*GEOLOGICA CARPATHICA, 51, 2, BRATISLAVA, APRIL 2000*
*69–82*

# ORIGIN OF THE PLIOCENE VERTEBRATE BONE ACCUMULATION AT HAJNÁČKA, SOUTHERN SLOVAKIA

DIONÝZ VASS[1], VLASTIMIL KONEČNÝ[2], IGOR TÚNYI[3], PETER DOLINSKÝ[4], KADOSA BALOGH[5], NATÁLIA HUDÁČKOVÁ[6], MARIANNA KOVÁČOVÁ-SLÁMKOVÁ[6] and BORIS BELÁČEK[1]

[1]Faculty of Forestry, Technical University Zvolen, Masarykova 24, 960 53 Zvolen, Slovak Republic
[2]Geological Survey of Slovak Republic, Mlynská dolina 1, 817 04 Bratislava, Slovak Republic
[3]Geophysical Institute of the Slovak Academy of Sciences, Dúbravská cesta 9, 842 28 Bratislava, Slovak Republic
[4]Geomagnetic Observatory GPI SAS Hurbanovo, Komárňanská 107, 947 01 Hurbanovo, Slovak Republic
[5]Institute of Nuclear Research of the Hungarian Academy of Sciences, H-4026 Debrecen, Bem tér 18/c, Hungary
[6]Faculty of Science, Commenius University, Mlynská dolina, 842 15 Bratislava, Slovak Republic

*(Manuscript received May 3, 1999; accepted in revised form December 8, 1999)*

**Abstract:** The accumulation of vertebrate mostly mammal skeleton fragments in the “Bone Valley” at Hajnáčka — a type locality of the European Neogene Mammal time-scale, zone MN 16 and/or subzone MN 16a came into existence in a lake with water influx and outlet. After cessation of the phreatomagmatic eruptions responsible for the maar creation, the maar was filled by the finely laminated sediments. The domatic rise of the Cerová vrchovina Upland motivated the erosional destruction of any relatively soft relief protuberance. The ring of the maar was partly destroyed and the sedimentary maar fill was swept out. Later on the emptied maar was filled by water. In the lake originated in this way sandy sediments and tuff were deposited together with the bones of mammals, killed by postvolcanic gas emanations, or tephra fall, when the animals drank the water of the lake. The age of the subzone MN 16a is 2.8–3.3 Ma BP (Fejfar & Heinrich 1987). The subzone corresponds to the middle part of the chron C2An. The maar originated earlier in the early period of the same chron, because the tuff has a normal magnetic polarity. It could not be generated before 3.55 Ma BP — that is the numerical age of the chron C2An/C2Ar, because the chron C2Ar lasting 0.6 Ma (3.55–4.15 Ma BP) was a period of the reverse polarity of the Earth’s magnetic field. From the comparison of the age of the bone accumulation in the Hajnáčka maar and the basalt lava flows of the Cerová Basalt Fm. it follows that effusive activity acted before both phases of the maar creation and its filling as well as after it.

**Key words:** Villafranchian, Southern Slovakia, Cerová Basalt Fm., Hajnáčka, subzone MN 16a, maar, remanent magnetism, Neogene Mammalia.

## Introduction

The Hajnáčka Site — the finding place of the vertebrate mostly mammal bones in the so-called “Bone Gorge” is one of the type localities of the European Neogene Mammal time scale zone MN 16 (Mein 1975). The bones or skeleton fragments are inside a small basalt maar. The maar originated by the volcanic activity of the Cerová Basalt Formation (Vass & Kraus 1985). The Formation extends over the Cerová vrchovina Upland of Southern Slovakia (Fig. 1) and the Cserhát Upland of Northern Hungary. In Hungary the Formation is known under the name Salgóvár Basalt Formation. The Cerová vrchovina Upland and the Cserhát Upland represent one geographical unit divided by the Hungarian/Slovak Republic state boundary. The Cerová Basalt Formation is Pliocene–Quaternary in age. The radiometric ages of the basalts vary from 5.03 to 1.16 Ma (Table 1). The Formation is built up of cinder cones, lava flows, necks, diatrems and maars. In consequence of young updoming of the Cerová vrchovina Upland (Vass et al. 1986) and intensive erosive destruction of the basalt volcanics particularly the volcanic chimneys, necks and dykes have been exhumed. As a consequence of erosional relief inversion, lava flows originally situated in river valleys are now on top of flat hills. The maars have been partly destroyed and their soft sedimentary fill has been swept out by erosion.

As a result of finds of mammalian skeleton fragments the “Bone Gorge” at Hajnáčka attracted the attention of scientists from the mid 19th century. The first mentions of the site in scientific literature are in the papers of Szabó (1861, 1865) and Krenner (1867). Schafarzik (1899) speculated about the site’s origin. In 1915, Kormos collected bones at the site and published his findings in 1917. New systematic collections of bones at the site continued after the Second World War. Špinár & Hokř (fide Fejfar 1964) were the first, but intensive excavations in the “Bone Gorge” were realized by Fejfar in 1956–1957 and the results published in a comprehensive paper (1964). He came back to the site several times publishing some new data, which resulted from reexamination of the bone findings or data concerning the biostratigraphic correlation and zonation. Fejfar described his excavations very precisely, and we also use his description of the maar fill in this paper. The latest campaign of bone collection and excavations started in 1996 in framework of the project: “Expedition Hajnáčka 1996–2000”, with continuation in the project “HAJNÁČKA 1998–2000” Hajnáčka 1998–2000, realized by the Faculty of Natural Sciences of the Comenius University, Bratislava (Sabol, responsible scientist). Convenor of

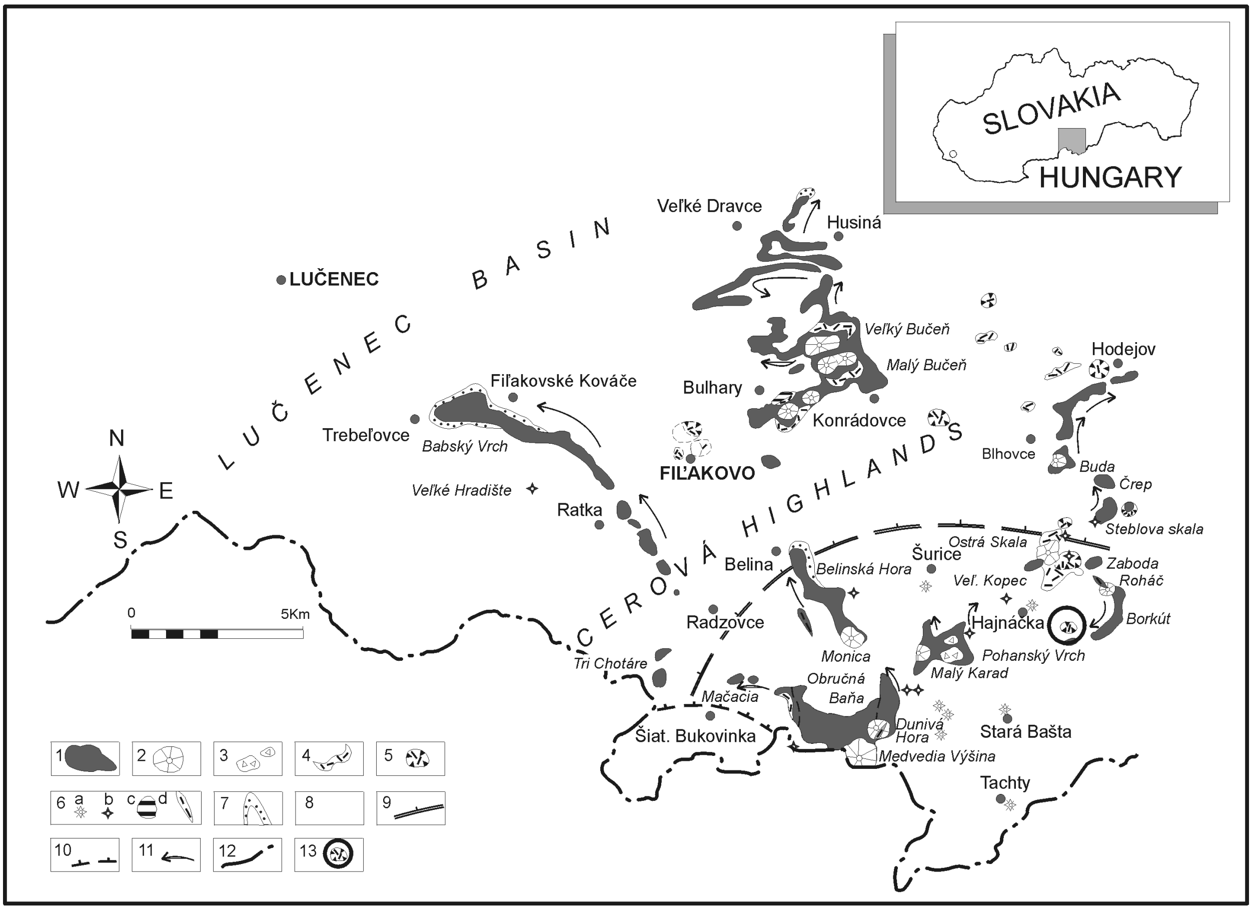



**Fig. 1.** Relicts of the Cerová Basalt Formation in Southern Slovakia. 1 — lava flow, 2 — scoria cone, 3 — agglomerate, 4 — lapilli tuff, 5 — maar, 6 — eruptive centres: a — diatreme, b — lava neck, c — extrusion, d — dyke, 7 — Belina Member: fluviatile deposits (gravel, sand, clay) immediately beneath the lava flows, 8 — pre-basalt rocks undivided, 9 — contour of updoming, 10 — local elevation (intrusions of andesite with garnet), 11 — lava flow direction, 12 — state boundary, 13 — "Bone Gorge" maar at Hajnáčka.

