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MORPHOTECTONIC EVIDENCES OF THE QUATERNARY GEODYNAMICS IN SELECTED LOCALITIES OF NUCLEAR POWER PLANTS

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Abstract: In the paper the hitherto obtained results of morphotectonic survey in construction and operation sites of the Temelín, Jaslovské Bohunice and Blahutovice nuclear power plants are briefly described. The sequence of dominating geodynamic events during the Late Cainozoic has been documented by the historic-genetical analysis of landforms and by interpretation of their relations to other data concerning the condition of the near-surface part of the Earth's crust. Evidences of Quaternary tectonic activities have been established in all of the three investigated localities, most pronounced being those found in the area of the Jaslovské Bohunice nuclear power plant.

Key words: morphotectonics; Quaternary geodynamics; nuclear power plants

1. INTRODUCTION

Maximum security of the construction and operation of nuclear power plants calls for the solution of several problems, one of the most important among them being the assessment of Quaternary and recent tectonic activity of the Earth's crust. The report summarizes the hitherto obtained results of the morphotectonic survey in sites of the Temelín, Jaslovské Bohunice and Blahutovice nuclear power plants. The sequence of dominating geodynamic events has been proved by the analysis of landforms and by interpretation of their relation to other particular data concerning the condition of the near-surface parts of the Earth's crust. The information obtained has then been expressed by means of special graphic and tabular diagrams (for details see Kalvoda *et al.*, 1988a, 1988b, 1989a), which represent a sort of model of the morphotectonic history of the investigated sites in the Late Cainozoic. The detailed geormorphological investigation is aimed at making the neotectonic features of the relief development more accurate; it reveals the morphostructurally conspicuous lengths of faults, their planary extent and also the possible evidences of the present-day activity.

2. TEMELÍN

At the construction site of the Temelín nuclear power plant, a special zoning of the distinctness of evidences of neotectonic processes has been carried out. After reconnaissance of areas whose relief deviates from the development results by climate-morphogenetic processes, this zoning has been drawn into a graphic sketch (Kalvoda *et al.,* 1989a) and is used as a basis for more detailed geomorphological surveying. The neotectonic activity is demonstrated, within the relief of the surveyed area, namely by differentiated uplifts and sinking of morphostructurally pronounced blocks. Its consequences are seen in massive ridges, basins, hollows and strips of frequently stair-like, regularly distributed belevelled surfaces with rectilined limits, a valley network following the directions of structural dislocations NW–SE, NE–SW, in parts N–S, W–E, with sudden bends and mouths of tributaries in opposite directions and alterations of the shape of valley slopes, when suppressing the different geomorphological resistance of rocks. The courses of rivers Vltava, Lužnice and Otava are subjected, in this area, to expressive changes of descents. The heights of relics of belevelled surfaces above both flanks of the rivers Vltava and Lužnice differ very substantially. There exist also differences in elevations of river accumulation terraces of Riss to Würm ages. Rock reefs are found on valley bottoms in areas where the transverse fault zones are overcome. The canyon-like Vltava valley has the appearance of basins in areas of intersection with main transverse and morphologically significant faults (e.g. the Vodňany mylonite zone, faults in N–S and W–E directions near the Purkarec village).

The relief development of the locality with building site of the Temelín nuclear power plant took place in the Quaternary under the influence of tectonic processes, the activity of which can be seen in the morphostructural record especially within the broad neighbourhood of the Vltava river between the southern part of the fault-bordered horst of Mehelník and the beginning of the river's canyon-like valley at Hluboká. We would like to comment that geophysical and geodetical measurements of the recent tectonic activities are so far insufficient.

3. JASLOVSKÉ BOHUNICE

The evaluation of data on palaeogeographic history of the Lower Carpathians during the Cainozoic Era (Table I), the field study of the relief development (see also Jakál *et al.,* 1988) and the morphotectonic interpretation of this knowledge obtained in the locality of the Jaslovské Bohunice nuclear power plant give evidence of the long-term function of seismically active fault zones and Earth's crust blocks. Their tectonic regime manifests itself by specific features of the set of landforms (Kalvoda *et al.,* 1988b).

The historic-genetical assessment of locations of seismically active zones within the area of Jaslovské Bohunice resulted in their classification into the morphotectonic categories mentioned below (see Fig. 1).

A. Areas of contact or crossing of morphologically pronounced depressions in the form of basins, hollows or flat-bottomed valleys, based on fault zones of different origin and age. This concerns mainly the Trnava, Trstín, Jablonica, Piešťany and Nové Mesto areas.

Table I. Scheme of neotectonic movements phases and origin stages of the preserved erosion-denudational belevelled relief surfaces at the locality of the Jaslovské Bohunice nuclear power plant (elaborated in Kalvoda *et al.*, 1988)

Geological age (in million years) and stratigraphic classification		Alpine orogeny	Origin of belevelled surfaces
			River accumulation system of
Quaternary		Valashian phase	Danube and Váh terraces.
			Oldest preserved river
1.6			terraces of the Danube and the Váh.
Pliocene	Ruman	After-effects of	Beginning of development of
5	Dak	tectonic movements	"riverside" belevelled surface.
	Pont	Rhodanian phase	Middle mountain level.
		Calm down of tectonic	Beginning of development of the
	Pannon	movements	middle mountain belevelled
10			surface.
	Sarmat	Attic phase	Belevelled surface of flat ridges.
			Uplift of the Lower Carpathian horst.
	Baden		
		Styrian phase	Beginning of subaeric
			development of morphostructures.
Miocene	Karpath	Old-Styrian phase	Marine sedimentation
			in the Lower Carpathians.
	Ottnang	Flysh sedimentation	Flat ridges as relics
		in depressions	of large elevations.
20	Eggenburg	Subsidence of basins	Denudation and erosion.
			Development of the primary
	Eger	Savian phase	horst of the Lower Carpathians.
22.5			
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B. Zones of continuing morphostructural differentiation of blocks and scales inside or on the periphery of the Lower Carpathians, especially (in relation to adjacent orographic elements) of subsidence character: B 1 – zone of the Lower Carpathian erosion-tectonic depressions begins on the western border of the Pezinok Carpathians by the subsident Buková basin, which can be followed towards S of Sološnica, continues to NE across the Senica-Jablonica-Trstín depression (with NW–SE basin direction) into the Dobrá Voda basin and further to the Pustá Ves basin up to the E border of the Prašnícka brána gate between the Brezová and Čachtice Carpathians; B 2 – zone of depressions on the E foot of the Lower Carpathians, which includes the Lošonec depression on the S, continuing across the Trstín area to NE by the Naháč-Dechtice depression

and erosion depression on the western foot of the Brezová Carpathians, which can be orographically divided into the Hradiště morphostructural unit and the Brezová depression.

