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Continental glaciation of the Moravian Gate (Czech Republic)

Kontinentální zalednění v Moravské bráně

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Abstract: Vast quantities of glacial sediments, up to 100 m thick, overlie most of the Ostrava Basin and the adjacent part of the Moravian Gate and are exotic for the local geological setting. They have, therefore, attracted attention since the beginning of geological fieldworks at the end of 19th century. Since then once they were recognised as glacial sediments, controversial views concerning the extent and age of the glaciations appeared in the literature for over a century since. Because of the endless debate, which still continues, a new revision was required. This is particularly so because of the increasing building activities and other development interests in this area. The study was performed under the framework of the VaV-1D/7/05 project, which is focused on the reconstruction of the continental glaciation throughout the whole of the Czech Republic. The revision in this region was also provoked by the partly obsolete statements that are found in a specialised monograph by Macoun et al. (1965) that is 50 years old and by controversial statements in the successive studies. The paper also responds to the large exposures disclosed by extensive earthworks for the new highway construction, and to some misinterpretations of exotic sediments in the study area. Last but not least it reflects the results of the new geological mapping during 1980s carried out by the Czech Geological Survey.

In order to allow a better understanding of the Pleistocene sequences, the study area has been subdivided into four sectors. They are: 1) the NW belt, 2) the Hynčice-Hrabětice platform, 3) the northern mouth of the Poruba Gate and 4) the Poruba Gate proper.

1) The NW belt stretches parallel to the elevated margin of the Bohemian Massif where the general structure resembles that of a kame terrace. 2) The Hynčice-Hrabětice platform comprises proglacial outwash (sandur type) sandy gravel and sand overlain by till up to 10 m thick. 3) The glacial sediments forming the platform on the right bank of Odra River are aligned due S where they are about 3–4 km wide over a deepened valley and further S infill an even narrower linear depression called the northern mouth of the Poruba Gate. The 25–30 m thick Pleistocene sedimentary sequence is analogous to that at the Hynčice-Hrabětice platform from which is separated by the Luha valley. The main terrace gravel body is preserved discontinuously along the right bank of the Odra River nevertheless, enters evidently the mouth. This gravel is missing in the more elevated part of the platform. 4) The Poruba Gate linear depression and its sediments is a unique form in the study area. The Pleistocene glacial sequence, underlain by the fluvial main terrace gravel, crosses the European water-divide and enters the Black Sea drainage basin.

The sediments of the maximum continental glaciation are of Saalian age and the Poruba Gate is an only place in northern Moravia where the glacial deposits and associated meltwaters entered the Morava (Danube) River drainage basin. The main terrace is the most important link for direct correlation of mountain Alpine and North-European (Fenoscandian) glaciations and their respective stratigraphic schemes.

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Introduction

The Middle Pleistocene North-European ice sheet advanced twice into the North-Moravian Ostrava Basin i.e. during the Elsterian and Saalian stage glacials in form of a large lobe from Poland. It covered most of the basin inclusive its southern continuation, into the adjacent part of Moravian Gate, and leaving vast quantities of glacial deposits. Regionally the glacial sediments are confined to the Odra River drainage basin except in the Poruba Gate linear depression, through which they cross the European water-divide between the Baltic and the Black seas. As a consequence of some previous geological and geomorphological misinterpretations, the extent of these glaciations was previously enormously exaggerated.

The glacial sediments are exotic to local geological setting. In addition they lie at almost the same altitude (about 310 m a.s.l.) as the lowest parts of the divide between Hranice and Bělotín, what afforded an idea of the glacier traverse in this sector of the water-divide. It is not surprising, therefore, that these peculiarities have attracted attention since the beginning of the geological activities in the region. The extent and chronology have been debated for over a hundred years (Tausch 1889, Cammerlander 1891) and the discussions still continue to this day (Czudek 1973, 1997, Macoun – Králík 1995, Růžička 2004, Tyráček – Havlíček 2004, Tyráček 2007), in spite of the summaries produced by Hassinger (1914), Macoun et al. (1965), Menčík et al. (1983) and Šibrava et al. (1986), and numerous articles (Dědina

1932, Žebera 1956, 1964, Tyráček 1961a, 1963, Šibrava 1964, 1972, Macoun – Růžička 1967, Plička 1973, Macoun 1987, 1989) in the intervening time.

Both questions, however, represent the most important topics of the Quaternary geology and geomorphology in northern Moravia. Moreover, their importance for the Central Europe is strengthened since they offer the opportunity of direct correlation between the Alpine and Scandinavian glaciations as well as the Alpine and north-European stratigraphic schemes. These schemes have been used independently in Europe and further underline their significance for regional correlations.

Geology and morphology

The area discussed in this article is confined by eastern slope of the Bohemian Massif in the west and by the West Carpathians (Beskydy) foothills in the east and occupies the whole width of the Carpathian foredeep (Fig. 1). For the sake of easy orientation, the marginal part is here subdivided into four sectors that are characterised by diverse Quaternary sediments and morphology.

1. The NW belt stretches between the eastern slope of the Bohemian Massif (Nížký Jeseník upland) and the valley of the small local Vražný brook. The geology and

Fig. 1. Regional scheme of the study area.

- 1 – Bohemian Massif,
- 2 – West Carpathians,
- 3 – European water-divide.

