Early Late Pliocene site of Hajnáčka I (Southern Slovakia) – geology, palaeovolcanic evolution, fossil assemblages and palaeoenvironment

With 9 figs, 2 tabs

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Abstract

The last systematic research (1996–2000) of the Early Villányian Hajnáčka I site (MN 16a) yielded many new fossils and geological data. Six stages could be identified in the evolution of Hajnáčka I's palaeoenvironment – from the initial phreatic explosions and phreatomagmatic eruptions which created the Bone Gorge maar where the maar lake formed after the end of the eruptions and where the oldest sediments accumulated under eutrophic conditions, to the period of accumulation of the lake's second maar-filling. The lake had an affluent river and an effluent river and was surrounded by bushy, humid forests and by steppes or open grasslands. Tapirs, mastodons, rhinos and cervids dominated the forest, whereas hyaenas, machairodontines, lagomorphs and some rodent species lived in the warm, open steppe.

Key words: Hajnáčka, palaeovolcanic evolution, fossil assemblages, palaeoenvironment, MN 16, Pliocene

Introduction

The South-Slovakian palaeontological site of Hajnáčka I is a typical MN 16a locality (Early Villányian, Late Pliocene in sense of Kretzoi 1956, Fejfar & Heinrich 1990, and Repenning et al. 1990) of the European Neogene Mammal time scale (Fejfar & Heinrich 1987).

Buried in volcanic ash, the vertebrate fossils of the site are known since the 19th century, when Emil von Ebeczky accidentally found skeletal remains of mastodons and tapirs (Fejfar 1964). The natural outcrops of the site were thus studied. After the first pioneer field-works accomplished by Kubinyi in 1863 (Fejfar 1964), and then by Szabó (1865), Paul (1866), Krenner (1867), Fusch (1879), and Schafarzik (1899), Kormos (1917a, b) carried out the first excavations, which disclosed new information on the site and on its fauna. In 1955, Fejfar, in the trace of Kormos's steps, started new excavations. His research was aimed at dating the Hajnáčka fossil assemblage and at obtaining the most complete palaeoecological reconstruction of the site. Fejfar published the results of his triennial fieldwork in several articles (1957, 1961a, b, c) and in a monograph (1964). New finds, over the last 20 years, provided progressively more information (Fejfar & Heinrich 1985, Fejfar et al. 1990, Konečný et al. 1995, Lindsay et al. 1997, Fejfar et al. 1998, Vass et al. 2000, Sabol 2001, 2003, Fejfar & Sabol 2004).

In 1996, more than 35 years after Fejfar's excavations, the site was the subject of a new systematic investigation. This research, whose field-work was completed in the summer of 2000, disclosed a great amount of new geological, sedimentological, volcanological, palaeomagnetic,
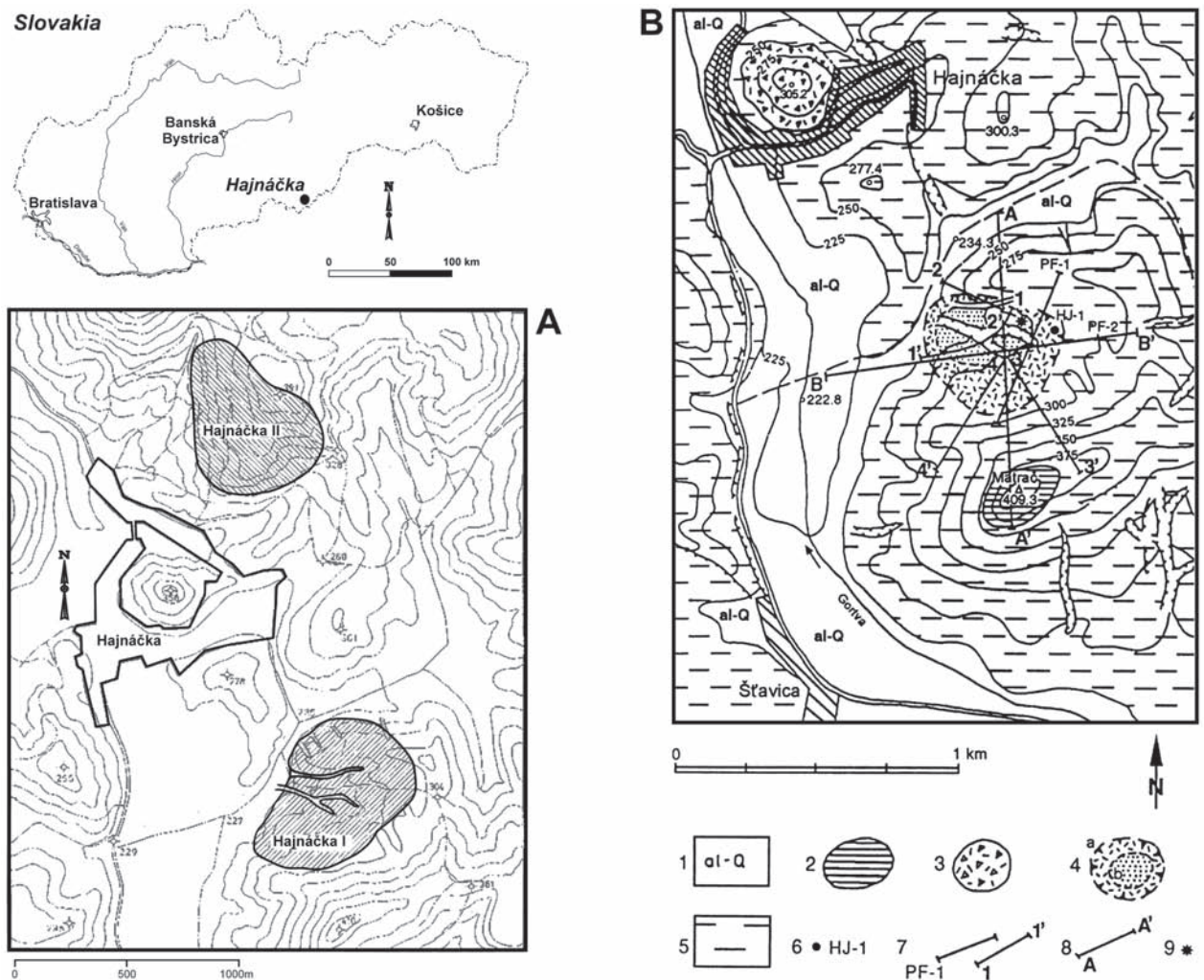
Fig. 1: Location of the Hajnáčka – Bone Gorge site.
a – Location of the Hajnáčka I paleontological site (modified from Fejfar 1964);
b – Geological scheme (partly reconstructed) of Hajnáčka's Bone Gorge maar: 1: alluvial deposits (Quaternary), 2: relict of lava flow on the top of Matrač Hill, 3: Hajnáčka's Castle Hill diatreme with ruins of a castle on the top, 4: relicts of the Bone Gorge maar (a – tuffaceous sand at the maar margin, b – second maar filling – sand with mammal skeleton fragments), 5: friable sandstone of the Fiľakovo Formation (Eggenburgian), 6: well HJ-1, 7: geomagnetic cross-sections, 8: geological cross-section, 9: sampling site for paleomagnetism.

floristic, and palaeoecological data. This new information provides us with a far more complete reconstruction of the history of Hajnáčka's palaeoenvironment. This article illustrates the results of the latest research on the site.

Locality

The site is situated about 1,200 m SE of Hajnáčka village near the town of Rimavská Sobota in Southern Slovakia (the geographic co-ordinates of the site are 48° 12' N and 19° 58' E) and it covers an area from 1,000 to 1,500 square metres (Fejfar 1964) (fig. 1a). Fossiliferous layers outcrop

in an elliptically-shaped maar depression (the Bone Gorge maar) at the northern foothills of Matrač Hill. They are exposed in deep, steep walled erosive gorges. The largest is an E-W trending erosive ravine, 400 m long, 30 m wide and over 20 m deep in several places (fig. 2).

