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# Terrestrial and Marine Faunas from the Miocene Deposits of the Mokrá Plateau (Drahany Upland, Czech Republic) – Impact on Palaeogeography

by

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## Abstract

The karst phenomena in the Upper Paleozoic limestones, including continental and marine Miocene sediments with associated fauna, were studied in quarries worked by Mokrá Cement Works, Inc. Mokrá Plateau, southern part of the Drahany Upland (Czech Republic).
Continental sediments in the karst joints yield vertebrates indicating the upper part of the Early Miocene, especially the mammal zone MN 4. The amphibians and reptiles represent a typical assemblage from the Early Miocene climatic optimum. Mokrá quarries represent a locality with continental assemblages consisting of ecologically different taxa (a dry karst landscape with open steppe vegetation, a lacustrine environment and swampy biotopes with stagnant to moderately-flowing waters). For the first time, representatives of the Early Miocene *Varanus*, among the most early European occurrences of this genus, are documented in the eastern part of Central Europe. However, the abundance of moschids is the most interesting phenomenon, since they are probably the earliest occurrence of the genus *Micromeryx* altogether.
Marine sediments are represented by debris, sands and calcareous clays with foraminifers. The relative abundance of *Praeorbulina glomerosa circularis* and the sporadic appearance of *Orbulina suturalis* correlate the calcareous clays with the Lower Badenian, especially with the lowermost part of planktonic foraminifera Zone M6 (Middle Miocene). These data also contributed to clarification of the palaeogeographical and karstological development of the Mokrá Plateau. The model of this development from the Paleogene up to the Holocene is presented.

**Key words**: Terrestrial and marine faunas, Taphonomy, Palaeoecology, Biostratigraphy, Palaeogeography, Miocene, Drahany Upland, Czech Republic

## Kurzfassung

Die Karstphänomene der jungpaläozoischen Kalke mit den dazugehörigen kontinentalen und marinen miozänen Sedimenten mit ihrer Fauna wurden in den Steinbrüchen der Mokrá Zementwerke am Mokrá Plateau, südliches Drahany Hochland (Tschechien), studiert.
Die kontinentalen Sedimente der Karsthohlräume haben Wirbeltiere erbracht, die typisch für das späte Jungmiozän, Säugetierzone MN 4, sind. Die Amphibien und Reptilienvergesellschaftung ist typisch für das Jungmiozäne Klimaoptimum. Die Mokrá Steinbrüche sind eine Fundstelle mit kontinentalen Faunen, die sich aus ökologisch unterschiedlichen Taxa (trockene Karstlandschaft mit Offensteppen-Vegetation, Seenlandschaften und sumpfige Biotope mit stagnierenden oder langsam fliessenden Wässern) zusammensetzen. Zum ersten Mal konnten Vertreter von *Varanus*, nahe dem Erstauftreten dieses Genus, im östlichen Teil Zentral-Europas nachgewiesen werden. Das interessanteste Phänomen aber ist die Häufigkeit der Moschidae, und das möglicherweise früheste Vorkommen des Genus *Micromeryx*.
Die marinen Sedimente umfassen Klastika, Sande und kalkhältige Tone mit Foraminiferen. Das häufige Auftreten von *Praeorbulina glomerosa circularis* und das sporadische Auftreten von *Orbulina suturalis* erlauben eine Einstufung der kalkhältigen Tone in das untere Badenien, vor allem mit dem untersten Abschnitt der planktonischen Foraminiferen-Zone M6 (Mittleres Miozän). Diese Daten haben auch zur Klärung der paläogeographischen und karstologischen Entwicklung des Mokrá Plateau beigetragen. Ein Modell dieser Entwicklung vom Paläogen bis zum Holozän wird vorgestellt.

## 1. Introduction

The Mokrá open-cast mine is located about 12 km ENE of the city of Brno on the Mokrá Plateau, itself situated in the southern part of the Drahany Upland (Moravia, Czech Republic). Altogether the mine consists of three separate quarries: the western, the central, and the eastern (Fig. 1). Karst predominates in the Western Quarry, the

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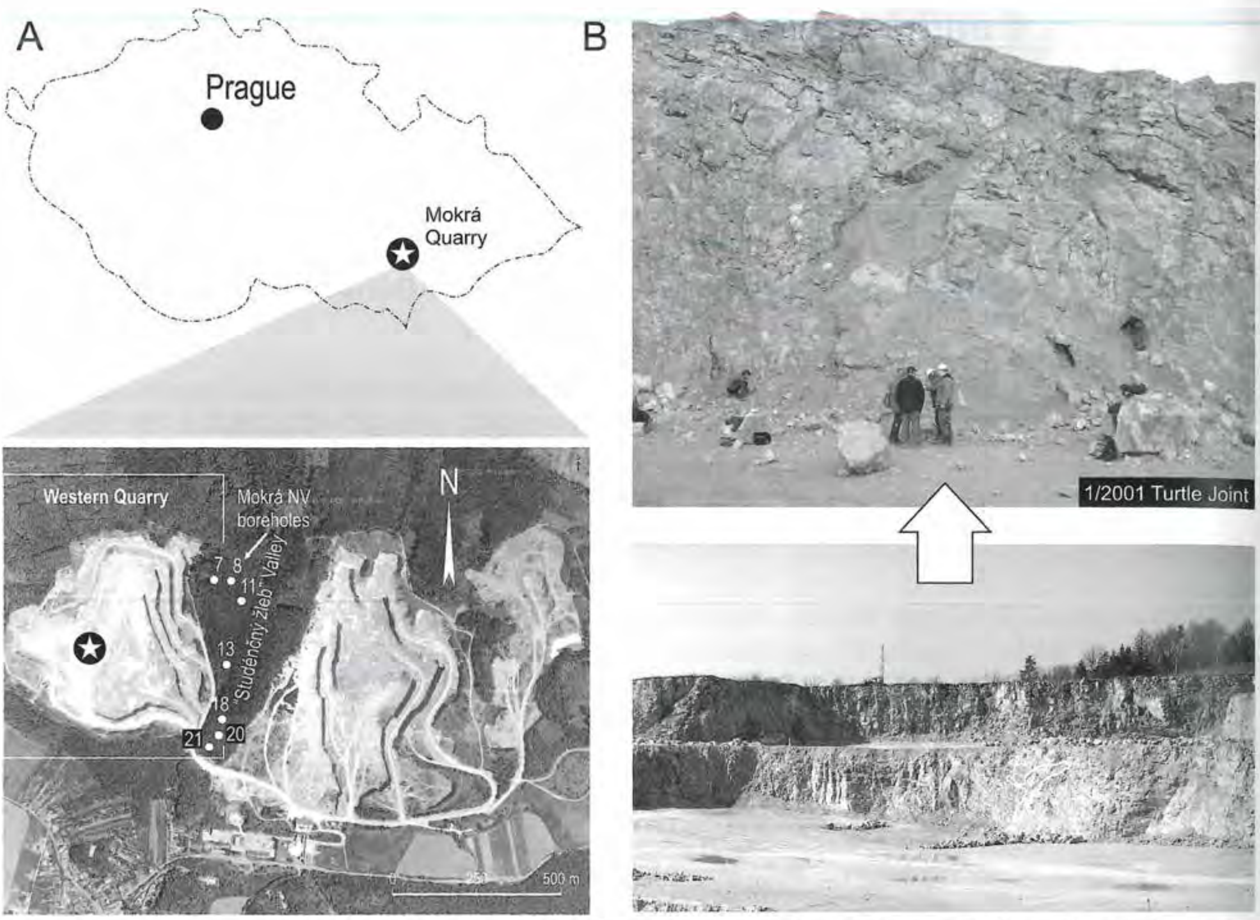