**Table 1:** Radiometric ages of some lava flows and/or dykes—Cerová Basalt Formation, Southern Slovakia.

| LOCALITY | VOLCANIC BODY | RADIOMETRIC AGE [Ma] |
|---|---|---|
| Dunivá Hora Hill | dyke | 1.32 ± 0.1; |
| Čirinč | lava flow | 1.42 ± 0.31 – 1.46 ± 0.15 |
| Polička | lava flow | 1.22 ± 0.36 |
| Konrádovce Quarry | lava flow | 1.51 ± 0.2; 1.02 ± 0.2 |
| Veľké Dravce Quarry | - " - | 1.27 ± 0.15 |
| Šávoľ | - " - | 1.29 ± 0.34; 1.16 ± 0.3 |
| Blhovce-Buda | - " - | 1.73 ± 0.1 |
| Bulhary Quarry | - " - | 1.47 ± 0.31 |
| Fiľakovské Kováče Quarry | - " - | 2.15 ± 0.13; 2.30 ± 0.47 |
| Trebeľovce Quarry | - " - | 2.59 ± 0.12 |
| Rátka Quarry | - " - | 1.93 ± 0.23 |
| Šid Quarry | - " - | 1.94 ± 0.16 |
| Mačacia Quarry | - " - | 1.87 ± 0.1 |
| Hajnáčka, Castle Hill | dyke | 2.60 ± 0.23; 2.87 ± 0.33 |
| "Bone Gorge" at Hajnáčka | | 2.80 – 3.30 (indirect dating) |
| Steblová skala Hill | lava flow | 4.63 ± 0.2 |
| Belinský vrch Hill | - " - | 4.76 ± 0.4 |
| Somoška, Castle Hill | - " - | 4.08 ± 0.03 |
| Pohanský vrch Hill | lava plateau | 5.03 ± 0.26; 4.7 ± 0.31 |

the project is the Gemer-Malohont Museum in Rimavská Sobota. New pits were excavated at the site in the summer of 1998. These pits have been visited by the authors of this paper.

The excavation pits were numbered by their excavators and the numbers are expressed as fractions. The denominator in fractions indicates the year when the pit was excavated. We refer to these numbers in some figures as well as in the text.

## Methods of investigation

Searching for the environment and the conditions of the mammal bone accumulation at the "Bone Gorge" site near the village of Hajnáčka (the name was given to the gorge because of plentiful bones findings), we have reinterpreted data obtained by Fejfar when he collected bones in the 50-ties, exploiting his precise graphical documentation and the explanatory text in his monograph (Fejfar 1964). We have also carried out a lithological study of the outcrops and new pits. New pits have been dug in the framework of the "Hajnáčka 1998–2000" project. We have reevaluated the shallow well HJ-1 sunk in the 80-ties during geological mapping in the area. Palinological methods have been used to make clear what kind of paleomicroorganisms are found in a fine laminated rock fragment from the secondary maar fill, and to explain its origin. The rock was macerated in HF and the pollen grains were separated in heavy liquid of 2 g.cm$^{-3}$ density.

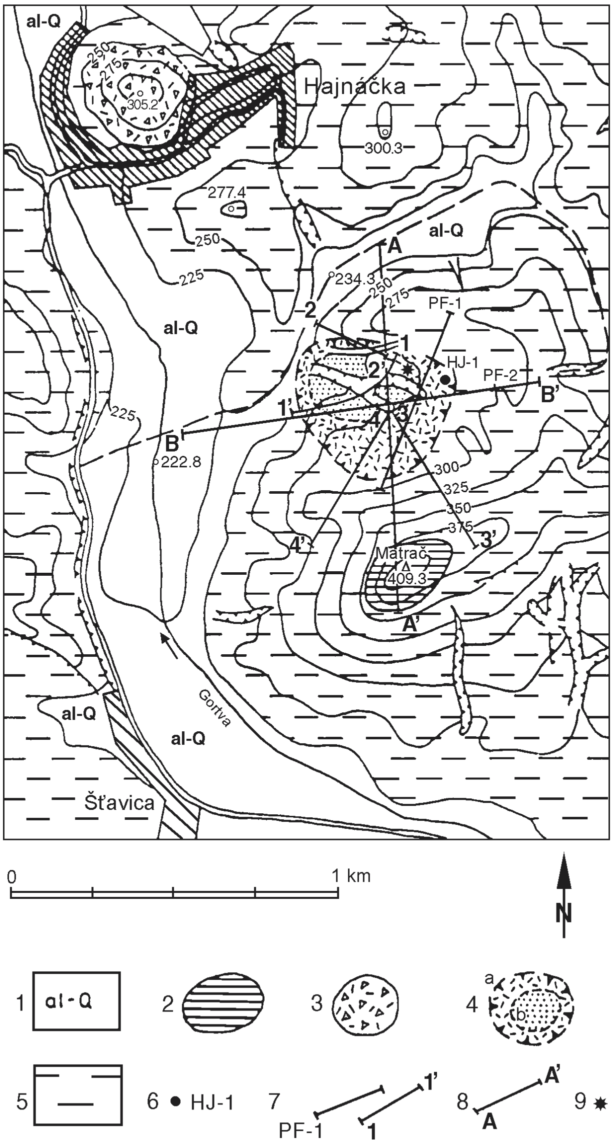



**Fig. 2.** Geological scheme (partly reconstruction) of "Bone Gorge" maar at Hajnáčka. 1 — alluvial deposits (Quarternary), 2 — relict of lava flow on the top of Matrač Hill, 3 — diatreme of Castle Hill in Hajnáčka with ruins of a castle on the top, 4 — relicts of the "Bone Gorge" maar: a — tuffaceous sand at the maar margin, b — secondary 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.

The basalt tuff of the maar ring relict outcropping in the field road cut (Fig. 2) underwent paleomagnetic investigation. Four samples were taken numbered from 1H to 4H. For the laboratory measurements only two of them were suitable (2H and 3H). The measured samples were divided into 12 pieces. They underwent the thermal magnetic cleaning in the Paleomagnetic Laboratory of the Slovak Academy of Sciences, Geophysical Institute (GPI SAS), using the MAVACS equipment for the demagnetization and spinner magnetometer JR 5 to measure the remanent magnetic polarization. After each step of demagnetization the magnetic volume susceptibility was measured on κ-bridge KL 4. All equipment used was produced by Geofyzika Brno. For demagnetization the thermal step of 30 °C was used.

In the area of the maar "Bone Gorge" and its near vicinity four geomagnetic sections have been measured. Two of them (PF 1, PF 2) were measured by the proton magnetometer PMG 1, operated by Geospektrum Bratislava (Vrubel 1998). Four other section (1–1', 2–2', 3–3', 4–4') have been measured by proton magnetometer EDA and measurements were carried out by GPI SAS, branch in Hurbanovo.

For making clear the age relationship between the maar studied and other volcanic products of the Cerová Basalt Formation, especially the basalt lava flows, the older, already published as well as some new previously unpublished radiometric K/Ar ages were used.

## Lithological and sedimentological characteristics of the "Bone Gorge" maar at Hajnáčka

The "Bone Gorge" maar is situated SE of the village of Hajnáčka. The maar centre is 1200 m SE of Hajnáčka Cas-

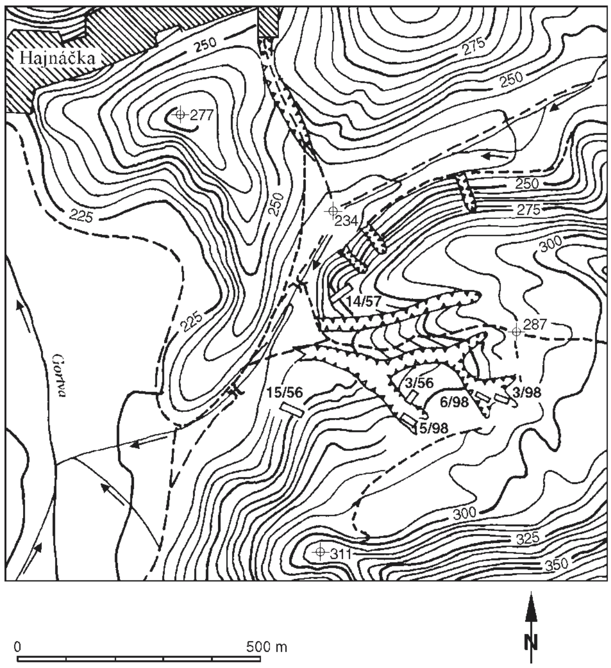



**Fig. 3.** Sketch showing the situation of the pits in the "Bone Gorge" mentioned in the paper.

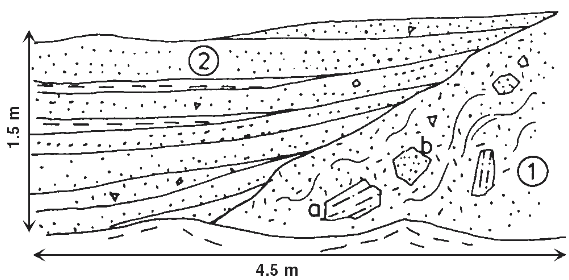
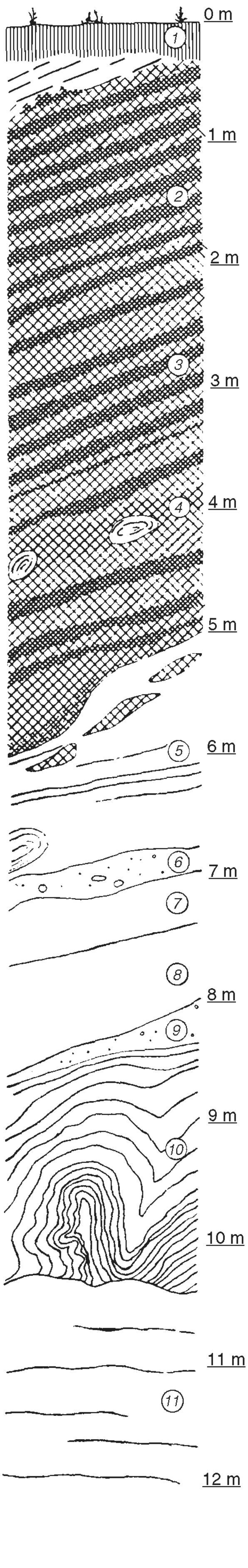



**Fig. 4.** Northern margin of the maar outcroping in the field road cut. 1 — blocks of Fiľakovo Formation sandstones (a) and of tuffaceous sandstones (b) chaotically distributed in sandy matrix, 2 — bedded tuffaceous sandstone and siltstone.




tle Hill with ruins of a medieval castle on the top (Fig. 2). The hill is a basalt volcanic chimney, a diatreme exhumed by erosion. The maar itself is not expressed in the relief of the country. Its original form has been wiped out by the erosional processes and it is almost completely covered by young Quaternary deposits and weathering products.

