gravels, which may represent a fragment of the pre-Elsterian valley system. Its bottom is at about 225 m a.s.l. and correlates well with the position of the bottom of the buried valley in its upper and lower courses (Fig. 2). The valley near Sobota currently has no glacial deposits on top, which may be explained as a result of Late Pleistocene erosion. A similar position for the buried valley was also suggested by Genieser (1936). The buried valley continues to the east and northeast, through Dłużec and Rochów to Twardocice, where it joins the pre-Bóbr valley (Fig. 1, 8).

THE PRE-KWISA VALLEY SYSTEM

A shallow buried valley was found on the left side of the upper course of the present-day Kwisa river valley (Fig. 1). It contains fluvial gravels up to 10 m thick topped by a till bed (Fig. 14). The valley continues to the NE reaching Gryfów Śląski (Schwarzbach, 1942), where it

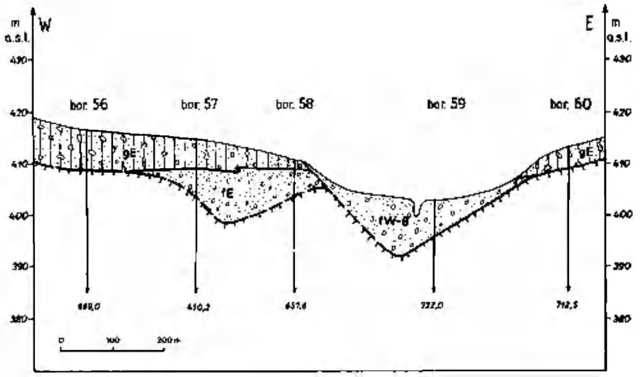

Fig. 14. Geological cross section (no 14) through the pre-Kwisa valley near Krobica. Location in Fig. 1, explanations in Fig. 3.

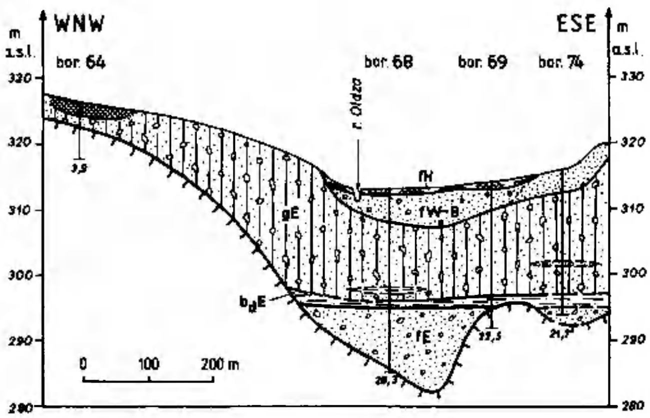

Fig. 15. Geological cross section (no 15) through the pre-Kwisa valley near Gryfów. Location in Fig. 1, explanations in Fig. 3.

contains a similar sediment sequence to the pre-Bóbr and pre-Kamienna valleys, namely the lower fluvial gravel, up to 10–15 m thick, glaciolacustrine clay and silt and a glacial till. The glacial deposits reach thickness up to 30 m (Fig. 15). The glaciolacustrine series is up to 2 m thick and lies directly below the till (Michniewicz *et al.*, 1995). Another glaciolacustrine series was found in the tributary valley – the pre-Oldza between Ubocze and Oleszna (Fig. 1), where clay and silt occur above the till (Fig. 16). Except for the different positions of the glaciolacustrine deposits, both the main and tributary valleys contain very similar sediment sequences and indicate similar depths and widths. It is possible that, as in the Jelenia Góra Basin, the borehole logs gave oversimplified lithological descriptions, and, in fact, the valleys contain only the one lithologically variable glaciolacustrine series.