**Figure 1**: A – Localisation of the Mokrá open-cast mine in Czech Republic, position of the Western Quarry in Mokrá open-cast mine (modified after http://www.mapy.cz). Position of the 1/2001 Turtle Joint and the 2/2003 Reptile Joint is indicated by an asterisk. Numbered circles indicate positions of Mokrá NV boreholes. B – Excavation of the 1/2001 Turtle Joint at floor 380 m a.s.l. The 2/2003 Reptile Joint has been discovered only few meters on the left from the 1/2001 Turtle Joint.

centre of which is located at 49°13'54,84" N, 16°45'8,15" E, 365 m a.s.l. and it has been intensively worked for the past sixteen years. Altogether four floors have been established during this time (410 m a.s.l., 395 m a.s.l., 380 m a.s.l., and 365 m a.s.l.), with the base of the lowest floor about 60 m below the present surface of the area. Palaeontological research into fossiliferous karst joints in the Western Quarry, the 1/2001 Turtle Joint (49°13' 58,16" N, 16°45'6,07" E, floor 380 m a.s.l.) and the 2/2003 Reptile Joint (49°13'57,81" N, 16°45'5,09", floor 380 m a.s.l.) has been in progress throughout commercial extraction work; both joints are considered mined out at the present time. Research into Early Badenian marine deposits in "Studénčný žleb" Valley between the Western and Central quarries has also been carried out in association with commercial quarrying.

The Western Quarry remains one of the most important Early Miocene localities in the Czech Republic, since research into recently discovered karst joints has provided records of later Early Miocene terrestrial vertebrates that are extremely rare in this area. Studies of the palaeontological content of terrestrial deposits supplemented by knowledge of Early Badenian marine sedimentation has enabled us to outline a probable palaeogeographical and karstological development for the Mokrá Plateau.

## 2. Geological setting

The Mokrá Plateau is situated in the SE part of the Moravian Karst. It lies in close proximity to the margin fault of the West Carpathian Foredeep. In the surface picture, it edges the Paleozoic of the Drahany Upland in the north-west towards the central depression of the Miocene foredeep in the south-east. It is made up prevailingly of Devonian carbonates passing into Lower Carboniferous flysh facies (Culm). The Devonian part of the section is represented in the platform development of the Moravian Karst. Apart from some isolated occurrences of basal clastics, the Vilémovice Limestone (Givetian-Frasnian) of the Macocha Formation dominates the Mokrá Plateau here. It is made up of massive and biodetritic limestones of light colours with a rich community of cliff organisms. The overlying Líšeň Formation (Frasnian-Tournai), represented by the nodular Křtiny Limestone and dark grey biodetritic and well-bedded Hády-Říčka Limestone, occurs only sporadically. The carbonate development comes to an end in the highest parts and the sedimentation of the Březina Formation (Tournai-Visé) then sets in without interruption, signalling the onset of Culm facies. The sandstones, shales and greywackes of the Rozstání Formation (Tournai) and the greywackes and conglomerates of the

Myslejovice Formation (Tournai-Visé) ascend only at the limits of the Mokrá Plateau. The Upper Paleozoic formations are tectonically much affected by several phases of folding. They have a complicated, scale-like structure with overthrusts; postvariscan breakage has also left a system of blocks. The chemical character of carbonates, mechanical deformations and processes of pressure dissolution are the reasons for their marked inclination to karstification (HLADIL et al., 1987, REZ, 2003). Mesozoic and Paleogene sediments are absent from the whole southern part of the Moravian Karst. It can be assumed that throughout the Mesozoic and Paleogene this territory was mostly land and subject to intense weathering. The palaeogeography of the broader surroundings, however, hints that during the Upper Jurassic, Upper Cretaceous (and/or Lower Cretaceous) this territory, or parts of it, may have been periodically flooded by ingressions from the Tethys Sea. Red-brown quartz sandstones and conglomerates of continental origin occurring in the form of isolated scattered boulders are Paleogene-ascribed, but perhaps belong to the Lower Miocene.

In the Neogene the Mokrá Plateau belonged to a northwestern foreland of the Carpathian Foredeep or was involved as a direct part of its sedimentation area. Due to orogenic movements in the Flysh Belt of the Western Carpathians, marine incursions of various proportions penetrate into the Mokrá Plateau. Sediments of the Eggenburgian in the region are evidently and originally absent, as indicated by biofacial analyses of Eggenburgian sediments in the vicinity of Brno. Furthermore, the Mokrá Plateau, and especially its surroundings, were among the elevated parts of the relief during the Ottnangian, which confined possible sedimentation to only small, isolated freshwater basins lacking marked communication with the oligohaline and/or brachyhaline environments of the more southern development of the foredeep. One of these basins was attached to the north-western margin of the plateau. Its sediments fill the old E-W valley between Bílovice n. S. and Ochoz, reaching on average a surface thickness of the first ten metres. Petromict gravels, higher medium to coarse-grained, rusty brown sands and variegated clays and silts are developed as a base. The high zirconium content in those sediments is explained by HYPR (1975) through their provenance in the Culm rocks of the northern edge of the Mokrá Plateau. Fossils are scarce, represented by indeterminable fragments of the shells of freshwater Gastropoda, the teeth of teleost fishes and redeposited remains (Foraminifera, sponge spicules). The relations of these sediments to the more continuous occurrences of the Ottnangian in the foredeep south of Brno are based on the character of the spectra of heavy minerals and faunistic redepositions.

In the Karpatian, the axis of the foredeep basin is shifted more to the north-west. Marine sediments of the Karpatian north of Brno (PETROVÁ et al., 2001), together with the absence of shallow water or marginal facies in the northernmost occurrences of sediments of that age at the south-eastern margin of the Drahany Upland indicate that the north-western margin of Karpatian sediments is of denudation character and that the Carpathian Foredeep was of a markedly larger extent at that time. Theoretically, the presence of rocks of that age in the southern part of the Drahany Upland and the Moravian Karst cannot be excluded. Younger Lower Badenian sediments in the depressions of the dissected relief, however, indicate that, even if sediments of the Karpatian were originally present there, they were removed by pre-Badenian denudation. This possibility is also supported by intraclasts with Karpatian fauna in sterile clastics of probably Badenian provenance in the Western Quarry (PETROVÁ, pers. comm.).