C. Zones of linear morphostructural elements, which reflect the course of faults of near-surface and probably also deeper geological structures with directions mostly N–S or NNE–SSW and NW–SE: central part of the Raková brook valley, erosion-fault slopes of the eastern border of the Dobrá Voda basin and its N and S continuation within the rock massif, the Bláva brook valley, the Vítek brook valley from Dolné Drešany towards Hrnčiarovice and the Ronava brook valley beneath Ružindol.

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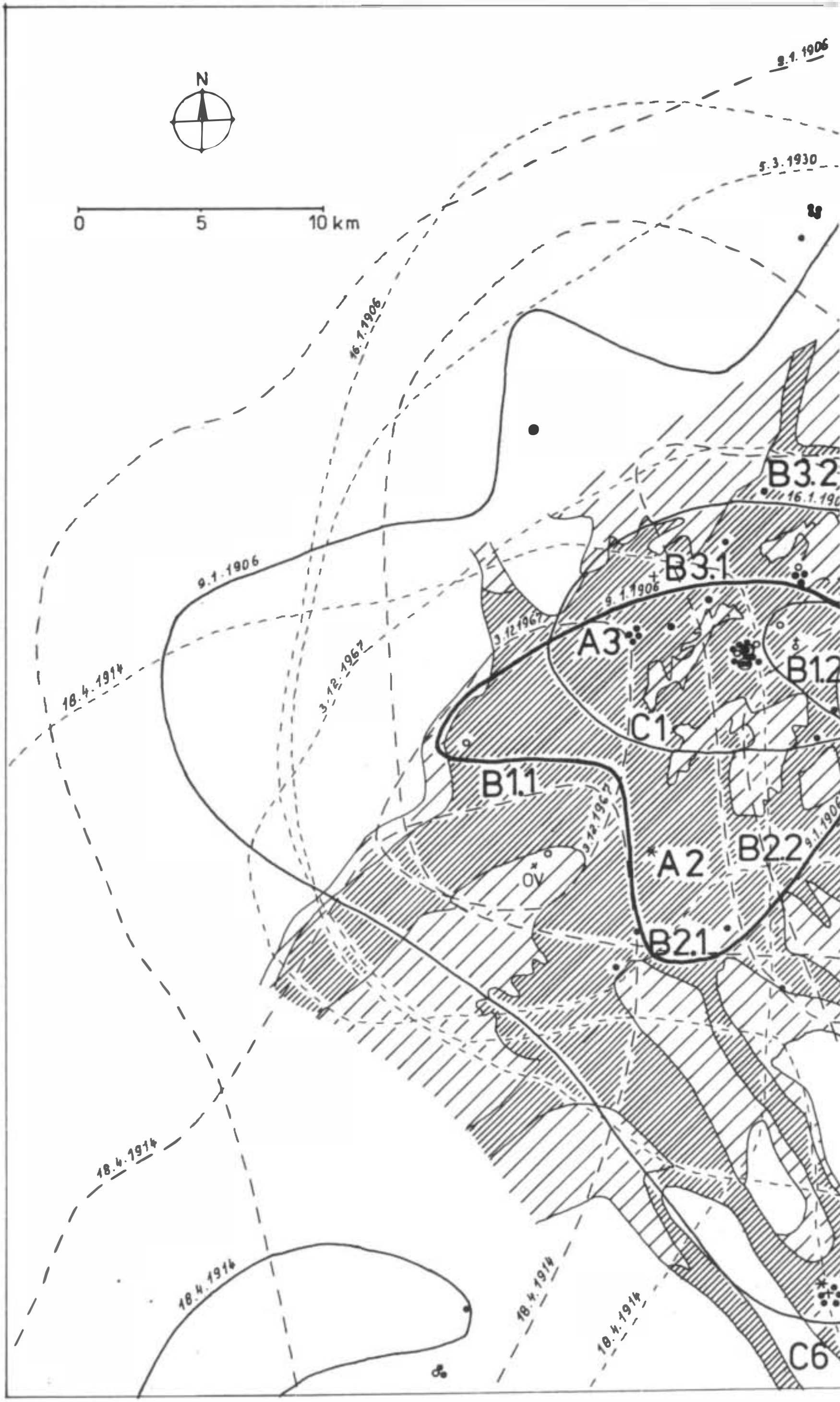

N
0
5
10 km
9.1.1906
5.3.1930
16.1.1906
18.4.1914
3.12.1967
B3.2
B3.1
A3
B1.2
C1
B1.1
A2
B2.2
B2.1
C6

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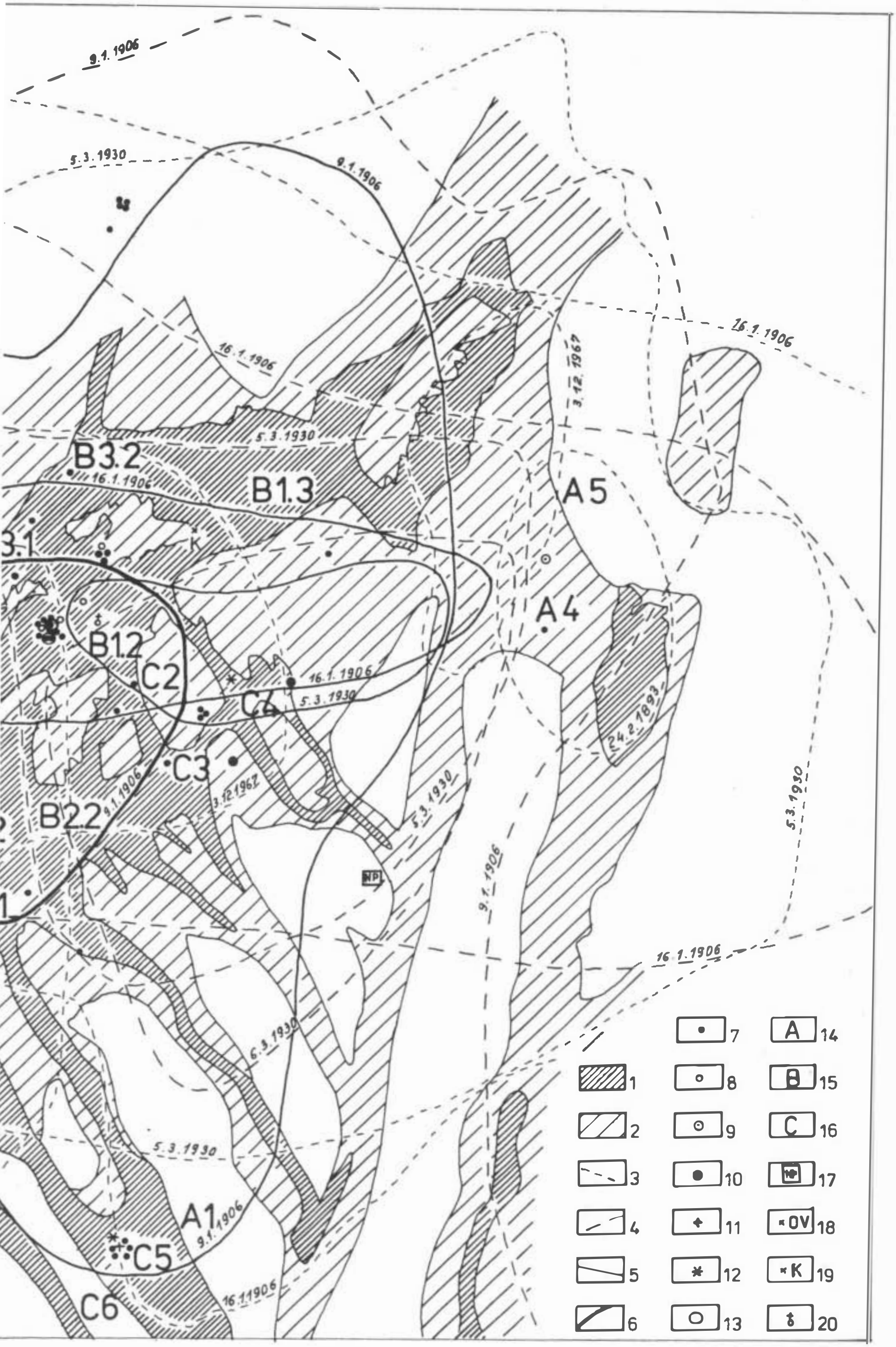

