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The glaciofluvial terrace in the Moravian Gate (Czech Republic)

Glacifluviální terasa v Moravské bráně

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Abstract: The sediments exotic to local geological setting that occur close to the European water-divide in the Moravian Gate have been primarily interpreted as glacial since the end of the 19th century. Because the Scandinavian ice sheet advanced twice into the Moravian Gate, the age of its maximum extent, level and direction of the meltwater drainage were the most important topics. The term glaciofluvial terrace, introduced into the literature by Hassinger (1914) is intimately linked with the maximum glaciation, which is here dated to the Elsterian Stage glacial. In fact, however, the Elsterian glacier halted far from the divide and no traces of its having crossed this barrier have been identified. Nor has the drainage via the Moravian Gate during the Elsterian times been confirmed. Two gravel occurrences at Nad dolama and Horecko about 70–80 m above the Bečva River have been proposed as the representatives of the glaciofluvial terrace. They are composed of local lithologies derived from the Nízký Jeseník upland. No exotic rocks have been identified in these sediments not even those from the flysch conglomerates, which occur in the upper Carpathian part of the Bečva River course. The Bečva River probably did not participate in the deposition of these highest gravels. Not even the largest older Saalian (Drenthe, Odranian, Palhanec) glacier, which was confined to the Odra drainage area, crossed the divide. The meltwaters from the latter drained via the Poruba Gate at the level of the main (12–15 m) terrace. The gravel and sand accumulation at the water-divide correlates with the informal freshwater Malhotice formation, which is of Pliocene age.

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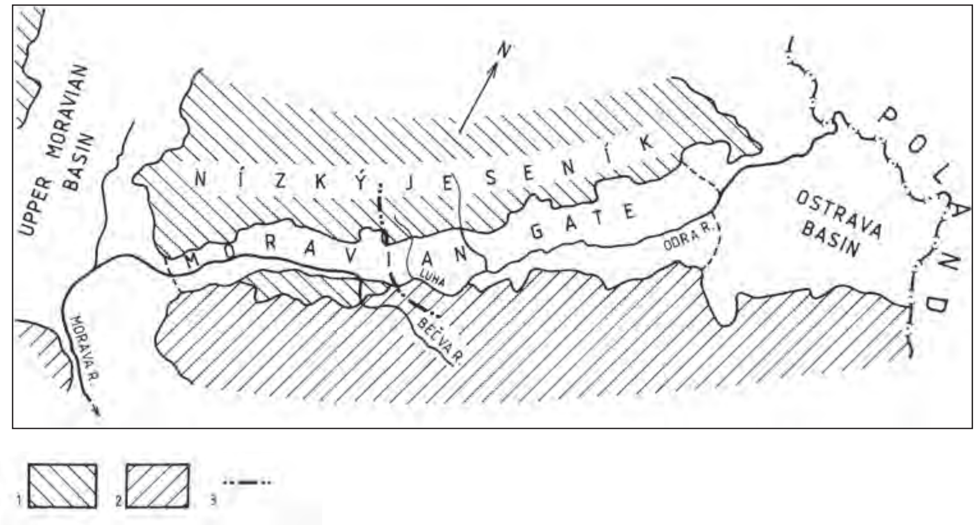
Background and rationale

The understanding of the Quaternary sediments and the Upper Cenozoic morphological development in the Ostrava Basin and the Moravian Gate are of vital importance not only for northern Moravia but equally for Central Europe. The Moravian Gate is, besides the Rhine valley, the only place in Europe where the direct correlation of both Alpine and Scandinavian glaciations and their associated stratigraphical schemes can theoretically be compared. The crossing of the Baltic-Black Sea drainage water-divide either by glaciers or by their associated meltwaters should create a marker level, which, if any, could be traced along the Moravian rivers as far as the river Danube valley. That is why the watershed itself, and in particular the denudation relics of the sediments exotic to the local geological setting in this area have attracted attention since the beginning of geological activities at the end of 19th century (Tausch 1889, Cammerlander 1891). Controversial views concerning the age and origin of those sediments have appeared in the literature for over a century since. Since their original interpretation as glacial deposits (Hassinger 1911, 1914), subsequent questions like the maximum extent of the Scandinavian ice sheet, its age and impact on the Danube (Black Sea) drainage area have been posed. The idea of a glacial origin for the non-marine sediments in the watershed region persisted throughout the first half of the 20th century (Zapletal 1929, Dědina 1932, Mohr 1943) and reapeared again in the latter part (Czudek 1973, 1997, Macoun – Králík 1995).

The glaciofluvial terrace, introduced into the literature by Hassinger (1914) is intimately linked to the problem of the maximum extent of the continental glaciation in the Moravian Gate. Advocating the glacier presence at the water-divide, Hassinger was forced to look for adequate paths, levels and directions of the meltwaters discharge. When interpreting the sediments on the watershed saddle at the altitude of 300–320 m a.s.l. as a glaciofluvial accumulation, he was easy able to correlate this level with the gravel occurrences at Nad dolama (318 m) and Horecko (295 m) that occur on the downstream Black Sea side of the watershed in the Bečva area of the Moravian Gate. Subsequently by applying the Bečva River gradient (1.1–0.9‰) to the supposed meltwater stream (1.0‰) some other corresponding levels were found wherever the Neogene ridges (even though they lacked gravel spread) seemed to be logical morphological indicators of the terrace. These he traced on the right bank of the river as far as the Upper Moravian Basin (cf. list of Hassinger's localities and the map; Fig. 3).