The pre-Kwisa valley most probably trended northwest of Gryfów, through Olszyna to Uniegoszcz, as documented by geophysical profiles (Fig. 1). Jahn (1995) suggested that the pre-Kwisa valley trended from Olszyna directly to the west. This is probably an incorrect interpretation, as the buried valley was also found northwest of Olszyna, near Radostów and Uniegoszcz. The cross section near Uniegoszcz (Fig. 17) suggests that there are no glaciolacustrine sediments in this part of the valley, which is mainly occupied by fluvial (lower part) and glaciofluvial (upper part) gravels. The occurrence of the till bed is not

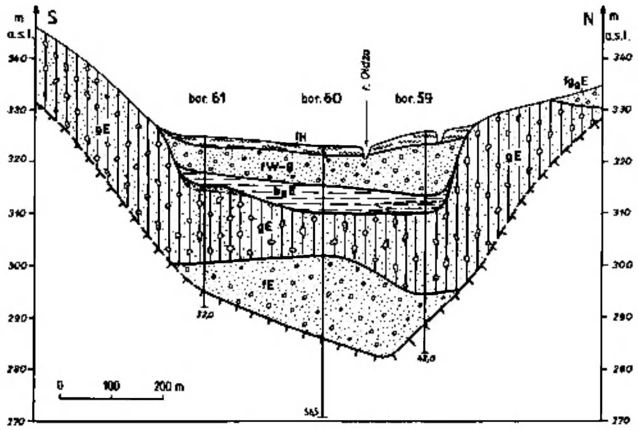

Fig. 16. Geological cross section (no 16) through the pre-Oldza valley near Oleszna Podgórska. Location in Fig. 1, explanations in Fig. 3.

certain, although possible. The geoelectrical prospecting did not show unambiguous characteristics (Mzyk, 1995) and only one borehole at Olszyna, which is located in the valley, does not contain a till.

The course of the pre-Kwisa valley north of Uniegoszcz is very ambiguous. Only directly NE of Uniegoszcz are some shallow troughs filled with gravels, similar to those of the pre-Kamienna valley near Sobota (Fig. 13). Michniewicz & Wojtkowiak (1983) suggested that the palaeovalley trends to the NW crossing the Sławniowicki Wał hills, but the geophysical prospecting work did not confirm this view (Mżyk, 1995). There is no buried valley in this region, and the low position of the base of the Pleistocene deposits near Pisarzowice and Wesołówka is probably due to glacial erosion (Fig. 1) (Berezowska & Berezowski, 1963). Thus, the old valley must have trended along the present-day Kwisa valley to the NE. However, the present-day valley is here very deep and possible old fluvial deposits were eroded. The buried valley was documented again near Zabłocie and Mierzwin (Fig. 1), although there the valley practically only contains sand and gravel (Fig. 17). The valley continues to the NE, through Bolesławiec to Kraśnik (Fig. 1). Further north, the position of the pre-Kwisa valley is not well documented. It may trend to the north to Krzyzowa, or to the east to Krzywa (Berezowska & Berezowski, 1982, 1985). The last case is more probable, as boreholes indicated deep troughs, similar to those documented at Krzywa (Sztromwasser, 1997) (Fig. 9). They may represent the glacially re-modelled pre-Elsterian valleys.

THE PRE-NYSA LUZYCKA VALLEY SYSTEM

The upper course of the pre-Nysa Łuzycka valley is in Germany (Fig. 1). This valley crosses the present-day Nysa valley near Ujazd and continues to the northeast. The valley contains fluvial sand and gravel and a till bed (Fig. 18). Eissmann (1975) suggested more southward position for the valley and its turning to the northwest, again to Germany. Recent investigations suggest that the pre-Nysa Łużycka valley trends continuously to the northeast and north, from Ujazd through Żarska Wies (Fig. 19) and Czerwona Woda (Fig. 20) to Węgliniec (Fig. 1).

The boreholes near Czerwona Woda comprises besides the lower fluvial gravels and the Elsterian till, and other glacial deposits, namely glaciofluvial gravel and sand, glaciolacustrine silt and an upper till, which represents, most probably, the Saalian glaciation (Fig. 20). The uppermost glacial series corresponds with deposits found in the Sławnikowicki Wał hills (Fig. 1).