The whole fossiliferous complex consists mainly of autochthonous tuff, lapilli tuffite, fragments of basalt, and fine sand with underlying redeposited Eggenburgian sandy sediments of the Fiľakovo Formation (Tachty sandstones). Quaternary loamy and loam-argillaceous deposits cover all these varied sediments forming the completely preserved and continuous stratigraphic unit.
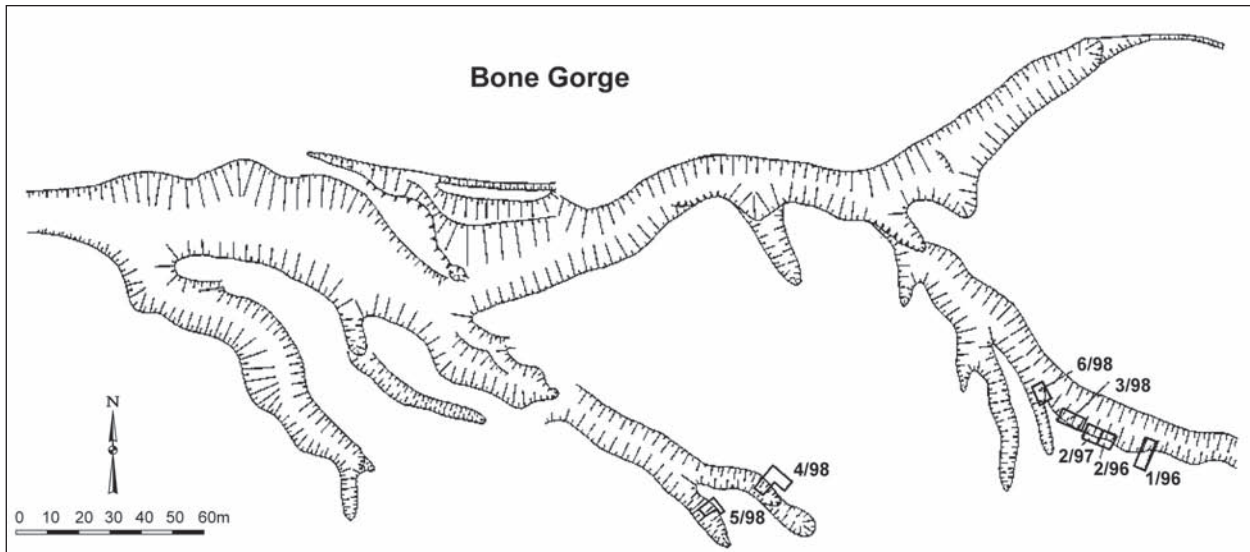
Fig. 2: A schematic sketch of Hajnáčka I's largest furrow (Bone Gorge) and single pits, which were excavated during the last research in 1996–2000.

Geology and evolution of the Bone Gorge maar

The Bone Gorge maar, which extends over an area approximately 580 x 370 m wide (fig. 1b), belongs to the Pliocene Cerová Basalt Formation. Its exact shape was defined using geomagnetic methods. Because the supposed original tuff ring around the maar has been completely removed by younger erosion, the reconstruction of the sedimentary and volcanic processes that created the maar is inferred from the lithology and the structures met by a number of pits, i.e. many of those made by FEJFAR, the borehole HJ-1, and newly excavated ones as well.

The Early Miocene sandstone of the Fiľakovo Formation (Eggenburgian) forms the pre-volcanic basement. Its blocks drowned in the sandy matrix are situated near the base of the maar-filling in its western part (fig. 3). They were blown up during the phreatic explosion and/or they reached their position by sliding from the outer maar walls after eruption. Overlying beds of friable sand with a high content of material ripped from the underlying Early Miocene sediment indicate the dominance of phreatic explosions during the first stages of volcanic activity. The higher section of the lithological profiles, which consists of fine tuffite sand and lapilli tuff with xenoliths of basement sediments, reflects a transition from phreatic to phreatomagmatic activity with a dominance of volcanic material. The sharp base of these sequences indicates the abrupt start of the volcanic activity just after the end of the lacustrine sedimentation. In the upper part of the lithological profiles, a coarse lapilli tuff alternates with finer sandy layers and/or with light grey silty tuffite with intercalations of light grey tuffite sand. This section originated during repeated phreatomagmatic eruptions.

The overlying part of the central maar-filling (fig. 4) consists of coarse lapilli tuff and tuffite sand with rounded blocks of Early Miocene fossiliferous sediments in the lower section. The upper section is formed by clayey sand with rare basalt blocks, probably coming from a fractured Roháč-Borkút basalt complex. The sedimentary complex is strongly disturbed and dissected into separately subsided blocks. FEJFAR (1964) describes these as limnic, near-shore sedimentary sequences connected with volcanic activity.

At the eastern side of the maar (fig. 5), the upper part of its filling consists of dominant grey fine tuffite sandstone with an interlayer of white-grey siltstone. A loaded sandy tuffite layer often deforms layers of siltstone. Fragments of siltstone, coarse sandstone and small basalt scoria are chaotically distributed within massive (non-bedded) sandy tuff layers, which were involved in slumping movements and mass transport. Locally, fragments of sandstone are included in whirled, deformed and slugged siltstone matrix. This sequence documents sedimentation in lake conditions interrupted episodically by mass transport, probably triggered by seismic activity and slumping, which caused the destruction of the silty layers. The sporadic presence of scoria fragments indicates explosive volcanic activity near the maar lake. The lower part of the maar sedimentary filling is intruded by brecciated basaltic body, which probably represents the uppermost part of the feeding system in a diatreme below the maar structure. The underlying Early Miocene sediments of the Fiľakovo Formation form the basement at a depth of 31.50 m.