Fig. 1. Regional scheme of the study area. 1 – Bohemian Massif, 2 – West Carpathians, 3 – European water-divide.



The glacial sediments and the corresponding glaciofluvial terrace were dated, based on their altitude (70–80 m above the Bečva River), to the Elsterian Stage glaciation (Hassinger 1914). This dating was generally accepted practically all over the Europe and applied in the Quaternary stratigraphy for many decades. This interpretation was also used in Czechia until the detailed geological survey carried out by the Quaternary department of the Czech Geological Survey during 1950s and 60s. The results were summarized in a monograph by Macoun et al. (1965), in which two glaciations Elsterian and Saalian of nearly the same regional extent were identified. The dating is based on the Stonava peat bog, the only genuine interglacial sediment (Holsteinian – Vodičková-Kneblová in Macoun et al. 1965), interbedded between the underlying Elsterian glaciofluvial and the overlying Saalian glacial deposits. In addition the index horizon of the main terrace gravel separating both glaciations preserved in most valleys in the Ostrava Basin and in the Bečva valley as well (Tyráček in Macoun et al. 1965) assisted much in identification of individual glacial stages represented by unfossiliferous sediments of similar lithology. The maximum glaciation was dated to the older Saalian substage (Drenthe, Odranian, Palhanec), taking also into account the morphostratigraphical position of the glacial sediments in the Poruba Gate. The Elsterian glacier did not cross the European water-divide. Or at least no traces of its having crossed it have been identified in the Bečva part of the Moravian Gate. The maximum glaciation was ranked within the European stratigraphy under the IGCP project 73/1/24 – Quaternary Glaciations in the Northern Hemisphere (Šibrava et al. 1986).

Footnote. The exposure of exotic-bearing gravel and sand exposed in a new road cutting near the water-divide monument re-opened the question of the maximum extent and age of the glaciation there. The sediments were misinterpreted as glaciofluvial deposits by Czudek (1973) and dated on the basis of their altitude to the Elsterian cold Stage. This interpretation was later on accepted uncritically by Macoun in a synthetic study (Macoun and Králík 1995). Based on this assumption it was wrongly interpreted that the meltwaters drained in both directions, i.e. via Moravian and Poruba Gates regardless of the altitude difference. The sediments are, in fact, Pliocene fresh-water deposits (Otava et al. 2004) and therefore there is no evidence of drainage via Moravian Gate during the Elsterian glaciation.

Nevertheless, irrespective of the subsequent muddle in dating and extent, the original interpretations dating from beginning of the 20th century still survive today. In particular this interpretation is quoted by those studies, which are concerned with the regional extent of both Middle Pleistocene ice-sheets and the response of the drainage system to their advance. Indeed, most of the summaries (Ehlers et al. 2004, Marks 2004, Litt et al. 2008) recurrently claim the maximum range of the Elsterian ice-sheet and its drainage of waters via the Moravian Gate. Generally without any details. However, these conclusions cannot be applied to the Moravian Gate proper where the Elsterian glaciation was of more limited extent, did not reach the watershed and was overridden by the Older Saalian (Drenthe, Odranian, Palhanec) glacier. This younger advance, in fact represents the most extensive glaciation in Northern Moravia.

List of Hassinger's localities

1. Nad dolama – near Slavíč village, 318 m a.s.l. An about 3 m thick accumulation of local gravel composed of 100% of local Lower Carboniferous lithologies (greywacke, sandstone and shale). No exotic rocks occur here, not even those from the Carpathian conglomerates which are exposed in the upper course of the Bečva River. The gravel was deposited by the Jezernice brook. No influence of the Bečva River and Elsterian meltwaters can be identified.

2. Loučka – 300 m a.s.l. No gravel is present at this site. Just a morphological level on the gentle slope underlain by Neogene clay overlain by loess.
3. Horecko – 295 m a.s.l. A few metres of local gravel derived from the Lower Carboniferous by the Loučka brook. The gravel body slopes gently from 305 to 280 m a.s.l., transverse to the assumed meltwater flow direction. No exotic rocks were identified here.
4. Tupec – 289 m a.s.l. No fluvial sediments are present at this site, only a flat ridge summit of Neogene overlain by loess. The gravel body deposited by the Lubeň brook or some tributary to Trnávka is preserved on the eastern flank of the hill and lies about 15 m lower. Local lithologies, no exotic rocks were found here.
5. Radvanice – 286 m a.s.l. This is a flat summit of a hill. It consists of Neogene sediments overlain by loess, but no gravel occurs here.

All these localities lie approximately 60 to 80 m above the present river. This morphological position played the main role in the dating of the accumulation. Based on this altitude the glaciofluvial terrace was primarily assigned to the Elsterian cold Stage. This level undoubtedly represents a certain phase in the development of the Bečva River valley and most probably corresponds to Lower Pleistocene.

The study area

The tectonically generated structure of the Moravian Gate extends lengthwise in SW-NE direction for a distance of about 50 km and is conventionally subdivided into the Bečva and Odra part. The main reason for the division is that the Bečva part belongs to the Black Sea (Danube) drainage area, whereas the Odra part drained towards the Baltic Sea. In addition the morphology and the Quaternary sediments in the latter were influenced by the Scandinavian ice sheet, whilst the Bečva part was beyond its reach. The boundary between those two parts follows the main European water-divide. Indeed both parts belong geologically to the same Carpathian foredeep, developed on the eastern slope of the Bohemian Massif. The Quaternary of the Odra part is discussed in a separate article (Tyráček – this volume), while this paper is focused on the Quaternary and morphological development of the Bečva part.