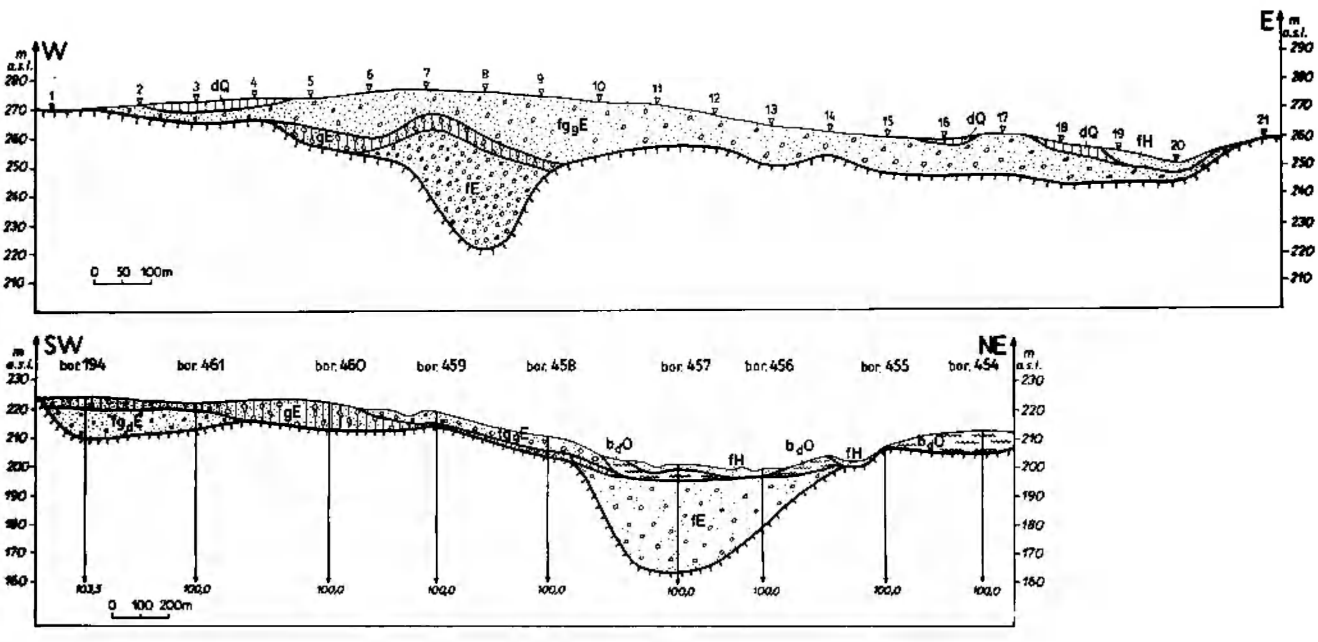

Fig. 17. Cross sections through the pre-Kwisa valley near Radostów (upper section, no 17, interpreted from geophysical data) and near Zabłocie (lower section, no 18, interpreted from borehole data). Location in Fig. 1, explanations in Fig. 3.

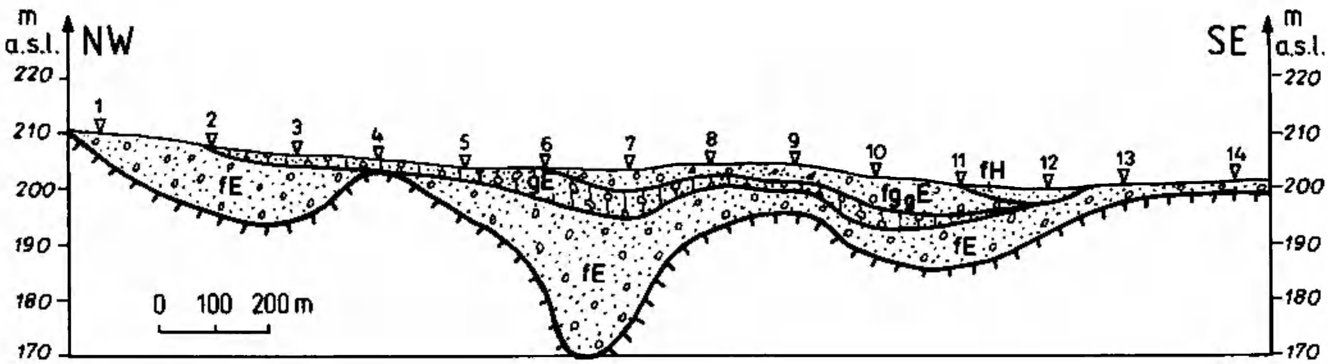

Fig. 18. Interpretation of the geological structure (section no 19) of the pre-Nysa Łuzycka valley near Ujazd based on geophysical data. Location in Fig. 1, explanations in Fig. 3.