During and after the Karpatian sedimentation, the nappes of the Outer Carpathians were shifted across the Lower Miocene of the foredeep. Marine sedimentation in the foredeep moved far to the north-west and the Badenian transgression extended at its maximum even to the central and southern parts of the Moravian Karst (PROCHÁZKA, 1899), and evidently also to the majority of the Drahany Upland, as follows from palaeobathymetric analysis of Badenian sediments (BRZOBOHATÝ, 1997). In the Mokrá Plateau, some Badenian phenomena have been revealed in the region of the Mokrá Cement Works quarries. Remnants of such sediments occur in karst joints and open faults, for example on the third floor of the Western Quarry, where they are limonitised and also contain oyster fragments (HLADIL et al., 1987). Recently, Badenian sediments were confirmed by a number of sampling boreholes in the N-S valley of the "Studénčný žleb" Valley, which is 1 km long and 300 m wide, situated between the Central and Western quarries (BRZOBOHATÝ et al., 2000). Light grey gravels and sands, yellow-brown in places, transgress the Vilémovice Limestone to a maximum thickness of 30 m, with the character of unsorted stone debris at the base. Sporadically, in the more clayey positions with hints of horizontal bedding they contain badly preserved planktonic Foraminifera: *Globigerina* ex. gr. *praebulloides*, *Globigerinoides trilobus* and *Praeorbulina glomerosa circularis*. These clastics are covered with green-grey, and calcareous clays (up to 4.6 m thick) with isolated Paleozoic pebbles. These have been found in seven sampling boreholes, although they are absent in others. Altogether, they contain a very rich microfauna (Foraminifera, Ostracoda, sponge spicules, fragments of sea urchin spines, rarely also mollusc shell fragments and otoliths). This community constitutes evidence for unequivocal dating to the Lower Badenian (see below). The Lower Badenian clays are mostly covered in deluvia up to 15 m thick, consisting of fragments and blocks of Devonian limestones and of Lower Carboniferous pebbles. A little thick loess completes the succession in places.

## 3. Material and methods

Altogether four fossiliferous karst joints were revealed in the course of research in the years 2002-2005 on floors at 410 m a.s.l., 395 m a.s.l., and 380 m a.s.l. All material from the palaeontologically richest joints, assigned 1/2001 (Turtle Joint) and 2/2003 (Reptile Joint), both from floor

380 m a.s.l., was washed in sieves (altogether 7.5 $m^3$, about 13 tons) of 2 mm, 1 mm and 0.5 mm mesh. For the purpose of simple separation of osteological material from non-calcareous sand-clayey sediments, $H_2O_2$ in aqueous solution was employed (optimum concentration corresponding approximately to the ratio 1 ($H_2O_2$ 30 %): 100 ($H_2O$). After the clayey component had dissolved, a regulated stream of running water served for final washing through. A Leica MZ 16 microscopic system was used for the purposes of examination and illustration of the material, together with a drawing tube and a Leica DFC 480 digital camera (5 mpx). The material is held in the collections of the Moravian Museum, Brno.

**Abbreviations in plates**:

MMB-Ge – Department of Geology and Palaeontology, Moravian Museum, Brno

IGS – Institute of Geological Sciences, Masaryk University, Brno

## 4. Results

### 4.1. Taphonomic studies

In the continental sediments, all the material gathered is of allochthonous origin. Most of the bones are very fragmentary, largely due to their being rolled by the current in a stream. The surface of the bones is mostly white, with some honey-coloured to lead-grey. Their surface is quite smooth, without traces of corrosion. Postdeposition deformation of bones was not found. The less damaged bones, mainly those of small vertebrates, were comparatively easy to determine thanks to a lower degree of rolling and consequent preservation of the finer structures (transverse processes and joint protrusions). Osteological material was freely dispersed in the sand-clayey sediment. Even in places with higher concentrations of bones, the various skeletal elements were not preserved in their anatomical positions, which indicates that the material had been transported over a small distance. Post-mortem disintegration appears to have taken place before the material was swept into extended joints. This is also confirmed in some cases by, for example, alveolae filled with clay and the foramen vertebrale in one vertebra, in which it was possible to identify red-brown soil, pointing to its original deposition. Numerous (and also larger) sharp-edged fragments of limestone indicate the dynamism of the environment during sedimentation, something which is also confirmed by the frequent disintegration of long bones into small, indeterminable fragments.

It is very probable that the small vertebrate material originates only from local animals, concentrated on an otherwise dry karst platform into karst depressions (dolines) characterised by relatively higher moisture levels. This phenomenon, quite common in the herpetofauna, is underlined by the fact that larger mammals are represented here predominantly by subadult individuals (Ivanov & Musil, 2004).

Most of the material found derives from only small and medium-sized vertebrates. The isolated find of a large second finger phalange (cf. *Brachypotherium* sp.) in the 2/2003 (Reptile Joint) indicates the presence of at least one sizeable mammal. Also exceptional are two bones from medium-sized birds. The bones of medium-sized mammals are all fragmentary, with the exception of some phalangae, tarsal or carpal elements. The great majority of the long bones of mammal extremities are transversally broken, with the fractures not necessarily in line. Longitudinally broken extremity bones are mainly cracked along the whole length of the diaphysis, and in two cases the fracture has even passed across existing epiphyses. The branches of two mandibles were also longitudinally broken. The transverse breaking of bones took place in the course of the deposition of the osteological material, while the longitudinal breakage appears to be a result of postdeposition contraction as the sand-clayey sediment dried out. Some fresh breakages may be associated with the collection process. Largely sharp edges on the breaks indicate short transport and swift deposition. In isolated cases, traces of chemical corrosion were found on the surfaces of two small bones of lower vertebrates (fishes); the same held true for fragments of small mammal bones (associated with rounded edges to the breaks).

In some small bones, possible crushing in the jaws of predators cannot be excluded (at least one fragment). On the surface of a compact bone, made up of several fragments, it was possible to distinguish a round imprint of about 1-2 mm circumference, pointing unequivocally to vertical pressure from approximately conical teeth. The predators in question are varanid lizards with pleurodont dentition, keel-shaped teeth inclined to the rear, in specimens from the Western Quarry. Imprints of teeth were found in three bones, but in only one they were completely unambiguous. These are the first finds of varanid lizard tooth imprints on the surface of bones of prey species, tracing the predation activities of the group.

Various ontogenetic stages are represented in the osteological material. Juvenile mammal individuals are relatively well represented. This was established partly on the basis of dentition, with minimally abraded crowns, but mostly based on the presence of the separated epiphyses on long bones. Among the herpetofauna, juvenile individuals were distinguished to a lesser extent by the presence of small bones with incompletely developed structures.

The proportions of the types of bones found in the herpetofauna are dependent on their taxonomic grouping. In caudate and squamate reptiles, fragmentary vertebrae predominate. The most frequently preserved remnants of cranial bones were assigned to representatives of the genus *Chelotriton*, which is characterised by the strongly developed sculpture of the dermal bones of the skull. In contrast, anuran fragments were represented rather by the presence of more resistant remnants of extremities and some cranial bones (frontoparietalia, maxillae) than by the gracile vertebrae.

Small mammals are represented above all by finds of teeth or fragments of mandible. Medium-sized mammals appear

uniformly in finds of skull fragments (maxillae, mandibles), mostly in joint 1/2001 (Turtle Joint), and further in free teeth from both lower and upper jaws and bones of the postcranial skeleton.
From all the above, it follows that predation and transport played major roles in dictating the final pattern of the faunistic community revealed.