The strongly morphologically expressed Bečva part of the Moravian Gate is flanked on both sides by Lower Carboniferous sedimentary rocks. This Paleozoic sedimentary sequence, up to several thousands metres thick, forms the eastern slope of the Bohemian Massif, which merges eastward deep beneath the West Carpathian flysh nappes. Both cliff-like gate edges tower some 200–300 m above the interior of the foredeep. The Paleozoic rims are broken by huge rockslides that might be tectonically controlled. The foredeep is filled by the Miocene (Lower Badenian) marine mainly clayey sediments up to several hundred metres thick. The surface occurrences of the Miocene clays are usually restricted to the deeper incised valleys. Otherwise they are, almost throughout their full extent, hidden under the terrestrial Quaternary deposits. These are represented by fluvial gravels

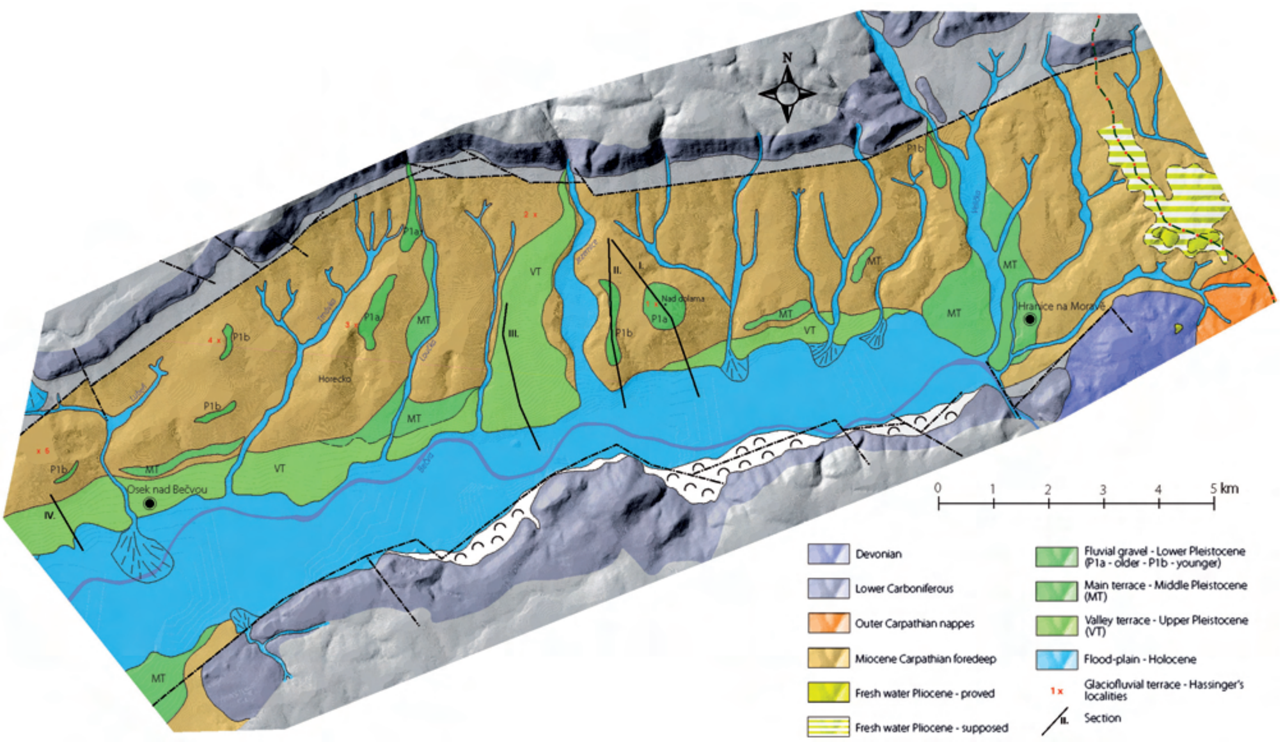


Fig. 2. Geological map of the study area with loess omitted.

Photo 1. A view from Nad dolama of the northern flank of the Moravian Gate across the Jezernice valley. Photo by J. Tyráček 1956.

preserved in diverse altitudes above the river and true aeolian calcareous loess deposited in relatively thin sheets on plateaux and in form of much thicker drifts on the lee sides of slopes. To show the regional distribution of the usually hidden fluvial deposits, the overlying loess was omitted from the map (Fig. 2).

Geology of the water-divide area

The lower part of the European water-divide between Bělotín village and the town of Hranice na Moravě coincides geologically with the Carpathian foredeep. All the unconsolidated to semi-consolidated calcareous clays, silts and sands several hundred metres thick, except for the younger overlying sediments, in this area belong to Miocene (Lower Badenian) marine deposits filling this tectonic structure. They are usually greyish to olive green silty clays and eventually silts and sands lighter in colour.

The fine-grained quartzose sand forms thin laminae or thicker, dm-size lense-like interbeds, occasionally consolidated to calcareous sandstone. This lithology is typical of the marine part of the sedimentary sequence up to an altitude of 280–290 m a.s.l. The topmost part of Miocene exposed to the elements, weathered to a depth of several metres, has a rusty brown tint and is usually decalcified.

