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Rockmagnetic and palaeomagnetic studies of unconsolidated sediments of Bukovynka Cave (Chernivtsi region, Ukraine)

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A B S T R A C T

Rockmagnetic, palaeomagnetic, and paleontological studies of loamy non-consolidated sediments of the Bukovynka Cave (Chernivtsi region, Ukraine) have been carried out. The sections include three main types of deposits: 1 – fluvial deposits containing travertine grus derived from the karst massif, 2 – fluvial deposits derived from temporary waterflows from outside the cave, 3 – aeolian deposits. Deposits of type 2 and 3 were examined in Sections 1 and 2 in the Trapeznyi Chamber. Their low field magnetic susceptibility ( ) reflects climatic conditions in the Late Pleistocene. The layer with cave hyena bones has higher magnetic susceptibility and appeared to indicate warmer climate. Deposits of type 1 and 2 were investigated in the Section 3 in the Dry Chamber of the cave. Low-field magnetic susceptibility of fluvial deposits, derived from inside of the karst massif, is much higher than for deposits derived from outside the cave. Deposits in Section 3 sharply differ in , NRM intensity and Keonigsberger ratio. The fluvial strata of type 1 in Section 3, dated using paleontological remains as Holocene, contains the record of palaeosecular variations of the geomagnetic field. The Etrussia excursion dated 2.8 ka BP was found at 1 m depth in Section 3. The lowest layer has anomalous polarity.

1. Introduction

Clastic cave sediments are important proxies of paleoenvironmental changes in karst areas (Bosch and White, 2004; Pospelova et al., 2007; White, 2007). The Podillja–Bukovynian karst area (Fig. 1) is rich in large and giant maze-caves developed in Neogene gypsum (Klimchouk, 2000). The first attempts to study cave sediments in this area began in the 1960s. Most contained only genetic descriptions of clastic deposits in some caves (Dublyansky and Smolnikov, 1969; Dublyansky and Lomaev, 1980) or paleohydrogeological reconstructions (Klimchouk and Rogozhnikov, 1982; Klimchouk, 1984). Paleozoological researchers were limited to collecting subfossil bones in caves (Tatarinov, 1966; Bachinsky, 1967; Tatarinov and Bachinsky, 1968). Active archeological study of some caves occurred in recent decades (Matskevyj, 2005), but these investigations concerned mostly open niches and grottoes in sandy limestone.

In the 1980s, for the first time in Ukraine, paleomagnetic research of cave fluvial sediments was conducted in Atlantida Cave, developed in the gypsum strata. At that time, it was believed that the formation of sediments took place during the Brunhes era (Bahmutov and Lagutin, 1985). Nowadays, it has been established that these sediments were formed before the Matuyama/Brunhes reversal (Bondar et al., 2010).

Nevertheless, sedimentary infills of gypsum caves remain poorly examined and are rarely used in paleogeographic reconstructions. Faunistic remains seem to be one of the most informative proxies in Quaternary sediments, but, unfortunately, they are rare in cave deposits. However, magnetic properties have measurable values in most of the loose sediments. Rockmagnetic and paleomagnetic investigations of unconsolidated deposits from karst caves provide new data about paleohydrogeological regimes, tectonic movements and climatic changes (Sroubek et al., 2001, 2007; Bosak et al., 2003; Pospelova et al., 2007; Bondar and Ridush, 2009). In this paper, we present the results of study of Quaternary deposits from Bukovynka Cave. Since 1976, the cave was explored by speleologists from Chernivtsi (Ridush and Kuprich, 2003). In 1998, paleontological and paleogeographical study of the cave started. Some data about Late Pleistocene paleontological finds was presented previously (Vremir et al., 2000; Ridush, 2004), as well as the general description of the cave (Ridush and Kuprich, 2003; Ridush and Levytska, 2005).

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Fig. 1. Location of Bukovynka Cave; A – map of the region; g –Neogene gypsum strata (after Klimchouk, 2000); B – local topographical map.

The purposes of our investigation were:

(a) To consider variations of rockmagnetic properties (low-field mass specific magnetic susceptibility, NRM intensity, Keonigsberger (NRM/J_i) ratio) and variations with depth of paleoclimate evaluated with paleontological methods in sections of sediments. This will help to identify the geological processes responsible for sedimentation in some doubtful cases, especially distinguishing between aeolian and fluvial deposits in the near-entrance part of the cave.
(b) To determine characteristic magnetic remanence values along the deepest section in order to check whether they reflect the secular variations or excursions of the geomagnetic field during Holocene–Late Pleistocene.