## 4.2. Palaeoecology

The relatively limited area of the Mokrá Plateau is formed by a limestone basement bordering on areas made up of conglomerates, shales and sandstones. These types of bedrock have quite different characteristics. While the limestone surface of the karst plateau was always dry, we may assume the presence of still, stagnant or slow-moving water in the remaining rocks. Laying next to one another, these different types of bedrock dictate the faunal makeup and consequently the balance of predator and prey.
The character of the sand-clayey sedimentation in the karst joints reveals the close proximity of a lacustrine environment. An absence of ostracods and a scarcity of gastropods indicate the presence of poor oligotrophic to mesotrophic nutrient conditions. A diversified aquatic amphibian (Pl. 1) fauna (*Mioproteus* sp., *Triturus roehrsi*, *Triturus* cf. *marmoratus*, *Chioglossa meini*, *Mertensiella mera*, *Mertensiella* sp., and *Rana* sp. (synkl. *Rana esculenta*), terrestrial tortoises of the families Testudinidae and Emydidae and squamate reptiles (*Natrix* sp., cf. *Neonatrix* sp.), indicate the presence of moist to swampy biotopes with stagnant to moderately-flowing waters. However, broadly terrestrial forms also occur in the Western Quarry, as shown (Pl. 1) by the presence of the genus *Chelotriton*, the adults of which probably inhabited humid biotopes with dense vegetation (Estes, 1981) in similar fashion to *Tylototriton*, the recent genus closely related to extinct *Chelotriton*. Böhme (2002) opts to assume more arid biotopes because of the occurrence of numerous *Chelotriton* remains, primarily in karst joints. Terrestrial amphibians are represented by *Pelobates* sp. (Pl. 1), the extant representatives of which are usually adapted to relatively arid climates and exhibit a preference for sandy or sandy loam soil substrates. Representatives of the genus *Bufo* may also be considered terrestrial forms. Terrestrial reptiles are represented by the genera *Varanus*, *Pseudopus*, *Lacerta*, *Coluber*, and *Vipera*.
The absence of some aquatic amphibians (*Triturus* cf. *marmoratus*, *Chioglossa meini* and representatives of the genus *Mertensiella*) in 1/2001 Turtle Joint indicates a somewhat more arid environment, an assumption also supported by the relatively high occurrence of *Vipera* sp. ("Oriental vipers" group).
The herpetofauna from the Western Quarry is an assemblage typical of the warm-humid stage within the Early Miocene climatic optimum, when average mean annual temperatures reached about 20°C in Central Europe (Böhme, 2003). A brief appearance of squamate reptiles of the family Cordylidae at several central European sites from the beginning of MN 4 (Petersbuch 2) to the beginning of MN 5 (Puttenhausen) reveals a mean annual temperature (MAT) that did not fall below 17.4 °C during this period (Böhme, 2003). Numerous varanid remains and boid snakes (*Bavarioboa* cf. *hermi*) discovered in 1/2001 Turtle Joint (Pl. 2) also testify to a markedly warm environment. *Bavarioboa hermi* has been reported only from the Biozone MN 4 sites and remains in quantity are known only from Petersbuch 2 (Szyndlar & Schleich, 1993, Szyndlar & Rage, 2003).
Ecological characterization of ground dwellers *Democricetodon* and *Megacricetodon* is considered to be similar to *Eumyarion* (Fahlbusch, 1996). Although *Eumyarion* was more likely adapted to semiaquatic environments, burrowing *Democricetodon* indicates somewhat drier warm and humid conditions above the groundwater (Daxner-Höck, 2003). *Megacricetodon* could indicate open-forest conditions but due to the broad geographic and chronologic distribution of this genus it is impossible to precise its habitat. *Melissiodon* was probably arboreal hamster indicating forested conditions (Agustí & Antón, 2002).
Most of the medium-sized mammals (about 60%) belong to the family Cervidae (*Lagomeryx* – Pl. 2, *Procervulus*). Cervid dominance indicates a warm and humid evergreen forest (Rössner, 2004). The presence of abundant Moschidae (genus *Micromeryx* – Pl. 2) indicates a somewhat different situation. The long metapodials of this genus are usually typical of bovids inhabiting open countryside. Tragulids are absent. Given the amount of material studied it is clear that this absence is real. This situation is quite normal for the karst areas of the southern part of Central Europe. If tragulids are present, they are always extremely rare. Their absence indicates the dry landscape that is typical of karst areas. The tragulids favoured marshy, wooded and swampy habitats with standing water. While we must assume the presence of streams and small isolated lakes in the surrounding non-limestone areas, the limestone of the Mokrá Plateau was a karst habitat; open water was absent and relatively dry conditions prevailed.
It follows that a warm climate predominated in this area during the terminal stage of the early Miocene. The Mokrá Plateau was typical for its dry karst landscape in open steppe rather than being a continuously forested area. The situation changes sharply not far from the Western Quarry, with a forested habitat and the possible presence of a lake with sandy beaches. Microclimatic conditions in the karst area of the Mokrá Plateau confirm the presence of a warm environment that was generally more arid than average for the second half of the Ottnangian and the beginning of the Karpatian (MN 4).

## 4.3. Biostratigraphy

**Marine sediments**. Greenish-grey nonlaminated calcareous clays found in NV – boreholes 7, 8, 11, 18, 20, and 21 contain a rich foraminiferal fauna (Tab. 1). Agglutinated foraminifers are scarce, whereas rotaliids and lagenids are relatively diversed. Planktonic foraminifers