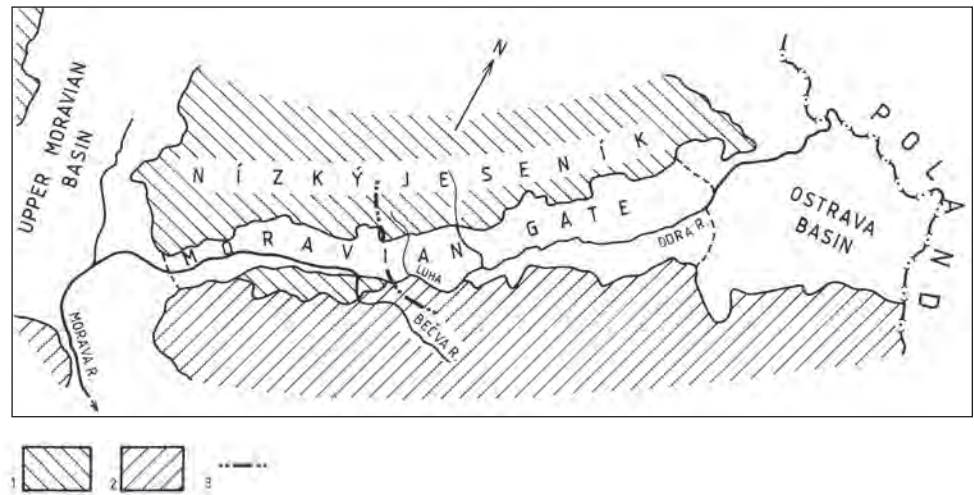
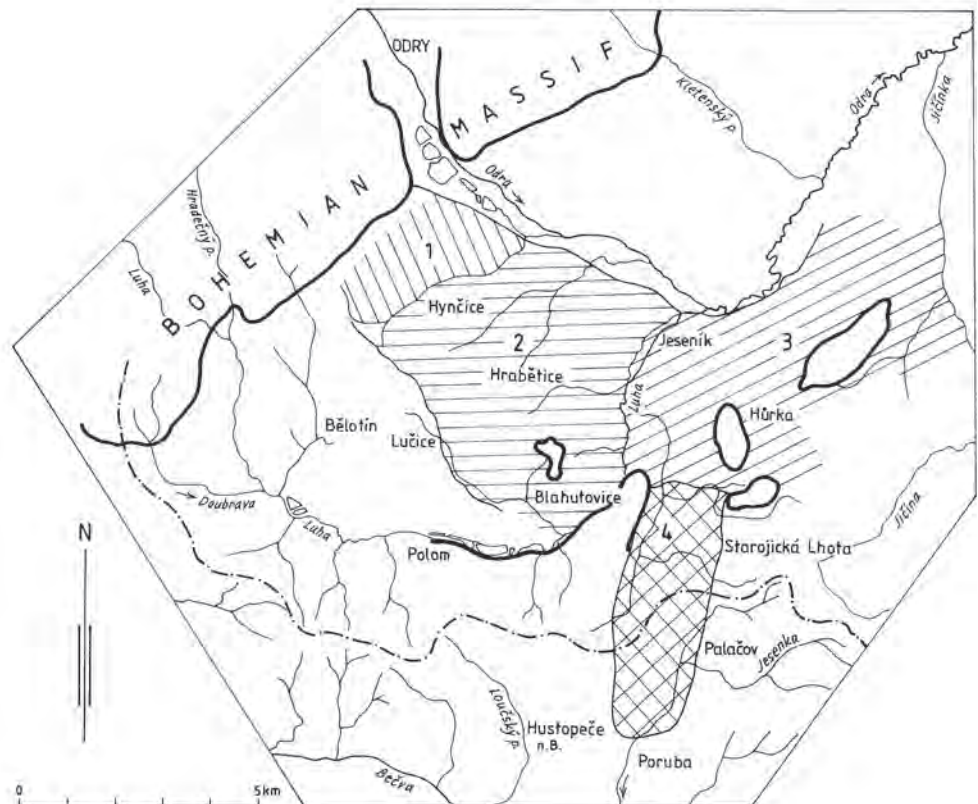


Fig. 2. Schematic map of the study area with individual sectors indicated.

- 1 – NW belt,
- 2 – Hynčice-Hrabětice platform,
- 3 – northern mouth of the Poruba Gate,
- 4 – Poruba Gate proper.



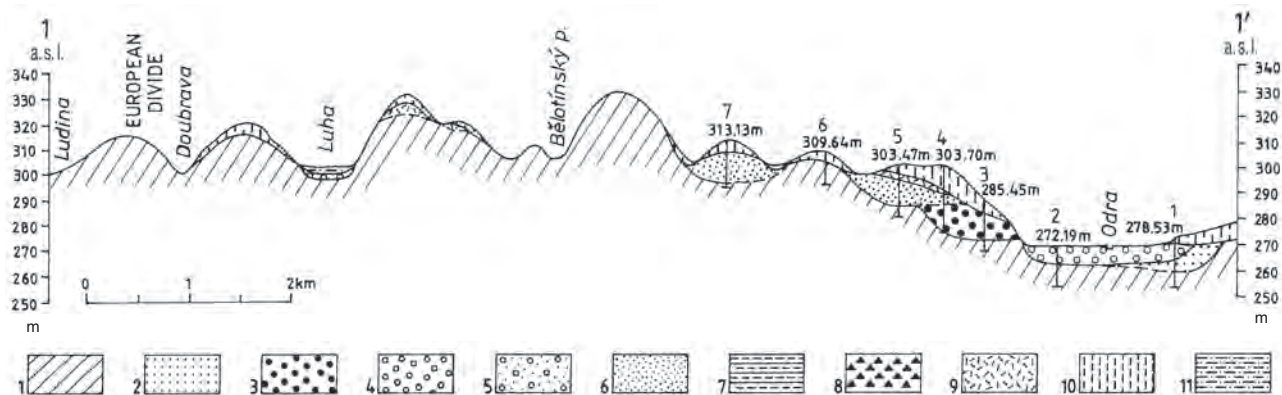


Fig. 3. Geological section 1–1'. 1 – pre-Quaternary bedrock, 2 – glaciofluvial sand (Elsterian), 3 – main terrace gravel, 4 – valley terrace gravel, 5 – sandy gravel (Saalian), 6 – glaciofluvial sand (Saalian), 7 – glaciolacustrine clay and silt (Saalian), 8 – till (Saalian), 9 – slope sediments, 10 – loess loam, 11 – overbank silt and loam (Holocene).

morphology can be seen on the Section 1–1' (Fig. 3). In particular this shows the relationship of the main terrace to both sequences of glacial sediments. The Saalian-age sand and gravel, up to 15 m thick, infills irregular shallow depressions in the Neogene (Lower Badenian) bedrock. The gravel body of the Odra River main terrace, composed of clasts of Lower Carboniferous lithologies separates the sediments of the Saalian complex from the underlying Elsterian-age sand, the latter preserved in an over-deepened depression. The relatively well-levelled surface in the north-eastern part of the section may be interpreted as a kame terrace formed by meltwaters flowing along the ice margin parallel to the tectonic contact of the Carboniferous (eastern slope of the Bohemian Massif) and the Neogene of the Carpathian foredeep. No tills have been observed and the surface glacial sediments are assigned to the undivided Older Saalian (Drenthe) substage complex.