2. Regional setting

Bukovynka Cave is situated in the southeastern part of the Podillja–Bukovynian karst area (Ukraine), in the middle part of the Prut River valley, close to the Romania and Moldova borders (Fig. 1A). The cave is developed in the upper part of the Upper Badenian gypsum strata (N_1bd_2), up to 35 m thick. The gypsum deposit in this area consists of two lithofacies. The lower lithofacies are represented by stromatolitic gypsum with intercalations of clastic gypsum, and the upper one is represented by sabre and crystalline gypsum (Peryt, 2001). The sulphate bed is underlain by few meters of sand (with 0.5–1.0 m sandstone cap) of the Lower Badenian age. The top of gypsum layer is covered with up to 1 m of Ratyn Limestone and up to 8 m of the dark-gray clay of Kosiv Formation (N_1ks), with abundant algae (*Lithothamnion*) limestone inclusions.

Quaternary deposits include river-terrace alluvium of the Prut River, composed of so-called ‘Carpathian Pebbles’ of Early Pleistocene, and grey sand, covered with Middle- and Late Pleistocene pale-yellow loess. Due to the different erosional opening of the massif, locally the Quaternary cover is directly on top of the Ratyn Limestone. The bedding of overlying deposits is strongly dislocated by slope failures, which involve both Quaternary deposits and the upper Neogene clays.

Modern cave entrances are artificial. They are located in the inactive gypsum quarry, cut in the foot of the left slope of the Matka River valley. This small river (average discharge ~100 l/s) is a left tributary of the Prut River (Fig. 1B). Two cave entrances are located

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at the foot of the quarry bench, and another entrance is a 5-m vertical shaft on the surface of the same bench (Fig. 2). The total length of the presently known cave passages is 5155 m; the height is about 15 m, the total area is about 7000 m^2, and the volume is 11,250 m^3. The altitude of entrances at the foot of the bench is 135 m a.s.l., 2 m above the adjacent valley bottom, and 25 m above the Prut River (Ridush and Kuprich, 2003).

The cave is of a maze type. It was developed in three levels/floors. The main (middle) floor consists of a series of sub-parallel galleries (2–3 m wide), connected by narrow (up to 1 m) passages. The upper floor is represented by mostly narrow fissures (0.5–1.0 m) of corrosive origin, narrowing upwards. Commonly, this floor is fragmented and is connected to the main floor by vertical pits/chimneys of 7–10-m height.

The lower floor is represented by mostly narrow (1.0–1.5 m) galleries with rounded vaults. They are partially filled with clay-loamy sediments. This floor is located at the zone of long-term groundwater table fluctuations, and therefore from time to time it is completely flooded. It connects to the main floor through short "windows" in the form of lakes-siphons (with areas to 1.3 m^2). Fluctuations of the water table in cave lakes and, consequently, aquifer varies within 0.2–1.0 m. There are both seasonal and long-term groundwater table fluctuations. The water temperature in the aquifer is 8.5 °C. Water is highly mineralized, with hydrocarbonate-sulfate mineralization to 2.0–2.5 g/l.

The bottom and partly the walls of corridors are covered with thick (up to 4 m) loam-clay deposits. Thin red and black interlayers can be observed in the cave lacustrine clay sequences, which correspond to the oxidizing and reducing hydrochemical conditions in underground paleoponds (Andreichouk, 2007). The upper unit of the Quaternary sequence usually is composed of light loam. It often includes fragments of white, gray and sometimes reddish calcite flowstone crusts that detached from the ceiling.

Today, the interior parts of the cave are thermoconstant with a year-round temperature of 9–10 °C. In the entrance, because of the existence of several inputs, there is an active air exchange with the surface, and inner temperatures depend on the outer atmosphere condition. In the winter due to the cooling of near-entrance galleries, the seasonal ice forms stalactite-like icicles, columns are formed, and clay-loamy sediments are frozen to 0.5 m depth (Ridush and Levytska, 2005).

Geological conditions of the cave location, galleries morphology, and a maze structure of the cavity indicate the hypogenic (artesian) origin of the cave (Klimchouk, 2000). Most of the maze system was developed before the gypsum strata, and the cave became exposed by erosion.

The above-cave relief is a high and ancient (Early–Middle Pleistocene) terrace of the Prut River, 70–80 m above the modern water level in the river. During Middle–Late Pleistocene, the local Matka River, a tributary of the Prut River, cut into this surface and exposed the gypsum strata. Sometimes the stream flowed underground, transiting through the cave chambers. The river stream flowed through a ponor, which was located at the foot of board of the valley, to north of the cave. Probably, the discharge of the cave stream on the surface occurred 100 m southwest from the present cave entrance, at the edge of the valley. This part of the cave, from the modern entrance to the place of former underground stream discharge, was destroyed by quarrying of gypsum deposits. The part of the Bukovynka Cave, which consists of the Entrance, Trapeznyi and Dry chambers differ from other parts of the cave in morphology and Quaternary sequence (Fig. 3A). These three chambers were, in the past, a single gallery, which later was divided by collapses (Fig. 3B).