| Foraminifers | Boreholes | | | | | | |
|---|---|---|---|---|---|---|---|
| | NV-7: 7.8m | NV-8: 2.6m | NV-11: 5.6-5.7 m | NV-13: 32.8 m | NV-18: 3.25 m | NV-20: 4.6-4.7 m | NV-21: 3.6 m |
| *Martinotiella communis* (D'ORBIGNY) | — | — | — | — | — | — | R |
| *Martinotiella karreri* (CUSHMAN) | — | — | — | — | — | R | R |
| *Spirorutilus carinatus* (D'ORBIGNY) | — | — | — | — | — | — | R |
| *Sigmoilinita tenuis* (CZJZEK) | — | — | — | — | — | R | — |
| *Ammonia vienensis* (D'ORBIGNY) | — | — | R | — | — | — | — |
| *Amphicoryna badenensis* (D'ORBIGNY) | — | — | — | — | — | — | R |
| *Bolivina dilatata* REUSS | — | — | — | — | — | R | — |
| *Bolivina hebes* MACFADYEN | — | — | — | — | R | R | — |
| *Bolivina aff. pokornyi* CICHA & ZAPLETALOVÁ | — | — | — | — | — | R | — |
| *Cassidulina laevigata* D'ORBIGNY | — | — | — | — | R | R | R |
| *Bulimina buchiana* D'ORBIGNY | — | — | — | — | C | — | R |
| *Bulimina striata mexicana* CUSHMAN | — | — | — | — | R | R | R |
| *Cancris auriculus* (FICHTEL & MOLL) | R | — | — | — | — | — | — |
| *Cibicidoides austriacus* (D'ORBIGNY) | R | — | — | — | — | — | — |
| *Cibicidoides ungerianus ungerianus* (D'ORBIGNY) | R | R | — | — | R | — | — |
| *Dentalina acuta* D'ORBIGNY | — | — | — | — | — | — | R |
| *Dimorphina akneriana* (NEUGEBOREN) | — | R | — | — | R | R | — |
| *Guttulina austriaca* D'ORBIGNY | — | — | — | — | R | — | — |
| *Heterolepa dutemplei* (D'ORBIGNY) | A | R | — | — | R | R | R |
| *Laevidentalina elegans* (D'ORBIGNY) | — | — | — | — | — | R | R |
| *Pygmaeseistron hispidum* (REUSS) | — | — | — | — | — | R | — |
| *Lenticulina calcar* (LINNÉ) | — | — | — | — | — | — | R |
| *Lenticulina cultrata* (MONTFORT) | — | — | — | — | R | — | — |
| *Lenticulina inornata* (D'ORBIGNY) | — | — | — | — | — | R | R |
| *Lobatula lobatula* (WALKER & JACOB) | — | — | — | — | — | — | R |
| *Marginulina hirsuta* D'ORBIGNY | R | R | — | — | — | — | — |
| *Melonis pompilioides* (FICHTEL & MOLL) | C | — | — | — | R | R | R |
| *Nodosaria hispida* (SOLDANI) | — | — | — | — | C | R | R |
| *Nonion commune* (D'ORBIGNY) | R | — | R | — | — | — | — |
| *Pappina parkeri* (KARRER) | — | — | R | — | — | — | — |
| *Pullenia bulloides* (D'ORBIGNY) | R | — | — | — | R | R | R |
| *Siphonodosaria verneuilli* (D'ORBIGNY) | — | — | — | — | — | R | — |
| *Sphaeroidina bulloides* D'ORBIGNY | — | — | — | — | — | R | C |
| *Stilostomella adolphina* (D'ORBIGNY) | — | — | — | — | R | — | — |
| *Uvigerina pygmoides* PAPP & TURNOVSKY | — | — | — | — | — | R | R |
| *Valvulineria complanata* (D'ORBIGNY) | C | — | — | — | — | — | — |
| *Globigerina bulloides* D'ORBIGNY | R | — | — | — | C | C | C |
| *Globigerina diplostoma* REUSS | — | — | — | — | C | C | C |
| *Globigerina praebulloides* BLOW | R | — | — | R | C | C | C |
| *Globigerina tarchanensis* SUBBOTINA & CHUTZIEVA | — | — | — | R | — | — | — |
| *Globigerinoides bisphericus* TODD | C | — | — | — | C | C | C |
| *Globigerinoides quadrilobatus* (D'ORBIGNY) | — | — | — | — | R | R | R |
| *Globigerinoides trilobus* (REUSS) | R | C | — | R | C | A | A |
| *Orbulina suturalis* BRÖNNIMANN | — | — | — | — | — | — | R |
| *Praeorbulina glomerosa circularis* (BLOW) | — | R | — | R | R | R | C |
| *Globoturborotalia druryi* AKERS | — | — | — | — | R | — | — |
| *Globorotalia bykovae* (AISENSTADT) | — | — | — | — | A | A | A |
| *Paragloborotalia ? mayeri* (CUSHMAN & ELLISOR) | — | — | — | — | R | R | — |

**Table 1**: Distribution of foraminifera in the NV boreholes ("Studénčný žleb" Valley between the middle and western quarries). Abundance: R = rare, C = common, A = abundant.

| Order | Family | Taxon | 1/2001 Turtle Joint | 2/2003 Reptile Joint |
|---|---|---|---|---|
| Proteoidea | Proteidae | *Mioproteus* sp. | — | R |
| Salamandroidea | Salamandridae | *Chelotriton* sp., type I | A | A |
| | | *Chelotriton* sp., type II | R | R |
| | | *Triturus roehrsi* HERRE, 1955 | R | R |
| | | *Triturus* cf. *marmoratus* (LATREILLE, 1800) | R | C |
| | | *Triturus* sp. (*T. marmoratus* - *T. vittatus* group) | — | C |
| | | *Chioglossa meini* ESTES & HOFFSTETTER, 1976 | — | R |
| | | *Mertensiella mera* HODROVÁ, 1984 | — | C |
| | | *Mertensiella* sp. | — | R |
| | | Salamandridae gen. et sp. indet. | C | C |
| Anura | Pelobatidae | *Pelobates* sp. | C | R |
| | Ranidae | *Rana* sp. (synkl. *Rana esculenta* LINNAEUS, 1758) | C | R |
| | Bufonidae | *Bufo* sp. | — | R |
| Squamata | Amphisbaenidae | *Blanus* sp. | — | R |
| | Lacertidae | *Lacerta* sp. (small form) | R | R |
| | Anguidae | *Pseudopus* sp. | R | R |
| | Varanidae | *Varanus* sp. | C | C |
| | Boidae | *Bavarioboa* cf. *hermi* SZYNDLAR & SCHLEICH, 1993 | R | — |
| | | Boidae gen. et sp. indet. | R | R |
| | Colubridae | *Coluber* sp., type I | R | R |
| | | *Coluber* sp., type II | R | — |
| | | cf. *Neonatrix* sp. | — | R |
| | | *Natrix* sp., type I | R | — |
| | | *Natrix* sp. | R | R |
| | Viperidae | *Vipera* sp. („Oriental vipers“ group) | C | C |
| | | *Vipera* sp. („European vipers“ group) | — | R |
| Carnivora | Mustelidae | Mustelidae gen. et sp. indet. | R | — |
| | Felidae | Felidae gen. et sp. indet. | R | — |
| Artiodactyla | Cervidae | *Lagomeryx* sp. | A | R |
| | | *Procervulus* sp. | C | R |
| | Moschidae | *Micromeryx* sp. | A | R |
| | Suidae | *Hyotherium* sp. | — | R |
| | Tayassuidae | *Aureliachoerus aurelianensis* (STEHLIN, 1900) | R | — |
| Perissodactyla | Rhinocerotidae | ? *Brachypotherium* sp. | R | — |

**Table 2**: Distribution of amphibians, squamate reptiles, and mammals in karst phenomena (1/2001 Turtle Joint; 2/2003 Reptile Joint) of the Mokrá Plateau. Abundance: R = rare, C = common, A = abundant.

are dominant in some levels of NV – boreholes 18, 20 and 21. Only one specimen of *Orbulina suturalis* was found, whereas *Praeorbulina glomerosa circularis* occurs nearly continuously in all samples. This could justify a biostratigraphic correlation with the lowermost part of planktonic foraminifera Zone M6. This position seems to be supported by the relatively abundant occurrence of *Globigerinoides bisphericus*, *G. trilobus*, and *Globorotalia bykovae*, together with the rare *Paragloborotalia* ? *mayeri*. It shows a possible correlation with the uppermost part of the Grund Formation in Lower Austria (CICHA et al., 2003, CORIĆ & RÖGL, 2004), also corresponding with the lower part of the M6 Zone (CORIĆ et al., 2004) and the middle part of the Langhian in standard chronostratigraphy (Tab. 3).