Contrary to that, the remaining south-western part of the section shows a normal erosion relief neither affected by the glaciation nor by its meltwaters. With respect to the distance and the existence of several intervening valleys draining waters via Luha valley along the ice-sheet front into the Poruba Gate and evidently through crevasses and fissures in the ice or underneath the upslope advancing glacier back into the Odra (Baltic) drainage basin, it can be concluded that neither the glacier nor its meltwaters crossed the European water-divide in this sector. This conclusion conforms the results of geological mapping by Tausch (1889), Cammerlander (1891), Tyráček (1961a, 1963), Dvořák et al. (1971) contrary to the morphology-based interpretations of Hassinger (1914), Dědina (1932) and Plička (1973).

2. The Quaternary sediments that form the Hynčice-Hrabětice (H-H) platform are up to 30 m thick and occur between the valleys of Vražný brook and Luha. The platform itself is a plateau inclined gently from SW to NE, which descends from 318 to 285 m a.s.l. The plateau was previously interpreted by geomorphologists

(Hassinger 1914, Zapletal 1929, Dědina 1932) as a 40 m terrace irrespective of its different inner geological structure. The Quaternary sequence begins with proglacial (sandur type) sand and gravel overlain by a more or less continuous stratum of till. The glacial drift is mantled by decalcified loess (Ostrava loess loam) up to 10 m thick. The Neogene bedrock produces gently rolling relief that is reflected particularly by irregular thicknesses of glacial deposits. The sand and gravel reaches up to 15–20 m in thickness in depressions, whereas it thins or even cuts out in elevations. These proglacial outwash sediments of the advance phase are represented by sand, sandy gravel and partly even coarse clast-supported gravel. The deposition is irregular and shows numerous facies transitions, which indicate changing meltwater outflow dynamics. The gravel lithology is dominated by Carpathian sandstone. Carboniferous greywacke, sandstone, shale and vein quartz are also well represented. Pebble of Scandinavian origin are rare, nevertheless, they are found occasionally and support the evidence of northerly provenance. Existence of smaller proglacial water bodies is indicated by lacustrine clay or varved units, which occur at diverse altitudes (compare sections 2–2' and 2a–2b). This distribution, therefore, disproves the former concept of a large single proglacial ice-dammed lake (Žebera 1956) flooding the whole basin.

The unusual thickness (in places over 10 m in thickness) of till (Vašíčková 1964, Mudrák 1989) can be explained by the merging of all three possible till facies (subglacial, englacial and supraglacial) deposited during the regional decay of the stagnant ice. The single flysch Blahutovice hill (331 m) protrudes above the platform. Nevertheless, even this elevation was probably overridden by the ice during the glaciation. The ice sheet halted far from the water-divide and no traces of its having crossed this barrier have been identified in this sector.

Footnote: Detailed dating of the glaciation is a delicate problem, especially on this platform if the main terrace gravel within the Odra valley is absent in this area. The Saalian age of the

maximum glaciation was never doubted since 1960s (Macoun et al. 1965). Contrary to this conclusion the detailed stratigraphy (Macoun 1989, Růžička 2004) was never universally accepted. This is because the study area is an inseparable part of the marginal oscillation zone that is characterised elsewhere by the possible frequent short-lived retreats and readvances of the ice front. This feature may be compared to the much younger, but better – known and more precise dated retreats and readvances (in tens of kilometres scale) of Younger Dryas ice front at Salpausselkä in Finland or Ra moraines in Norway. Several till intercalations in the sedimentary sequences lacking separation by a palaeontologically substantiated warm climate events may not necessarily provide evidence of separate ice ages of glacial or stadial rank. The lack of exposures or new boreholes prevents the confirmation of Macoun's (1989) detailed stratigraphy in this study. Owing to this lack of evidence, all glacial deposits, except for the Elsterian sediments in deep depressions at the base of Quaternary sequence are, therefore, assigned to the undivided Saalian complex, which is sufficient for the project requirements. Here the maximum glaciation and all its sediments are correlated with the older Saalian substage (Drenthe, Odranian, Palhanec). The younger Saalian glaciation (Warthe, Wartanian substage) stopped in Poland and did not reach the Czech Republic.

3. The platform on the right bank of the Odra River between Jeseník nad Odrou and Bernartice represents a direct geological and morphological continuation of the previous Hynčice-Hrabětice platform. These glacial sediments are again of the outwash proglacial type and of similar petrology. The till stratum that overlies the glaciofluvial deposits is only preserved in places. Gravel of the main terrace confined mostly to the linear depression is 6–8 m thick, but is not developed in higher parts of the platform. In the coarser gravelly marginal parts of the glaciofluvial outwash spread the diverse types of the Carpathian sandstone are dominant, the Scandinavian lithologies are more abundant.

The main terrace, which can be traced along the right bank of the Odra River from its outlet from the Bohemian Massif across the Carpathian foredeep, as far as the northern mouth of the Poruba Gate, represents a uniform gravel body. The Odra course was diverted during its aggradation into the gate by the advancing Saalian ice sheet. The terrace deposits, therefore, have been interpreted as the upper (anaglacial) accumulation of the double main terrace (Tyráček in Macoun et al. 1965). There is no indication of the existence of more accumulations within the terrace gravel body postulated by Macoun (1989). The lower accumulation in this part of the valley is typically developed further downstream.

Continuing further south the platform narrows and enters a sector called the northern mouth of the Poruba Gate. Because of some differences in the geology of Quaternary deposits, and the surface and bedrock morphology the area was subdivided into three segments.

In the northern segment (N of the Hůrka–Jeseník road) the platform narrows to some 3–4 km between the

Panský kopec hill (363 m) and the Luha valley. The glacial sediments directly overlie the flysch bedrock in the higher cotas and again consist of the proglacial outwash sand and sandy gravel-type. Tills are usually absent. The main terrace gravel is not easily separated from the coarser glaciofluvial sediments, which are insufficiently defined in the older borehole logs. Nevertheless, there is no doubt about its existence in this area. The maximum thickness of the Quaternary deposits, inclusive of a 10 m thick loess loam, may reach 35 m in total. The bedrock again shows a gently rolling relief, resembling that of the Hynčice-Hrabětice platform (cf. above).