3. Material and methods

3.1. Deposits

To characterize clastic deposits in the cave, three sections were selected in the alignment of the paleostream riverbed. Sections 1 (Fig. 4A) and 2 (Fig. 4B) are situated in the Trapeznyi Chamber, and can be observed in natural outcrops on the sides of the chamber. They became exposed due to the subsidence of sediments in the central part of the gallery-like chamber. Preliminary stratigraphic and granulometric study of these sections were published (Ridush, 2004; Korzun and Ridush, 2011). The sequences in both sections are similar but the description is given for Section 2 as the more complete one (Table 1, Fig. 4).

Table 1
Section 2 of clastic sediments in Trapeznyi Chamber.

Unit	Depth, m	Description
T1	0.0–0.3	Light loam, loess-like, laminated, light yellow, with numerous inclusions of secondary gypsum crystals, with rare inclusions of coprolites, small bone fragments, with interbeds enriched with fine-crystalline gypsum (up to 1–2 cm).
T2	0.3–0.6	Light-brown loam, cloddy, with rare inclusions of gruss of limestone and gruss solid laminated (argillite-like) clay, occasionally inclusions of quartz gravel and *Lithothamnion* limestone debris, as well as coprolites and bone remains from small (up to 0.5–2.0 cm) to individual Mammals teeth and large bones fragments.
T3	0.6–0.9	Gray laminated sandy clay, sometimes as gruss of the same clay. In Section 2 the gravel interlayer (less than 10 cm) with a predominance of *Lithothamnion* limestone gruss and with inclusions of pebbles and gravel can be observed on top of the unit.
T4	0.9–1.2	Gravel-pebble deposits (predominance of gravel of quartz and sandstone rocks), with an admixture of limestone gravel (*Lithothamnion*) up to 30%, reddish, enriched with FeO_2 (redeposited river terrace pebble)
T5	>1.2	Bedrock: macrocrystalline, grayish-brown gypsum

Section 3 is situated in the Dry (Sukhyi) Chamber (Fig. 3B). To avoid confusion in units from different localities, the lithofacies units in Trapeznyi Chamber are designated "T", and units from the Dry Chamber are marked "S".

The characteristic features of sediments of Unit T1 (Fig. 4A, 1), such as silty composition, stratification, and lack of gravel inclusions, as well as the presence of gypsified intercalations, indicate that the top of Sections 1 and 2 (Unit T1) include airborne sediments (Korzun and Ridush, 2011). The modern accumulation of so-called "cave loess" of aeolian origin was observed in caves of Eastern Pamirs (Ridush, 1993). There, this process takes place under the modern alpine arid periglacial climate. Therefore, at least during the last phase of terrigenous sediment accumulation in the Trapeznyi Chamber (Unit T1), an arid periglacial climate dominated, corresponding to one of the cold and dry phases of the Würm (Valdai) Glaciation.

Unit T2 (Fig. 4A, 2), containing bones and coprolites, could be considered as alluvial because of the inclusions of individual gravel-size clasts. However, stratification was not observed, and all bones and coprolites found in it have no rolling traces, while most of the

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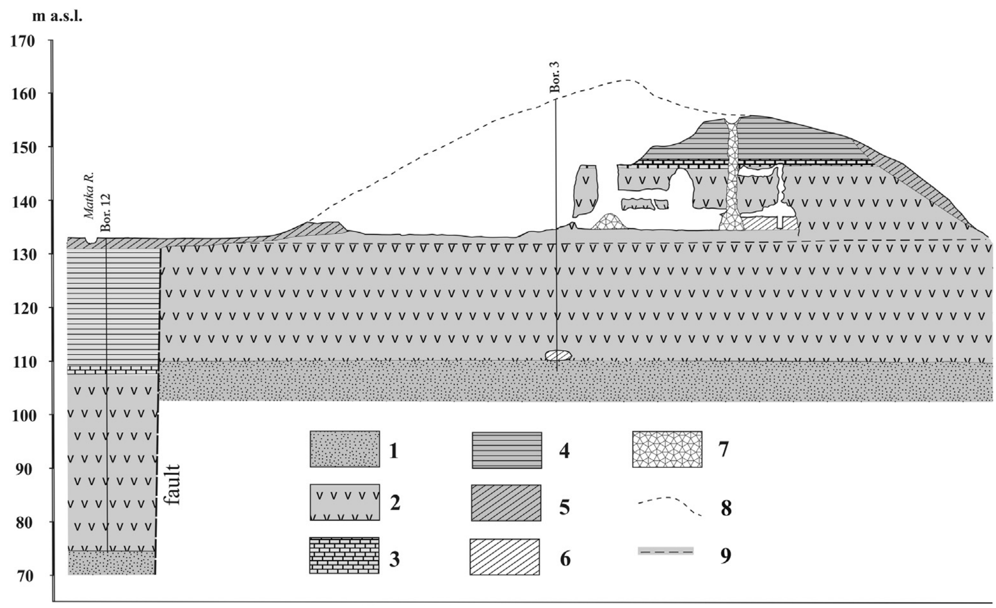