9.1.1906
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16.1.1906
3.12.1967
16.1.1906
5.3.1930
B3.2
16.1.1906
B1.3
A5
3.1
A4
B1.2
C2
16.1.1906
5.3.1930
C4
C3
3.12.1967
24.2.1893
9.1.1906
B2.2
5.3.1930
5.3.1930
9.1.1906
NP
16.1.1906
6.3.1930
5.3.1930
A1
9.1.1906
C5
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16.1.1906
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4
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6
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12
13
A 14
B 15
C 16
17
OV 18
K 19
20

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MORFOTEKTONICKÉ PROJEVY KVARTÉRNÍ DYNAMIKY ZEMSKÉ KŮRY VYBRANÝCH LOKALIT JADERNÝCH ELEKTRÁREN

Jan Kalvoda a Josef Stemberk

V práci jsou stručně popsány dosavadní výsledky morfotektonického průzkumu v lokalitách jaderných elektráren Temelín, Jaslovské Bohunice a Blahutovice. Historicko-genetickou analýzou povrchových tvarů a interpretací jejich vztahů k dalším údajům o stavu připovrchové části zemské kůry byl dokumentován sled vůdčích geodynamických událostí v mladším kenozoiku. Ve všech třech sledovaných oblastech byly prokázány projevy kvartérní tektonické aktivity, nejvýraznější pak v lokalitě provozu jaderné elektrárny Jaslovské Bohunice.

by the Temenicský fault zone and the Odra basin fault system, in the cross direction by morphostructural elements of the Poruba Gate and of the eastern edge of the Lower Jeseník Mts.;

b) the morphostructural zone C3 (see Fig. 3) runs within the space defined in this way and, at the same time, further tectonically related features of its relief can be covered with Quaternary sediments.

5. CONCLUSIONS

The dynamic geomorphology is one connecting link of multidisciplinary research of tectonic activity (Demek and Kalvoda 1991; Kalvoda and Demek 1991) and can form an adequate basis for the comprehensive interpretation aimed at the Earth's crust development during the Late Cainozoic. The historic-genetical analysis of landforms proved the existence of Quaternary tectonic activity in all of the three investigated localities of construction and operation of nuclear power plants (Temelín, Jaslovské Bohunice and Blahutovice). The morphotectonic observation of the dynamics of actual geological processes in the wider surroundings of the nuclear power plants should be consistently combined and correlated with geophysical and geodetical measurements of recent movements of the Earth's surface.

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is changing from ENE–WSW to NE–SW. Quite outstanding is also the alteration of relative heights of these slopes. Their relative heights vary, in the section between the Olšovec depression and the valley beneath the village of Veselá, between 80–100 m (with elevations of the top ridge 440–450 m a.s.l.), they have lower gradients and a convex shape. Between Veselá and the Odra basin attains the relative elevation of slopes up to 200 m, the landscape dominant being the Veselovský vrch hill (557 m). The short and relatively deep crossing valleys have mostly directions NW–SE, with the exception of the Hradečný brook valley, which follows directions of NNW–SSE to N–S.

Area C3 – Valley of the Hradečný brook in the Lower Jeseník Mts. and its continuation in the Moravian Gate, then over Kunčice to Špičky: The cross profile of this valley is markedly asymmetrical. The left-hand slopes of the Hradečný brook slopes have (in the marginal part of the Lower Jeseník Mts.) heights up to 100 m and their gradients attain values of 45 to 40°. Unlike that, the right-hand slopes have elevations up to 50 m and much lower gradients. This asymmetry can, to a certain extent, be seen also in the valley section pertaining orographically already to the Moravian Gate. The course of this continuation agrees practically with the photolineament accentuated by A. Zeman in Čížek *et al.* (1985).

Area D1 – The Poruba Gate itself: The depression of Poruba Gate runs from Jeseník nad Odrou across Starojická Lhota to the Poruba town and Hustopeče nad Bečvou in the NNE–SSW direction. The highest thickness of the preserved Quaternary sediments (more than 40 m) is there between Palačov and Starojická Lhota. Conspicuous alterations in relative height of the marginal parts of the Poruba Gate after the Riss glaciation were described already by J. Tyráček (for details see e.g. Macoun, 1989). This is obviously connected with the gradient changes of the main river terrace, induced by tectonic movements. The European watershed runs across the Poruba Gate. At the outlet of the Poruba Gate into the Bečva valley, several large ponds have been established in very shallow parts of the main valley close to Hustopeče.

Area D2 – Opening of the Poruba Gate into the Bečva valley mouth (and its environs) of the counter-current valley near Choryně: Two morphologic phenomena are crossing here, both of pre-Quaternary age and structurally related. Striking are, at some places, relatively steep denudational slopes on the left side of Bečva (N part of the Kelčská pahorkatina hills) especially in contrast to the wider and shallow bottoms of main valleys. The structure-related valley near Choryně continues to S as far as behind the oval depression close to Kelč, which was created in its crossing with the morphologically prominent continuation of the Temenický fault zone.