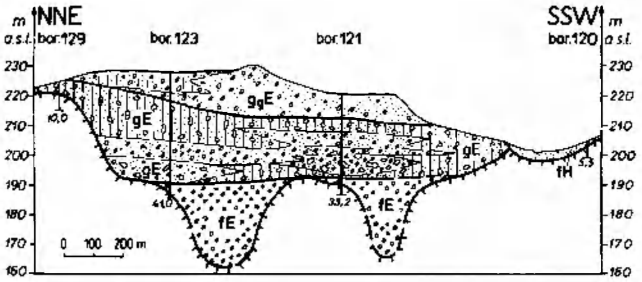

Fig. 19. Geological cross section (no 20) through the pre-Nysa Łuzycka valley near Zarska Wieś. Location in Fig. 1, explanations in Fig. 3.

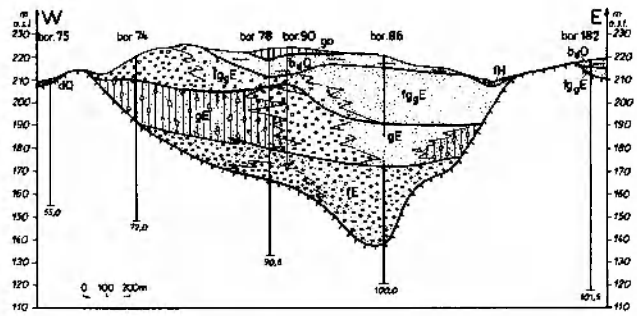

Fig. 20. Geological cross section (no 21) through the pre-Nysa Łuzycka valley near Czerwona Woda. Location in Fig. 1, explanations in Fig. 3.

Beyond the mountaineous region, near Węgliniec, the pre-Elsterian Nysa Łuzycka valley was glacially remodelled. The glacial trough, which probably contains pre-Elsterian fluvial sediments, was only documented by geophysical methods. It is a narrow trough filled with sands which occur below the lowest till in the region (Fig. 21). The base of the valley occurs about 50 m lower than at Czerwona Woda, which probably reflects displacement along the fault line separating the Sudetes from its foreland (Fig. 1, 21) (Michniewicz *et al.*, 1995). It is also possible that the trough represents a glacially re-modelled valley and/or tunnel valley, as suggested by Urbański (1996).

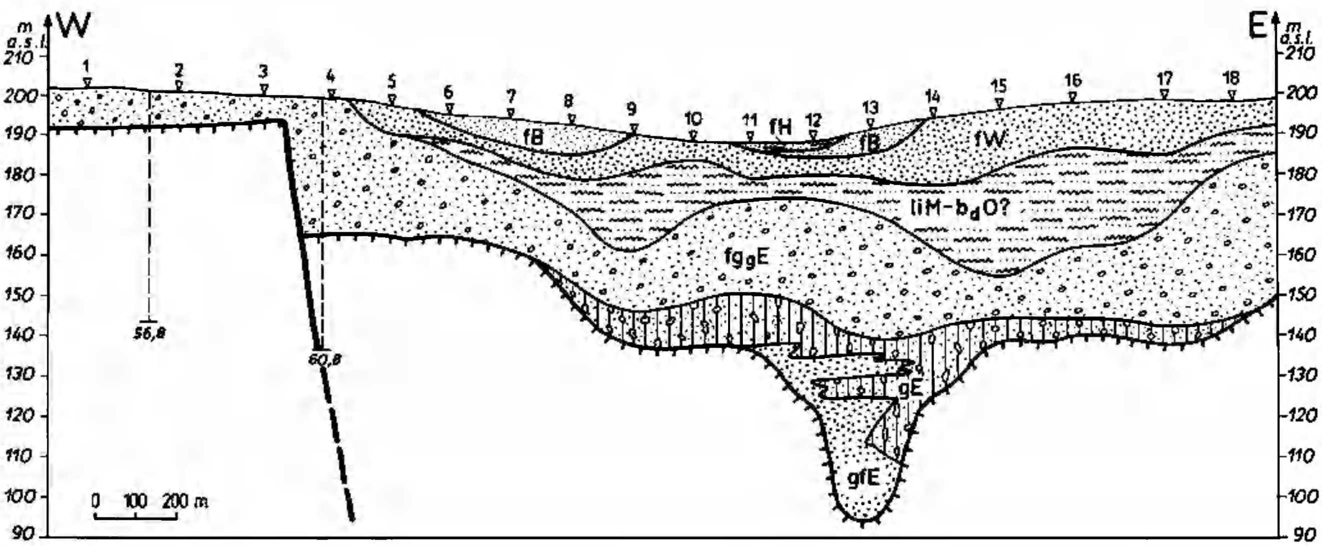

Fig. 21. Geological cross section (no 22) of the marginal zone of the western Sudetes with the remodeled pre-Nysa Łuzycka valley and glacial tunnel valley near Węgliniec Location in Fig. 1, explanations in Fig. 3.