During the last excavations, a block (50 x 50 cm) of fine, pelitic laminated sediment was also found in one of the new pits (fig. 6). The block represents a redeposited lacustrine sedimentary fragment drowning in fine, non-consolidated sand in the uppermost part of the maar
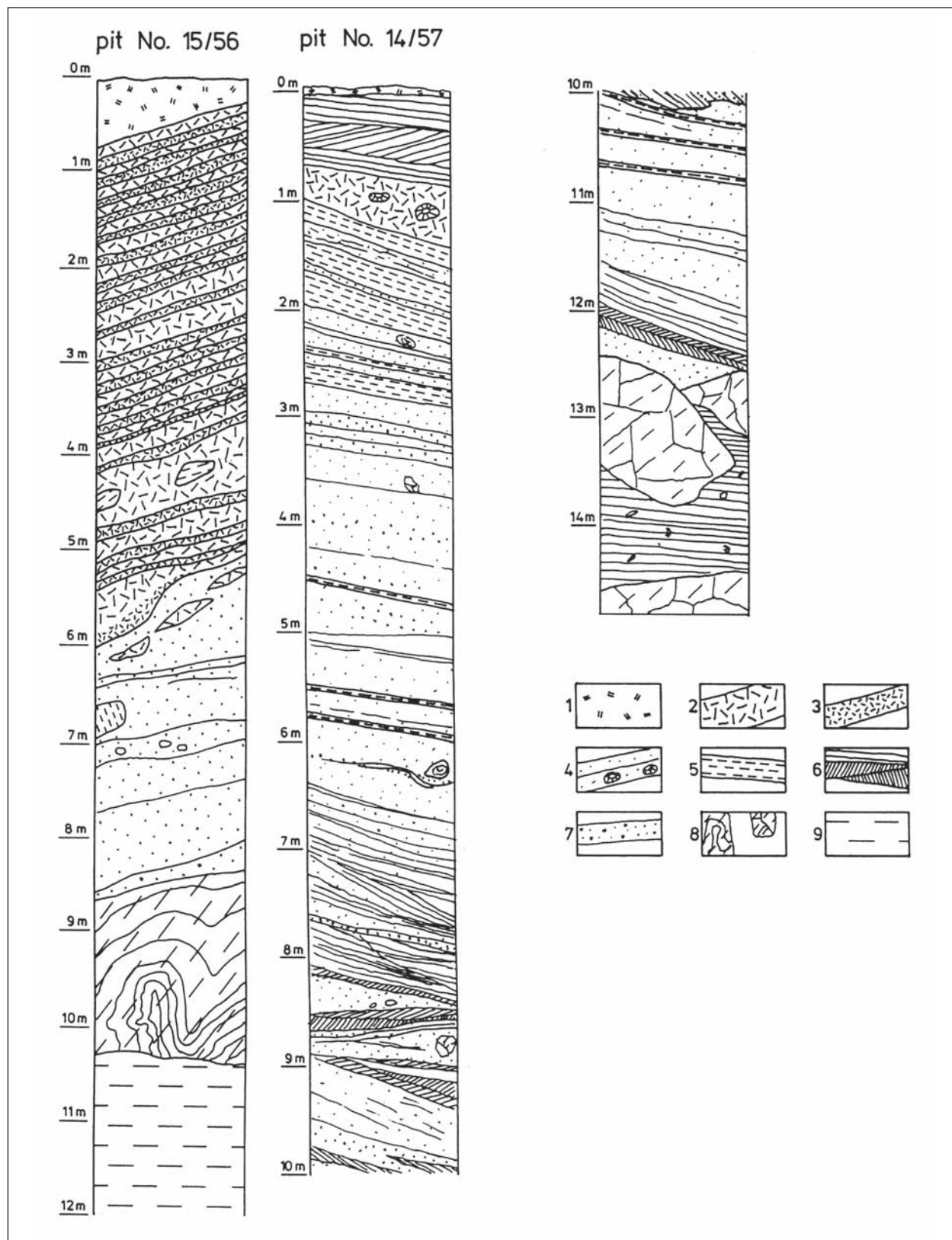
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Fig. 3: Cross-sections through the Bone Gorge maar's tuff ring at Hajnáčka (according to FEJFAR 1964, FEJFAR & HEINRICH 1985, FEJFAR et al. 1990; modified).
1 – dark brown humic loam, 2 – coarse grey, grey-brown lapilli tuff with fragments of limonitic sandstones, 3 – finer sandy tuff, 4 – fine tuffitic sands with small rounded fragment of Eggenburgian sandstones, 5 – silty tuffite, 6 – diagonally bedded fine tuffitic sand, 7 – coarse sand, 8 – blocks of Eggenburgian sandstones (rusty banded, Liesegang circles?), 9 – the maar's basement: light yellowish-brown slightly calcareous micaceous friable sandstones of the Fiľakovo Formation (Eggenburgian).
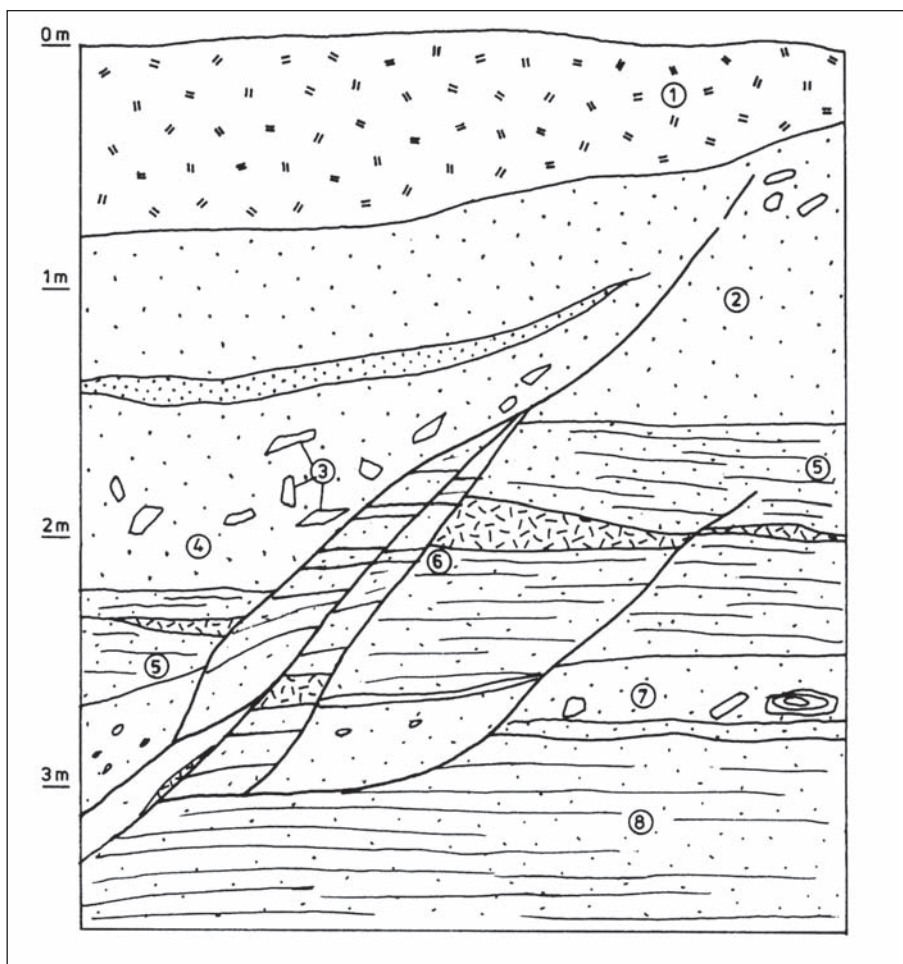
Fig. 4: The Bone Gorge maar's second chaotic fill with mammal bones, Pit No. 3/56 (according to Fejfar 1964, modified).
Note the slump bodes. 1 – loam, 2 – rusty-brown clayed sand, 3 – basalt boulders, 4 – light brown fine sand, 5 – light-brownish-grey bedded slightly calcareous tuffaceous sand, 6 – coarse lapilli tuffs, 7 – light grey fine sand with small fragments of sandstones, 8 – rusty-brown bedded fine tuffaceous friable sandstone/siltstone.

sequence. Thin (0.1–0.3 mm) pelitic laminae alternate with sandy ones (0.5 mm thick). The pelitic laminae are rich in palynoremains (pollen, spores and algae). Algae dominate (75–80 %) the whole palyno-assemblage. They probably belong to heterotrophic cysts of the peridinioid dinoflagellates like *Peridiniopsis borelinense*, *Peridiniopsis* sp., and *Selenopempyx* sp. Rarely, *Halodinium* sp. and incertae sedis algae (*Leiosphaera* sp. and *Cyclopsiella* sp.) are observed in the algal association as well (Hudáčková in Vass et al. 2000). Similar algae inhabit eutrophic lakes and pools in recent Europe. Therefore, it is supposed that the mentioned pelitic laminated sediment originated in the primary maar lake under eutrophic conditions, and in many other maar pools as well.

Slump balls and lenses of tuffaceous sandstone, which likely come from the inner slopes of the maar, are occasionally present in the sandy deposits that enclose the block. Layers, lenticels and/or blocks of lapilli tuff, basalt fragments and Eggenburgian sandstone fragments with a rim of thermal alterations are also present in the imperfectly bedded sand. Structural features and lithology suggest a deposition by water currents in a drained lake. These sediments are younger than the primary maar filling. They represent the secondary fill and their chaotic structure (in contrast to the undisturbed bedded basalt tuff in the deeper part of the maar) is the result of epigenetic sliding.