In contrast to the northern segment, the middle area differs in relief and structure of Quaternary sediments. The flysch bedrock shows a considerably higher relief with conspicuous uplands including Hůrka (389 m), Panský kopec (368 m) and Stříbrnice (355 m) and still higher elevations (exceeding 400 m) in the West Carpathian foreland confining the basin. Here the glacial drift fills an elongated depression, which has the form of a wide shallow U-shaped valley in cross section. In the glaciofluvial sediments (up to 30 m thick) fine- to coarse-grained sand with irregular sandy gravel layers predominates. Laterally to both valley margins the sand passes into the gravel (compare section 4–4'). The basal gravel, which reaches a maximum thickness of 10 m correlates with the main terrace. In the W part of the section, the till intercalations have been found in some boreholes (Figs 5 and 6).

In the southernmost part the main terrace gravel is overlain by a more or less uniform sand complex of the sandur type about 20 m thick, which is capped by a till in places. The cross-section 5–5' again shows an even clearer U-shaped form. The linear depression of the Poruba Gate begins in the vicinity of Starojická Lhota and continues across the continental European water-divide as far as the Bečva valley.

4. The term Poruba Gate was introduced into the literature by V. Dědina (1932) for an elongated linear depression that connects the Odra River valley to that of the river Bečva. Originally it was defined as a surface topographic feature without any knowledge about its depth and unusual sedimentary filling. The article was published prior the appearance of the geological map of the Ostrava Basin by Beck and Göttinger (1932) and, therefore, it did not record the glaciofluvial sediments, which had been identified there. The over-deepened character of this depression, however, was recognised and the sediments defined some 30 years later by Tyráček (1961a, 1963).

The sedimentary sequence has a regular structure, and individual beds can be traced throughout the whole Poruba Gate depression. The basal gravel is overlain by clay and silt. The uppermost part of the glacial sequence is composed of glaciofluvial sand, which typically includes irregular pebbly or gravely interlayers. The top is represented by decalcified aeolian loam.

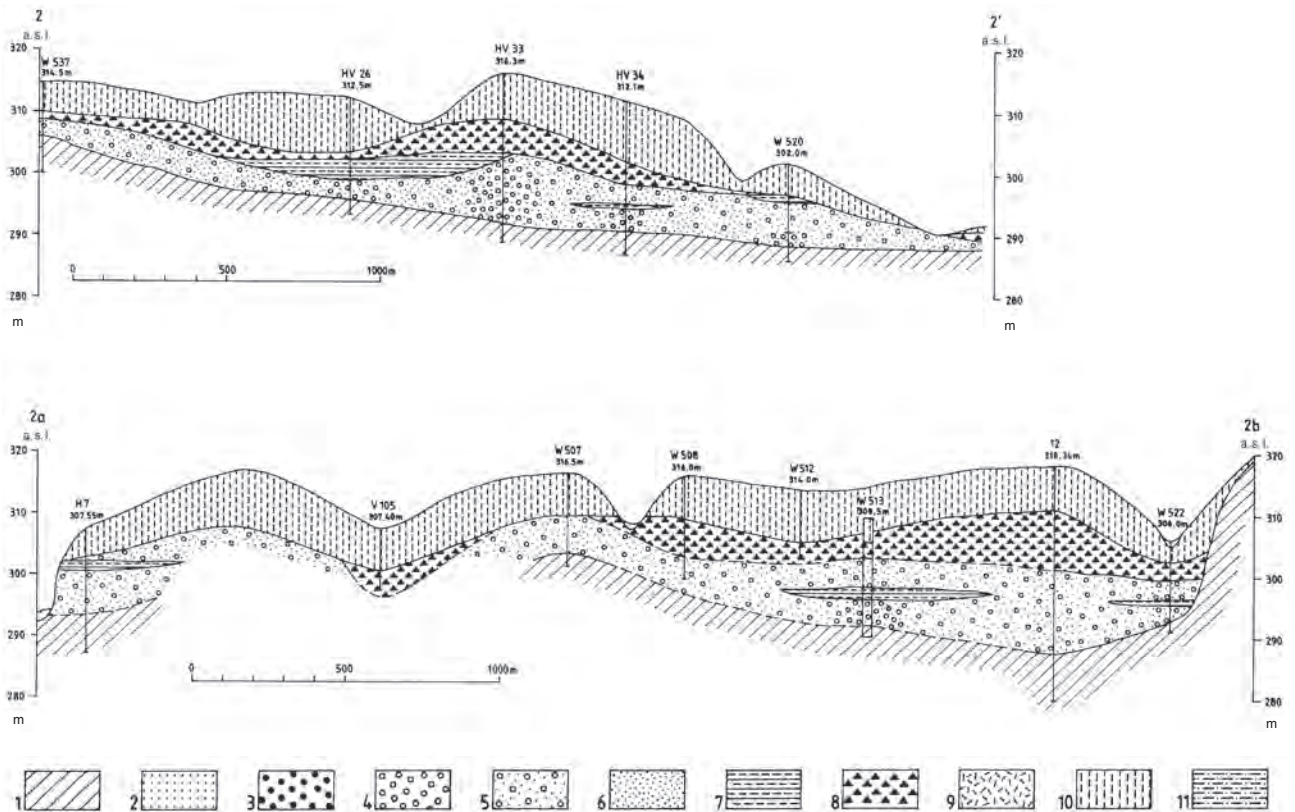


Fig. 4. Sections 2–2', 2a–2b. 1 – pre-Quaternary bedrock, 2 – glaciofluvial sand (Elsterian), 3 – main terrace gravel, 4 – valley terrace gravel, 5 – sandy gravel (Saalian), 6 – glaciofluvial sand (Saalian), 7 – glaciolacustrine clay and silt (Saalian), 8 – till (Saalian), 9 – slope sediments, 10 – loess loam, 11 – overbank silt and loam (Holocene).