THE PRE-WITKA VALLEY SYSTEM

Geological and geophysical investigations near Radzimów indicated the occurrence of a thick, extensive sandy-gravelly series (Berezowska & Berezowski, 1965; Mzyk, 1995). Originally, these deposits were interpreted as representing the Neogene series (Michniewicz *et al.*, 1995; Michniewicz *et al.*, 1996). However, Scandinavian material was recently found within this series in the Zawidów borehole (J. Badura & B. Przybylski, *pers. information*). The revised interpretation of the geophysical profile is presented in Fig. 22. It seems that there is a set of from 20 to 90 m deep troughs which are filled with sands or gravels. The occurrence of a till is also possible. These troughs probably represent a tunnel valley system cut into the bedrock during the Elsterian glaciation. Some shallower troughs may represent the remnants of the pre-Elsterian valley system (Fig. 22). Similar troughs were also described by Macoun & Kralik (1995) between Višňova and Frydlant, several kilometres to the south.

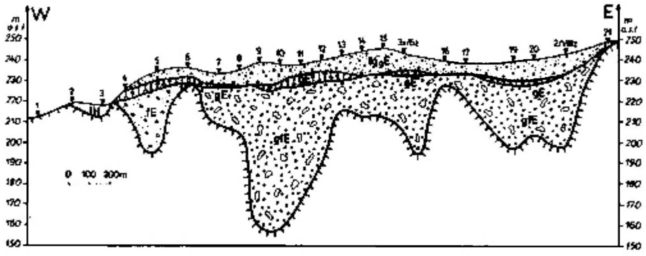

Fig. 22. Interpretation of the geological structure (section no 23) of the pre-Witka valley nad glacial tunnel valleys near Radzimów based on geophysical data. Location in Fig. 1, explanations in Fig. 3.

Geophysical research indicated that the buried valley is sinuous (Fig. 1). The pre-Witka valley trends at first to the northeast and then to the west and north, through Mikułowa and Studniska to Jerzmanki, where it joins the pre-Nysa Łużycka valley. Its geological structure is there very similar to the pre-Nysa Łuzycka valley near Ujazd (Fig. 18).

MAIN FEATURES OF THE PRE-ELSTERIAN VALLEYS AND THEIR SEDIMENTS

An analysis of the longitudinal profiles of the bottoms of the analysed buried valleys shows that they form uniform downvalley inclined surfaces that can easily be interpreted as fluvial surfaces. The only exceptions are the valley fragments beyond the mountainous region (Fig. 2). The valleys generally have four fragments, each with a different morphology and different valley fill. These are:

1. valley fragments of the high mountainous region located beyond the glaciated area; these valleys are usually narrow, with the present-day valleys often in superposition, and containing no glacial sediments between fluvial horizons.

2. valley fragments of the high mountainous region located within the glaciated area; these valleys are usually located beyond the present-day valleys or on their margins and are wider and deeper and are buried beneath a thick glacial deposit or at least separated from the younger fluvial series by glacial sediments. Almost all these valleys contain glaciolacustrine sediments, often varved clays, suggesting the occurrence of proglacial lakes in the valleys prior to the final ice sheet advance into the mountain interior.

3. valley fragments of the low mountainous region located near the margin of the Sudetes Mts; these valley fragments are much less developed, sometimes being very wide and shallow and filled with only sand and gravel, occasionally topped by a till.

4. valley fragments located in the mountain foreland (lowland area); these are valley fragments re-modelled by glacial and glaciofluvial erosion and the formation of tunnel valleys. The pre-Elsterian valleys can only locally be reconstructed. The occurrence of deep troughs near Radzimów suggests that tunnel valleys may also occur in the low mountainous region, although the structure near Zawidów is the only one which is well documented.

It seems that the position of the pre-Elsterian valley bottoms drops rapidly at the boundary between the mountainous region and its foreland (Fig. 2). The height difference is from about 30–35 m to 50 m over very short distances (Fig. 2), which may be interpreted as having formed due to faulting and the downthrow of the lowland valley fragments. The northern margin of the Western Sudetes contains a set of faults with different orientations, and this fault zone continues to the west, forming the Main Łusatian Fault Zone. Viete (1961) described very distinct features of Pleistocene faulting along this zone, and it seems, that the faults of the Western Sudetes might have been active at the same time.