Deluvial-proluvial sediments near the western margins of the maar represent the youngest deposits, probably of Late Pleistocene age. These loam-sandy deposits contain frequent platy basaltic blocks from the fractured Borkút lava flow (radiometrically dated on 1.35 Ma).

The accumulated evidence indicates the existence of several stages in the palaeovolcanic evolution of the Bone Gorge maar (fig. 7):

1st stage. At the beginning, a dish-like or funnel-like depression was created by strong phreatic explosions. These explosions were caused by water/magma interaction during the ascent of basaltic magma to the surface. The water was likely that saturating the Lower Miocene sediment and/or the water table at the base of the Lower Miocene sedimentary sequences. Strong phreatic eruptions surfaced blocks and sandy material from crushed and crumbled Lower Miocene sediments. This material was deposited at the bottom of the maar depression, and partly outside. Later on, CO_2 emanations calcified the sandy material in the maar.

2nd stage. Because of the expansion of the funnel feeding system and of permanent magma supply the original
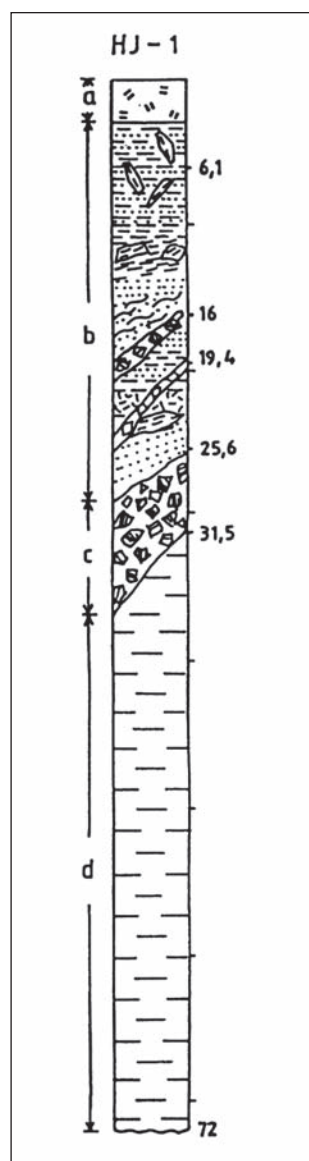
Fig. 5: Schematic section of the well HJ-1.

a – loam, b – tuffaceous deposits with interbedded siltstone and fragments of finegrained deposit, c – breccia with fragments of porous basalt, d – friable sandstone of the Fiľakovo Fm. (Eggenburgian).
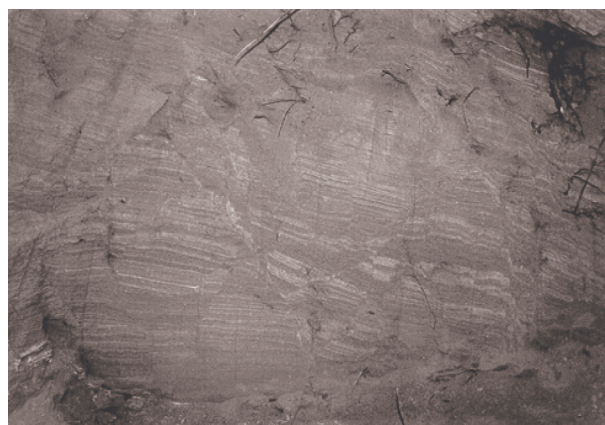

Fig. 6: Particular of a fragment of the first maar filling represented by the fine laminated rock from pit No. 5/98. — photo: J. Ferleťáková.

Ephemeral streams cut through the northwestern border of the maar depression and destroyed and removed the soft laminated sedimentary maar fill. We assume that a lake thus formed in the deepened depression. Sandy sediments accumulated in this new lake, which had an affluent and effluent river, forming the maar's present-day second fill. Basalt volcanic activity continued in the maar's surroundings and supplied some tephra to the lake, forming lapilli tuff and tuffaceous sand layers in the sandy maar fill. The maar's second filling was much more dynamic than the first one. Synsedimentary sliding and slumping brought already deposited material from the maar's margins to its centre. Finally, the new fill was partly disrupted by the continuing updoming of the Cerová vrchovina Upland.

5th stage. Destructive processes, still active today, removed the original tuff ring and a substantial part of the second maar filling.

Age of the site

The spatial and temporal relationships between the deposition of the fossiliferous second maar filling and the effusive volcanic activity responsible for the dominant basalt forms, such as lava flows, have long been discussed. Koch (1904) presumed that the explosions that produced Hajnáčka I's fossiliferous lapilli tuff preceded the effusion of the lava flows. Schafarzik (1899) supposed that the sedimentation in Hajnáčka I's lake and the basalt extrusions and effusions occurred simultaneously. Also Fejfar (1964) believed that the effusion of the lava flows and the sedimentation of the fossiliferous deposits in Hajnáčka I's lake were almost simultaneous. Recent volcanological studies of the Cerová Basalt Formation by Konečný & Lexa (in Vass & Elečko et al. 1992) as well as the radiometric datings of several lava flows and dykes (Balogh et al. 1981, 1994) show that the lava flows of the Cerová Basalt Formation originated before, but also after the deposition of Hajnáčka I's fos-

phreatic activity passed to phreatomagmatic eruptions. These shoved to the surface more pyroclastic material as lapilli tuff: a tuff ring started to form around the central depression. Lake conditions recurred periodically in the maar depression during this stage and this probably set off repeated phreatomagmatic explosions. The water saturated lapilli tuff, produced by the phreatomagmatic eruptions and accumulated on the inner slope of the maar depression, often slid down towards the centre of the depression. Earthquakes associated with repeated eruptions could start the sliding of non-consolidated material.

3rd stage. The end of the magma supply finally stopped the phreatomagmatic eruptions. The fine pelitic sedimentation nonetheless continued in the maar lake under eutrophic conditions.