The clayey marine sequence is overlain by a more sandy unfossiliferous sediment, which occurs in the wider surroundings of the watershed at the altitude over 300 m a.s.l. The sequence consists of two lithologically different units, both rusty brown in colour. Because of the limited exposure, both units had been often mistaken for each other and alternatingly classified as Pleistocene or as Miocene. The new road cuttings exposed partly both units and have thus provided valuable information pertinent the understandings of local geology.

The lower unit, over 20–25 m thick, is represented by rhythmic bedding of rusty-brown sand and brownish-grey clay in dm-scale, with occasional well rounded chert gravel and subangular to subrounded limestone clasts. The lower boundary has not been exposed and never mentioned in older borehole logs. Therefore, the character of the contact and total thickness remained, in general, obscure. Only lately one contact was seen at a single locality in the railway cutting on the watershed near the Bělotín village. According to Otava et al. (2008) the lower unit overlies unconformably the folded marine Miocene there. Such folding of the Miocene is very rare and, therefore, seemingly transitional contacts exist in other places. The establishment of the Pliocene for the older marine sediments was difficult because of its conformable stratification and partly similar lithology. Surprisingly a very long period of non-deposition and terrestrial development (erosion, fossil weathering) are not sufficiently represented or had not been identified at the top of the Miocene. In spite of these uncertainties it can be stated that a roughly estimated altitude of the contact at about 290–300 m a.s.l. seems to be well founded.

The upper unit 3–5 m thick, was exposed in a new road cutting (Czudek 1973) at the altitude of 335 m a.s.l., near the water-divide monument. It is represented by irregular beds of rusty brown medium- to coarse-grained sand with scattered well-rounded pebbles and even boulders (over 30 cm in the longer axis). The sediment was apparently deposited in the fluvial environment. Besides various types of Carpathian sandstones the gravel contains amphibole gneiss, two-mica granite and granodiorite (Czudek 1997). Such petrology is not of undoubted Scandinavian source. The gravel also includes limestone clasts, which are generally very rare in the Moravian glaciofluvial sequence.

This sandy gravel was interpreted as a glaciofluvial sediment by Czudek (1973, 1997) and dated, again based on its morphostratigraphical position, to the Elsterian Stage glaciation. According to this author the sediment was deposited by the meltwaters draining the glacier, which halted near the water-divide. This interpretation was assumed in a survey by Macoun and Králík (1995), these authors returned without any comments, to Hassinger´s (1914) 80 years old view, ignoring the results of the detailed geological survey. Lately the knowledge was considerably enriched by the translucent heavy mineral analysis of the sample taken from the same locality. The heavy mineral association (Fig. 3), represented above all by rutile, tourmaline, staurolite and kyanite is a fossil-weathering product of the local Palaeozoic (Otava et al. 2004). The minerals were redeposited, probably together with the limestone clasts from the Hranice Devonian. Both, the limestone clasts as well as the heavy minerals indicate that the transport occurred from the south, i.e. in the opposite direction from the supposed glaciofluvial material.

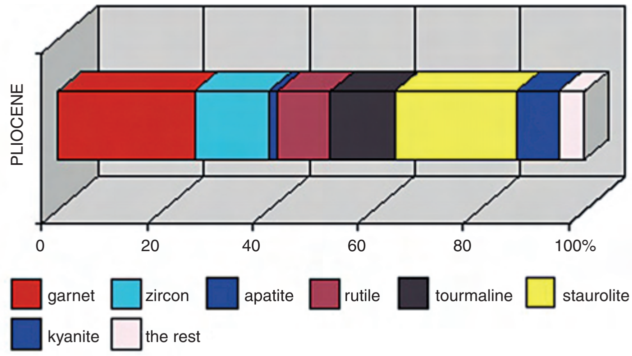


Fig. 3. Bělotín watershed – sand sample of the Malhotice formation, heavy mineral association (courtesy J. Otava).

The results of a pebble analysis from the lower unit were published by Gába et al. (2008). The sample was taken from a sedimentary sequence composed of alternating sand and clay beds exposed in another road cutting situated some 500 m north of the monument. The well-rounded gravel is composed of chert (62.2%), sandstone (28.4%) and quartz (3.4%), Surprisingly there is the total absence of Lower Carboniferous lithologies irrespective of their occurrences some 3 km north of the site in favourable morphological position in the Nízký Jeseník upland. The rocks identified at this site are of local provenance. The chert represents the classical menilite type derived from local Palaeogene (transport from the southeast for a distance of 4 km). The sandstones occur in the West Carpathian nappes (Cretaceous, Palaeogene – Gába et al. 2008). The crystalline rocks known from the wider surroundings (Tyráček 1963), which are not mentioned by Gába (l. c.) are exotic elements from the flysch conglomerates (cf. also Otava et al. 2008).

The lower unit is of lacustrine origin and the material was supplied from the east. Also the comparative heavy mineral analyses from the wider area (Otava et al. 1991) confirmed that the localities Lučice and Bělotín contain a significant portion of local association. Nevertheless, the association does not correspond to that of the marine Neogene. The results of heavy mineral analyses are in general reliable, though there is no index mineral to specifically relate to individual formations. Regardless of this, most important minerals, indicating the transport from the south at the same time document different origin and age of these sediments and help to differentiate them from the far transported Pleistocene glaciofluvial material.