- a) The basal fluvial gravel, up to 15 m thick in deepest parts of the valley, forms a continuous stratum that connects both the Odra and Bečva valleys. The gravel is composed of various types of Carpathian sandstones accompanied by Carboniferous lithologies (sandstone, greywacke, shale and vein quartz). The Scandinavian rocks, mostly redeposited from Elsterian glaciofluvial deposits are less frequent, but still provide sufficient evidence to support a post-Elsterian age for these sediments. The gravel body is nowhere exposed but has been identified only in borehole cores. The sedimentary structures and associated architectonic elements are, therefore, obscure at present. Throughout almost all of its extent the gravel body is overlain by younger sediments except in its southernmost part where it, being exhumed, forms a striking 12–15 m Bečva terrace (base about +3 m). In the Odra valley it is still buried beneath the Saalian sediments and the gravel occurs only in the terrace bluff. The change of the valley shape or more accurately the valley bottom morphology is more interesting. Contrary to the U-shape present in the North (compare sections 4 and 5), the gravel base in the Poruba Gate (sections 6 to 8) is relatively rather level and its form resembles the typical base form of a normal fluvial aggradation terrace.
- b) The overlying silt and clay bed again reaches a maximum thickness of 15 m. The lower part of the bed is usually represented by a grey to dark grey calcareous clay, the upper part of which is more silty and lighter in colour. The lower clay is usually laminated or even varved in places, whereas the upper silt is more homogenous. This bed represents sedimentation in stagnant or slowly flowing water.
- c) The glacial sequence is completed by a 10–12 m thick sand with irregular pebbly to gravelly interlayers. The sand is fine- to coarse-grained and of typical proglacial outwash type. The petrological analyses confirm a considerably stronger frequency of Scandinavian rocks.
- d) The surface loess loam up to 10 m thick overlies the underlying Quaternary strata and sometimes extends beyond its limits and rests directly on the bedrock. The total thickness of the Quaternary sediments in the Poruba Gate may reach 30 m.

Survey of conflicting misinterpretations

Since field investigations begun in Moravia diverse deposits have been observed, which did not match the geology of the study area. These sediments have been

interpreted in different ways, which, nevertheless, reflected the stage of knowledge at that time. Irrespective of this the final solution of the glaciation of the Ostrava region, proposed in the monograph by Macoun et al. (1965) based on detailed geological mapping 1 : 25 000, diverse modifications have been advanced periodically ever since. Some of these proposed were first offered

decades ago and have been repeated in original wording without appropriate verification. Other appeared more recently being based on new exposures or field observations of exotic sediments, sometimes erroneously interpreted. All these occurrences discussed are located close to the watershed and, therefore, the correct interpretation is of vital importance.

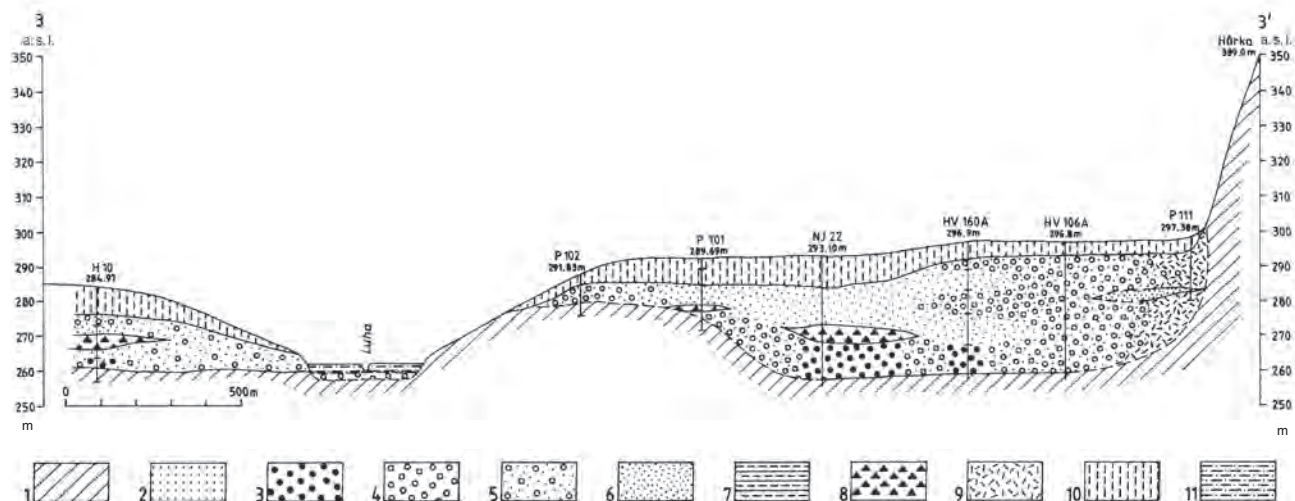


Fig. 5. Geological section 3-3'. 1 - pre-Quaternary bedrock, 2 - glaciofluvial sand (Elsterian), 3 - main terrace gravel, 4 - valley terrace gravel, 5 - sandy gravel (Saalian), 6 - glaciofluvial sand (Saalian), 7 - glaciolacustrine clay and silt (Saalian), 8 - till (Saalian), 9 - slope sediments, 10 - loess loam, 11 - overbank silt and loam (Holocene).