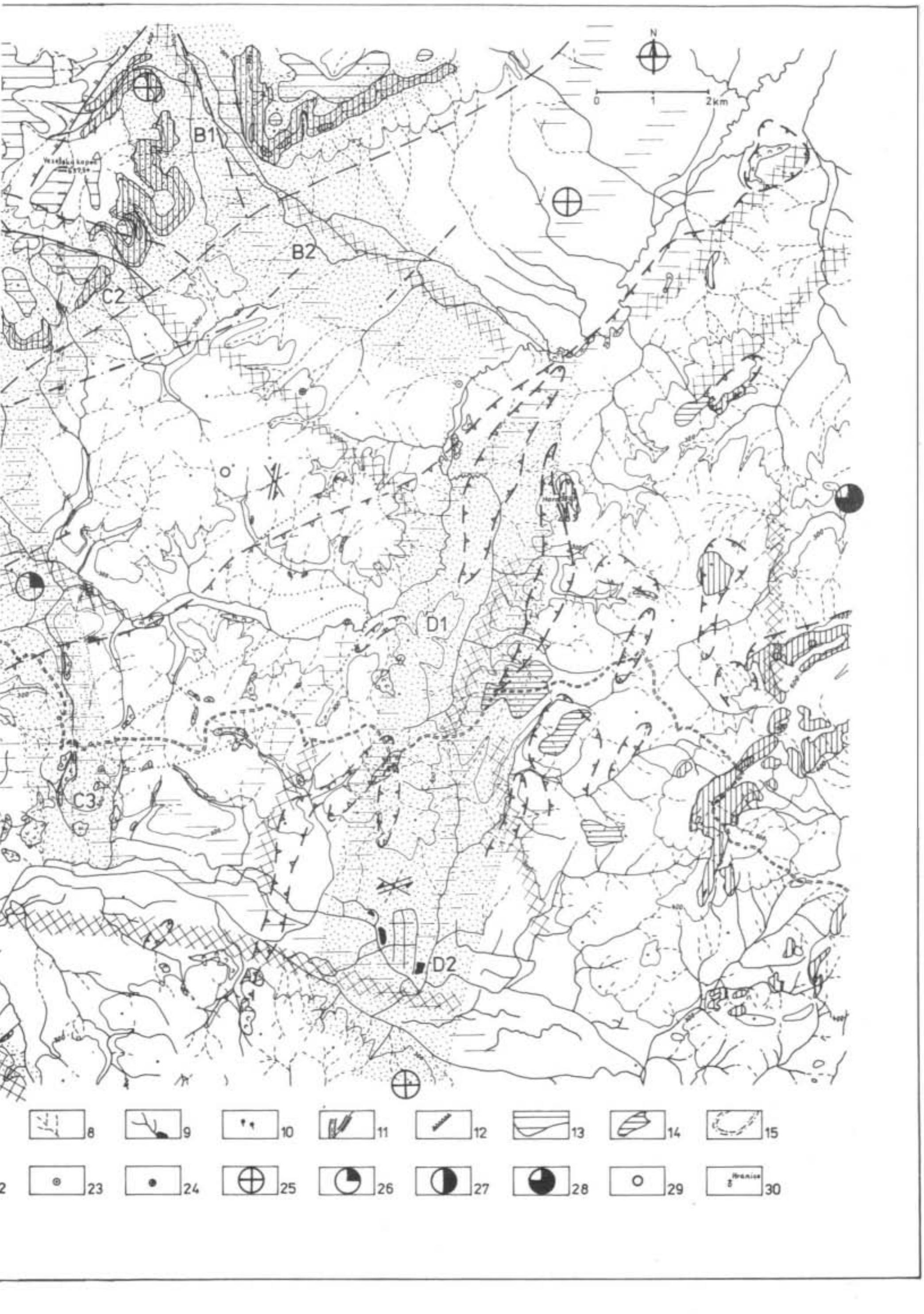
In addition to defining the morphostructural areas, to which main attention should be paid when systematically following the actual geological processes, we put special stress on the exposed situation of the ridge elevation forming the actual European watershed (perpendicular to the Moravian Gate axis) between the Black and Baltic Seas. It is quite probable that the tectonically induced secular uplift of the watershed ridge continues till our time. Moreover, we would like to point the attention to the marked morphotectonic differentiation of this elevation:

a) It is bordered, in the marginal parts, by fault zones, especially longitudinally approx. directions NW–SE. The cross profile of a part of the NW and intermediate Odra basin is markedly asymmetrical. Eastern slopes are gentle and they pass, without distinct slope alterations, from the ridge part down to the valley. In places, relics of the so-called main river accumulation terrace are preserved. Unlike that, the western slopes have mostly a concave shape and are in places broken by young erosion cuts. The Pohoř valley, SE of Odry, has a general direction W–E, which deviates, in its central part, to direction of SW–NE. A large dejection cone was formed in the lower part of this valley, which is cut, on its S border, by the actual stream to a depth of 5 m. The brook cuts the edge of the dejection cone down to the bedrock of the erosion-denudational slope, up to the elevation of 337–340 m a.s.l. The cutting bottom is partly filled with slope sediments, including debris. The Pohoř valley is an example of a frequent phenomenon that valleys leading out into the Odra basin are to a great extent clogged by outwash and slope sediments. At the same time, small streams tend there to carve downward. At the outlets of these valleys, there are usually dejection cones, cut by the younger vertical erosion. In places, the outlets of younger cuts are accompanied by further small dejection cones, which gives evidence that the processes of episodical (seasonal, at adequate water supply) downward cutting are still continuing.

Area B2 – Outlet of the Odra basin into the Moravian Gate and its continuation toward SE: The Odra basin leads into the Moravian Gate in the crossing zone of the fault system of the Odra basin with the marginal fault of the Lower Jeseník Mts. An accumulation plane on glacigenic, glacifluvial and fluvial sediments (actually used for building a system of ponds) in the shape of an oval depression has been formed in direct neighbourhood with the steepest slopes of the border of the Odra basin. The marginal slope of the Lower Jeseník Mts. is quite steep towards E and its relative height is 150 m at the top elevation of 400 m a.s.l. This slope passes convexly into the Odra part of the Moravian Gate. Its integrity is broken by a single short valley S of the Pohoř village. The youngest erosion phase has been detected in this valley. Its highest point, affected by backward erosion, lies at the elevation of 349 m a.s.l. The continuation of the Odra basin bottom towards SE can be followed up to Jeseník nad Odrou, although the surface relief is formed by landforms modelled in Quaternary sediments.

Area C1 – Marginal structural denudational slopes of the Lower Jeseník Mts. between Milenov and the Olšovec depression: Structural denudational slopes of the Lower Jeseník Mts. attain here relative elevations up to 150 m and gradients up to 35°. With the exception of pre-Quaternary deep valleys (such as that of the Uhřínov brook), they are only little dissected by erosion. These slopes on the SE border of the Lower Jeseník Mts. lie in the fault zone or tectonic bending of the rock complexes of the Bohemian Massif as a relic superficial manifestation of mostly buried relief of the Moravian Gate depression originated in the Tertiary Era.