The lithology of maar ring was described in some pits and outcrops. In the field road-cut at the northern margin of the maar there is a layer of tuff with fragments and blocks of sandstone of diverse grain-size including Eggenburgian sandstone chaotically distributed in a sandy matrix (Fig. 4). The layer has signs of explosive disturbance and it is a transition to the diatreme. The layer is covered by the brown, bedded tuffaceous sandstone and siltstone inclining 35°–40° to the SE, that is to the centre of the maar (Fig. 4). The rocks are disturbed by slumps, synsedimentary faults and by water escape structures. These sedimentary features testify to phreatomagmatics eruptions. The tephra and volcanic ash saturated by water after their deposition were unstable and on the slope of the maar ring they slid down.

More complete sections were available in two pits excavated in the years 1956 and 1957 (pits 14/57 and 15/56, Fig. 3). In one of them (pit 15/56, Fig. 5) at the depth of 10.4 m the pre-volcanic basement rock a friable sandstone of the Fiľakovo Formation (Eggenburgian in age) was reached. Both pits well have shown that the lower part of the ring is predominantly formed by blocks of basement sandstone drowned in a sandy matrix. This rock stuff was disintegrated, shot up and again deposited by the first phreatomagmatic eruptions. Layers of tuffaceous sand with basaltic lapilli and/ or silty basalt tuff are present sporadically. Some sedimentary structures and bedding disturbances are synsedimentary sliding features. The upper part of the ring is built up of bedded lapilli tuff. Finer and coarser layers alternate (Fig. 5). The lower portion of the ring crops out in a small outcrop at the western maar margin, at the entrance to the "Bone Gorge".

The recent inner filling of the maar was studied in the pits dug in the "Bone Gorge" itself. The deepest portion of maar

**Fig. 5.** Section through the ring of the "Bone Gorge" maar at Hajnáčka. In the upper half of the ring section volcanic material is dominant. In the lower half sandy material desintegrated by the explosion and blocks of Eggenburgian sandstone (maar basement) prevail. Pit No. 15/56 (situation see Fig. 2). 1 — loam, 2 — grey, grey-brown bedded lapilli tuff alternating with layers of tuffaceous siltstone and sandstone, 3 — light grey bedded lapilli tuff with coarser layers containing rusty limonitic intercalation, 4 — coarse greenish, dark-grey lapilli tuff with xenoliths of Fiľakovo Formation (Eggenburgian) sandstone, note sharp base against the underlaying rocks, 5 — rusty-brown sands, in the upper part with lences of grey lapilli tuff, 6 — rusty-brown, fine tuffaceous sand with small limonitic concretions, 7 — sand, 8 — light, greyish-brown fine sand, 9 — rusty-brown fine sand with numerous lapilli, 10 — light rusty-brown, rusty banded (Liesegang circles?) friable sandstone, a block resting unconformably on the basement, 11 — the basement of the ring: light yellowish-brown slightly calcareous micaceous friable sandstone of the Fiľakovo Formation (Eggenburgian). Lithological description and drawing according to Fejfar (1964).

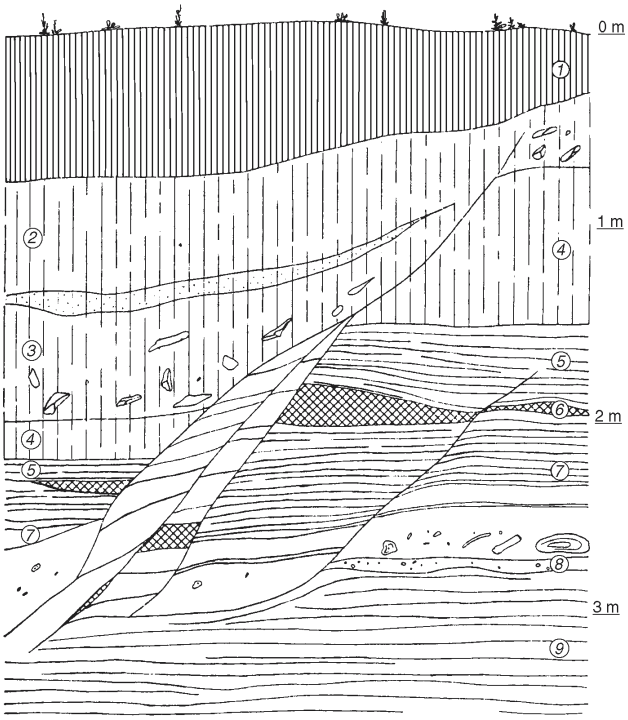



Fig. 6. The secondary chaotic fill of the "Bone Gorge" maar at Hajnáčka with mammal bones. Note the slump bodies. Pit No. 3/56 (situation see Fig. 2). 1 — loam, 2 — rusty-brown clayey sand, 3 — the same as 2 with basalt boulders, 4 — light-brown fine sand, 5 — light brownish-grey bedded slightly calcareous tuffaceous sand, 6 — dark-grey coarse lapilli tuff with xenoliths of baked sandstone, 7 — light brownish-grey bedded fine sand, the lower part is unbedded rusty-brown sand with the mammal skeleton fragments and with blocks of friable sandstone of Fiľakovo Formation (Eggenburgian), 8 — light-grey fine sand with small fragments of sandstones as in 7, 9 — rusty-brown bedded fine tuffaceous friable sandstone/siltstone. According to Fejfar (1964).

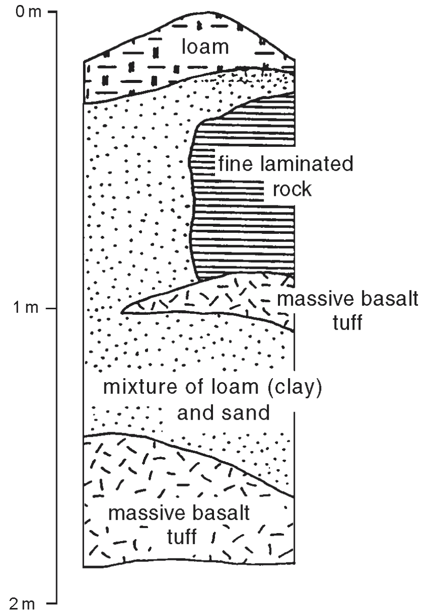



Fig. 7. Secondary chaotic fill of the "Bone Gorge" maar at Hajnáčka with a block of laminated rock — a fragment of the primary maar fill. Pit No. 5/98, situation see Fig. 2.

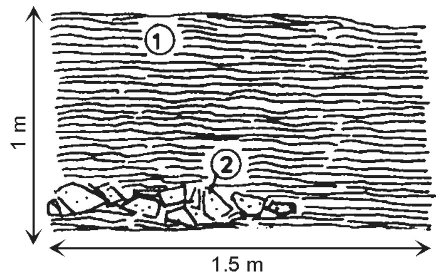



Fig. 8. Slumpballs and lenses of tuffaceous sandstone (2) in fine-grained re-deposited sand (1).

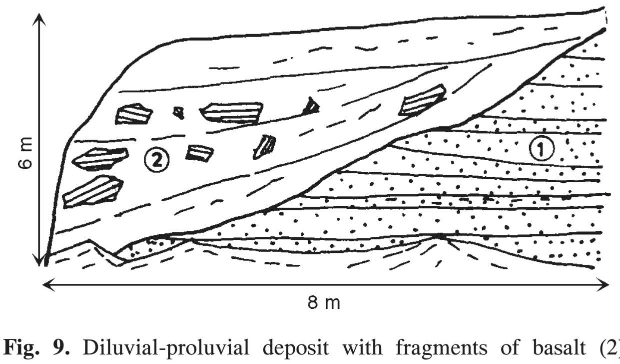



Fig. 9. Diluvial-proluvial deposit with fragments of basalt (2) formed by erosional activity during the destruction of the original maar. They are laying on the prevolcanic basement (1), i.e. on the Fiľakovo Fm. sandstone (Eggenburgian). Outcrop on the western margin of the maar.

fill is the bedded, undisturbed basalt tuff. Certainly the erosion did not sweep out the basal portion of the original maar filling. The upper portion of the fill has a chaotic structure. Loose sand and/or clayey sand of disintegrated sandstone of the Fiľakovo Formation prevails. There were sporadical findings of shark teeth also redeposited from the Fiľakovo Formation (Fejfar 1964). In the loose sandy rock there is some admixture of basalt volcanic material. The sand is poorly bedded. It forms lenticular bodies. The textural features testify to deposition by water currents in a drained lake. In the sand there are layers, lenses and/or blocks of the lapilli tuff, basalt fragments, fragments of Eggenburgian sandstone with a rim of thermal alternation. The chaotic structure of maar fill is the result of epigenetic sliding. Fejfar (1964) described several sliding bodies in the pits during his excavation in "Bone Gorge" (Fig. 6). The chaotic maar fill contains abundant autochthonous findings of mammal bones. Isolated bone fragments in allochthonous position were found in sandy loam covering the chaotic maar fill (layer 2 in the pit 3/56, Fig. 6).