Fig. 2. Geological section of the gypsum karst massif, enclosing the Bukovynka Cave. Legend: 1 – Lower Badenian sands; 2 – Lower Badenian gypsum; 3 – 'Ratyn' Limestone; 4 – clays of the Kosiv Formation; 5 – Quaternary terrace loamy deposits; 6 – Quaternary loamy deposits in the cave; 7 – collapse deposits in the cave; 8 – surface line of the massif before gypsum formation; 9 – average groundwater table. Bor. – borehole.

coprolites are quite fragile and would be destroyed if moved by water-flow. All these remains were found *in situ* and were not transported and redeposited by water flows. This unit genesis probably is almost entirely zoogenic, with minor aeolian input. The lower part of the Sections (units T3–T4) is composed of alluvial cave deposits containing redeposited sediments.

The ^{14}C age of Unit T2, based on an included hyena tooth is 41300 (+1300/−1100) BP (VERA-2529), which corresponds with the Vitachiv warm Stage (MIS-3) (Gerasimenko, 2004). Zoogenic accumulation took place probably continuously during this phase. The overlying aeolian sediments (Unit T1) could correlate to one of cold episodes during MIS-3 (Korzun and Ridush, 2011). It could be a short stadial (Hosselo?), dividing Molodovo 8-1 and Molodovo 8-2 interstadials (Moershoft and Hengelo) (Haesaerts et al., 2009).

The sediments of Section 3 were studied here for the first time. They are represented mainly with grayish-brown loams with limestone gruss inclusions (Table 2; Fig. 4C). A prospecting shaft 2.5 m deep was excavated for this purpose.

The screening of loams from Unit S17b showed impurities of travertine gruss up to 5%. A similar type of travertine, which was formed underwater, can be observed on the walls and ceiling of Zolushka Cave (7 km to the east (Fig. 1B) (Andreichouk, 2007). The last was drained by a quarry only a few decades ago, and preserved many subaquatic features, including this fragile travertine, only 1–3 mm thick.

3.2. Paleontological finds

In the Trapeznyi Chamber of the cave, the remains of several genera and species of large Late Pleistocene mammals were found in Unit T2: woolly rhinoceros (*Coelodonta antiquitatis*), cave hyenas (*Crocuta spelaea*), cave bear (*Ursus spelaeus*), horse (*Equus caballus*), aurochs (*Bos primigenius*), steppe bison (*Bison priscus*), giant deer (*Megaceros giganteus*), wild pig (*Sus scrofa*), and red fox (*Vulpes vulpes*). Cave hyena remains are represented mainly by numerous fragments of mandibles, maxillae, and separate teeth of at least ten individuals. In the same unit that contains bone remains, cave hyena coprolites are quite abundant. Some coprolite material forms

Table 2
Section 3 of clastic sediments in Dry Chamber.

Unit	Depth, m	Description
S0	+0.05	Bulk ground, excavation of the pit.
S1	0.0–0.08	Light-brown loam, thinly laminated, with silty interlayers up to 1 cm thick. On the NW side of the pit, 1.5 cm grayish-yellow loam and 2–3 mm gypsum "sand" above this unit.
S2	0.08–0.13	Light loam, dark brown, with admixture of limestone gruss 0.2–1 cm in diameter (up to 5%).
S3	0.13–0.16	Light-brown loam, laminated, similar to Unit S1, but mixed with limestone gruss (up to 5%). There is a 1 cm gruss interbed in the bottom.
S4	0.16–0.27	Dark-brown loam, similar to Unit S2; 2-cm lens of dark-gray clay in the bottom (Unit S4a).
S5	0.27–0.32	Grayish-brown loam, not layered, mixed with limestone gruss 2–3 mm in diameter (up to 3%)
S6	0.32–0.35	Light loam, pale brown, thin-laminated, without gruss admixture.
S7	0.35–0.49	Grayish-brown loam, with interbeds (up to 1 cm) of light-brown laminated loam; mixed with limestone gruss up to 40% (D 2–3 mm) and with rare inclusions of jasper pebbles up to 1 cm in diameter. The lower boundary is sharp.
S8	0.49–0.61	Dark-brown loam, not layered, mixed with limestone gruss up to 30%, with interbeds of laminated heavy loam without impurities.
S8a	0.61–0.67	The same, limestone gruss admixture up to 10%.
S9	0.67–0.68	Light-brown (coffee-milk) loam, thinly-laminated, without inclusions.
S10	0.68–0.71	Dark-gray loam, not bedded, with gruss of limestone and clay (up to 5%).