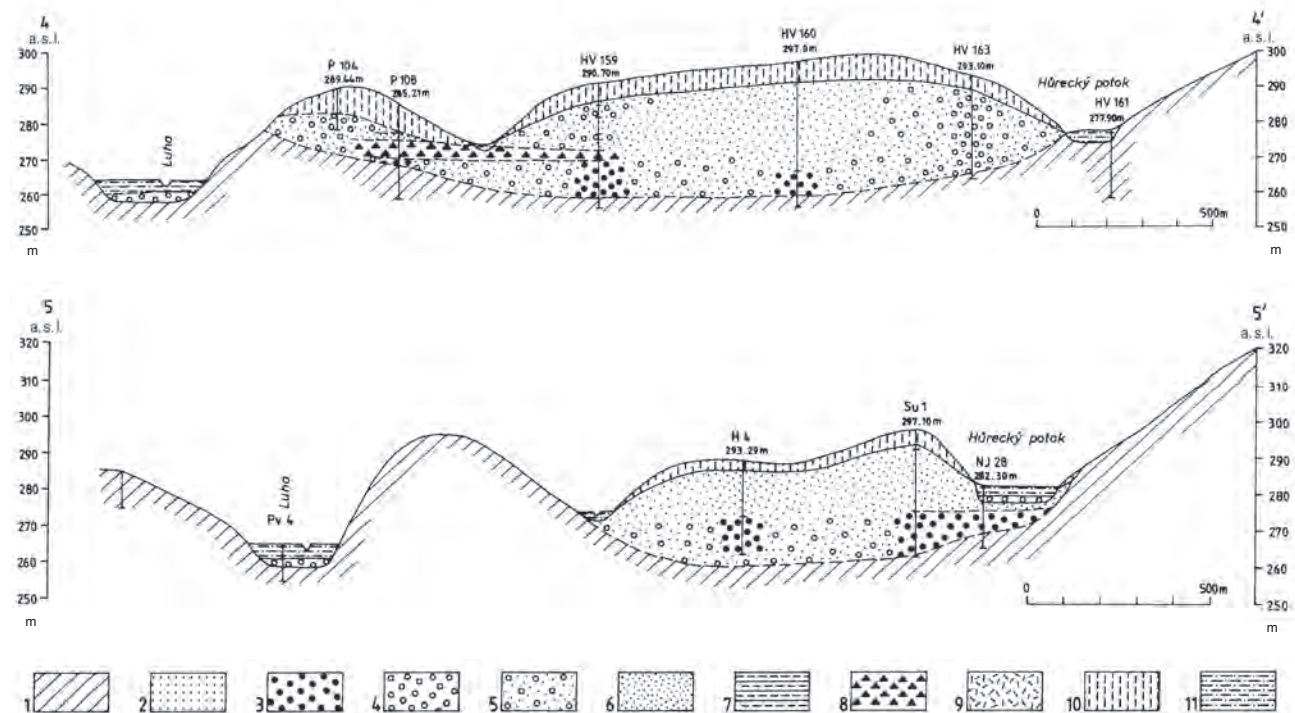


Fig. 6. Geological section 4-4', 5-5'. 1 - pre-Quaternary bedrock, 2 - glaciofluvial sand (Elsterian), 3 - main terrace gravel, 4 - valley terrace gravel, 5 - sandy gravel (Saalian), 6 - glaciofluvial sand (Saalian), 7 - glaciolacustrine clay and silt (Saalian), 8 - till (Saalian), 9 - slope sediments, 10 - loess loam, 11 - overbank silt and loam (Holocene).

I have divided the study area into two sectors for easier orientation. The Hranice-Běloutín sector comprises the part between the eastern slope of the Bohemian Massif and the foreland of West Carpathians, i.e. practically the whole width of the Neogene foredeep. The Bečva sector includes the Carpathian section of the water-divide within the West-Carpathian flysch foreland.

The Hranice-Běloutín sector

a) The thinly bedded, rhythmically alternating and occasionally folded sand and clay beds, exposed in the railway cutting near Běloutín have been interpreted as varved clay (Cammerlander 1891, Hassinger 1914). However, they are, in fact, decalcified Lower Badenian marine sediments. The more sandy overlying