Area C2 – Marginal structural denudational slopes of the Lower Jeseník Mts. between the Olšovec depression and the Odra basin: Fault-related slopes in area C2 exhibit generally similar features as the above-mentioned area C1. Their course is interrupted particularly by the valley of the Hradečný brook close to Nejdek (see area C3) and there also the direction of marginal slopes of the Lower Jeseník Mts.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V-shaped cross profile, which passes suddenly, against the dip of the longitudinal profile, into a wide shallow valley of an older stream. A relatively large dejection cone is preserved at the outlet of the Krkavec valley into the Bečva valley. This cone lies on fluvial sediments of the main Bečva terrace and in its neighbourhood there are also accumulation dumps of small fossil slope failures. The reflection of the Temenický fault system can be morphologically followed in the near-surface structure of the Western Carpathians up to the region of Kelč.

Area B1 – north-western and middle part of the Odra basin: The Odra basin was created by the erosion activity of the Odra river, especially on a fault system with

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Fig. 3. Morphotectonic map of the wider environs of the planned building site of the Blahutovice nuclear power plant (according to Kalvoda *et al.* 1989b). Legend: **1–3** areas with slope gradients: **1** – 0–15°, **2** – 15.1–30°, **3** – above 30°, **4** – summits exceeding 500 m a.s.l., **5** – summits 300 to 500 m a.s.l., **6** – contour lines (100 m) with indicated altitude a.s.l., **7** – course of the divide line of European watershed between the Black Sea (Bečva river basin) and the Baltic Sea (Odra river basin), **8** – part of erosion network without actual water streams, **9** – water streams and levels of water reservoirs, **10** – springs, **11** – manifestations of vertical erosion (ravines and erosion furrows) of the Holocene age, **12** – antecedent and epigenetical valley sections or fault gap valleys; **13–14** – relicts of belevelled surfaces of the pre-Quaternary age in the territory of: **13** – Bohemian Massif, **14** – Outer Carpathians; **15** – known karst territories with subsurface cavities, **16** – landslides, rockslides and other slope deformations of larger extent, **17** – big quarries actually in operation, **18** – areas with maximum recent sinking of the Earth's surface, determined by repeated levelling, **19** – directions of the horizontal movement component, determined by repeated horizontal surveys (generalized for the eastern border of the Lower Jeseník Mts., Moravian Gate and the western border of the Podbeskydská pahorkatina hills), **20** – minimum gravity axis in the area of the Moravian Gate, **21** – main geologically established faults, frontal parts of nappes cover and other significant structural or lithological borders, **22** – photolineaments (according to the map by A. Zeman in Čížek *et al.*, 1985), **23** – gas outbursts, **24** – hydrogeological drilling hole HV-21 with maximum known concentration of ^{222}Rn 41.3 Bq l^{-1}, **25–28** – sites with macroscopically determined I (in ° MSK-64) during the earthquake of 27. 2. 1896 at Český Těšín: **25** – 4°, **26** – 5°, **27** – 6°, **28** – 7°, **29** – central part of the planned construction site of the Blahutovice nuclear power plant, **30** – church in the town of Hranice na Moravě; **31–34** morphostructural areas (see also descriptions in the text) of: **31** – Temenický fault zone (A), **32** – Odra basin (B), **33** – Moravian Gate (C), **34** – Poruba Gate (D): A1 – valley of the Velička and its tributaries in the Lower Jeseník Mts., A2 – Olšovec depression at the emptying site of the Velička valley into the Moravian Gate, A3 – Teplice fault gap of the river Bečva, its surroundings and continuation towards Kelč, B1 – NW and central part of the Odra basin, B2 – outlet of the Odra basin into the Moravian Gate and its continuation to SE, C1 – marginal structural denudation slope of the Lower Jeseník Mts. between Milenov and the Olšovec depression, C2 – structural denudation slope of the Lower Jeseník Mts. between the Olšovec depression and the Odra basin, C3 – Hradečný brook valley in the Lower Jeseník Mts. and its continuation in the Moravian Gate, then over Kunčice to Špičky, D1 – the Poruba Gate itself, D2 – outlet of the Poruba Gate into the Bečva valley mouth (and its surroundings) of the counter-current valley near Choryně.

are also dejection cones, which can be found at the outlets of erosion furrows into the valley. In its upper part, the Bradlný brook valley (with the V-cross profile) passes into a shallow and broad older valley. Ahead of this transition, the brook formed an expressive cut-off meander, whose spur is divided, from the left bank, by a depression. In the transition from the shallow into the deep-cut valley, a distinct asymmetry of its slopes can be seen – the left one is steeper and higher. A recent erosion is also witnessed by the character of the Hraničný brook (left tributary of the Velička) valley and also by the main valley of the Velička with steep slopes and impressive rock outcrops. The Velička valley follows the NW–SE direction generally, but cut-off meanders are developed in places. This valley is 120–130 m deep and has a pronounced trough-like cross profile with a flat plain up to several tens of metres wide. The sides of the Velička valley are steep, on rock outcrops even vertical, with characteristic sharp transition of slope foot into the alluvial. With the exception of the Bradlný and Hraničný brooks, all other tributaries of the stream Velička are short, with steep stream gradient; also the erosion furrows are frequent.

Area A2 – The Olšovec depression at the mouth of the Velička into the Moravian Gate: In this area is the proper foot of the Lower Jeseník Mts. shifted by about 2.5 km towards the mountains. The Olšovec depression has a rhomboidal shape, its shorter side pointing to NW and/or NNW, the longer ones towards ENE. The depression is (in its southern part) opened into the Moravian Gate and is filled, according to geological survey, by a group of sedimentary strata of the Neogene age up to 100 m thick. Its western limits are formed by a fault system, in which the Velička valley has been created. Close by the village of Lhotka, these faults limit a block formed by rocks of the Moravice group of strata (elevation point 333.4 m a.s.l.), from ridges (Hůrka 441.2 m a.s.l.) at the border of the Lower Jeseník Mts. The Velička valley has an outstanding trough-like cross profile with an expressive (about 50 m wide) alluvial plain. There are relatively steep slopes projecting sharply from this alluvial plain, practically without the foot rim of slope sediments. The eastern border of the depression is formed by marginal blocks of the Lower Jeseník Mts., whose tops are bended towards the mountain chain (e.g. elevation point Vrchy 455.6 m). The described Olšovec depression is situated within the wider crossing zone of the Potštát shear zone both with the marginal fault of the Lower Jeseník Mts. (with the local direction ENE–WSW) and the Temenický fault zone.