Table 2 (*continued*)

Unit	Depth, m	Description
S11	0.71–0.94	Grayish-brown loam with barely visible lamination, limestone gruss admixture (up to 10%).
S12	0.94–1.02	Dark-brown loam, not laminated, fine-lumpy. Limestone gruss admixture up to 3%. The upper limit is clear, but the lower boundary is not sharp.
S13	1.02–1.36	Loam pale-gray, limestone gruss (up to 40%), and sporadic inclusions of quartz and jasper pebbles. At 1.1 m depth, *Marmota bobac* bones were found.
S14	1.36–1.59	Grayish-brown (darker than the previous) loam, fine-lumpy. Gruss admixture is up to 20%. Isolated inclusion of pebbles and algal (*Lithothamnion*) limestone D 1–2 cm
S15	1.59–1.75	Dark-brown loam, lumpy. Limestone and clay gruss admixture (up to 10%). The inclusions of algal (*Lithothamnion*) limestone fragments.
S16	1.75–1.82	Gravel consisting from limestone gruss, with gray-brown loam filling (up to 20%), with the inclusion of gypsum fragments.
S17	1.82–2.14	Heavy loam, dark-brown colored, with admixture of limestone and clay gruss (up to 5%). At 2.05–2.10 m, small-sized brown bear (*Ursus arctos*) phalanxes buried.
S17a	2.14–2.24	Heavy loam, dark brown, admixture of hard clay gruss up to 30%.
S17b	2.24–2.26	Pale-gray loams, not layered, without visible inclusions. In the SW wall of the same pit, brown bear (*Ursus arctos*) skull.
S18	2.26–2.50	Greenish-gray sandy loam. 3–4 mm thick fragments of white carbonate flowstone crusts on the top. Rare inclusions of coprolites and bone fragments.

continuous layers that apparently formed floors of the cave hyena den. The remains of most species, excluding fox, are the remnants of hyena prey, including old and young individuals of cave bear. Evidence of cave hyena activity as unidentified fragments of crushed bones and coprolites were found in a broad area of cave maze, more than 100 m from all possible ancient entrances (Vremir et al., 2000; Ridush, 2004, 2009).

In the Dry Chamber and adjoining galleries, Holocene faunal remains were found. In the trench (Section 3) at a depth of 1.1 m in Unit S13 a partly preserved cranium and a mandible branch together with some postcranial bones of marmot (*Marmota bobac*) were found. In the same section at 1.8 m deep in the bottom of Unit S17b, an almost complete cranium (without mandible) of brown bear (*Ursus arctos*) was excavated (Fig. 4C). Direct ^{14}C dating shows an age of the Late Pleistocene to Early Holocene transition (10,730 ± 60 BP, Poz-46240) (Ridush et al., 2012).

3.3. Sampling and measurements

Samples from sections 1 and 2 were collected into standard 10 cm^3 plastic boxes. From Section 3, we collected 144 monolithic 2.5 cm samples for magnetic and paleomagnetic measurements using the standard procedure (Butler, 1992). A magnetic compass was used to provide an unequivocal *in situ* geographic orientation of each manually cut sample. The vertical spacing in sampling was 4–8 cm; 2–4 samples were collected from each level, excluding layers containing excessive carbonate gruss.

The measurements were performed in the Paleomagnetic Laboratory of the Institute of Geophysics of Polish Academy of Sciences (Warsaw, Poland) and the magnetic laboratory of Geological faculty of the Taras Shevchenko National University of Kyiv (Kyiv, Ukraine). The measurements of all samples were carried out using Geofyzika KLY-2 Kappabridge. Mass-specific values of low-field magnetic susceptibility (χ) were obtained.

Additional measurements were made on samples from Section 3. Magnetic fabric of specimens was determined by measuring anisotropy (AMS) of low-field magnetic susceptibility using a Geofyzika KLY-2 Kappabridge. The remanent magnetization of specimens was measured using a three-axis 2G Enterprises cryogenic rock magnetometer with in-line alternating field demagnetization coils. The stable characteristic remanent magnetization of 12 selected pilot samples was isolated by stepwise alternating field demagnetization in a 2G demagnetizer (with steps of 2.5 mT until 120 mT). A shortened selected field/step approach was applied to the other samples along Section 3. The Keonigsberger (NRM/J_i) ratio characterizing relative magnetic hardness of the material (Evans and Heller, 2003), was calculated.

Magnetic mineralogy was determined by thermal demagnetization of saturation isothermal remanence. The experiments were carried out with the use of a device made by TUSK, Poland. The SIRM decay curves provide the blocking temperature (T_b) spectra. SIRM was imparted on a sample in the field of 2T. SIRM was then measured during heating of the sample to 700 °C in a magnetic screen. The temperature at which SIRM was completely demagnetized was accepted as the blocking temperature (T_b).