4th stage. When the volcanic activity stopped the original tuff ring around the maar depression was intensely eroded.
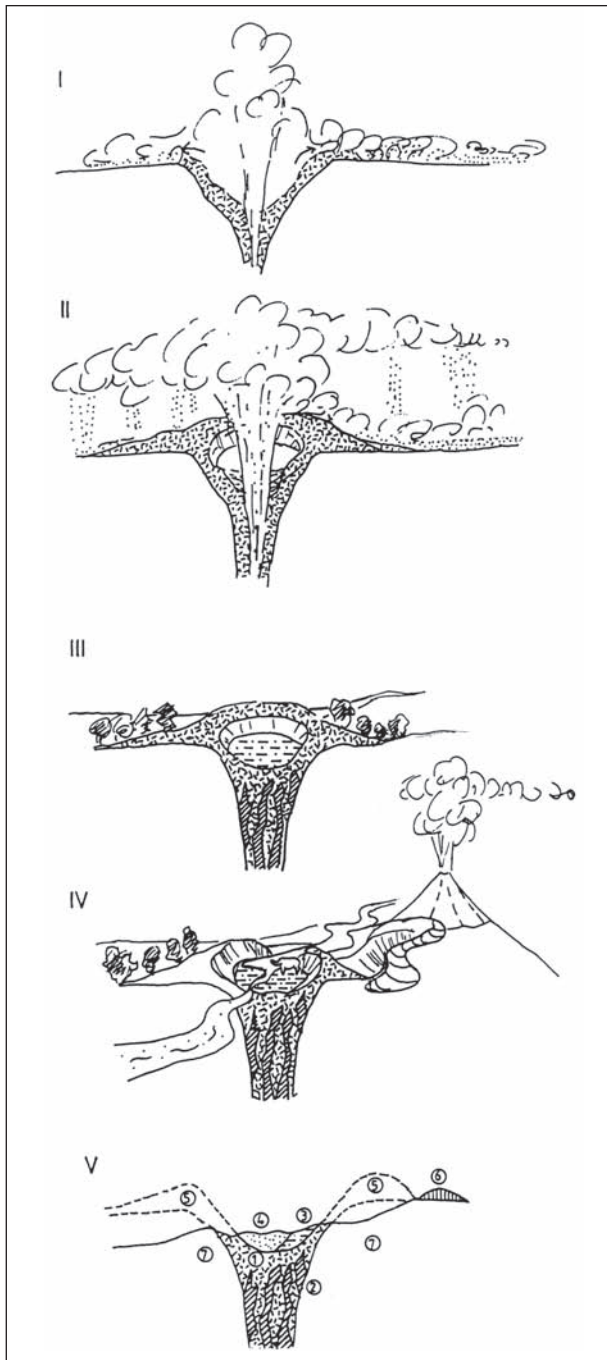
Fig. 7: Evolution of Hajnáčka's (I–V) Bone Gorge maar.
I. stage – formation of the maar depression during phreatic erup-
tion. II. stage – phreatomagmatic eruptions (base surges) created
tuff ring around maar depression. III. stage – sedimentation in
maar lake. IV. stage – partial destruction of tuff ring, ephemeral
streams cut through the maar depression and redeposition of
the first maar fill, volcanic activity in neighbourhood. V. stage
– erosive processes removed tuff ring and a substantial part of
the second maar fill.
1 – tuff filling of the diatreme and maar (tuff-breccia); 2 – younger
basaltic breccia intruding through tuff-breccia; 3 – first sediments
of the maar lake; 4 – second maar filling (resedimented sand
with fragments of mammal skeletons); 5 – supposed tuff ring;
6 – basaltic lava flow; 7 – friable sandstones of the Fiľakovo
Fm. (Eggenburgian).

siliferous beds in the maar. Also the stratigraphic age of the
Hajnáčka fauna was discussed in past literature. Whereas
Dietrich (1953) suggested an Early Pleistocene age,
Thenius (1959) placed the Hajnáčka fauna in the so-called
Levantinian Period (Middle Pliocene), and Fejfar (1964)
correlated it with other Villafranchian faunas, especially on
the basis of rodent evidence. Later on, Fejfar & Heinrich
(1987) referred the Hajnáčka assemblage, which contains
the advanced species *Mimomys* (*Mimomys*) *hassiacus*
(= *M. hajnackensis*; Fejfar & Storch 1990) and *Mimo-
mys* (*Cseria*) *stehlini*, to the Late Pliocene MN 16a zone
(Early Villányian, formerly called Arondellian or early
Villafranchian). Thus, this fauna distinctly differs from
the Late Ruscinian assemblages, which are characterized
by *Mimomys gracilis*, *Dolomys occitanus* or *Propliomys
hungaricus*, not present at Hajnáčka.

The palaeomagnetic measurements are consistent with
the lithostratigraphic and palaeontological evidence, show-
ing that the Bone Gorge maar and its fillings originated dur-
ing the Gauss magnetic chron (C2An). The bones started
to accumulate during the middle part of the chron C2An,
whereas the original maar and its ring most probably origi-
nated during the earlier part of this magnetic event.

On the basis of biostratigraphic and magnetostrati-
graphic evidence Hajnáčka I can be correlated with other
Late Pliocene sites, such as Jucar (Carrasco, Valdeganga),
Moreda, Teruel (Concud) in Spain; Seynes and Valensole
(Cornillet, Grenouillet) in France; San Giusto, Arcille,
Vialette, Arondelli-Triversa in Italy; Hambach, Frechen,
Gundersheim "Findling" in Germany; Beremend 1–3 and
5 in Hungary; Barault C in Romania; Uryv 1, Akkulaevo,
Liventsovka 5, Kotlovina, Kryzhanovka in the former
Soviet Union; or Kadiözü, Sivricek, and Ziyaret in Turkey
(Fejfar et al. 1990, Lindsay et al. 1997, Fejfar 2001).

Palaeovegetation

Hajnáčka I's macroflora and pollen were also analyzed.
The results of the study of the macroflora were published
by Sitár et al. (1989), while the pollen is examined here for
the first time. These analyses indicate two palaeovegetation
assemblages, different in age and composition (tab. 1).

The pollen analyzed for the present research is that
contained in the block of fine laminated pelitic sediments
mentioned above. It provides information on the vegetation
that lived in the neighbourhood of the maar when the first
fill was formed. Arctotertiary geofloristic elements close
to *Abies* sp., *Picea* sp., *Sciadopytis* sp., *Tsuga* sp., *Pinus*
sp., less *Carya* sp. and *Acer* sp. prevail in this section.
Most are conifers with bisaccate (*Pinus, Picea, Abies*)
or monosaccate (*Tsuga*) pollen, which can disperse a far
distance from their source area. Saccate pollen of these
allochthonous taxa are very abundant in the studied mate-
rial (90%); angiosperms, in contrast, are sporadic. Hence,
the flora recorded in the site lived far from the lake shore
(Vass et al. 2000). The dominance of warm temperate taxa

Table 1: List of palaeovegetation assemblages found in the sediments of Hajnáčka (Bone Gorge) maar's first and second fill (according to SITÁR et al. 1989 and VASS et al. 2000, modified).

Floristic taxa of primary maar fill	Floristic taxa of secondary maar fill
-	Polyporaceae gen. et spec. indet.
-	*Pteris paeoaurita* E. Kovács
-	*Torreya fejfarii* Sitár, Bůžek & Kvaček
Picea sp.	*Picea* sp. div.
-	*Salix* sp.
-	cf. *Alnus* sp.
-	*Betula* sp. div.
-	*Carpinus grandis* Ung.
-	cf. *Pterocarya* sp.
-	*Quercus* ex gr. *roburoides* Gaudin
-	*Ulmus braunii* Heer
-	*Zelkova zelkovifolia* (Ung.) Bůžek & Kotlaba
-	*Vitis teutonica* Al. Br.
-	*Acer integerrinum* (Viv.) Massal.
Acer sp.	*Acer* sp. div.
-	*Tilia* cf. *platyphyllos* Scop.
-	*Buxus pliocenica* Saporta & Marion
-	Magnoliophyta gen. et spec. indet.
Abies sp.	-
Tsuga sp.	-
Pinus sp.	-
Sciadopytis sp.	-
Carya sp.	-

(*Sciadopytis* sp., *Tsuga* sp., *Pinus* sp., *Carya* sp. and *Acer* sp.) indicates temperate climatic conditions.

Fossil macroflora from the second maar fill are dated to the early Late Pliocene on the basis of vertebrate data. These are mixed mesophytic forest elements dominated by *Quercus*, *Tilia*, *Ulmus*, *Acer*, and *Torreya*. The rich shrub layer included evergreen forms (*Buxus*) and lianas (*Vitis*). Silicified wood fragments (Magnoliopsida indet.) have also been found. Hajnáčka I's macroflora comprises warm temperate elements (*Torreya*), which are missing in the flora of the next cooler climatic phase (SITÁR et al. 1989).

Fauna

The latest excavations yielded a large amount of vertebrate fossils, as FEJFAR's had too years before. The specimens were mainly associated with lenses and intercalations of the gravel rusty-brown tuffaceous sand, which often contained limonite concretions and small pyroclastics. Most of the fossil remains were isolated and reworked. Only a few (e. g. some vertebrae of tapirs) were still articulated and arranged almost in life-position.