The sedimentary sequence mentioned above most probably represents a stratigraphical equivalent of the informal Malhotice formation recently defined by Otava et al. (2008), although it shows marked facies differences. According to the original definition this freshwater formation contains three members at the type locality near Malhotice village.

1. The basal laminated to ripple-marked fine-grained sand with occasional 20–30 cm thick interbeds of calcareous sandstone, bears claystone and/or siltstone balls and lenses in its upper part. Ample admixture of quartz gravel appears in places. This member is of lacustrine origin and reaches over 10 m in thickness. The upper contact with the middle member is conformable and seemingly transitional. Nevertheless, mostly it is well defined by the first claystone bed. The member rests directly upon the folded flysch bedrock. The presence of the clay balls indicates occasional stronger currents.
2. The middle member is composed of a rhythmic alternation of violet-brown and greyish-green claystone and siltstone beds with occasional fine-grained sandstone interlayers. The member is, similar to the previous one, lacustrine in origin. Its sediments indicate deepening of the basin and more quiet sedimentary environment. The thickness is irregular since its top part is irregularly eroded by a river, which flowed from the east or southeast carying the coarse material for the upper member. Well-marked scours and channels appear at the upper contact making the assessment of its thickness difficult. Indeed, the original thickness was probably about 10 m. The sediments of both members are unfossiliferous. The microfauna found occassionally within the claystone was redeposited from the Palaeogene.
3. The upper member is formed of irregular sand and gravel bodies deposited in a fluvial environment. The clast size ranges from 3 to 10 cm, however the haphazardly arranged cobbles and boulders also occur.

Photo 2. Lučice sand pit. Horizontally bedded medium-grained sand with subordinate thin clay interbeds. Non-marine Tertiary, Malhotice formation. Photo by J. Tyráček 1957.

Exceptionally large (up to 2 m) limestone boulders appear in places. The lower boundary is sharp, erosional and, therefore, the resulting thickness varies considerably. The gravel usually fills channels and scours, incised sometimes to the depths of several metres into the underlying rhythmites. Irrespective of this, the total thickness can be assessed again to some 10 m. Besides the most abundant sandstones, the limonitic and calcareous concretions together with quartz, limestones, breccias, mylonites, volcanites, granitoids and quartzites appear. The material was mostly derived from the Outer Carpathians (Otava et al. 2008).

The results confirm the effectiveness of the provenance studies for distinguishing the individual sedimentary sequences. They also suggest that the local lithologies were the dominant sources for the sediments by contrast to the far-transported glaciofluvial materials.

Comparing the watershed sedimentary sequence, which can be considered as a separate formation, with the newly-defined Malhotice formation, several resemblances can be emphasised. Some of them like dating, origin and geological position apply for the formation as a whole, whilst the other properties only concern individual members.

1. The sediments unconformably overlie well-dated bedrock, explicitly the Palaeogene flysch nappes of the West Carpathians or Miocene (Lower Badenian) clay in the foredeep. By contrast to the West Carpathians, the geological position in the foredeep narrows the time gap for the origin of this formation to the interval Miocene-Quaternary.
2. The formation ubdoubtedly falls into the time interval Quaternary and Miocene, though no palaeontological evidence exists. The formation lies above the level of Quaternary incision, which indicates the beginning of the modern drainage pattern, dated usually to the onset of the Quaternary. This morphostratigraphical position can be used as an additional indicator for its dating (Tyráček 2007).
3. All members either the lacustrine or the fluvial in both areas are of freshwater origin and were deposited in different environments compared to those of the bedrock.

By contrast the lacustrine sedimentary sequence over 20–25 m thick in the foredeep near Bělotín is relatively uniform alternation of sand and clay beds and apparently replaces both lower members at the type locality. Over 10 m thick rusty-brown medium sand with clay interbeds and scattered gravel overlying the marine