4. Results

4.1. Rockmagnetic properties and magnetic minerals

Low-field mass-specific magnetic susceptibility examined along three sections varies from 5 to 8 * 10^{-8} m^3/kg for samples from Section 1, 2 (Fig. 5) and from 5 to 37 * 10^{-8} m^3/kg for samples from Section 3 (Fig. 6). In Sections 1 and 2, the lowest values of χ are observed in Units S1 and S3. A slight enhancement is noticed in Unit S2, indicating warm outdoor conditions in the fluvial sediments (type 2) containing hyena bones in the Trapeznyi Chamber. Both types of fluvial sediments were excavated in Section 3 in the Dry Chamber. For Section 3, the average values of χ, NRM and Q have been calculated from measurements done on 2–4 specimens per level. Variations of magnetic susceptibility, NRM intensity and Keonigsberger ratio reflect sediment types (Fig. 6). The enhancement is observed in sediments of type 1 from Units S2–S17(b) compared to sediments of type 2 from Unit S18. Thus, rockmagnetic measurements indicate that material transported into the cave by wind or temporary water flows is significantly less magnetic than fluvial sediments presumably derived from inside the massif.

Magnetic minerals were identified with thermal decay of isothermal remanence SIRM during heating Fig. 7). Maghemite is supposed to be the main magnetic mineral in fluvial deposits of type 1 from Units S4, S13, and S15, identified by the shape of SIRM(T) curves and final blocking temperatures 635–640 °C. From Unit S13, a bend near 200 °C is observed (Fig. 7b). The bend can be related to the presence of either maghemite or fine-grained pyrrhotite (Dekkers, 1988). Sandy loam from Unit S18 contains a small amount of magnetite with $T_b = 575$ °C.

4.2. Paleomagnetic results

The paleomagnetic study has been performed on sediments from Section 3. Examples of AF demagnetization of specimens from Unit S14 and Unit S18 of Section 3 are shown in Fig. 8. Characteristic remanence (ChRM) of pilot 12 specimens was obtained from multi-component analysis. For the other specimens,

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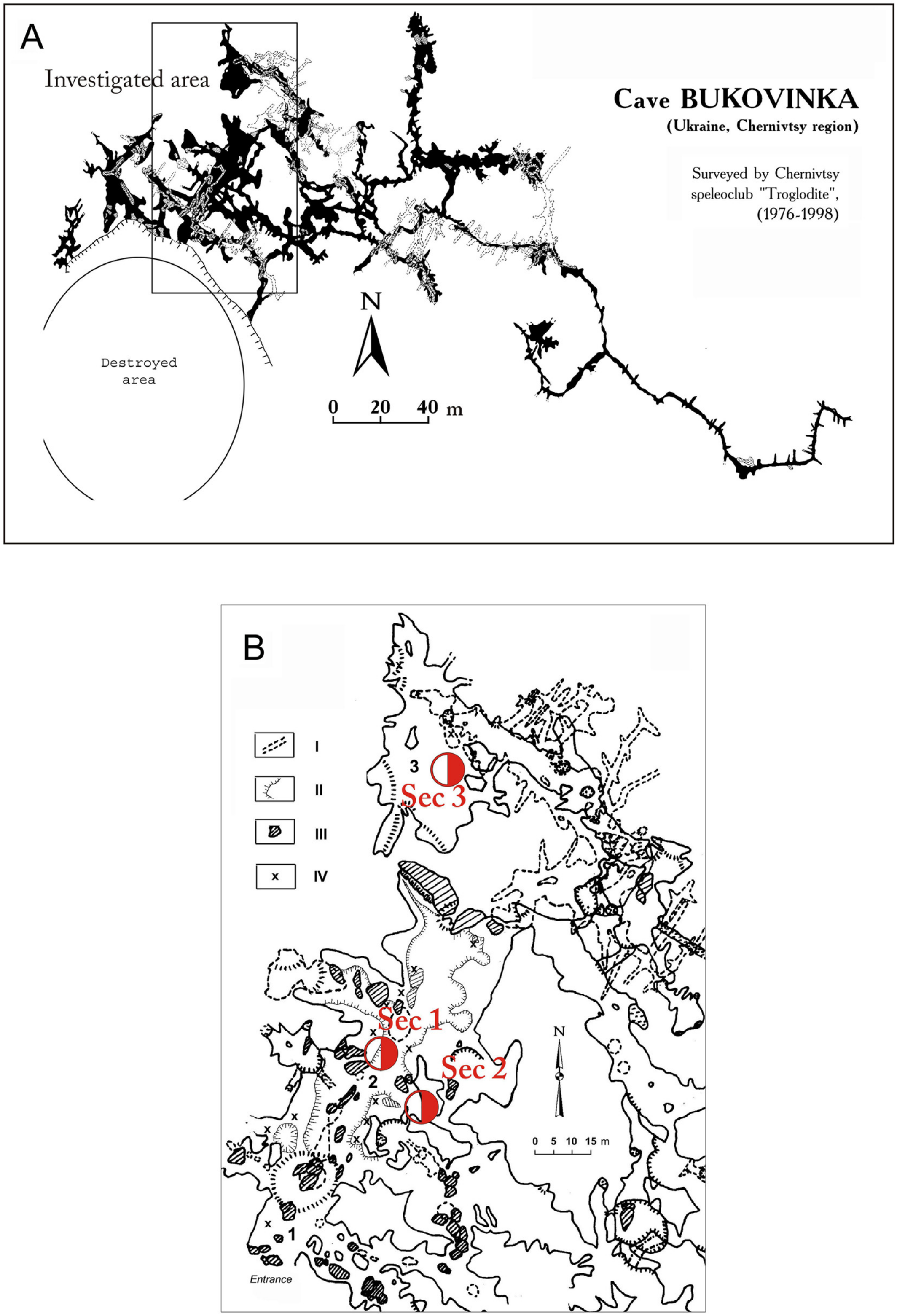