So far, the site yielded fossil remains of fish (*Scardinius ?erythrophthalmus, Scardinius* sp., *Tinca furcata, Tinca* sp., *Esox* sp., ?*Parasilurus* sp., Percidae gen. et spec. indet.) (OBRHELOVÁ 1970, HENSEL in SABOL et al. 2004); amphibians (*Pliobatrachus* sp., *Bufo bufo, Rana* cf. *temporaria, R.* cf. *arvalis, R.* cf. ex gr. *dalmatina-latastei,* Anura gen. et spec. indet.) (HODROVÁ 1981, FEJFAR et al. 1990); reptiles (*Chelydra* aff. *decheni, Emys orbicularis,* Testudinata gen. et spec. indet., Serpentes gen. et spec. indet.) (MŁYNARSKI 1963, FEJFAR et al. 1990, KLEMBARA in SABOL et al. 2004); birds (*Mergus* sp.) (FEJFAR et al. 1990), and mammals (tab. 2). Mammals outnumber all other vertebrate groups, reaching a total of over 1,800 specimens all found during the latest excavation.

In terms of relative skeletal frequencies, the perissodactyl remains, chiefly those of tapirs, are by far the most abundant in Hajnáčka's Late Pliocene taphocoenosis. In contrast, insectivores and rodents are the most frequent taxa (figs. 8a, 9), reaching a total of 10 insectivores taxa and 14 rodent taxa, which include a minimum of 7 new taxa which had never been found before in this site (*Talpa* cf. *minor*, *T. fossilis*, *Talpa* sp., *Deinsdorfia hibbardi*, Soricidae gen. et spec. indet., *Sciurus* sp., and *Ungaromys*

Table 2: List of mammals from Hajnáčka I (MN 16a).
a – according to Fejfar et al. (1990), b – based on the last research (1996–2000).

Taxa of Mammals	Hajnáčka I a	Hajnáčka I b	Taxa of Mammals	Hajnáčka I a	Hajnáčka I b
LAGOMORPHA			**SORICOMORPHA**		
Leporidae			**Soricidae**		
Hypolagus brachygnathus Kormos, 1934	+		*Deinsdorfia hibbardi* (Sulimski, 1962)		+
Lagomorpha gen. et spec. indet.		+	*Petenyia hungarica* Kormos, 1934	+	
RODENTIA			*Blarinoides mariae* Sulimski, 1959	+	cf.
Sciuridae			*Beremendia fissidens* (Petényi, 1864)	+	
Sciurus sp.		+	Soricidae gen. et spec. indet.		+
Pliopetaurista pliocaenica (Depéret, 1897)	+		**Talpidae**		
Castoridae			*Talpa minor* Freudenberg, 1914		cf.
Castor fiber ssp.	+	+	*Talpa fossilis* Petényi, 1864		+
Trogontherium minus Newton, 1890	+		*Talpa* sp.		+
Seleviniidae			*Desmana nehringi* Kormos, 1913	+	+
Seleviniidae gen. et spec. indet.	+		**PRIMATES**		
Cricetidae			**Cercopithecidae**		
Baranomys loczyi Kormos, 1933	+		Colobinae gen. et spec. indet.	+	
Germanomys sp.	+	+	**ARTIODACTYLA**		
Ungaromys sp.		+	**Suidae**		
Mimomys (*Mimomys*) *hassiacus* Heller, 1936	+	+	*Sus minor* Depéret, 1890	+	
Mimomys (*Cseria*) *stehlini* Kormos, 1931	+	+	**Cervidae**		
Mimomys sp.		+	*Cervus perrieri - Ardenoceros ardei*	+	
Arvicolinae gen. et spec. indet.		+	*Cervus pardinensis* Croizet et Jobert, 1828	+	
Muridae			*Croizetoceros ramosus* (Croizet et Jobert, 1828)	+	
Apodemus sp.	+		*Capreolus* sp.	+	
Anomalomyidae			*Muntiacus* sp.	+	+
Prospalax priscus (Nehring, 1897)	+	+	Cervidae gen. et spec. indet.		+
CARNIVORA			**PERISSODACTYLA**		
Mustelidae			**Rhinocerotidae**		
Lutra bravardi Pomel, 1843	cf.	cf.	*Dicerorhinus jeanvireti* Guerin, 1972	+	+
Procyonidae			*Dicerorhinus* sp.		+
Parailurus hungaricus Kormos, 1934	+		Rhinocerotidae gen. et spec. indet.	+	
Ursidae			**Tapiridae**		
Ursidae gen. et spec. indet.		+	*Tapirus arvernensis* Croizet et Jobert, 1828	+	+
Felidae			**PROBOSCIDEA**		
Megantereon sp.	+		**Mammutidae**		
Hyaenidae			*Mammut borsoni* (Hays, 1834)	+	+
Hyaena perrieri Croizet et Jobert, 1828	+	+	**Gomphotheriidae**		
			Anancus arvernensis (Croizet et Jobert, 1828)	+	+

sp.). An undetermined ursid (Ursidae gen. et spec. indet.) remain was also found recently.

If we consider the number of species in particular, Fejfar (1964) divided the Hajnáčka fossil assemblage into three groups: 1) taxa abundant in all the facies of the sedimentary filling (e.g. *Tapirus arvernensis*, *Dicerorhinus jeanvireti*, *Mammut borsoni*, and *Anancus arvernensis*); 2) taxa frequent in the coarse tuff or arenaceous tuffite of the coastal facies (e.g. *Mimomys stehlini*, *Trogontherium minus*, *Muntiacus* sp., *Capreolus* sp., *Castor fiber*, *Hypolagus brachygnathus*, and *Prospalax priscus*); 3) rare taxa represented by 1 or 2 specimens only (e.g. *Desmana nehringi*, *Petenyia hungarica*, *Beremendia fissidens*, Colobinae sp., *Mimomys hassiacus*, *Baranomys loczyi*, *Apodemus* sp., *Pliopetaurista pliocaenica*, *Hyaena perrieri*, *Parailurus hungaricus*, *Lutra* cf. *bravardi*, *Megantereon* sp., *Sus minor*, *Croizetoceros ramosus*). The latest excavation allowed to relocate the new numerous finds of *Mimomys hassiacus* into the second group, while the third group was "enriched" with new rare taxa (e.g. *Talpa* cf. *minor*, *T. fossilis*, *Deinsdorfia hibbardi*, *Sciurus* sp., *Ungaromys* sp., Ursidae gen. et spec. indet.). The Hajnáčka faunal assemblage also includes remains of molluscs (*Anodonta* sp.) (Fejfar et al. 1990) and ostracods (*Darwinulla* sp., *Ilyocypris* sp., *Candona* sp., and *Pseudocandona* sp.) (Pipík 2000).