**Continental sediments.** Both karst joints studied (1/2001 Turtle Joint and 2/2003 Reptile Joint) contain about the same assemblage of small and medium-sized mammals and it is therefore possible to consider both joints to be of equal age. Preliminary results from the determination of small mammals performed by M. Sabol (Dept. of Geology and Palaeontology, Comenius University, Bratislava) confirm the formerly assumed stratigraphic age corresponding to MN 4 (IVANOV & MUSIL, 2004). Rodents of the genus *Melissiodon*, as well as early modern representatives of cricetids (*Megacricetodon*, *Democricetodon*) were found in both joints (1/2001 Turtle Joint; 2/2003 Reptile Joint). Their co-occurrence indicates the correlation of the Western Quarry assemblages with the upper part of the Early Miocene, MN 4 (MEIN, 1999). The last representatives of the melissiodontids dissapear from Europe and the first representatives of the cricetids appear as Asiatic

immigrants at this time (MEIN, 1999). The medium-sized mammals (Tab. 2) correspond to MN 4 to MN 6 in most cases. In this context, the presence of *Micromeryx* is of particular interest because the first occurrence of *Micromeryx* has been recorded as late as MN 5 from the Greek-Iranian Province to Central Spain. This genus dispersed rapidly over all of Western and Central Europe during the Middle Miocene and persisted in this range even until the Late Turolian (AGUSTÍ & ANTÓN, 2002). The presence of *Micromeryx* in the eastern part of Central Europe as early as MN 4 indicates a possible earlier appearance of this Asiatic taxon in this area.
Although biostratigraphic application of herpetological taxa can be considered only as extremely limited, the possible occurrence of *Bavarioboa hermi* (Tab. 2), which is known only from central European MN 4 localities, is in line with the proposed stratigraphic position of the 1/2001 Turtle Joint.

## 5. Continental Cenozoic development of the Mokrá Plateau

The continental Cenozoic development of the Mokrá Plateau can be divided into two different stages: the period before the Badenian transgression and the period after the regression of the Badenian Sea.
Dating to before the Badenian transgression, vertical karst joints are to be found all over the Mokrá Plateau, ending at a depth of about 30 m from the current surface without having formed horizontal cave corridors. The quarry floors through those joints are based at altitudes of 410 m a.s.l., 395 m a.s.l., and 380 m a.s.l. In isolated cases these joints are also weakly developed on the floor at 365 m a.s.l. These were formed by autochthonous surface-water corrosion of vertical cracks. Waters from precipitation permeated the dolines into the vertical joints, widening them by dissolving activity, but did not create horizontal cave systems. The connection with the dolines is documented by palaeontological findings. Karstification to any important extent at that time is missing altogether at the altitude of 365 m a.s.l.
The vertical fossiliferous joints have various kinds of sedimentary filling. In the southernmost part of the Mokrá Plateau, this consists of fine, sandy clays of lacustrine origin with mammal Zone MN 4 (Ottnangian – Karpatian) fauna indicating the proximity of a freshwater basin. It cannot be excluded that sandy clays originated in a freshwater basin once situated on the north-western margin of the Mokrá Plateau between today's villages of Bílovice n. Svitavou and Ochoz. The north-to-south drainage of that area at the time would seem to indicate this. Further to the north-west, the joints no longer hold clays, but are filled with reworked terra rossa soil, with fragments of limestones and also, in places, small mammal bone fragments from the Early Biharian period (FEJFAR & HORÁČEK, 1983). An interpretation is at hand, in that the two types of joint are isochronous, but the lacustrine sediments were removed before the Early Pleistocene in the north-west.
Besides vertical joints, the Western Quarry also has a horizontal cave, the Mokrská cave, not particularly deep below the present surface and of relatively generous dimensions. It is about 25 m high, with a width of 3-6 m (VÍT et al., 2001, KOS, 2004), and is completely filled with palaeontologically sterile fluvial sediments which, towards their overlying beds, become progressively finer and appear to have been laid down in fits and starts of sedimentation, and very quickly. Their coarse fraction indicates local origin, rather than materials from near the Mokrá Plateau, whereas the source region for the clastics underlying the Badenian clays in the "Studénčný žleb" Valley have a far broader provenance (NEHYBA, 2001). The petrographic sedimentation pattern points Mokrská cave not being part of an extended cave system, but rather of regional importance. It has yielded only relatively poor finds of fragments of turtle carapaces. These lay in grey-green clay above red to rusty loams in the top part of its Eastern branch (KOS, 2004). Remnants of turtle carapaces also occur in vertical karst joints among the MN 4 fauna. If they would prove to be taxonomically close enough, something that cannot be excluded, the fluvial sediments of the Mokrská cave would represent the earliest terrestrial sediments in the region. This would shift the age of establishment for the karstification of the Mokrá Plateau to pre-Ottnangian (? Eggenburgian).
East of the Mokrská cave, in the Western Quarry, there is a relatively wide, canyon-like erosion rock cut, filled with sterile, brown-yellow sands and gravels, probably from the Lower Badenian. They are interpreted as sediments of a shallow, delta-shaped system, into which, judging from the conspicuous morphological margin, water of relatively large transport capacity emptied into a deposition basin. The associations of heavy minerals of these sediments are very similar to those of the Lower Badenian clastics in the surroundings of Brno (NEHYBA, 2001).
After the Badenian, what remained of the prebadenian relief was preserved. Only valleys and underground cave corridors had to undergo changes. The entire area NW of the foredeep marginal fault rose up and subsequent erosion removed the marine sediments almost entirely. The north of the Mokrá Plateau developed in a different way than the southern part. Successive changes from the south to the northwest and north suggest that after the Badenian regression came marked changes associated with a lowering of the erosion bases in the present-day Hostěnice Valley and Říčka Valley. Until the Badenian transgression, the vertical karst joints of the entire Mokrá Plateau developed in similar fashion to that of today's joints in the southern part of Mokrá Plateau. Later, in the northern part of the plateau, the sediments were removed from the karst joints. These became deeper and horizontal cave corridors were created. At the same time, the endokarst in the southern part of the Mokrá Plateau remained unchanged. The original N-S drainage reversed direction after the Badenian regression. Before the Lower Badenian transgression, the "Mechový závrt" Doline, situated in the northern part of the Mokrá Plateau, was probably originally similar to