Similar lithology was found in the middle of the maar in the pits trenched in 1998. There is fine-grained, friable gray-green, sorted and bedded tuffaceous sandstone and/or sand inclined 20° to SE. Blocks of calcified laminated sediment are frequent. A 50×50 cm block of this kind of rock was found in the pit 5/98 (Fig. 7). Fragments and blocks of lami-

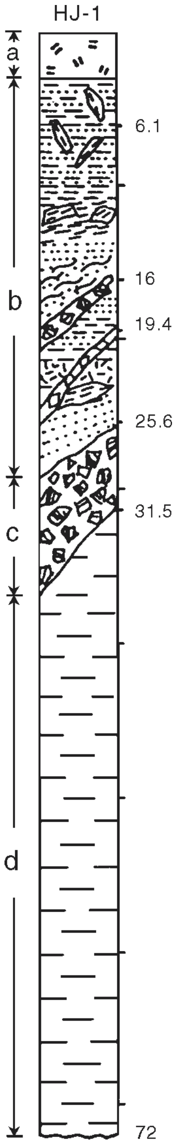



**Fig. 10.** Schematic section of the well HJ-1. a — loam, b — tuffaceous deposits with interbedded siltstone and fragments of fine-grained deposit, c — breccia with fragments of porous basalt, d — friable sandstone of Fiľakovo Fm. (Eggenburgian).

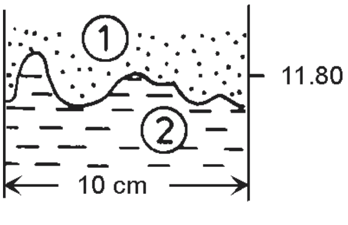



**Fig. 11.** Load cast structures: tuffaceous sandstone (1) loaded onto tuffaceous siltstone (2).

nated sediment are redeposited remnants of the primary maar filling originated in eutrophic lake conditions. The slump balls and lenses of tuffaceous sandstone are occasionally present. They come from the inner ring slope and underwent erosional destruction (Fig. 8). Tuffaceous sand and friable

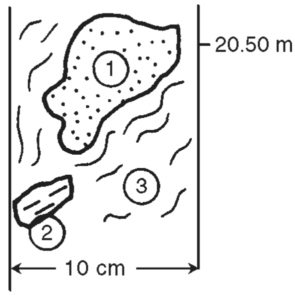



**Fig. 12.** Inclusion of the tuffaceous sandstone (1) and sandstones (2) in tuffaceous matrix (3).

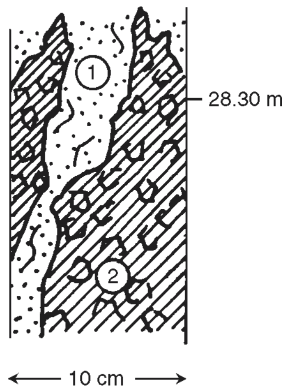



**Fig. 13.** Interfingering of the basalt breccia (2) into the maar filling (1). Detail from the well HJ-1 core.

sandstone come from the slopes of the cauldron-like depression incised in pre-volcanic sandstone. Sedimentary structures are of fluvial and/or drained lake origin. These sediments are younger than the primary maar filling. They represent the secondary fill and they contain the mammal bones and skeleton fragments.

At the western outer margin of the maar the deluvial-proluvial deposit with fragments of basalt plates crops out (Fig. 9). It shows the depth of the erosion.

The geological structure of the maar was made clear by re-examination of a well HJ-1 drilled in the 1980s at the eastern maar margin (see Fig. 2). The upper portion of the well core is formed by fine-grained sandy tuffaceous rock (Fig. 10) interbedded by gray to white-gray siltstone with fine sandy laminae 1 mm thick. Siltstone is often deformed by the load of sandy layer (Fig. 11). The well core contains bodies of massive friable sandstone with fragments of siltstone and porous basalt (till 0.8 cm). These rocks prove that slumping movements occurred. Locally the sandy rock is surrounded by whirled and sludged siltstone (Fig. 12). In some intervals the well core is penetrated by the basalt breccia with strongly and/or extremely foamy cinder fragments of irregular shape (Fig. 13). At the contact of the breccia with the deposits, they are destroyed, crushed and/or surrounded by the breccia.

The basalt breccia in the well belongs to the feeding system of the diatreme below the maar structure. Beneath the depth 31.50 m the well penetrated the marginal part of the maar filling into the pre-volcanic rocks — sandstone of the Fiľakovo Formation Eggenburgian in age (Fig. 10).

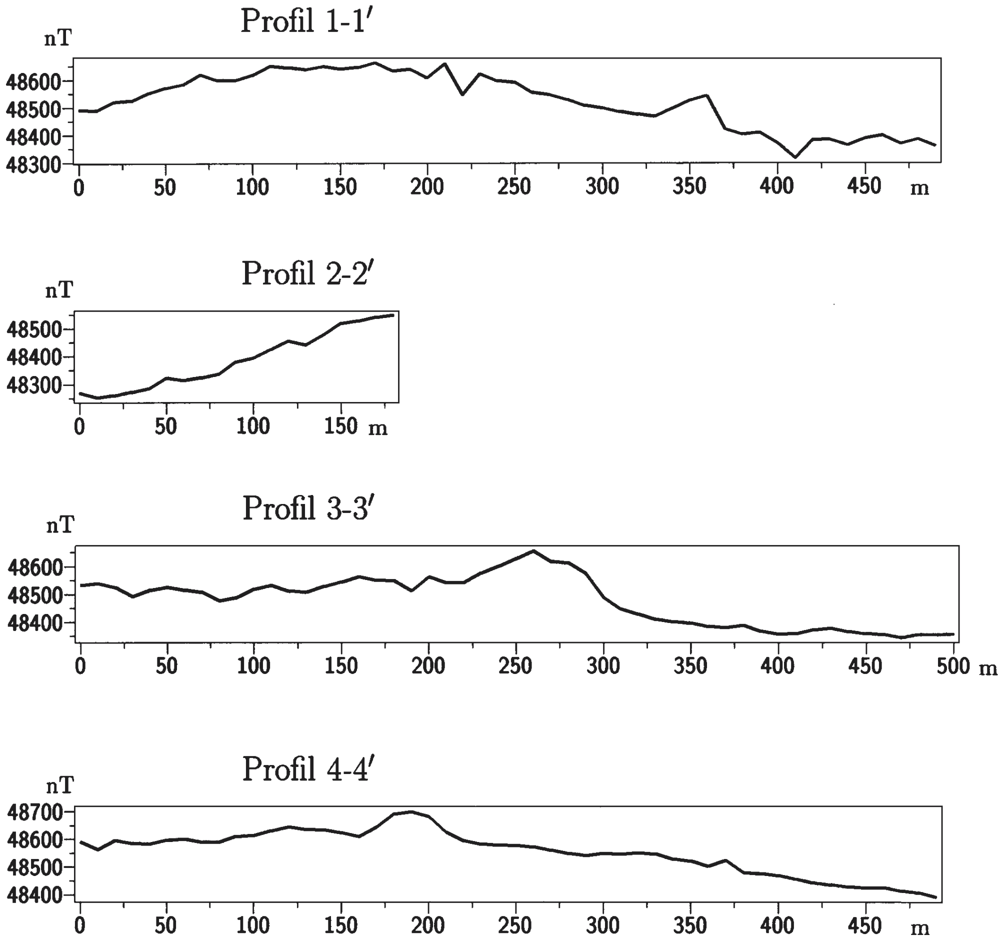



**Fig. 14.** Geomagnetic cross-sections 1-1', 2-2', 3-3' and 4-4' (the positions see Fig. 2). The values are corrected according to the Geomagnetic Observatory GPI SAS Hurbanovo.

The establishment of the maar's shape and its geological structure was enabled by the magnetometric lines. The maar filling is magnetically harder than the surrounding Eggenburgian deposits. The higest intensity of the magnetic field measured at lines 1-1', 2-2', 3-3' and 4-4' (Fig. 1, Fig. 14), represents the maar's center. In the line 1-1' it is the section from 50 to 350 m. The elevated magnetic curve reflects the buried magnetic rocks of the diatreme. To both ends of this line the magnetic effect decreases.

The remnants of the maar ring are formed by magnetically harder rock, such as basalt tuff. In such rocks the measured magnetic effect is again higher and in the magnetic curve is represented by the local maximum on the line 1-1'at the point 370 m. From this point the magnetic curve is definitively flattened. The line 2-2' is perpendicular, or oblique to the line 1-1'. The measurements started in the sedimentary environment and magnetic curve up to points 80-100 m is flat. The latter line crosses the ring remnants, the presence of which was verified by pit 14/57 (Fig. 2). Line 2-2' ends immediately after the crossing with the line 1-1'. Rising of the magnetic field corresponds to the growth of magnetically harder rocks in the basalt tuff. The major part of the line 2-2' crosses in an oblique direction the marginal portion of the maar. The profiles 3-3' and 4-4' start in the maar and cross the maar ring in the 250-300 m and 175-225 m respectively (Fig. 2, Fig. 14).

Magnetic measurements on the maar were also done by Geospektrum Co. (Vrubel 1998) along two lines PF-1 and PF-2 (Fig. 15). The results are conformable with the results of the 1-1', 2-2' lines. The line PF-2 passes through the maar and the elevated part of the magnetic curve reflects inner structure of the maar with diatreme in its centre (section from 260 to 610 m). The line PF-1 follows the maar margin. The magnetic intensity of the first half of the line is lower. At the point 130 m the line enters the maar filling and the magnetic intensity rises.

The results of the magnetic measurements have been used for the geological reconstructions of the maar as it is shown on Fig. 2.