Species diversity declined in the Villányian assemblages with respect to the Ruscinian ones. Whereas some species were already missing in the western part of Central Europe during the Villányian Stage, they were still relatively abundant in the eastern part (Dahlmann 2001). These changes in the faunal compositions were probably a response to climatic changes which occurred between the end of the Early Pliocene (Ruscinian, MN 15) and the beginning of the Late Pliocene (MN 16), approximately 3.4 Ma ago, when the warm humid climate of Central Europe turned increasingly cooler (Thompson & Fleming 1996).
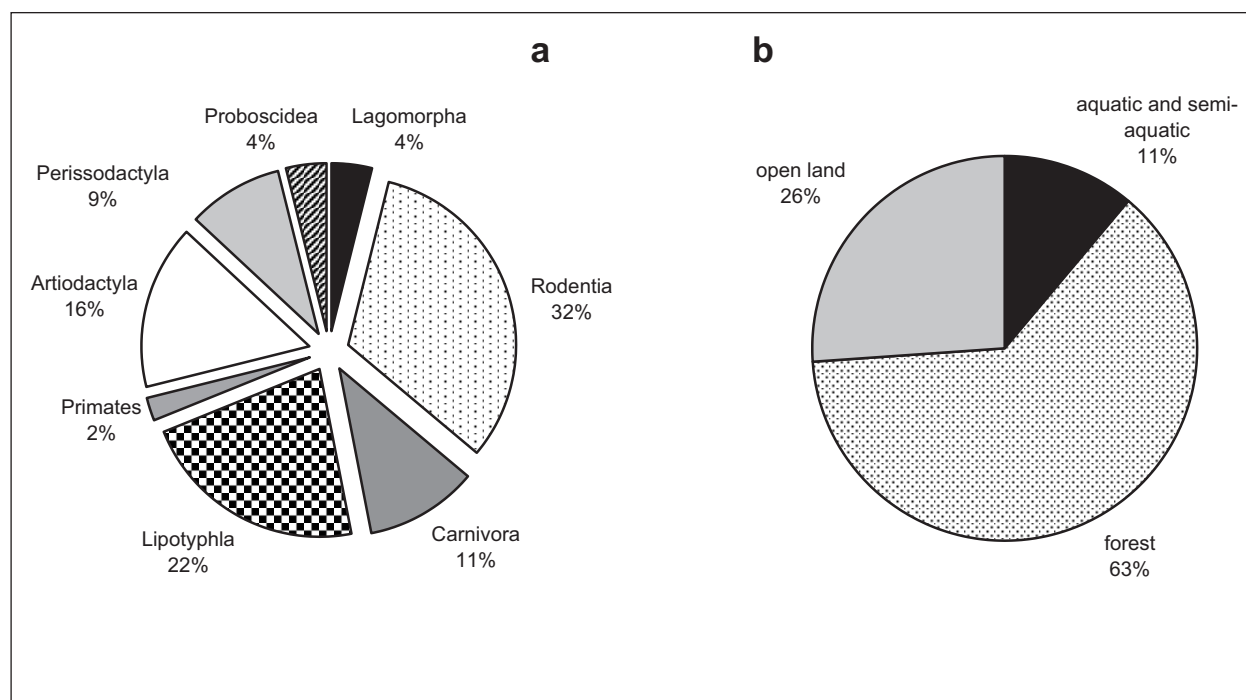
Fig. 8: Late Pliocene mammal assemblage of Hajnáčka I site.
a – proportion of taxa (compilation of former and latest data); b – identification of the ecological groups represented.

Reconstruction of the palaeoenvironment

Hajnáčka's palaeoenvironmental history has been the topic of numerous researches. According to KORMOS (1917b), Hajnáčka's fauna and flora peopled the banks of a shallow lake when one of the basaltic eruptions began. FEJFAR (1961a, 1964) focused on the origin of the lake basin, concluding that it was formed when a basaltic flow dammed the water stream. Later on, KONEČNÝ and LEXA (in VASS & ELEČKO 1992) recognized the Bone Gorge as a maar structure, and VASS et al. (2000) believed that the bone accumulated in a lake with an inlet and an outlet, where the sediments of the second maar filling were deposited as well. This second filling deposited after the first fill had been removed: fragments of this first deposit are rarely found as blocks of fine laminated sediments which had deposited in the original maar lake under eutrophic conditions. Finally, also the second maar filling was partly eroded and redeposited together with some of the bones, which are now isolated.

When the second maar filling deposited, swamps occurred on the banks of the maar lake. They were surrounded by bushy, humid (but not swampy; LINDSAY et al. 1997) primeval forests, inhabited by *Anancus arvernensis, Mammut borsoni, Tapirus arvernensis, Dicerorhinus jeanvireti, Muntiacus* sp. The presence of *Hyaena, Megantereon, Hypolagus*, *Prospalax* and *Baranomys*, however, indicate also the occurrence of steppe or open grassland

in the Hajnáčka palaeoenvironment (FEJFAR 1964, FEJFAR et al. 1990).

The whole mammalian assemblage can thus be divided into three main ecological groups (fig. 8b): 1) aquatic and semi-aquatic taxa (*Desmana, Lutra, Castor, Trogontherium*); 2) forest dwellers (moles, shrews, primates, ursids, *Parailurus, Pliopetaurista, Sciurus, Tapirus, Dicerorhinus, Sus*, cervids, proboscideans); and 3) open land dwellers (*Hyaena, Megantereon*, cricetids, murids, *Prospalax, Hypolagus*). FEJFAR (1964) considered the first two groups as autochthonous taxa, and those of the third ecological group as allochthonous taxa.

In contrary the palaeoenvironmental conditions at the site during the accumulation of the second maar-filling, the primary maar-filling accumulated in an eutrophic lake, in which unicellular heterotrophic peridinioid dinoflagellates played a major role. At that time a thermophile forest, dominated by coniferous species (*Tsuga, Abies, Picea, Pinus*) and with sporadic occurrences of angiosperms (*Carya, Acer*), grew on a dry substratum far from the lake bank.

The fauna and flora that lived in the vicinity of the maar during the deposition of the second filling was destroyed by the eruption of some near volcano (FEJFAR 1964). SCHA-FARZIK (1899) was the first to connect the extinction of the Hajnáčka taphocoenosis with the eruption and fall of the volcanic ash. FEJFAR (1964) shared this opinion after he found vertebrate bones and teeth in the basalt agglomer-

ate facies. He found bones showing point corrosion and connected this phenomenon with the falling ash. The same kind of alteration could be found, however, in bones of animals that had been killed at the lake bank by gas emanations prior to the volcanic eruption and after the tephra fall. Furthermore, some bones gnawed by the hyaenas indicate that dead animals could have rested for some time on the coast (FEJFAR 1964). Animal carcasses, which could have been killed by the gas emanations while watering, or by the fall of volcanic ash, possibly were swept into the lake later and deposited on its bottom near the coast. The mixed fish bones, fragments of bivalve and ostracod shells and mammal bones in the fossiliferous sediments support this interpretation. Moreover, the presence of closed clam shells can also indicate a rapid sedimentation of the volcanic ash. VASS et al. (2000) suppose that affluent and effluent currents in and from the lake disarticulated the skeletons. Some fossils, however, were found in natural life position (FEJFAR 1964). Hence, most skeletons were probably disarticulated and removed with the sediments most probably only by later geological processes.

The palaeobiogeographical evidence from Hajnáčka indicates the co-existence of primitive taxa (e.g. tapirs or primitive cricetids, such as *Germanomys*) and advanced ones (e.g. advanced species of *Mimomys*) in the area. The existence of Hajnáčka taphocoenosis prohably corresponds with the time of the transition from the second (5.43 to 3.58 Ma ago) to the third phase (2.92 to 2.60 Ma ago) of local volcanism in southern Slovakia (KONEČNÝ et al. 1995).

Conclusion

The latest excavations at Hajnáčka I unlocked new information on the palaeoenvironmental evolution of the area. This is the reconstruction we propose:

1. Phreatic explosions began to form the dish-like depression of Bone Gorge maar at the beginning of the Gauss magnetochron (C2An), after the end of the second (5.43 to 3.58 Ma ago) of the six phases of volcanic activity in southern Slovakia. The phreatic explosions also ejected a sandy material, which accumulated forming a layer at the bottom of maar depression, from disintegrated Eggenburgian sandstones.

2. Successive phreatomagmatic eruptions of pyroclastic material formed a tuff ring around the central depression. Gravitational slides, triggered by seismic shocks and repeated explosions, redistributed the tuff material from the inner slopes of the ring to the lower levels of the maar depression.

3. When the phreatomagmatic eruptions finally ended, the finely laminated first maar fill accumulated in the central part of the maar lake under eutrophic conditions. Unicellular heterotrophic peridinioid dinoflagelates bloomed in the lake, while a forest of temperate coniferous taxa, with sporadic angiosperms, surrounded

it. These formed a pioneer assemblage which initially colonized the slopes then spread from the maar lake shores when the climate turned mild.