Fig. 3. Map of Bukovynka Cave with location of the sections studied. A – general plan of the cave. B – investigated area of the cave maze. I – upper level of galleries, II – inner benches formed by unconsolidated deposits, III – fallen rock blocks, IV – places of bone finds; 1 – Entrance Chamber, 2 – Trapeznyi Chamber, 3 – Dry Chamber; "Sec 1" – places and numbers of Quaternary deposits.

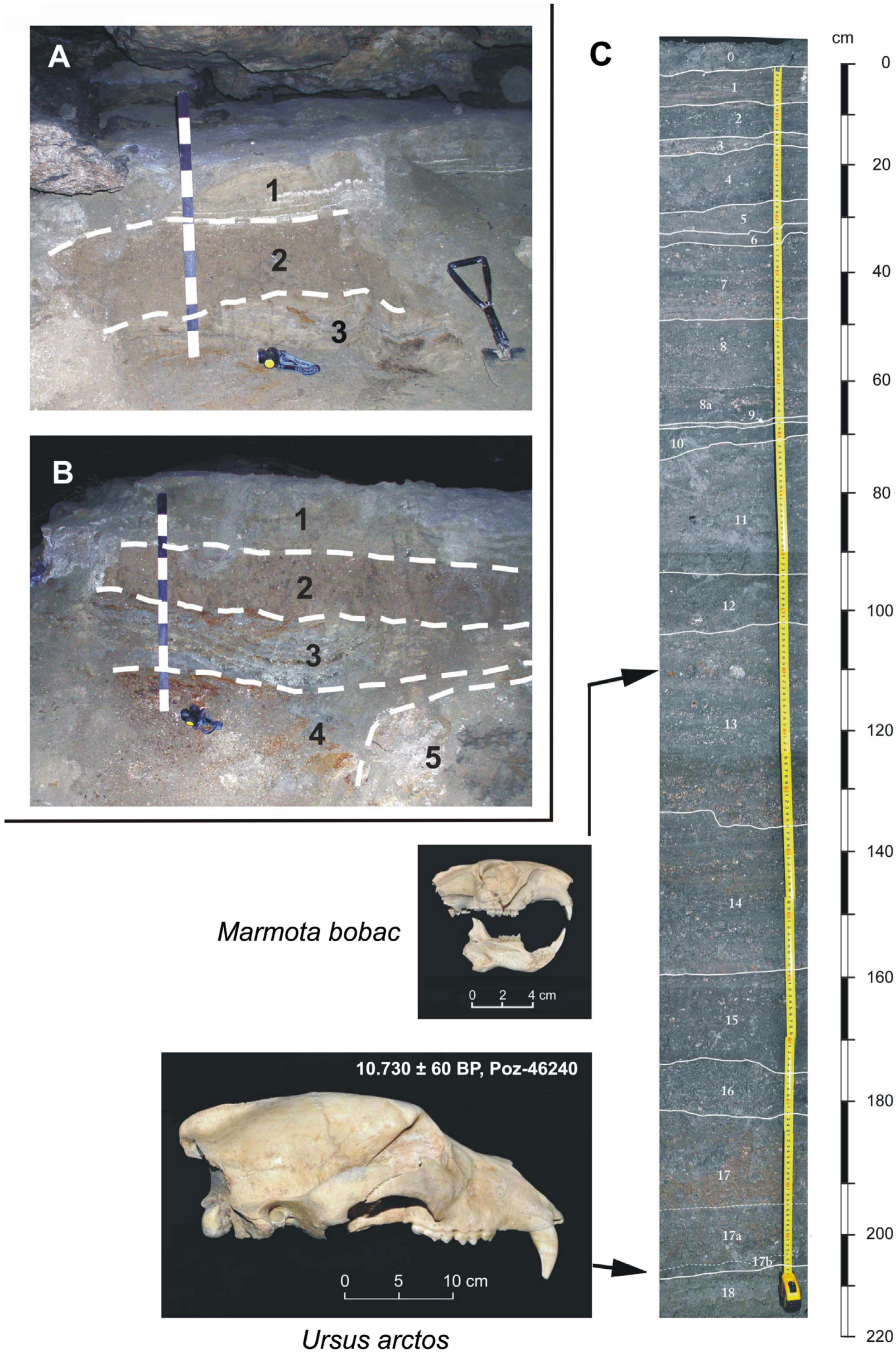

Fig. 4. A, B: Late Pleistocene deposits of the Sections 1 and 2. 1 – Unit T1, Aeolian deposits ("cave loess"); 2 – Unit T2, zoogenic layer ("hyena layer"); 3 – Unit T3, fine alluvial deposits of cave stream; 4 – Unit T4, gravel alluvial; 5 – Unit T5, gypsum bedrock. C: Late Pleistocene–Holocene deposits in Dry Chamber. 1–18 – Units S1–S18 (see description in the text).

treatment with alternating field 30 mT was enough to recognize ChRM. Specimens from Units S1–S17b demonstrated ChRM directions close to the recent geomagnetic field. NRM of all specimens from Unit S18 had two components. The softer one, probably, had a viscous origin and was imposed on samples during transportation to the laboratory. The harder one was considered to be ChRM. It differs from the recent geomagnetic filed direction.

Palaeomagnetic curves of temporal variations of inclination and declination of ChRM along the section were composed on the basis of results of AF-demagnetization of natural remanence (Fig. 9). Study of the deepest Section 3 reveals the presence of

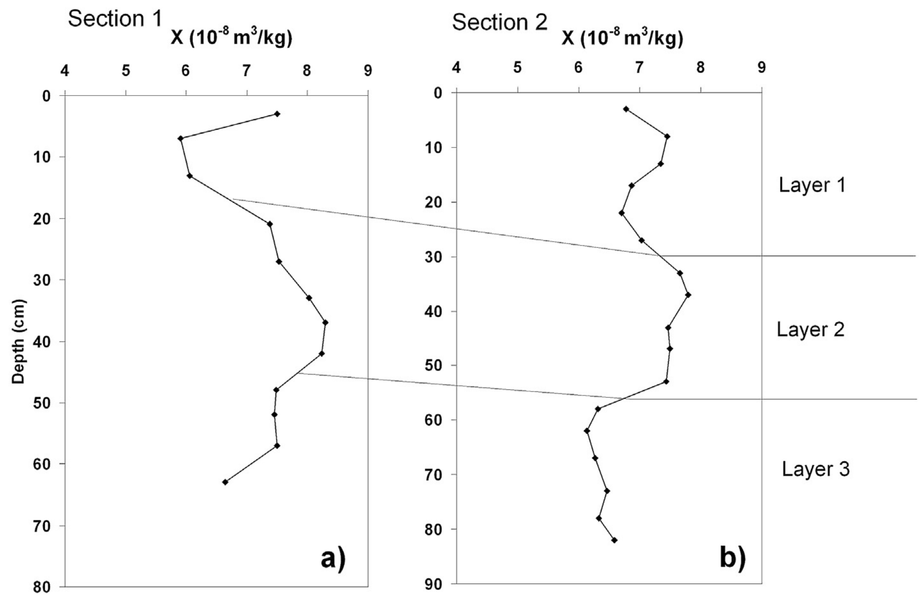