## Reconstruction of maar's shape and its evolution

On the basis of natural outcrops, the HJ-1 well and the magnetic measurements it is possible to summarize the evolution at the "Bone Gorge" maar as follows:

At the beginning a dishlike or funnellike depression was created by resolute phreatic explosions. Its base was approx. 150

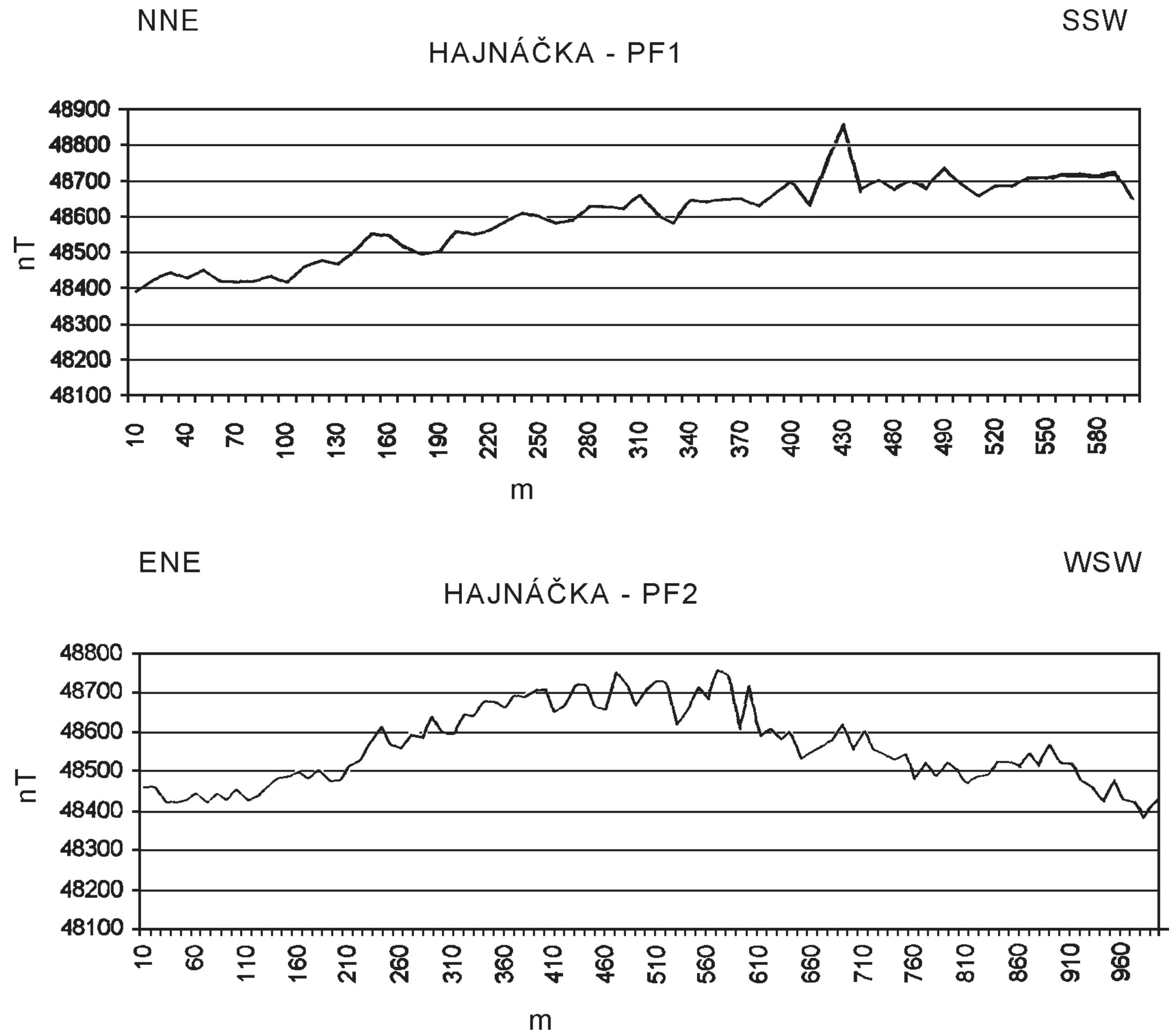



**Fig. 15.** Geomagnetic cross-sections PF-1, PF-2 (Vrubel 1998).

m below the surrounding relief. The base of lava flow erosional remnant on the top of the Matrač Hill is 380 m above sea level. The phreatic explosions (predominantly gaseous and steam explosions) brought to the surface sandy material coming from disintegrated Eggenburgian sandstone. This material was deposited on the bottom of the depression as sand, unconsolidated or consolidated by calcification ($CO_2$ emanation). A deposit of this kind was described by Fejfar (1964) from the trenched pits. It directly overlays the Eggenburgian sandstone of the pre-volcanic basement. Later on the ring surrounding the maar was built up by phreatomagmatic eruptions (explosions with pyroclastic material). The transition to the phreatomagmatic activity is indicated by the presence of breccia in well HJ-1 disintegrated during its rise to the surface. The tephra loaded during the explosions on the inner side of the ring saturated by water was unstable, underwent gravitational sliding and was replaced down the slope. The sliding could be initiated by the earthquakes associated with the repeated eruptions. During the breaks in volcanic activity in the centre of the maar the fine-grained maar lake deposits originated.

In the pit 5/98 a block of fine laminated rock was found. Thin (0.1–0.3 mm) pelitic laminae alternate with sandy ones (0.5 mm thick). The pelitic laminae are often rich in palynorests (pollen, spores and algae). The scarcely identified one-cell algae show dominant abundance (75–80 %) in the whole palyno-assemblage. We can propose that they belong to the heterotrophic cysts of the peridinioid dinoflagellates like *Peridiniopsis borelinense* (Lemmernann) Bourrely, *Peridiniopsis* spp., *Selenopempyx* sp. The *Halodinium* sp. rarely, and incerte sedis algae — *Leiosphaera* sp. and *Cyclopsiella* sp. are observed in the algae association too. Similar algae inhabit eutrophic lakes and pools and live in similar environments in recent Europe (Popovský & Pfiester 1990). In accordance with the data mentioned above we can suppose that the rocks which have been found in the secondary maar fill originated in the primary maar lake, with a eutrophic character, like many other maar pools.

A lot of arctotertiary geofloral elements, such as *Abiespollenites* sp., *Piceapollis* sp., *Sciadopytispollenites* sp., *Tsugaepollenites* sp., *Pinuspollenites* sp., less *Caryapollenites simplex*, and *Acer* type have been identified in the palinospectrum of the sample. They belong to the coniferous with bisacate (*Pinus, Picea, Abies*) or monosacate (*Tsuga*) pollen. Saccate pollen are characterized by long fly distance from their place of

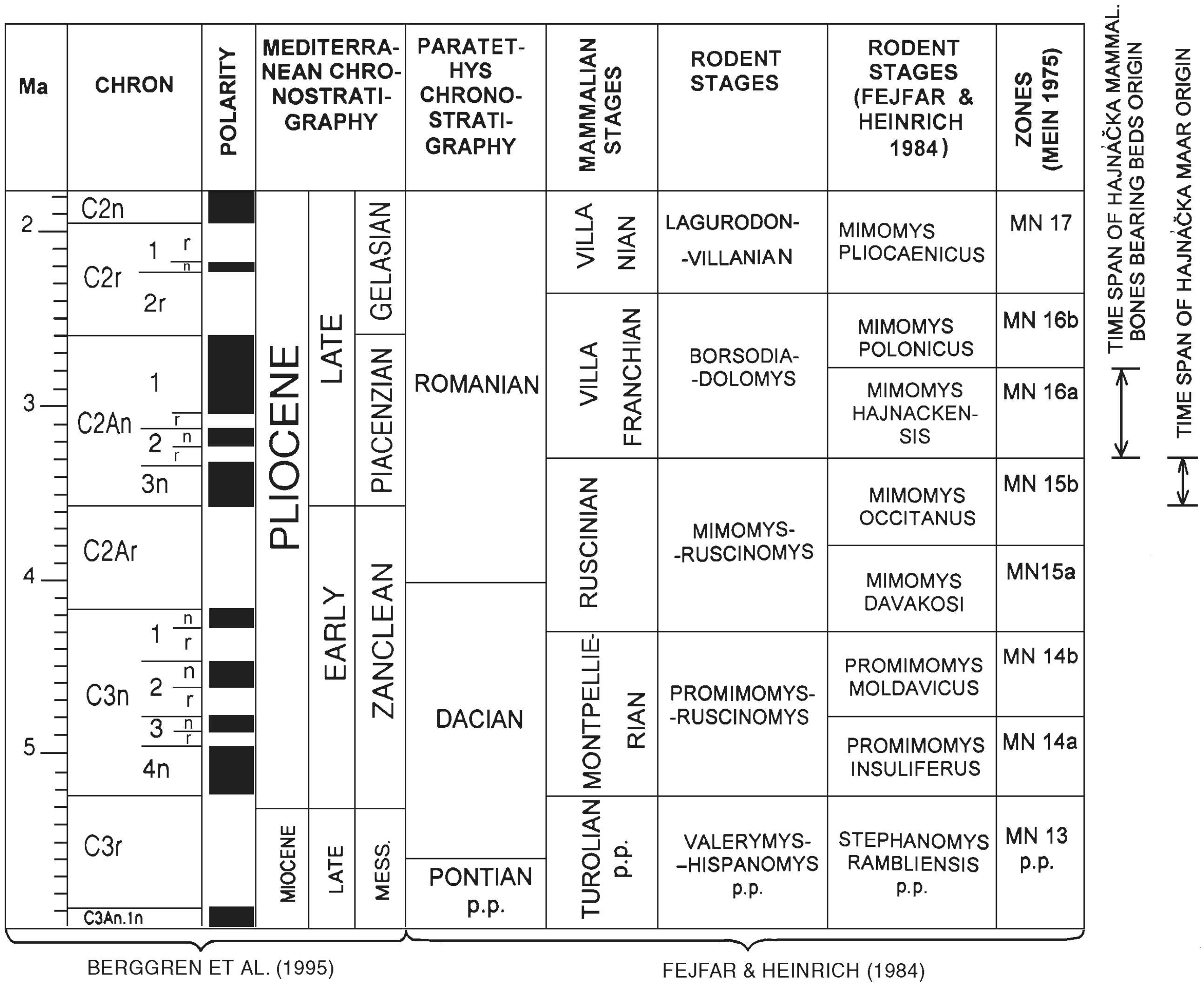



**Fig. 16.** The cross-correlation of the Pliocene magnetostratigraphic the Mediterranean Paratethys and the European mammal chronostratigraphic time-scales and the position of the Hajnáčka site in the framework of the Pliocene.

origin. Because saccate pollen highly prevail in the studied material (90 %), with angiosperms occurring only sporadically, we can suppose that the original flora was placed at a long distance from the lake shore. After dividing the flora into two groups to A1-group *Sciadopytispollenites* sp., *Tsugaepollenites* sp., *Pinuspollenites* sp., *Caryapollenites simplex*, *Acer* type and to A2-group *Abiespollenites* sp. and *Piceapollis* sp. the climatic character of the outpost is clearly visible. Dominance of the A1-group members documents a temperate climate. A dry substratum with mostly coniferous vesture in the long distance from the pool shore is documented by the high amount of saccate pollen.