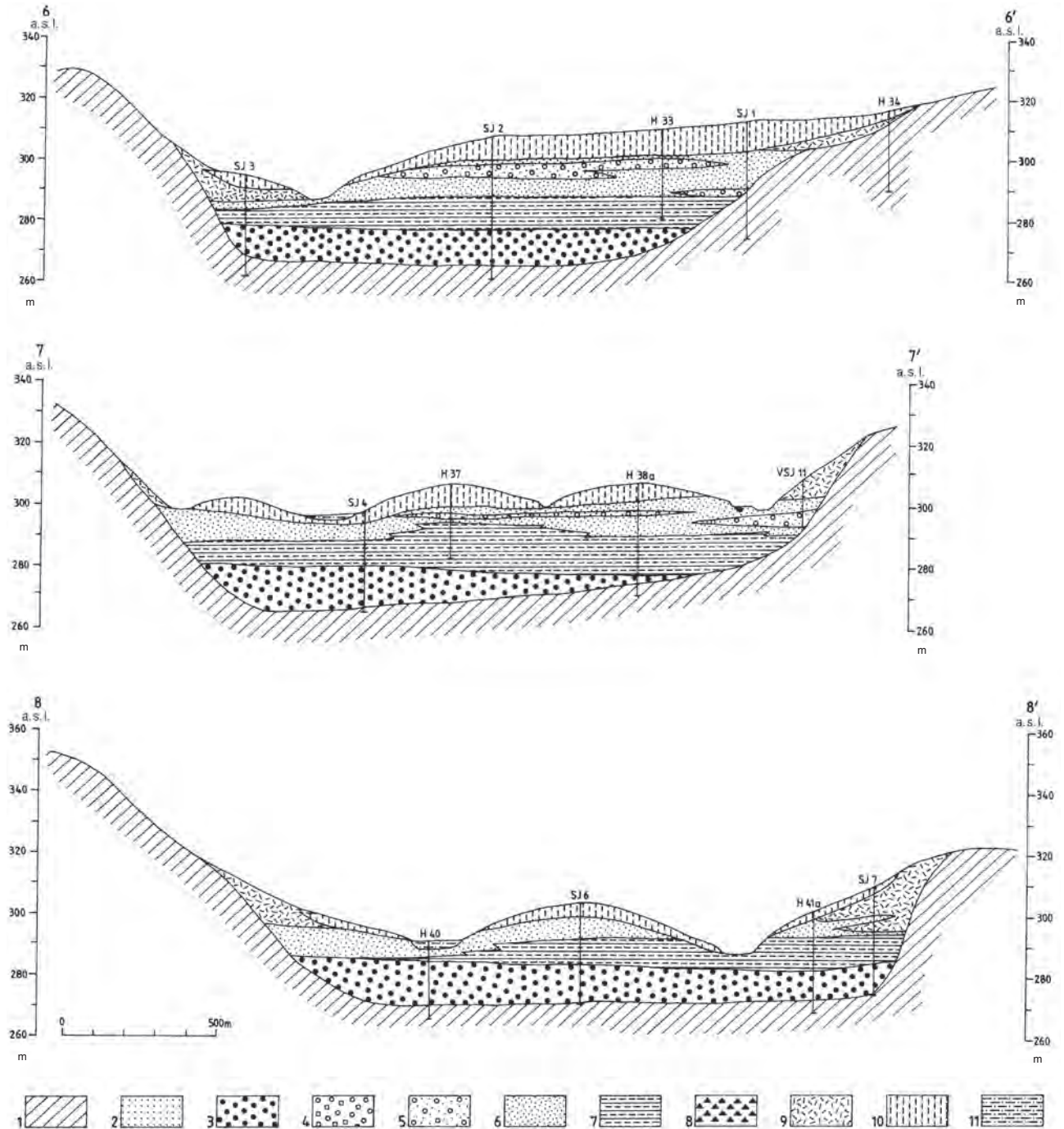


Fig. 7. Geological section 6-6', 7-7', 8-8' (according to Tyráček in Macoun et al. 1965). 1 – pre-Quaternary bedrock, 2 – glaciofluvial sand (Elsterian), 3 – main terrace gravel, 4 – valley terrace gravel, 5 – sandy gravel (Saalian), 6 – glaciofluvial sand (Saalian), 7 – glaciolacustrine clay and silt (Saalian), 8 – till (Saalian), 9 – slope sediments, 10 – loess loam, 11 – overbank silt and loam (Holocene).

deposits, which occur in other places equate most probably to the freshwater sediments of the Pliocene Malhotice formation (Otava et al. 1991, 2008).

- b) Sandy hillocks on the watershed north of Lučice, interpreted like glacial (sedimentary?) landforms by Hassinger (1914) are denudation relics of partly marine Neogene and probably partly of Pliocene deposits above. Since no contact has been found between both formations, their differentiation in old borehole logs is difficult because of their similar lithology and conformable stratification.
- c) The sand over 10 m thick with occasional clay intercalations and scattered gravel occurring east of Běloutín and in the vicinity of Lučice village which has been erroneously regarded as the regression littoral facies of marine Lower Badenian sediments by Tyráček (1961) coincides with the Pliocene deposits mentioned above.
- d) The 3–4 m thick sand with scattered gravel exposed in a new road cutting near the water-divide monument has been interpreted as a glaciofluvial deposit and dated, based on its altitude to the Elsterian stage glaciation (Czudek 1973) and assumed in the summarizing studies by Macoun and Králík (1995), Czudek (1997) and Růžička (2004). Besides various types of Carpathian sandstones the gravel contains the amphibole gneiss, biotite-muscovite granite and two-mica granodiorite (Czudek 1997), and also includes limestone clasts, which are generally very rare in typical glaciofluvial sediments. Such petrology need not be of undoubted Scandinavian provenance. On the basis of present-day interpretation (Otava et al. 2008, Tyráček this volume), the sand represents the uppermost part of an over 20 m thick freshwater Pliocene sequence whilst the crystalline rocks present known from other localities outside the watershed are exotic elements derived from flysch conglomerates.

The Bečva valley sector

- e) Isolated occurrences of gravel containing exotic rocks at the water-divide near Loučky and Špičky villages have been mistaken for relics of local moraines by Hassinger (1914) and by Beck and Götzinger (1932) are the weathering residues of Palaeogene flysch conglomerates (Tyráček 1961a).
- f) The sand accumulations on flat summits of the watershed hills along the road Heřmanice-Loučky-Špičky-Hluzov on the right bank of Bečva River regarded by Hassinger (1914) as glaciofluvial, are deposits of the uppermost parts of the freshwater Pliocene (cf. geological maps by Plička et al. 1972 and Otava et al. 2004, 2008).

Introduction of a new formation

The main source of the misunderstandings, doubts and contradictions are the newly defined freshwater sedi-

ments preserved in the form of denuded relics in both sectors of the water-divide. It is reasonable to support previous authors interpretations and to admit that they correctly identified the occurrence of some questionable deposits, which were exotic to local geological setting. These diverse interpretations, however, represent a typical image of the historical development of geological knowledge in general.

The establishment of the new formation for the marine Badenian was difficult in the Hranice-Běloutín sector, because of its conformable stratification and in part because of its similar lithology (rhythmic alternation of claystones and siltstones with sand interlayers). Moreover some redepositions of the unconsolidated bedrock at the base of Pliocene and mixing the Miocene material with the Pliocene can be expected, that make the location of the contact uncertain. It may also explain the admixture of a contained Palaeogene microfauna. The subsequent geological investigations in the Bečva sector made the differentiation possible. Here it was achieved thanks to the recognition of a sharp unconformable contact between the folded Palaeogene flysch and the overlying freshwater Pliocene deposits. A new informal Malhotice formation was, therefore, introduced by Otava et al. (2008) in the area.

According to the original definition, this formation is composed of three members at the type locality near the Malhotice village. The lower member is composed of the laminated micaceous sand with occasional 20–30 cm thick calcareous sandstone interbeds. Ample admixture of quartz gravel appears in places. Large claystone and siltstone balls and lenses are typical of this member. The member is supposed to be of lacustrine origin, though no palaeontological evidence is at hand. Its thickness reaches over 10 m. The middle member is built up by rhythmic alternation of violet brown and greyish-green claystone and siltstone beds with occasional fine-grained sandstone interlayers. These sediments are, likewise the previous member, typically of lacustrine origin and have been deposited in a deeper and more stagnant water. Thickness is irregular as the upper part was eroded and dissected by up to several metres deep channels and scours. Nevertheless, the original thickness can be estimated to some 10 m minimum. The youngest upper member forms irregular gravel and sand bodies and mostly represents fluvial channel sediments. The contact with the lower member is irregular and results from erosion. The gravel is typically polymict and contains besides local rocks other lithologies including gneisses, granitoids, volcanites, mylonites, limestones, breccias and marlstones. In addition, redeposited limonite and calcareous concretions and calcareous sandstones and calcarenites occur. Practically all these rock types were probably derived from Outer Carpathian nappes (Otava et al. 2008).