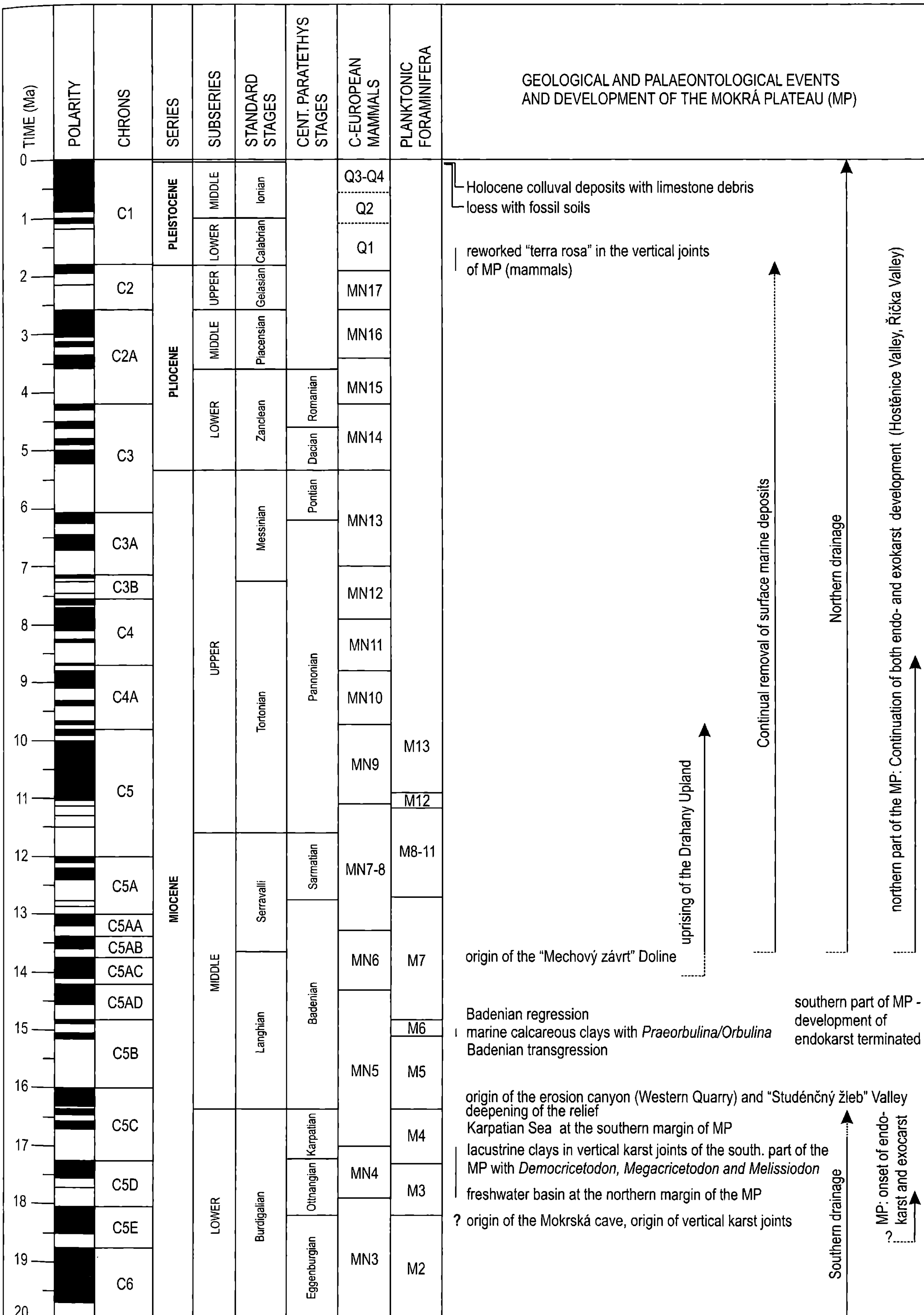


**Table 3**: Standard chronostratigraphy, magnetostratigraphy, biostratigraphy (modified after DAXNER-HÖCK et al., 2004; STEININGER, 1999; HORÁČEK & LOŽEK, 1988) and geological and palaeontological events in the Mokrá Miocene-Pleistocene section.

the joints in the southern part of the plateau. At present it is uncovered to a depth of about 45 m and runs out to form horizontal cave corridors (at present-day altitudes of 390-354 m a.s.l.; Kos, 2004). In the northern part, a substantial rejuvenation of the vertical joints begins after the Badenian. The opinion that the development of the "Mechový závrt" Doline dates to the Pliocene (Kos 2004) is perfectly acceptable. However, the process of its deepening had already begun after the Badenian regression. It was the Lower Badenian transgression that interrupted the previous development of this region. The subsequent regression markedly affected and changed the development of the karst phenomenon, not only in the Mokrá Plateau but possibly over a far wider area.

The data above suggest that the karst phenomenon already existed on the Mokrá Plateau during the Ottnangian. During this era, dolines developed that emptied into vertical joints without giving rise to horizontal cave corridors. Their base (365 m a.s.l.) nearly coincides with the "Studénčný žleb" Valley base (372 m a.s.l.) and is deeper as the Mokrská cave base. The dolines filled up with sediments carried by the Ottnangian freshwater basin running at the northern margin of the Mokrá Plateau. The erosional karst valley and its sedimentary filling is of far more recent origin, probably connected with the Lower Badenian transgression. Loess with fossil soils and Holocene colluvium with limestone debris fill the surface depressions and represent the most recent sediments on the Mokrá Plateau.

In contrast to other parts of the Moravian Karst, the sediments of the southern part of the Mokrá Plateau contain Miocene terrestrial palaeontological remains and were not fully removed from the area. The southern drainage changed to northern after the Badenian regression. Underground waters found different paths and only the sediments filling the karst phenomena in the southernmost part of the Mokrá Plateau remained. A more precise model of the Neogene development of the Mokrá Plateau follows from their relationships and the testimony of the fossil fauna (Tab. 3).

## 6. Conclusions

The karst phenomena in the Upper Paleozoic limestones, including continental and marine Miocene sediments with associated fauna, were studied in quarries worked by Mokrá Cement Works a.s. in the past ten years. The relationships of the karst phenomena, sediments and faunas in time and space facilitate a synthesis view of palaeogeographical development in the southern part of the Moravian Karst and the onset of some continental assemblages in Central Europe. Several concluding remarks are as follows:

• Continental sediments in the karst joints yield vertebrates indicating the upper part of the Early Miocene (MN 4). The amphibians and reptiles represent a typical assemblage from the Early Miocene climatic optimum. Both "ancient" non-erycine Boidae (Boidae gen. et sp. indet., *Bavarioboa* cf. *hermi*) and "modern" representatives of the Colubridae and Viperidae are present here. A generally slow evolution of herpetological species is emphasized, with the presence of species such as *Triturus* cf. *marmoratus* being morphologically not unambiguously different from their present-day equivalents. For the first time, representatives of the Early Miocene *Varanus*, among the earliest European occurrences of this genus, are documented in the eastern part of Central Europe. However, from the palaeogeographical point of view, the abundance of moschids is the most interesting phenomenon, since they are probably the earliest occurrence of the genus *Micromeryx* altogether.

• During the accumulation of the osteological remains analysed, the Mokrá Plateau was a typical dry karst landscape with open steppe vegetation and few trees and shrubs. A quite different environment, with a forested habitat based on different rock, was situated in close proximity to the plateau. Both sandy-clayey sediments in karst joints and some species of vertebrates also indicate a nearby lacustrine environment and swampy biotopes with stagnant to moderately-flowing waters. This emphasizes the importance of the Mokrá quarries as a locality with continental assemblages consisting of ecologically different taxa.

• Marine sediments are represented by debris, sands and calcareous clays with foraminifers occurring primarily in the "Studénčný žleb" Valley, which is between the Western and Middle quarries. The relative abundance of *Praeorbulina glomerosa circularis* and the sporadic appearance of *Orbulina suturalis* correlate the calcareous clays with the lowermost part of planktonic foraminifera Zone M6 and with the uppermost part of the Grund Formation (Lower Badenian) in the regional stratigraphical sense.