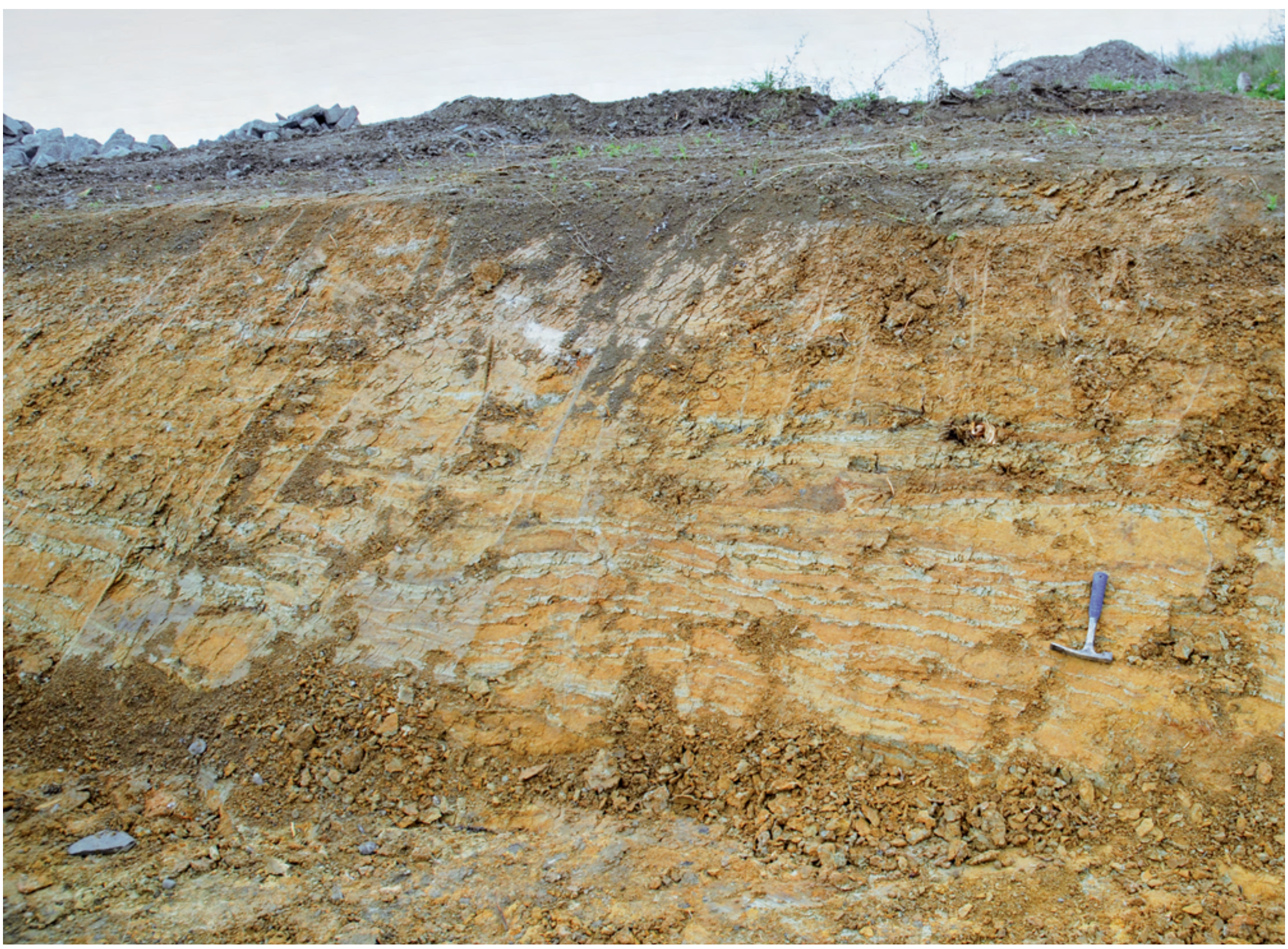


Photo 3. Bělotín road cutting. Alternation of sand and clay beds, Malhotice formation. Photo by D. Nývlt 2008.

Miocene has been previously documented by Tyráček (1961) in a sand pit near Lučice (outside the map) and misinterpreted as regressive marine Neogene at those times. These sediments also contain large balls (over 50 cm) of grey and violet-brown claystone. The volcanites, cherts, menilite shales and strongly weathered unspecified crystalline rocks are present in the gravel. These lithologies can be considered as a coarser equivalent of the lacustrine members of the Malhotice formation and may thus confirm a regional facies change and a larger regional extent of the formation. The clast petrology indicates a prevalent provenance from the Outer Carpathian flysch in the Malhotice area, whereas the foredeep region was partly supplied from the Hranice Palaeozoic in the south.

The definition of the Pliocene Malhotice formation clarified the aged problem of the glaciofluvial sediments and the maximum extent of the continental glaciation in the water-divide part of the Moravian Gate.

Fluvial sediments

River valleys belong among the major zones of continental deposition as pertinent sediments in combination with the loess sequences provide important records of the landscape evolution and palaeoclimatic fluctuations upon which the non-marine Quaternary stratigraphy is based. Fluvial sequences, particularly well articulated terrace staircases are essential for establishing a terrestrial stratigraphical framework in general (cf. Soergel's 1939 Vollgliederung) and for contingent neotectonic movements in particular. The same holds good for the Bečva River valley in the Moravian Gate. In addition the fluvial sediments may help to identify the regional extent and the age of the continental glaciation there. Contrary to the cratogen of the Bohemian Massif with typically rich terrace staircases, the Bečva terrace flight is reduced to four levels only.

The fluvial sediments with minor exceptions are preserved on the right bank of the river. Most do not belong to the main stream since they were deposited by the right Bečva tributaries, which drained the Nízký Jeseník upland.

1. The gravel occurrences at Nad dolama (318 m a.s.l.) and Horecko (295 m a.s.l.) occur at an altitude of 70–80 m above the river and represent the highest terrace in the region.

The Nad dolama terrace is represented by a gravel about 3 m thick, which is overlain by 5 to 7 m of loess. The gravel body shows a marked gradient southward, toward the Bečva valley (see section I on Fig. 4). The clast size in these sediments ranges from 3 to 5 cm, max. 7 cm. The gravel is composed of Lower Carboniferous lithologies (greywacke, sandstone and clayey shale). Very well-rounded quartz pebbles and subangular to subrounded quartz clasts typically occur in the gravel, the former derived from the broken Carboniferous conglomerates and the latter from the quartz veins. No other petrologies were found. The origin of the gravel can be attributed to the Jezernice brook. The presence of less resistant clayey shales indicates a relatively short transport.