After cessation of basalt maar volcanic activity the erosional destruction and denudation of the maar began. The maar ring was strongly eroded. Only remnants of the inner ring slopes at the margin of the maar depression are preserved (Fig. 20). The western part of the maar was opened by erosion and the primary soft maar filling, that is the laminated deposit of the eutrophic lake, was swept out. In the deepened maar depression a drained lake originated and its deposits are recent maar filling.

## The age of maar and of its secondary filling

The age of the actual fill of "Bone Gorge" maar at Hajnáčka is well proved by the skeleton remnants of mammals. The site is the type locality of the European Mammal time-scale, zone MN 16 together with localities such as Villafranca, Villaroya, Midas, Seynes Belaruc 2, Vialett, Stanzendorf, Rembielice Krolewskie, Bezimjane, Gülyazi a.v. (Mein 1975). According to biostratigraphic zonation on the basis of rodents (Rodentia, Mammalia) the Hajnáčka site belongs to subzone MN 16a with *Mimomys hajnackensis*. The subzone corresponds to the early Borsodia–Dolomys Stage and to the early Villafranchian Stage of the Mammal scale (Fejfar & Heinrich 1987). The numerical age of the subzone MN 16a is 2.8–3.3 Ma (Fejfar & Heinrich l.c.). This time interval in the magnetostratigraphic time scale corresponds to the middle part of the C2An chron (normal polarity prevailed). The whole zone MN 16 corresponds in the chronostratigraphic scale of the Paratethys Neogene to the Romanian Stage and in Mediterranean chronostratigraphy to the Piacenzian stage (Fig. 16).

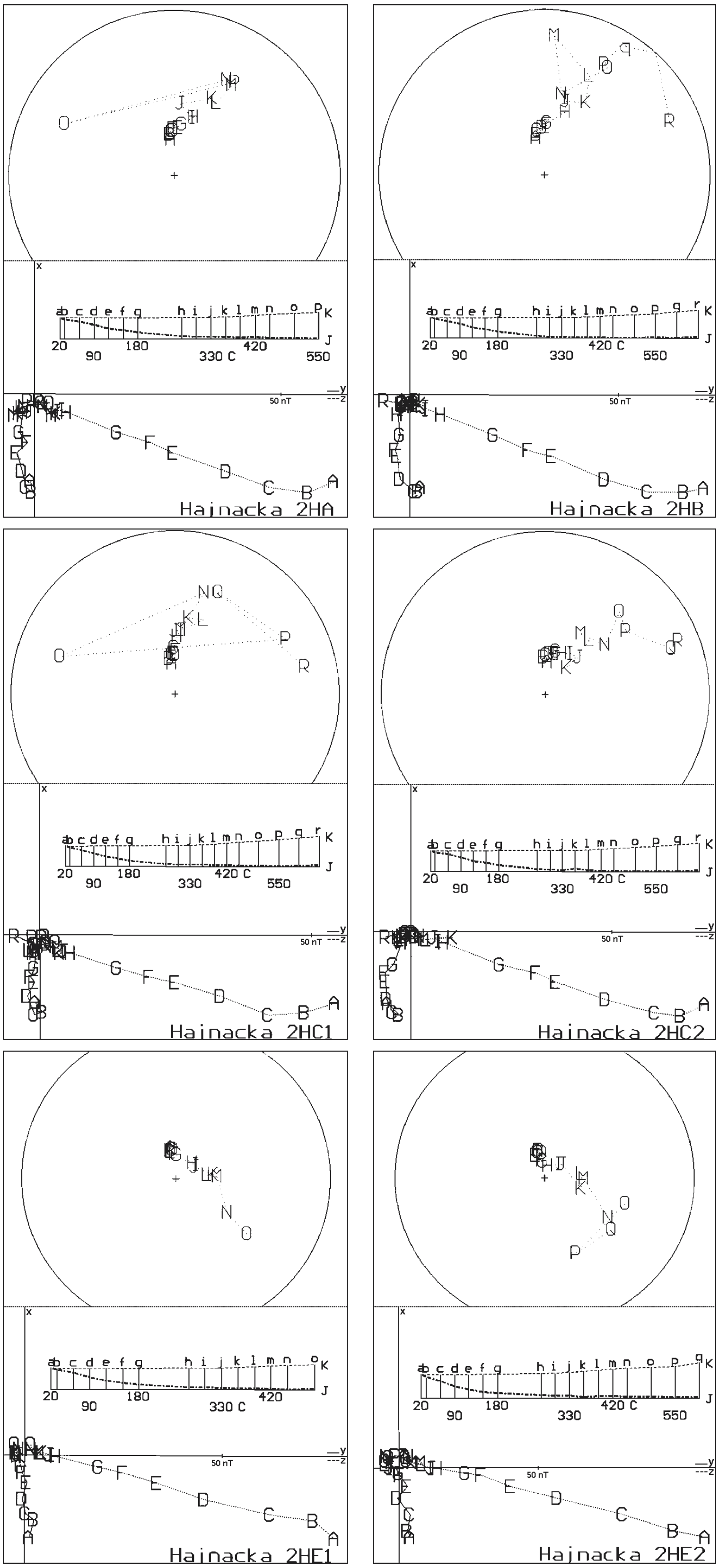



**Fig. 17.** Thermal demagnetization of the basalt tuff (samples 2HA, 2HB, 2HC1, 2HC2, 2HE1 and 2HE2). The dotted lines — volume magnetic susceptibility; the broken lines — remanent magnetic polarization; demagnetization of the XY and XZ components; stereographic projections of the paleodirections after each steps of demagnetization. Capitals — normal paleodirections.

The position of the Hajnáčka site in the framework of the magnetostratigraphic Neogene scale is supported by the paleomagnetic measurements of the site.

The remanent magnetization of the basalt tuff samples in the field road-cut at the maar northern margin, where a remnant of the maar ring outcrops (see Fig. 2), has been studied. According to the laboratory measurements the basalt tuff has a high magnetic stability and the course of the demagnetization curves is smooth up to a high temperature (Figs. 17, 18). The rock contains one carrier of magnetism. It is probably some mineral from the group of titanomagnetite. From the graphs on Figs. 17 and 18, the values at the temperature 210 °C and 240 °C are missing. For technical reasons the measurements have not been taken, but their absence does not harm the final result, because the samples were mostly demagnetized at the temperature 180 °C.

The stereoprojection in Fig. 19 shows the direction of the remanent magnetic polarization, computed as the mean direction of 12 samples by the Fischer's statistics (Fisher 1953). Because there is no deep of burial rocks, the paleodirections represent the in situ position of the samples. The direction convergence is very good as shown by Fig. 19. The polarity of the remanent magnetization is normal. The mean direction is almost identical with the present-day one. It is proof of the unrotated position of measured tuff.

As paleomagnetic measurements show, the maar "Bone Gorge" originated during a period of normal polarity of the Earth's magnetic field. This is in agreement with the lithostratigraphic proofs of the secondary origin of the maar filling containing mammal bones. The accumulation of bones originated during the middle part of the chron C2An. The chron was a time interval when the normal polarity of the Earth's magnetic field prevailed. The original maar and its ring most probably originated during a normal magnetic event of the chron C2An lower part (Fig. 16).

## Discussion

The accumulation of mammal skeleton fragments of the Hajnáčka site must have taken place in a shallow fresh water lake (Schafarzik 1899; Kormos 1917; Fejfar 1964; Fejfar & Heinrich 1985).