• These data also contributed to clarification of the palaeogeographical and karstological development of the Mokrá Plateau, neither of them well known even today. The model is presented as follows: During the Paleogene the Mokrá Plateau was a dry area of land with drainage to the south. Vertical joints, dolines and the Mokrská cave probably originated in the Eggenburgian-Ottnangian. In the Ottnangian, the northern part of the plateau bordered on a small lacustrine basin. From time to time its sediments, together with the bones of vertebrates, were carried into the dolines by water. A deepening of the relief took place before the Badenian transgression and the erosional canyon in the Western Quarry and the "Studénčný žleb" Valley was formed. At the beginning of the Lower Badenian transgression these were successively filled up with debris and sands. Finally, a transgression associated with calcareous clay sedimentation covered the entire southern part of the Moravian Karst. After the Badenian regression, the entire area north of the margin fault of the Carpathian Foredeep rose up and the erosional base of rivers north and northwest of the Mokrá Plateau was lowered. In the northern part of the plateau, drainage turned to the north, older sediments were removed from joints and dolines and the latter deepened. The creation of horizontal corridors took place at the same time, whereas the endokarst in the southern part of the plateau remained without marked changes. During the Early Pleistocene some joints were filled up with terra rossa, which yielded an Early Biharian fauna. In the Late Pleistocene, depressions were covered with loess and the development of the entire region was completed by the formation of a thin colluvium (~ 15 m) in the Holocene.

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# PLATE 1

## Amphibians from the Mokrá Plateau, Western Quarry, MN 4, 1/2001 Turtle Joint and 2/2003 Reptile Joint

### *Chelotriton* sp., type I

Fig. A-F A, B – right frontal (2/2003 Reptile Joint; MMB-Ge29641/5), C-D – atlas (2/2003 Reptile Joint; MMB-Ge29651/3), E, F – anterior precaudal vertebra (2/2003 Reptile Joint; MMB-Ge29652/12).

### *Pelobates* sp.

Fig. G-J G, H – left frontoparietal (1/2001 Turtle Joint; MMB-Ge29677/1), I, J – right maxilla (2/2003 Reptile Joint; MMB-Ge29679/3).

### *Rana* sp. (synkl. *Rana esculenta* LINNAEUS, 1758)

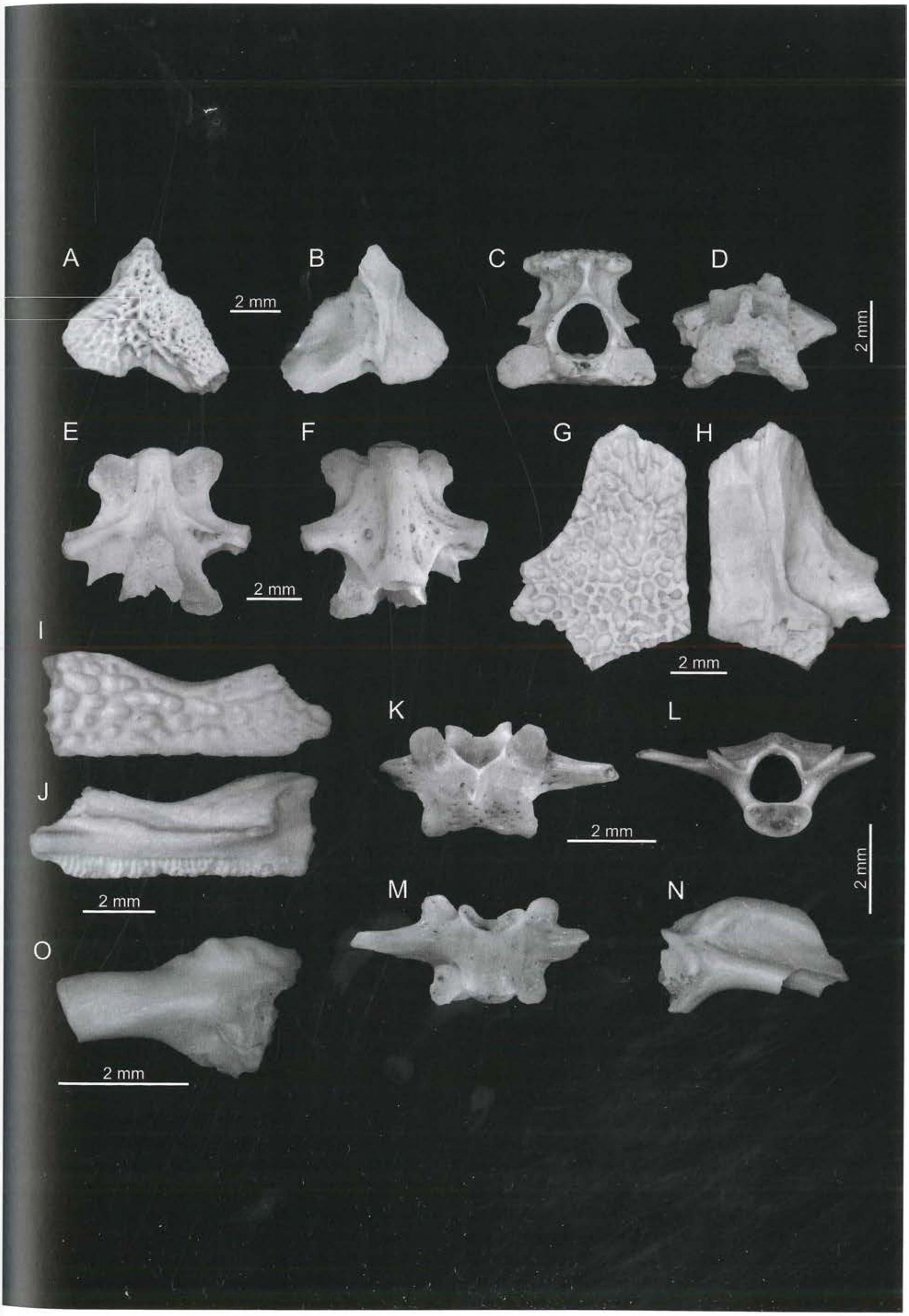
Fig. K-N K-M – presacral vertebra (1/2001 Turtle Joint; MMB-Ge29687), N – right ilium (2/2003 Reptile Joint; MMB-Ge29685/1).

### *Bufo* sp.

Fig. O left ilium (2/2003 Reptile Joint; MMB-Ge29689/1).

A, D, G, K – dorsal, B, F, H, M – ventral, C, L – cranial, N, O – lateral, I – labial, J – lingual views.

**PLATE 1**



# PLATE 2

## Squamate reptiles and mammals from the Mokrá Plateau, Western Quarry, MN 4, 1/2001 Turtle Joint and 2/2003 Reptile Joint

### *Varanus* sp.

Fig. A-C trunk vertebra (2/2003 Reptile Joint; IGS-MOi-365).

### *Bavarioboa* cf. *hermi* Szyndlar & Schleich, 1993

Fig. D-F trunk vertebra (1/2001 Turtle Joint; IGS-MOi-172).

### *Vipera* sp. ("Oriental Vipers" group)

Fig. G-I precaudal vertebra (1/2001 Turtle Joint; IGS-MOi-265).

### *Lagomeryx* sp.

Fig. J, K right mandible, premolares slightly worn down, M1 severely worn down; P2-M1, after P1 only alveola (1/2001 Turtle Joint; IGS-MOm-1).

### *Micromeryx* sp.

Fig. L-N right mandible (1/2001 Turtle Joint; IGS-MOm-73). *Micromeryx* sp.: O – left maxilla (1/2001 Turtle Joint; IGS-MOm-48).

A, D, G – lateral, B, E, I – dorsal, C, F – ventral, H – cranial, J, L, O – occlusal, K, M – buccal, N – lingual views.

# PLATE 2