Area A3 – The Teplice fault gap of the Bečva river, its surroundings and continuation towards Kelč: The gap of the Bečva river at Teplice nad Bečvou presents a morphotectonic continuation of the Temenický fault zone in the western border part of the Outer Carpathians. Its development began in the late Pliocene to the oldest Pleistocene and has, actually, the shape of a canyon-like valley, 70–80 m deep. Slopes of this fault gap are relatively steep (up to 40°), at the rocky outcrops sometimes vertical. On the right side of the Teplice fault gap, the Hranice karst chasm and on its left side the aragonite cave of Zbrašov were formed. In the river bed of the Bečva, distinct CO_2 gas-outbursts can be found. In the Krkavec brook valley, the youngest erosion phase developed. The lower part of its valley has a siltstones were proved in the bore-hole Blahutovice-1. Low unit weights of these sediments (1.78 to 2.05 g . cm^{-3}) are accompanied, from the surface to a depth of 110 m, by an expressive crock-like disintegration, which is interpreted as a consequence of the action of freezing and regelation processes at least during the last 200,000 years. On the other hand, the unit weight of the Karpath sediments at depths between 342.8 and 405 m was quite inhomogeneous (1.55 to 2.38 g . cm^{-3}), reaching maximum at a depth of 435 m (2.54 g . cm^{-3}). It can be assumed, from the smoothing traces and tectonic mirrors in the rock content of drilling cores, that they were subjected to different compression degrees during the upthrusting of the overlying nappes. The decrease of the unit weight of Baden sediments gives evidence of irreversible textural alterations including the loosening of rocks and thus of the possible exertion of their large volume changes connected with the high water sorption ability of montmorillonite.

Manifestations of the recent activity of geological processes, evaluated in the context with the Baden and younger morphotectonic history, give, above all, the evidence on the course of secular development trends of the near-surface part of the Earth's crust. The denudation of rocks continues, in places also the deepening of ravines and grooves by the down-side erosion, in depressions the weathered material accumulates and the most recent dejection cones are created. Local outbursts of hot waters and carbon dioxide can be considered as direct evidences of the present-day tectonic activity; some hydrogeological drilling holes in the neighbourhood of the planned building site (for example HV-41, HV-33) revealed also a slight increase of the concentration of ^{222}Ra and natural uranium.

The seismic hazard of the investigated locality is caused by the zones of possible origin of foci on the Temenický fault, on the border fault of the Lower Jeseník Mts. (Odra Hills) and on the more remote zone of the Těšín faults. The maximum observed intensity of earthquakes at the investigated locality did not exceed, according to historical data, 8° MSK-64. The geomorphological analysis was aimed not only at the identification of the extent of the participation of endogenic processes in the relief development in the Quaternary, but namely at the detection of existence of eventual manifestations of recent (i.e. the last 10^1–10^4 years) tectonic or other significant geodynamic activities. The general morphotectonic situation has been illustrated (Kalvoda *et al.* 1989b) by means of an interpreting sketch map (Fig. 3).

The morphotectonic and other geodynamic phenomena, considered significant for the security of construction and operation of the Blahutovice nuclear power plant within the investigated region (see explanations to Fig. 3), are concentrated into several expressive relief zones. This concerns the morphostructural areas within the Temenický fault zone (A), Odra basin (B), Moravian Gate (C), and Poruba Gate (D).

Area A1 – Valley of Velička and its tributaries in the Lower Jeseník Mts.: The Temenický fault system (direction roughly NW–SE) is followed by the lower stream of the Velička river; near the village of Božkov, it passes into the valley of its right-hand tributary Bradlný brook. In the valley of the Bradlný brook, there exists a well-developed erosion network as the youngest phase of down-cutting. Expressive

Moravian Gate, a left-side horizontal movement probably took place during the Cainozoic Era, and the reactivation of some faults had, in the structural record, a downward movement character. The structural geological situation can be satisfactorily correlated also with results of gravimetric survey in the wider surroundings of the building site of the Blahutovice nuclear power plant (comp. Cidlinský, 1985). For example, the axis of gravity minimum follows the axis of depression of the Carpathian foredeep in the pre-Neogenic basement of the Moravian Gate. Moreover, the linear indications of the evaluation of detailed gravimetric measurements give supporting evidence for the existence of faults with main directions N–S, NW to SE, WNW–ESE, E–W, and NE–SW. However, for a morphotectonic analysis it is substantial which – among these indications of the buried relief of geological structures – have a response in the actual arrangement of landforms.

J. Macoun (comp. enclosure 2 in Macoun, 1989) assumes, from the general development of glacigenic sediments within the Moravian Gate, that the tectonic activity attained in the Quaternary a maximum after the Elsterian glacial stage and then, after retreat of the last continental glacier from our region, during the Saalian glacial stage. Geological processes of endogenic origin affected the relief development at the locality of the planned Blahutovice nuclear power plant as late as in the Middle and Upper Pleistocene.

The evidence has been shown at the mentioned building site (A. Zeman *et al.* in Kalvoda *et al.*, 1989b) , that Tertiary rocks in its underlying bed were subjected to long-term disintegration by periglacial processes, probably up to depths of about 100 m. Volume changes and other secondary alterations of Baden claystones and

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Fig. 2. Geomorphological sketch of locality of the Blahutovice nuclear power plant (modified according to Balatka *et al.* 1965) with designation of position of the morphotectonic map (Fig. 3) of the wider surroundings of this planned engineering work. Legend: **1–6** – landforms of the erosion-denudational relief: **1–2** – on the Variscian fold and fault structures: **1** – highlands of the Bohemian Highland in the region of the Palaeogene belevelled surface dissected by erosion and tectonically, **2** – Bohemian Highland hills in the region of Palaeogene and exhumed pre-Cretaceous belevelled surface dissected by erosion and tectonically; **3–4** – on pre-Cretaceous and disrupted fold structures of the Mesozoic and Tertiary age: **3** – highlands of ranges of the Outer Carpathians belt in the regions of Neogenic uplifts, **4** – foothills of ranges of the Outer Carpathians belt originated by erosional dissection of slightly tectonically faulted late Tertiary belevelled surfaces; **5–6** – on structures of subhorizontally deposited unstabilized sediments: **5** – tectonically induced basins filled with unconsolidated sediments of the pre-Quaternary age, **6** – flat hills with traces of strong periglacial modellation on sediments of glacial origin, **7–11** – landforms of the accumulation relief: **7** – valley alluvial plains, **8** – river terrace plains, **9** – foothill alluvial cones, **10** – detrital heaps at the foot of hills, **11** – loess blanket plateaus; **12–19** – sporadic and single landforms: **12** – morphologically expressive fault slopes, **13** – structural slopes and ridges, **14** – tors and knobs, **15** – deeply cut and fault gap valleys, **16** – denudational fronts of fold nappes, **17** – nappes blocks, **18** – caves, **19** – chasms, **20** – water streams, **21** – border of the territory of morphotectonic map (Fig. 3), **22** – Valašské Meziříčí, **23** – Hranice na Moravě.