Deposition in the lake is supported by finds of fresh water molluscs — *Anodonta* sp. (Kormos 1917). Detailed investigation of basalt volcanic activity of the Cerová Formation in

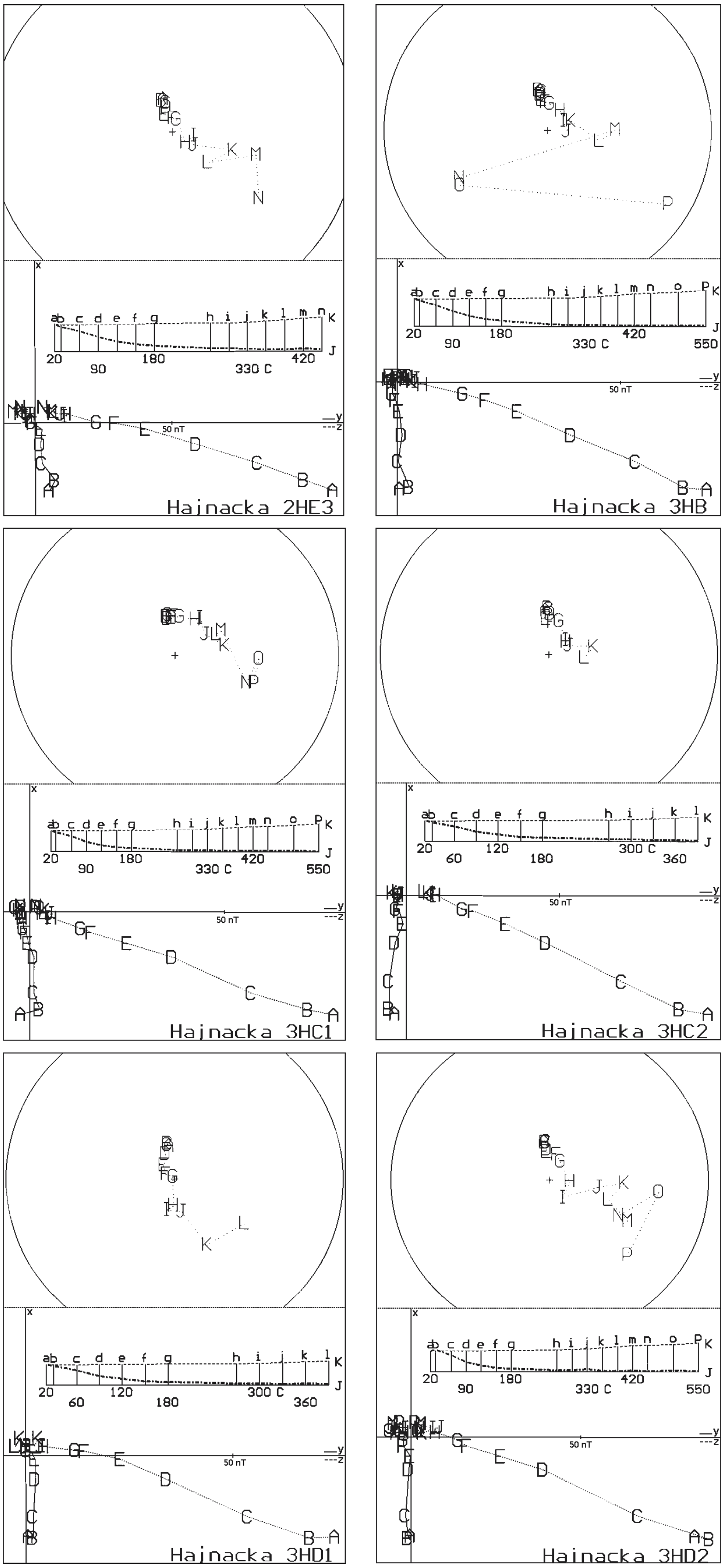



**Fig. 18.** Demagnetization of the basalt tuff (samples 2HE3, 3HB, 3HC1, 3HC2, 3HD1 and 3HD2; expl. see Fig. 17).

the Cerová vrchovina Upland leads to the conclusion that the fossiliferous deposits in the "Bone Gorge" belong to the basalt maar fill (Konečný & Lexa in Vass & Elečko et al. 1992).

As a result of the quiet sedimentary conditions in the maar lake, generated after cessation of the maar explosions, the maars are usually filled up by fine laminated deposits. In southern Slovakia two basalt maars filled up by laminated oil shale have been described — alginite (maar at Pinciná, Vass et al. 1997) or laminated diatomite (maar at Jelšovec, Vass et al. 1998). The basalt maars in Hungary on the slopes of the Bakony Mts. and in Transdanubia are filled up by laminated alginite (Solti in Russell 1990).

The "Gorge of Bones" maar at Hajnáčka, like the above mentioned maars, has a roughly circular shape (Fig. 2). Due to a phreatomagmatic activity a maar depression surrounded by a tuff ring was formed (Fig. 20-I). The central part of the maar depression was filled by precipitation water and a small maar lake came up into existence. The lake was progressively filled up by fine laminated lake sediments (tuffitic silt and clay). This is shown by a block of fine laminated tuffitic sediment found in the pit 5/98 (Fig. 5).

A basalt lava flow probably of younger age (dated to 1.35 ± 0.32 Ma by K/Ar method) was emplaced on the southern slope of the tuff ring.

As the Cerová vrchovina Upland was gradually uplifted during volcanic activity and transformed into dome-like structure, the maar was affected by deep erosion. The ephemeral streams partly destroyed the tuff ring around the maar depression and then swept out the soft laminated sedimentary maar fill (Fig. 20-II).

In the newly deepened maar depression a lake with inflow and outfow originated. In such a lake the sandy sediments accumulated forming the present day-secondary fill of the maar. Because of continuing basalt volcanic activity in the maar surroundings some tephra fell into the lake forming lapilli tuffs and tuffaceous sand layers inside the redeposited sandy maar fill. The rocks generated in this way contain autochthonous fragments of mammal skeletons. It is possible that the animals descended to the lake to drink the water and some of them there were killed by poisonous volcanic gas emanation, or by abrupt fall of tephra from distal volcanic explosions. The latter case of animal death is supported by rich bone findings in lapilli tuffs of various grain-size excavated in one of the pits on the

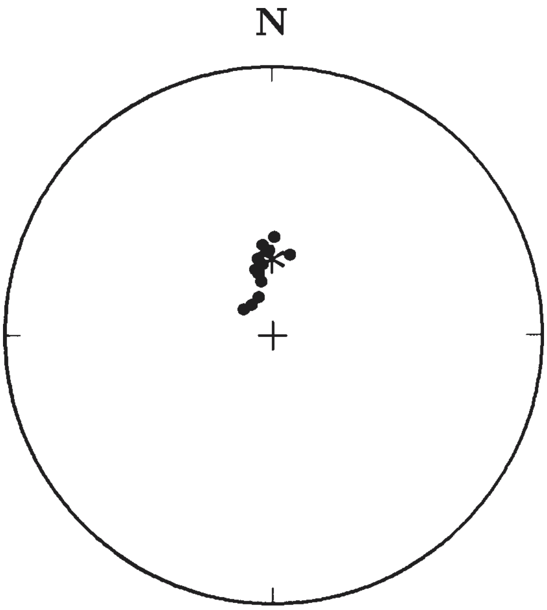



**Fig. 19.** Stereographic projection of the paleodirections. Asterisc — the mean direction.

eastern margin of the maar (pit No. 9/56, Fejfar 1964). Due to the stream and current interference in the lake the skeletons of killed animals were desintegrated and consequently the findings are usually fragments of mammal skeletons.

The secondary filling of the maar was much more dynamic than the original filling of the maar. The sedimentation was accompanied by sliding and slumping of already deposited material from the maar margins to its centre. This is well proved by numerous slump bodies described by Fejfar (l.c.). Up to the end of the secondary maar filling, the new fill was partly disintegrated, as a consequence of continuing updoming of the Cerová vrchovina Upland, and the mammal bones were resedimented. Rare findings of resedimented bones were found by Fejfar in sandy loam lying discomformably on secondary chaotic maar fill (pit 3/56, Fejfar 1964).

As a result of reconstruction of the "Bone Gorge" maar, the assemblage of mammals, particularly of rodents, enables us to correlate the secondary maar fill with the Villafranchian, more precisely with the zone MN 16a — *Mimomys hajnackensis* in the numerical time scale corresponding to 2.8–3.3 Ma. Of course, the origin of the maar ring and of the primary maar fill preceded the origin of the secondary fill.

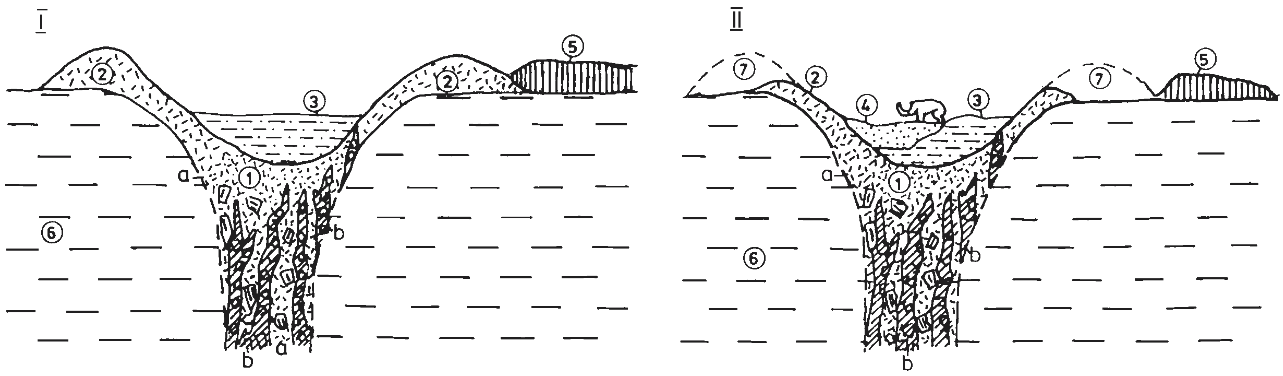



**Fig. 20.** Evolution of the "Bone Gorge" maar at Hajnáčka (I, II). I-st stage — formation of the maar with tuff ring and sedimentary filling in central depression. II-nd stage — partial erosion of tuff ring and maar filling replaced by sands with fragments of mammal skeletons. (1) filling of the diatreme: a) palagonitized tuff breccia, b) younger basaltic breccia intruding through tuff-breccia. (2) tuff ring, (3) primary maar filling (tuffitic siltstones and sandstones), (4) secondary maar filling (resedimented sand with fragments of mammal skeletons), (5) basaltic lava flow, (6) friable sandstones of Fiľakovo Fm. (Eggenburgian), (7) reconstruction of the tuff-ring removed by erosion.