The thicknesses of the glacial deposits which fill the buried valleys vary from a few metres to more than 100 m. These deposits are also lithologically variable. Besides till, the glacial series consists of glaciofluvial sand and gravel and glaciolacustrine sediments. The latter are especially lithologically variable with varved clays in some valleys, through massive clay and silts, to fine- and medium-grained sand and diamicton beds. The thickness of the glaciolacustrine sediments is also variable, from 40 m near Ciechanowice (pre-Bóbr), to 18 m near Siedlęcin (pre-Kamienna) and only 1–3 m near Gryfów Śląski (pre-Kwisa). There are no glaciolacustrine sediments in the pre-Nysa Łużycka valley. The glaciolacustrine deposits are thin or do not occur in all valleys in the marginal part of the Western Sudetes. The glaciolacustrine sediments generally occur at higher altitude in the eastern zone (369 m a.s.l. near Ciechanowice and 293 m a.s.l. nera Siedlęcin) than in the western zone (287 m a.s.l. near Gryfów and 170 m a.sł. near Jerzmanki), which directly follows the preglacial morphology. All these facts suggest that the proglacial lakes existed for a longer time in the high mountainous area which has narrow and isolated valleys, than in the low mountainous areas in the west and north. In the latter region the valleys are wider and the watersheds much lower. It seems that the Elsterian ice sheet advanced at first into the wide valleys of the pre-Nysa Łuzycka and pre-Kwisa, soon reaching its maximum position, whereas the relatively narrow and isolated valleys of the pre-Kamienna and pre-Bóbr become occupied at the same time by proglacial lakes, and were covered by ice sheet only during its last phase.

Moreover, some profiles suggest that the uppermost part of the 'pre-glacial' gravels in the mountain interior are interdigitated with glaciolacustrine sediments. At the mountain margin, the fluvial and glaciofluvial sediments are very similar to each other and they often cannnot be precisely separated. This suggests that at least the uppermost part, if not the all of the lower fluvial series was deposited in front of an advancing ice sheet, and thus is, in fact, of early Elsterian age.

MIDDLE AND LATE PLEISTOCENE CHANGES IN THE VALLEY PATTERN

The main changes in the valley pattern took place directly after the Elsterian glaciation. They are presented in Fig. 1. These are:

1. formation of the Ciechanowice gorge and piracy of the upper Bóbr to the Jelenia Góra Basin, where it joined the Kamienica and Łomnica valleys, and the formation of the gorge near Pilchowice and the shifting of the valley into its recent position,

2. formation of the new Bóbr–Kamienna valley near Sobota, which trends to the northwest, and the abandoning the former valley which trended to the northeast,

3. formation of the new valleys of the Kaczawa and Skora rivers which partly used the pre-Elsterian Bóbr valley,

4. formation of the gorge between Gryfów and Leśna and the piracy of the Kwisa river to the west,

5. formation of the new Kwisa valley near Nowogrodziec, which trends to the northwest and the abandoning of former valley which trended to the northeast,

6. formation of the new Nysa Łużycka and Witka valleys, which trend to the north and northwest and the abandoning the former valleys, which trended to the northeast and north.

It seems that all these changes were not due to tectonic activity, even if the river deflections took place near the fault lines, but that they were the result of the old valleys being buried by a thick glacial sequence. In this case, the majority of the new valleys are of epigenetic origin and they were created during deglaciation. The new valley positions are due to the primary outflow of glaciofluvial water through the tributary valleys and their subsequent incision.

The Saalian ice sheet only extended to the margin of the Western Sudetes. Only some minor changes in valley pattern can be documented for post-Saalian times; these are:

1. shifting of the Kwisa valley near Nowogrodziec to the north, to its present-day position,

2. shifting of the Skora valley near Zagrodno to the east.

Besides the changes in valley pattern, the formation of the new valleys and river piracy, there are some other important changes in the old valleys. The valley fragments which are stable and did not change their position, were deeply incised during the next stages of valley formation. Any pre-Elsterian deposits, except in the uppermost valley courses, were usually completely removed from them. Such valley fragments occur along the Bóbr river between Pilchowice and Sobota and between Mierzwin and Bolesławiec, along the Kaczawa river near Sędziszów, and along the Kwisa river near Mirsk and between Uniegoszcz and Nowogrodziec (Fig. 1).

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