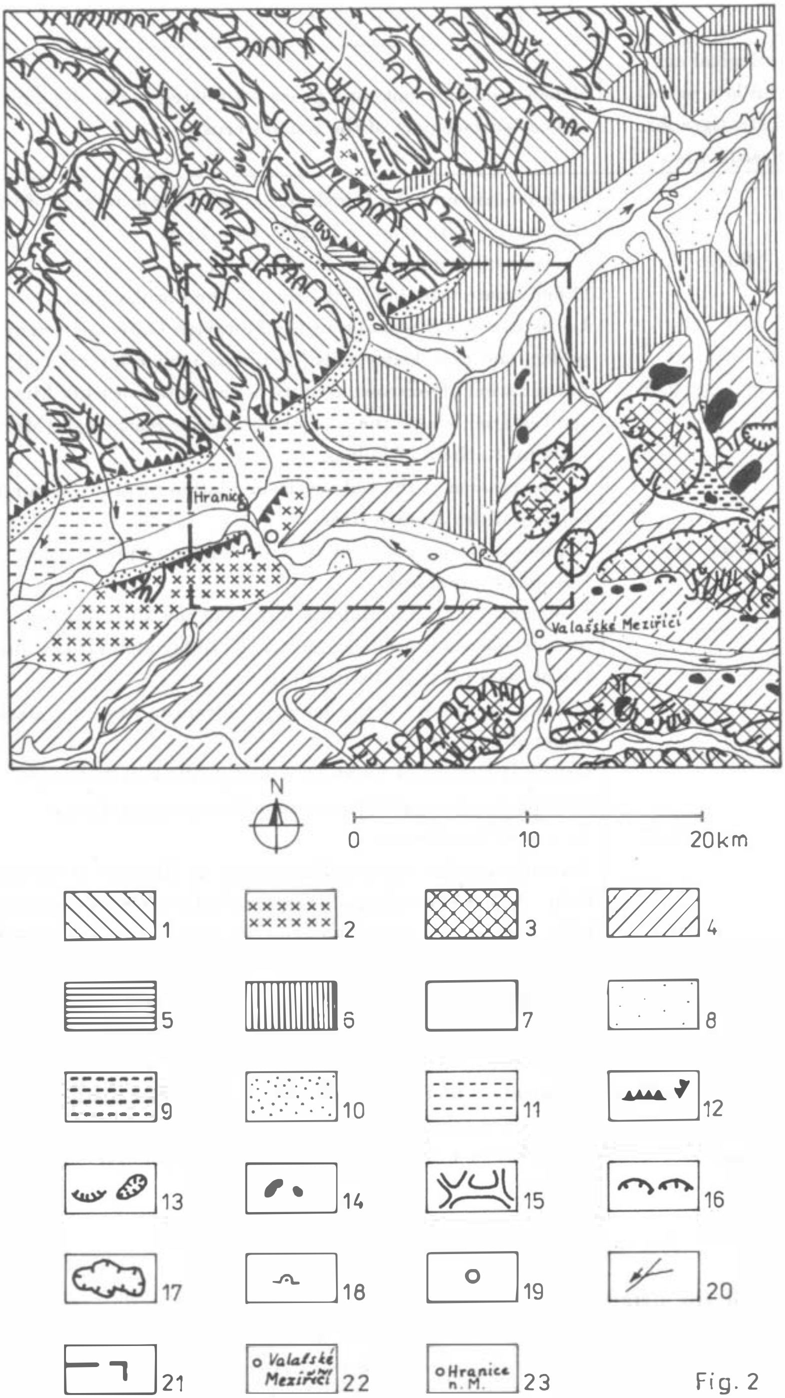
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Fig. 2

Table II, Part B (*continued*)

Geological age (in million years) and stratigraphic classification	Relief-building events and processes related to the dynamics of near-surface part of the Earth's crust
PLEISTOCENE, Middle	Sedimentation of the Radslavice accumulation terrace of the Bečva river with relative height of 15–20 m.
	Relative uplifting of the Maleník block.
	Differentiated sinking in the zone of the Poruba Gate.
	Lacustrine sedimentation in the Moravian Gate and origin of podzol and pseudogley soils (Elsterian-Saalian interglacial).
0.40 –	Termination of volcanic activity in the Lower Jeseník Mts. In the Elsterian stage, the continental glacier reached the Moravian Gate up to the S of Fulnek.
	Sedimentation of the Lukava accumulation terrace (30 m relative height) of the Morava river.
PLEISTOCENE, Lower	Beginning of development of the elevation of present-day European watershed.
	Sedimentation of the Holešov terrace of the Morava river. Origin of cone-shaped gravel accumulations, today about 70 m above the alluvial plain of the Bečva river.
	2nd and 3rd phase of the Jeseníky volcanism (during Valashian phase of orogeny).
1.67 –	Origin of the Bečva break at Teplice; differential tectonic movements of morphostructural units occurring during the whole Quaternary.
PLIOCENE, Upper	Tectonic movements, conspicuous, e.g., in the zone of the Holešov fault. Across the region of the present-day Kelčská pahorkatina hills, a river flew probably in the NE–SW direction from NW Moravia into the Dolnomoravský úval basin (gravel relics at elevation of 350 m a.s.l., about 100 m of relative height).
	Origin of relatively deep gorges, directed from the Lower Jeseník Mts. into the N part of the Hornomoravský úval basin.
3.0 –	Sedimentation of a variegated series on a lower platform in the Kelčská pahorkatina hills.
PLIOCENE, Lower	Transport of weathered material from the younger belevelled surface.

shift induced the origin of thrusts and duplex structures. Similar structural discontinuities, originally of Variscian age, tended, during Alpine orogeny, towards the reactivation of movements, which died away also in the Quaternary (Kalvoda *et al.*, 1989a,b; Demek *et al.*, 1990; Prášek *et al.*, 1991). Within the area of the

Table II

Part B. Pliocene and Quaternary

Geological age (in million years) and stratigraphic classification			Relief-building events and processes related to the dynamics of near-surface part of the Earth's crust
HOLOCENE		0.0 –	Continuing outbursts of warm water and CO_2 occurring during the whole Quaternary.
	Recent		Erosion phenomena prevail over denudation in uplands; origin of ravines and youngest dejection cones; in places, the vertical erosion involves also the bed rock.
		0.001 –	Sedimentation of slope clays at the foot of high denudation, structural, and erosion-denudational slopes and
	Upper		sedimentation of alluvial deposits.
			Peat-bogs are formed in places in the sinking Hornomoravský úval basin.
			Sedimentation of the upper part of gravels in the actual
	Lower		underlying bed of the Morava river flood.
			Differential tectonic movements of morphostructural units
PLEISTOCENE		0.01 –	(probably continuing till now).
			Loess blankets are formed under conditions of the semiarid periglacial climate, in places covering the "valley" accumulation terrace.
			During intensive denudation processes, most of the older Pleistocene sediments were removed and large dejection
	Upper		cones were formed.
			Origin of so-called "valley" accumulation terraces of main streams (Weichselian).
			At interglacial conditions (Saalian-Weichselian), the travertine mounds at Radslavice, today in places pervaded by joints and fissures of tectonic origin; at Předmostí near Přerov, terra fusca developed on older travertines.
			In connection with tectonic movements, the direction of gradient of the main river terrace changed in the Poruba Gate.
		0.12 –	The glacifluvial and glacilacustrine sedimentation took place in the foreland of the continental glacier. During the Saalian glaciation stage, the front of the continental glacier reached
	Middle		into the area of the Moravian Gate in two pushes as far as to the line Fulnek-Odry-Hynčice-Blahutovice-Hůrka.