The Horecko gravel caps an elongated N-S trending ridge on the left bank of the Trnávka brook. Its roots can be traced northwards as far as the foot of the Nízký Jeseník near Loučka village at the altitude of 310 m a.s.l. From there it slopes gently downstream to 295 m, so its terminal part hangs 70 m above the river. The clast size differs strongly. Whereas in the proximal part the largest clasts may reach the size of boulder (over 30–35 cm), downstreams the size diminishes to 10 cm maximum. The gravel petrology is similar to that at Nad dolama. The only difference is a stronger frequency of medium- to coarse-grained greywacke derived from the coarser facies of the Carboniferous Moravice Formation. The gravel was evidently deposited by the Trnávka brook (cf. Fig. 2).

Both gravel accumulations correlate with the Hassinger's (1914) glaciofluvial terrace. The gravel petrology documents their provenance from the Nízký Jeseník upland. No exotic rocks had been identified, not even those derived by Bečva River from the West Carpathian conglomerates. The Nad dolama terrace was deposited by the Jezernice brook, without any intervention of the Bečva River. The Horecko terrace slopes N-S ward, transverse to the presumed meltwater flow direction. The dating of both occurrences is relatively simple. If it is accepted that, thanks to a higher relief, possible uplift and climatically forced repeated downcutting and aggradation, the lower terraces are younger than the higher ones. Therefore, these highest gravels in the Bečva part of the Moravian Gate are undoubtedly the oldest and are of Lower Pleistocene age. Because of their morphostratigraphical position this level marks, at the same time, the beginning of terracing in the region. Because this phase is usually correlated with the Pliocene-Pleistocene transition, this terrace cannot be considered as a representative of a Middle Pleistocene Elsterian glacial Stage.

2. The 40–50 m terrace is in the best development preserved on the left bank of the Jezernice brook, to which it owes its origin. The N-S trending elongated gravel body slopes gently from 300 to 270 m a.s.l. Its southern outlier lies nowadays about 45 m above the river (Fig. 4, level II). Nevertheless, because of the ancient course gradient the original Jezernice junction had evidently been lower, probably at the relative altitude between 30 to 40 m above Bečva River. The terrace follows the Jezernice valley. The gravel lithology equates with that Nad dolama and thus gives evidence to their joint source and origin. Neither Carpathian sandstones

nor exotic rocks are present in the gravel. Therefore, no effect of the Bečva River had been felt during its deposition. Two more relics located by boreholes below the loess cover between Lipník and Osek nad Bečvou at the relative altitude 30 m, belong to the Bečva River. This level correlates stratigraphically either with the close of Lower Pleistocene or with the preglacial part of the Elsterian Stage. The gravel accumulation, in which the Carpathian sandstones dominate, is only 1–1.5 m thick and probably corresponds to the 45 m Jezernice terrace.

3. The relics of the main terrace gravel are preserved here and there in the study area. Its gravel forms a 13–15 m terrace (surface) the base of which is about 3 m above the river. The relics on the right bank are mostly hidden beneath a continuous loess mantle over 10 m thick. The maximum thickness of an exceptional loess series, overlying the main terrace at the famous archaeological mammoth hunters site Předmostí reaches over 23 m. The only larger gravelly main terrace platform without any younger cover is preserved on the left bank near Radslavice, where the loess on the upwind side is not developed.

The sandy gravel is usually 6–8 m thick except for the southern mouth of the Poruba Gate where it reaches over 12 m. The domination of various types of Carpathian sandstones upstream the Poruba Gate indicates the Bečva origin. The Lower Carboniferous lithologies appear from the Poruba Gate downstream. However their frequency rises rapidly in the same direction from Hranice na Moravě, where it is supplied from both flanks of the Moravian Gate. Besides the two main components mentioned, some accessories are also present. They are quartz, chert, menilite shale and crystalline rocks, which had been mostly derived from Palaeogene conglomerates. The crystalline rocks, particularly gneiss, granodiorite and granite need not to be of undoubted Scandinavian provenance. Therefore, the authentic glacial representatives are rapakivi-type of granite, porphyry and flint. The Scandinavian lithologies are extremely rare, nevertheless, their presence is sufficient to indicate the impact of the glacial meltwaters on the terrace deposition.

The relationship of the glacial sediments to the Bečva River terrace system is of vital importance for dating the maximum glaciation. On the other hand the existence of the main terrace sediments upstream of the Poruba Gate indicates the typical climatic character of the main terrace. The morphostratigraphy of the main terrace and its position in the Bečva terrace flight are illustrated in Fig. 4.

4. The Bečva floodplain terrace (valley-fill alluvium) is the youngest gravel accumulation in the study area. Its sandy gravel and sand fill the valley floor, over-deepened some 4 to 6 m below the river. The surface reaches about 4 m above the river and the thickness of the sediments ranges from 6 to 10 m. The clast size, dominated by Carpathian sandstones, diminishes from 15–20 cm near the Poruba Gate to 5 cm within a distance of several tens of kilometres. The thickness of sand beds increases in the same direction. The Pleistocene age is documented by overlying Upper Pleistocene loess, which may reach over 6 m in places. The gravel body which follows the Jezernice right bank from Pohoří as far as the Bečva flood plain (cf. Fig. 4, level III) is of the same age. Both are dated to the onset of the last glacial. The overlying homogeneous loess, composed of far transported dust, is analogous to the youngest loess occurring elsewhere in Czechia. On the right bank of the river the loess falls into the floodplain with a marked 2–4 m high bluff (see Fig. 5).