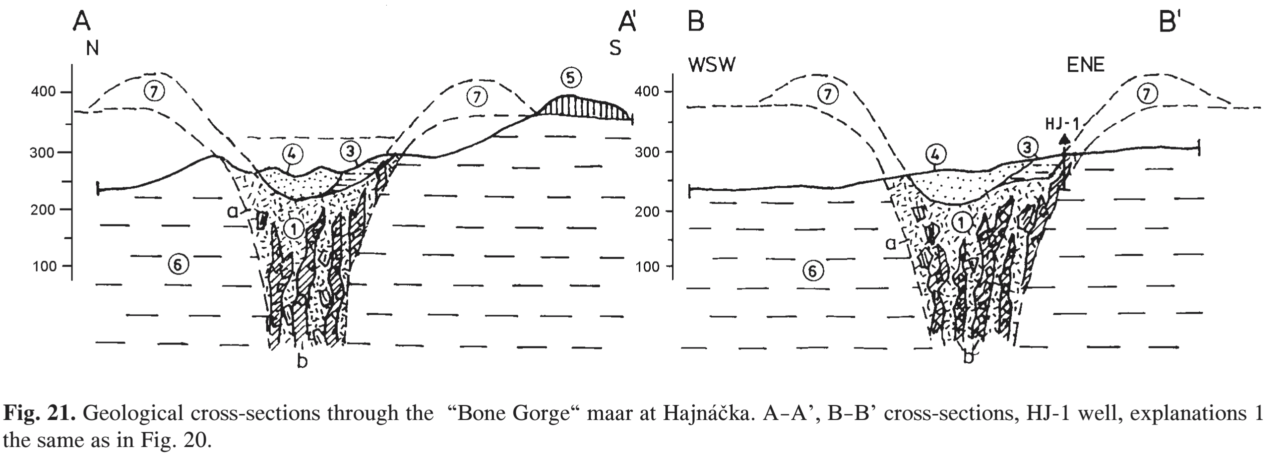



**Fig. 21.** Geological cross-sections through the "Bone Gorge" maar at Hajnáčka. A–A', B–B' cross-sections, HJ-1 well, explanations 1–7 the same as in Fig. 20.

The paleomagnetic properties of the tuff of ring, as the normal polarity of remanent magnetic polarization, indicates the time of the maar's formation at the beginning of the chron C2An, when the polarity of the Earth's magnetic field was normal. The maar ring could not originate earlier than 3.55 Ma B.P., because during the preceding time interval of the chron C2Ar, the polarity was reversed and its time span was from 3.55 to 4.15 Ma (Fig. 16).

In the past the time relation between deposition of the fossiliferous secondary maar fill and the effusive volcanic activity producing the dominant forms of the basalt volcanic area, the lava flows, was discussed. Koch (1904) presumed that the explosions producing the lapilli tuffs including the fossiliferous tuff at Hajnáčka preceded the lava flows effusion. Schafarzik (1899) supposed that sedimentation in the lake at Hajnáčka and basalt extrusions and effusions acted simultaneously. Fejfar (1964) considered a close time relation between the effusion of lava flows and sedimentation of the fossiliferous deposits in the lake at Hajnáčka.

The volcanological studies of the Cerová Basalt Formation by Konečný & Lexa (in Vass & Elečko et al. 1992) and the radiometic ages of several lava flows and dykes (Balogh et al. 1981, 1994 in: Konečný et al. 1995) show that the lava flows of the Cerová Basalt Formation originated before, but also after the deposition of the fossiliferous beds in the maar at Hajnáčka. The Pohanský vrch basalt plateau — (approx. 5 Ma), the short lava flow of Somoška Castle Hill (4.08 Ma) and Steblová skala Hill (4.63 Ma) are older. The lava flows of Blhovce-Buda, Mačacia, Rátka-Trebeľovce, Bulhary (2.59–1.73 Ma) are younger than the Hajnáčka fauna. The youngest are the lava flows of Konradovce, Veľké Dravce, Šávoľ (1.9–1.27 Ma).

## Conclusion

The "Bone Gorge" at Hajnáčka, southern Slovakia, is a type locality of the European Neogene Mammal Time-Scale zone MN 16 and MN 16a (Mein 1975; Fejfar & Heinrich 1987). The mammal bones are inside a maar of the Cerová Basalt Formation. The maar originated by phreatomagmatic explosions. Those ceased after deepening the crater and after building up the ring. The maar crater was filled by precipitation water. A small maar lake with a calm water table originated. The lake was progressively filled by laminated sediment. Later erosion, caused by the updoming of the Cerová vrchovina Upland, partially destroyed the ring and swept out the laminated maar fill with the exception of some isolated blocks. In the renewed maar depression, a lake with water influx and outlet came into existence. In this lake, sand redeposited from the Fiľakovo Formation of Eggenburgian age, was deposited together with basaltic tephra, ash and bombs coming from distal volcanic explosions and bones and skeleton fragments of mammals killed by postvolcanic gas emanations and by tephra fall. This new secondary maar fill is disturbed by slumping and sliding. So firstly the maar was formed and later on after sweeping out the original fill, it was filled again by sandy sediments and tuff rich in mammal bones. The mammal assemblage dated the age of secondary fill as early as Villafranchian and/or subzone MN 16a: 2.8–3.3 Ma B.P. This time interval, according to the cross-correlation with the magnetostratigraphic time-scale corresponds to the middle part of the chron C2An. The maar itself was deepened earlier. The normal remanent magnetic polarization of the ring supports the time correlation.

**Acknowledgements:** The paper was published with help of the Grant Agency VEGA Projects No. 1/4032/97, 2/5136/98 and 1/5222/98. K/Ar dating was sponsored partly by the Hungarian Science Foundation (OTKA) No. T 014961.

## References

Balogh K., Mihaliková A. & Vass D. 1981: Radiometric dating of basalts in Southern and Central Slovakia. *Západ. Karpaty, Sér. Geol.* 7, 113–126.

Balogh K., Vass D. & Ravasz-Baranyai L. 1994: K/Ar ages in the case of correlated K and excess Ar concentrations: A case study for the alkaline olivine basalt of Somoška, Slovak-Hungarian boundary. *Geol. Carpathica* 45, 2, 97–102.

Berggren W.A., Kent D.V., Aubry M.P. & Hardenbol J. 1995: Geochronology, time scales and global stratigraphic correlation. *Soc. Sed. Geol. Spec. Publ.* 54, 1–386.

Fejfar O. 1964: The Lower, Villafranchian Vertebrates from Hajnáčka near Fiľakovo in Southern Slovakia. *Ústř. Úst. Geol., Nakl. ČSAV,* Praha, 1–115.

Fejfar O. & Heinrich W.D. 1987: Zur biostratigraphischen Gliederung des jngeren Känozoikums in Europa an Hand von Muriden und Cricetiden (Rodentia, Mammalia). *Čas. Mineral. Geol.* 32, 1, 1–16.

Fisher R. 1953: Dispersion on a sphere. *Proc. Roy. Soc., A* 217, 295–305.

Koch A. 1904: Basalt lakkolith of Castle-hill at Hajnáčka. *Földrajzi Közlem.* 34, 242–244 (in Hungarian).

Konečný V., Balogh K., Orlický O., Lexa J. & Vass D. 1995: Evolution of the Neogene-Quaternary alkali basalt volcanism in Central and Southern Slovakia (W. Carpathians). Proccedings of the XVth Congress of the Carpato-Balkan Geol. Ass., Sept. 1995, Athens. *Geol. Soc. Spec. Publ.* 4, 2, 535–538.

Kormos Th. 1917: Die pliozänen Schichten von Ajnácskó und ihre Fauna. *Jber. Ung. Geol. R. Anst. 1915,* 564–582.

Krenner J.S. 1867: Observation in Hajnáčka. *Magy. Földt. Társ. Munkál.* 3, 113–132 (in Hungarian).

Mein P. 1975: Biozonation du néogene mediterraneen á partir des Mammiferes. *Proceedings of the VIth Congress RCMNS, Bratislava, Sept. 4–7th, vol. 2, enclosure.*

Popovský J. & Pfiester L.A. 1990: Dinophyceae (Dinoflagellida): In: Pascher A. (Ed.): *Sűswasserflora von Mitteleuropa.* Band 6, Jena, Stuttgart, 1–270.

Russell P.L. 1990: Oil shales of the world, their origin, occurrence and exploitation. *Pergamon Press,* Oxford, Toronto, 1–753.

Schafarzik F. 1899: Daten zur Geologie der Knochenfundstätte von Ajnácskó. *Földt. Közlön.* 29, 363–366 (in Hungarian).

Szabó J. 1861: Geology of Hajnáčka. *Magy. kir. term. tudom. And. Közlem.,* Budapest (in Hungarian).

Szabó J. 1865: Pogányvár hill of Gemer county as a basalt crater. *Math. Term. Közlem.* 3, 334–335 (in Hungarian).

Vass D., Bezák V., Elečko M., Konečný V., Lexa J., Pristaš J., Straka P. & Vozár J. 1992: Geological map of Lučenská kotlina Depression and Cerová vrchovina Upland. *GÚDŠ*, Bratislava.

Vass D. & Elečko M. et al. 1992: Explanatory notes to Lučenská kotlina Depression and Cerová vrchovina Upland geological maps 1:50,000. *GÚDŠ,* Bratislava, 1–196 (in Slovak).

Vass D., Elečko M. & Pristaš J. 1986: Dome of Cerová vrchovina Upland — a young structure of Southern Slovakia. *Geol. Práce, Spr.* 84, 135–140 (in Slovak).

Vass D., Konečný V., Elečko M., Kozač J., Molnár A. & Zakovič M. 1998: Diatomite deposit in basalt maar near the village of Jelšovec (S. Slovakia) and its possibility of utilization. *Miner. Slovaca* 30, 333–356 (in Slovak, English summary).

Vass D., Konečný V., Elečko M., Milička J., Snopková P., Šucha V., Kozač J. & Škraban R. 1997: Alginite — a new resource of the Slovak industrial minerals potential, Pinciná deposit. *Miner. Slovaca* 29, 1–39 (in Slovak).

Vass D. & Kraus I. 1985: Two-fold age of basalts in Southern Slovakia and their relation to Poltár Formation. *Miner. Slovaca* 17, 5, 435–440 (in Slovak).

Vrubel J. 1998: Final report of geophysical measurements in the frame of Geological investigation of the bituminose rocks in investigation area of Hajnáčka — Geophysics. *Manuscript, Archives GAMART s.r.o.* Lučenec, (in Slovak).