(continued)

Table II, Part A (*continued*)

Geological age (in million years) and stratigraphic classification	Relief-building events and processes related to the dynamics of near-surface part of the Earth's crust
Eggenburg	Main thrusting of nappes of the internal part of the Outer Carpathians (Savian phase of orogeny).
22.5 –	Revival of tectonic activity (Laramian phase of orogeny) and differential block movements, namely along faults in NW–SE directions.
Oligocene	Belevelled surfaces of the Lower Jeseník Mts. and the Maleník block were dissected, in the middle Oligocene, by the 1st phase of deepening of wide shallow valleys.
38 –	Flat to hilly relief is transformed by denudation, affected by
Eocene	differential movements of blocks.
45 –	Intensive weathering and denudation of the relief at relative quiet tectonics; flysh sedimentation in the Outer Carpathians
Palaeocene	region.
65 –	Cretaceous belevelled surfaces were covered by tropical weathered material; the geosyncline of the Outer Carpathians is developed in the Upper Cretaceous.
Mesozoic	Differential block movements in the Jurassic under formation of longitudinally extended fault-related depressions and thresholds with prevailing directions NW–SE.
	Moderately dissected relief and tectonic quiet in the Triassic.
225 –	Relief denudation in arid climate conditions and relative quiet tectonics in the Permian.
	Terminated sedimentation during the regional uplift and rock folding of the Lower Jeseník Mts. (Astorian phase of orogeny), probably also horizontal shifts in the Carboniferous.
Palaeozoic	Origin of flysh rocks (kulm) and folding of sediments (Bretonian phase of orogeny) in the Upper Devonian.
	Transgression of the sea with carbonate sedimentation and submarine basic outbursts (Middle Devonian).
	Extended denudation and formation of a partially belevelled surface of the region at relative tectonic quiet in the Cambrian and the Silurian.
570 –	Regional uplift and beginning of the tectonic development of relief.

Table II. Scheme of main features of the relief development at the locality of planned building site of the Blahutovice nuclear power plant

Part A. Palaeozoic to Miocene

Geological age (in million years) and stratigraphic classification	Relief-building events and processes related to the dynamics of near-surface part of the Earth's crust
5 –	Denudation and removal of weathered rocks, during the Rhodanian phase of orogeny relative tectonic quiet.
Pont	Gradual creation of the younger belevelled surface, large denudation of relief.
Pannon	Differentiated uplift of the Lower Jeseník Mts. (Attic phase of orogeny).
10 –	Exhumation of old valleys and formation of a new valley network.
Sarmat	Removal of fossil weathered material of the belevelled surface by sea transgression during the subsidence of the SE part of the Lower Jeseník region. The Moravice river heads towards the Moravian Gate.
	Origin of the fault gap of Bečva into the Moravian Gate and then the deposition of so-called basal clastic.
	Revival of erosion and exhumation of pre-Badenian valleys.
Baden	Final overfault of flysh thrusts of the Western Carpathians (Late-Styrian phase of orogeny), differential tectonic uplifts, reactivation of (mainly) radial faults with directions NW–SE.
	Regional sinking and origin of a new foredeep inundation of the Lower Jeseník area by sea.
	Continuation of thrusting of the Outer Carpathian nappes towards NW and deformation of marginal parts of the Bohemian Massif.
	Erosive dissection of the Lower Jeseník region.
	Eastern part of the territory close to the Odra gate and the Ostrava basin are dissected by deep valleys.
Karpat	Thrusting of Outer Carpathian nappes of the Early-Styrian phase of orogeny and radial block movements. Sinking in S of the Lower Jeseník area and formation of the Carpathian foredeep.
20 –	Thrusting of the Ždanice-Subsilesian and Silesian nappes by about 30 km towards NW.
Ottnang	Horizontal slip of the Western Carpathians along the Mura-Littau-Smolenice line.
	Beginning of the development of deep valleys in the E part of the Lower Jeseník Mts.

(continued)

elements approach to contact or, in a certain section, they even pervade each other. In spite of the occurrence of the young local uplifts, the sinking features of long-term morphotectonic development of relief prevail in the detailed geomorphological record of the set of landforms of seismically active zones. It is striking to state that the epicentral zones of historical and present-day earthquakes in the locality of the Jaslovské Bohunice nuclear power plant are located within areas and zones, where greatest gradients of the Late Quaternary (?) up to recent changes of landforms of morphostructural origin have been detected.

4. BLAHUTOVICE

The locality of the planned construction site of the Blahutovice nuclear power plant has a relief of expressively polygenetic character and both in the geologic structure and on landforms, the evidences of activities of tectonic processes in the Cainozoic Era have been established. Table II illustrates the sequence of dominating relief-building events in the area of the planned construction of the Blahutovice nuclear power plant. The morphotectonic development of the studied territory (Fig. 2) was very diversified in the Tertiary involving relatively significant effects of the orogenic activity. The arrangement of the existing morphostructural (and, practically also orographic) units of the landscape was terminated in the course of the Neogene. Evidences of Quaternary tectonic activities in the relief are mostly concealed by intensive processes of exogenic origin. However, there is no doubt about the continuation of tectonic activities in the Quaternary, and their local manifestations are keeping line with the situation within the broader region of interest. Růžička (1989) proved, for example, that the group of strata of Pliocene sediments of the Hornomoravský úval basin and the Mohelnická brázda furrow, with thickness of up to 200 m, is divided in two complexes. The upper complex was settled within a substantially narrower space, connected with segments subsided along faults. Further downward movements caused local preservation of the Pliocene strata measures in thickness of 200 – 250 m. The angle discordance between sediments of the variegated series of the Pliocene age and the overlying fluviolacustrine sediments in the Určice brick factory SE of Prostějov was described by Zeman (1969), who placed its origin to the Valashian phase of orogeny. Some sites in the Hornomoravský úval basin and the Mohelnická brázda furrow exhibit proofs of tectonic activites also in the Pleistocene, namely the trend towards sinking.

At the locality and even in the surroundings of the construction site of the planned Blahutovice nuclear power plant, the existence of tectonically active faults in the Quaternary has been proved, which is a consequence of its general location within the Neoidic zone of the structural contact of the Bohemian Massif and the Western Carpathians. The Quaternary tectonic activity manifested itself both on structural discontinuities along this contact and on the fault system of directions roughly NE–SW, which proceeds from the Jeseníky part of the Bohemian Massif into the Carpathian System. Another pronounced structural phenomenon is the "Potštát shear zone", where the Neoidic movements on the right-side horizontal