Two levels are usually developed within the youngest terrace. The original Upper Pleistocene accumulation surface is conventionally 2–3 m higher and uses to be preserved beneath the loess. The lower erosional level

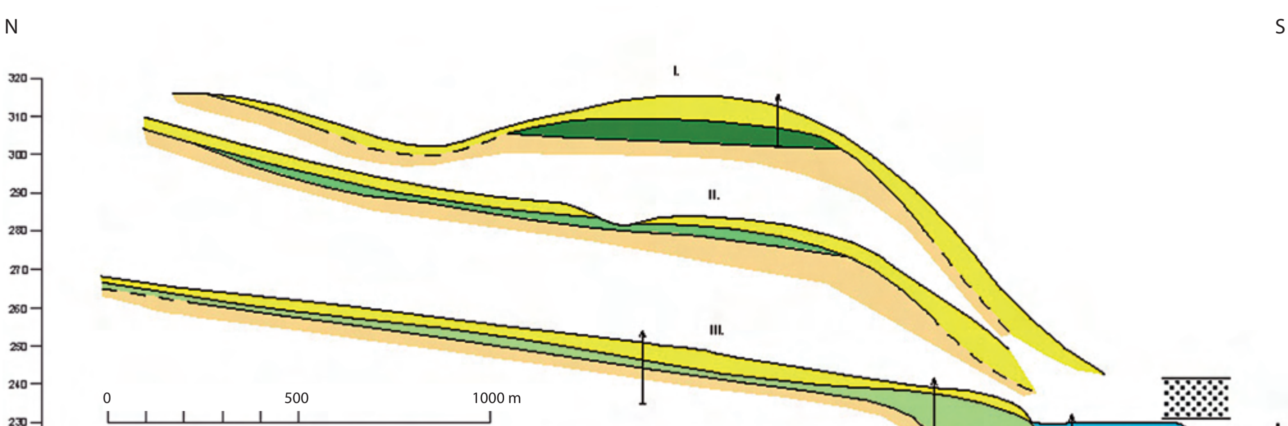


Fig. 4. Nad dolama sector, cross sections. 1 – Neogene bedrock, 2 – Lower Pleistocene gravel (Nad dolama terrace), 3 – 40 m terrace (Lower–Middle Pleistocene), 4 – Main terrace, 5 – Upper Pleistocene terrace, 6 – Loess, 7 – Holocene overbank silt and loam.

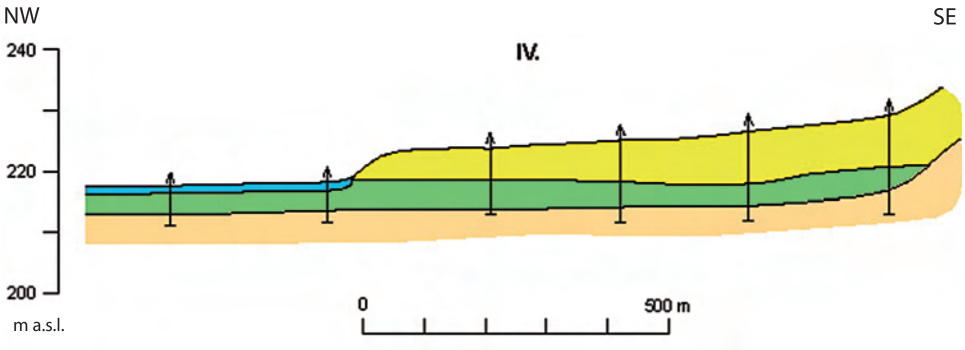


Fig. 5. Cross section IV. Upper Pleistocene Bečva terrace; for explanations see Fig. 4.

is limited to the floodplain in which the upper 2–3 m thick part of the gravel had been removed and the lowered surface subsequently overlain by overbank silts.

In places the Pleistocene gravel is reworked by the meandering stream and redeposited anew in the form of a fill-in-fill terrace. The thickness of the recent aggradation probably reflects the depth of the migrating channel. The lower part of the accumulation shows diagonal bedding deposited by lateral accretion within the channel. The upper horizontally bedded sand with gravel lenses formed again within the channel, probably under the upper flow regime (Růžička 1968). The sediment up to several metres thick is again represented by sandy gravel and coarse-grained sand, which is practically undiscernible from its Pleistocene equivalent. It was identified by its archaeological context (bronze sicle – Tyráček 1957, 17th and 18th century ceramic shreds, Franz I coin, porcelain pipe and brick pebbles – Růžička 1968).

Conclusions

1. The Elsterian glacier halted in the Odra River valley and no traces of its having crossed the European watershed have been identified.
2. No representatives of the glaciofluvial terrace and the drainage via the Moravian Gate at the altitude 70–80 m during the Elsterian times have been found.
3. The Saalian ice sheet, the largest in the area and dated to the Older Saalian (Dutch Drente, German Drenthe, Middle Polish Odranian or Czech Palhanec) Substage did not cross the water-divide either.
4. The Saalian meltwaters drained via the Poruba Gate at the altitude of the 15 m (main) terrace.
5. The Moravian Gate terrace staircase is only represented by four levels.
6. The highest 70–80 m gravel accumulation, primarily taken for the glaciofluvial terrace is the local product of the right tributaries to Bečva, Jezernice and Trnávka respectively. The gravel is composed of local lithologies derived from the near Nízký Jeseník Palaeozoic. No exotic rocks appear in this unit, not even those transported from the Bečva upper course.

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