A Neogene non-marine sedimentary sequence about 7 m thick was exposed in a new road cutting west of Běloutín and recorded by Gába et al. (2007). The lower

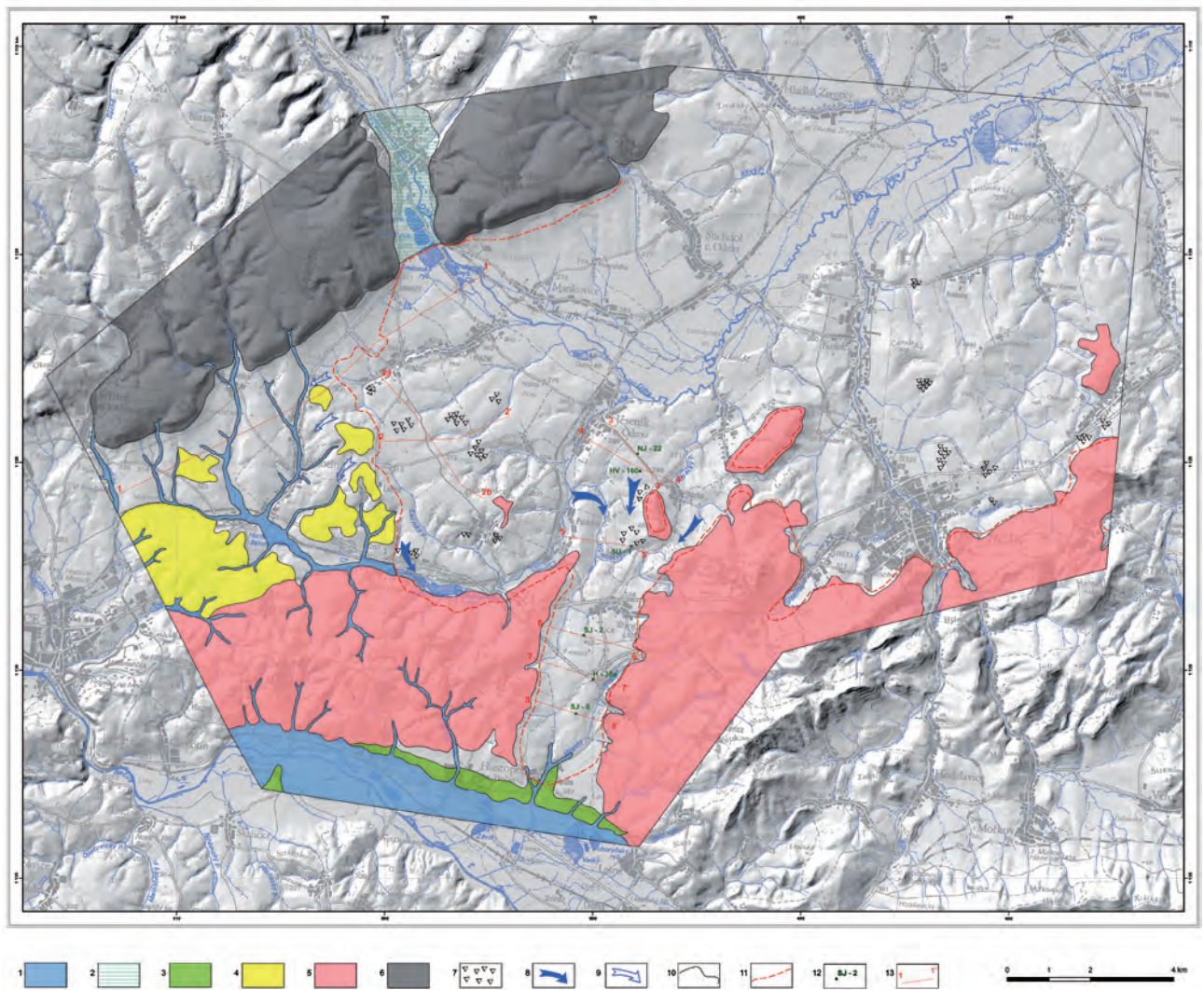


Fig. 8. Palaeogeographic reconstruction of the continental glaciation in the Moravian Gate. 1 – Holocene floodplains, 2 – ice dammed lake in the Odry Basin, 3 – main terrace, 4 – Neogene of the Carpathian foredeep, 5 – West Carpathian flysch, 6 – Lower Carboniferous of the Bohemian Massif, 7 – till, 8 – direction of the meltwater drainage – proved, 9 – theoretically possible meltwater drainage – unproved, 10 – geological boundary, 11 – maximum limits of the continental glaciation sediments, 12 – key borehole, 13 – geological sections.

part is built up of an alternation of brownish-grey claystone (thickness of individual layers 2–10 cm) and yellowish-brown fine- to medium-grained sandstone (thickness 5–20 cm). The coarser fraction is mostly well-rounded clasts composed of chert (68.2%), sandstone (28.4%) and quartz (3.4%). In addition, a sole granite pebble was found at the surface near by Gába et al. (2007). The cherts represent the classical menilite type derived from the local Palaeogene, whilst the sandstones are derived from the West Carpathian Cretaceous and Palaeogene nappes. No typical Scandinavian rocks were identified. Relatively frequent subangular limestone clasts of the Hranice Devonian type, which appear within the topsoil at the surface, are not mentioned in the article. The sediments correlate with those of the Malhotice formation, though they were interpreted as marine Miocene.

In fact the formation is much thicker and extends along another road as far as Běloutín village, where it is over 20 m thick. In my opinion (Tyráček this volume) it represents a different facies of the newly recognised Malhotice formation (Otava et al 2008). The occurrence, geology and regional distribution of the Pliocene deposits in the Hranice-Běloutín sector should, therefore, be revised.

Conclusions

1. The glacial deposits representing the maximum Pleistocene glaciation in the Moravian Gate are confined to the Odra River drainage basin and are of older Saalian (Drenthe, Odranian, Palhanec) substage age.

2. The only exception is the glaciolacustrine and glaciofluvial sediment in the Poruba Gate that crosses, and includes the main terrace gravel body, the European water-divide and enters the Black Sea drainage basin.
3. The glaciated part of the Moravian Gate drained through the Poruba Gate at the level of 15 m (main) terrace.
4. The origin and age of the U-shaped northern part of the Poruba Gate is still open to debate.
5. The Elsterian glacier, which also halted in the Odra River drainage basin had a smaller regional extent and did not cross the main water-divide either. No traces of waters having drained via Moravian Gate during those times have been identified.
6. All the questionable sand and gravel occurrences, beyond the limits of the maximum glaciation are either weathered pre-Quaternary rocks or freshwater Pliocene deposits.
7. The main terrace, which can be traced from the upper course of the Bečva River as far as the Danube valley represents an important and the only index (marker) horizon for correlation both of the Alpine and the Scandinavian glaciations as well as both stratigraphical schemes.

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