4. At approximately 3.3 Ma, the tuff ring was partly eroded as a consequence of the updoming of the Cerová vrchovina Upland. The north-western part of the maar depression was cut by ephemeral streams which destroyed and removed the sediments of first maar filling. The second maar filling (limnic sand, sandy tuffite, lapilli ash and limonite sandstone fragments) accumulated in the then originated lake, which now possessed an inlet and an outlet. From 3.3 to 2.8 Ma the lake was surrounded by a bushy, humid deciduous to mixed mesophytic forest, which was here and there interrupted by steppe or open grassland areas. Tapirs, mastodons, rhinos and cervids dominated in the forest areas, whereas hyaenas, machairodontines, lagomorphs and rodent species lived in the warm, open steppe. We assume that the extinction of the Hajnáčka fauna and flora was probably caused by the eruption of a nearby volcano and by the subsequent falls of volcanic ash and/or by the emissions of poisonous gas.

5. During the next period (the third volcanic phase: 2.92 to 2.60 Ma), the volcanic activity continued near the site and finally the entire area was uplifted. The sediments of the second maar filling, and the vertebrate skeletons they contained, possibly could be then reworked by water erosion.

6. Quaternary geological processes (erosion, solifluction and repeated landslides) removed what remained of the maar together with its sediments. The maar sediments were therefore disturbed again and partly mixed up with the Upper Pleistocene sediments.

Acknowledgement

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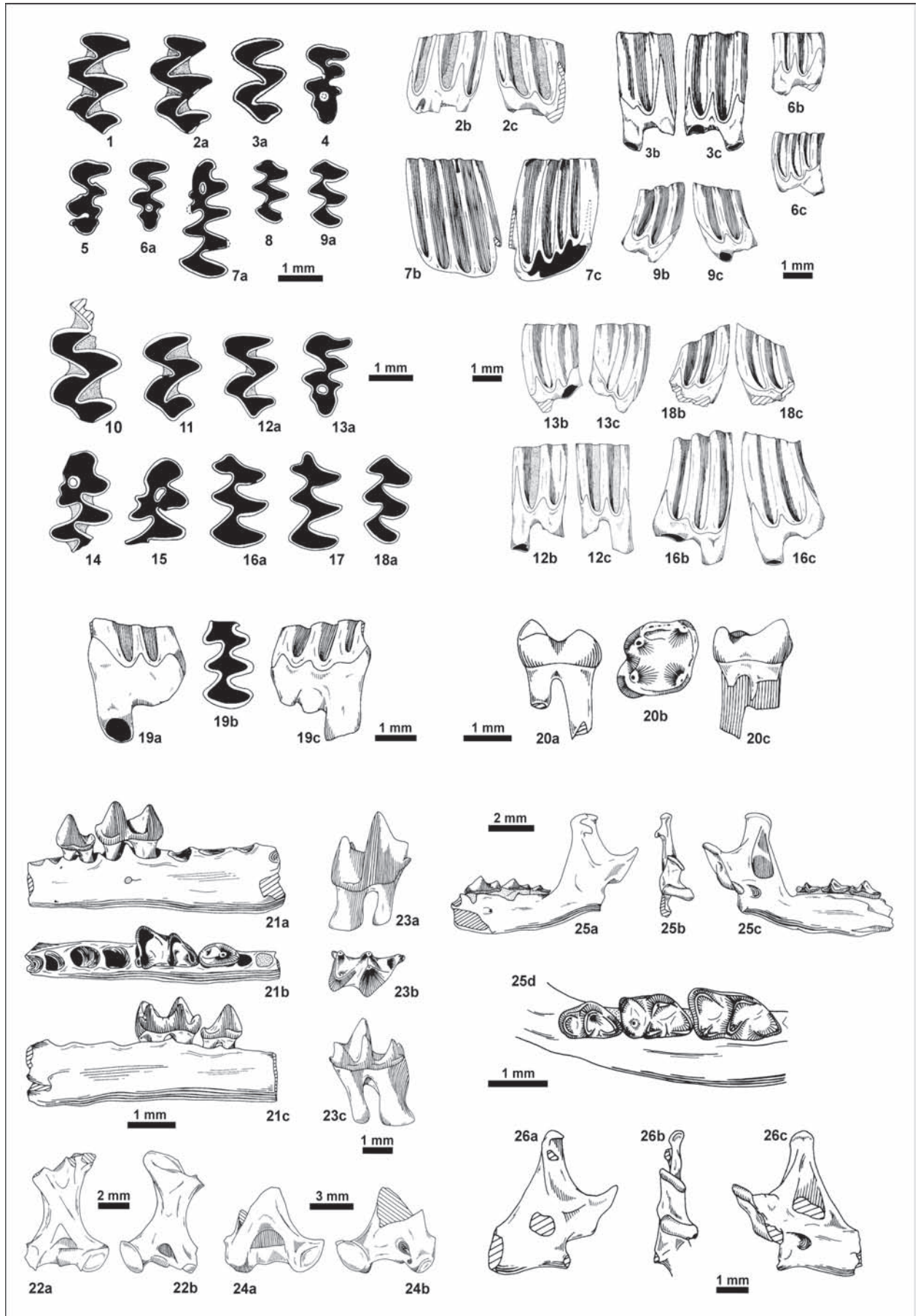
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Fig. 9: Key-fossils and new faunal elements of Hajnáčka I micromammalian assemblage.

1–9: *Mimomys* (*Cseria*) *stehlini* KORMOS, 1931 (1–M1 sin., B–4035, occlusal view; 2–M1 sin., B–4015; 3–M2 dext., B–4111; 4–M3 sin., B–4122, occlusal view; 5–M3 dext., B–4133, occlusal view, inv.; 6–M3 dext., B–4038; 7–m1 dext., B–4130, occlusal view, inv.; 8–m3 dext., B–4036, occlusal view, inv.; 9–m3 sin., B–4016; a – occlusal view, b – lingual view, c – buccal view).

10–18: *Mimomys* (*Mimomys*) *hassiacus* HELLER, 1936 (10–M1 sin., B–4001, occlusal view; 11–M2 sin., B–4014, occlusal view; 12–M2 sin., B–4058; 13–M3 sin., B–4032; 14–m1 sin., B–4033; 15–m1 dext., B–4138, occlusal view, inv.; 16–m2 sin., B–4131; 17–m2 sin., B–4129; 18–m3 dext., B–4037, inv. (occlusal); a – occlusal view, b – lingual view, c – buccal view).

19: *Ungaromys* sp., m1 sin. (B–4119; a – buccal view, b – occlusal view, c – lingual view).

20: *Sciurus* sp., m1–2 sin. (B-4012; a – buccal view, b – occlusal view, c – lingual view).

21–22: *Talpa* cf. *minor* FREUDENBERG, 1914 (21 – fragment of the left mandible with p4 and m1, B–4152; a – buccal view, b – occlusal view, c – lingual view; 22 – right humerus, B–4103; a – caudal view, b – cranial view).

23: *Talpa fossilis* PETÉNYI, 1864; m2 dext. (B–4142; a – buccal view, b – occlusal view, c – lingual view).

24: *Talpa* sp., distal part of the right humerus (B–4079; a – caudal view, b – cranial view).

25: *Deinsdorfia hibbardi* (SULIMSKI, 1962); fragment of the left mandible with m1–3 (B–4144; a – buccal view, b – caudal view of condyle, c – lingual view, d – detail view to occlusal surface of molars).

26: Soricidae gen. et spec. indet., posterior part of the left mandible (B–4145; a – buccal view, b – caudal view of condyle, c – lingual view).

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