Fig. 5. Variations of low-field mass-specific magnetic susceptibility along Sections 1 (a) and 2 (b).

two separate intervals of direct and anomalous polarity, corresponding to fluvial strata of type 1 (Units S2–S17b) and lower Unit S18 of type 2, respectively.

Anisotropy of magnetic susceptibility of sediments from Section 3 is very low (P does not exceed 1.009). Grains of magnetic minerals were deposited chaotically, and there was no possibility for magnetic grains to catch the orientation of the geomagnetic field.

5. Discussion

Analyzing the stratigraphy, the origins of the clastic sediments represent three types:

Type 1 – fluvial deposits, containing autochthonous travertine tuff gruss, derived from inside the karst massif through pits and cracks in the top of gypsum strata by transportation and re-sedimentation of allochthonous material from upper stratigraphic levels.

Type 2 – allochthonous fluvial-zoogenic deposits, partly derived from outside by temporary water-flows through the paleoentrances, sometimes containing paleontological material.

Type 3 – aeolian deposits.

An *U. arctos* cranium found in Section 3 was dated to 10,730 ± 60 BP. Paleomagnetic features of upper fluvial deposits (type 1) show correspondence to archaeomagnetic master curves for Ukraine and Moldova for the period of 5500 y (Zagnij and Rusakov, 1982). The eastern peak of declination observed in Unit S12 is the most intensive declination palaeosecular feature, dated 2.8 ka BP (Zagnij and Rusakov, 1982). This paleosecular feature was earlier found in aeolian cave deposits in Emine-Bair-Khosar cave

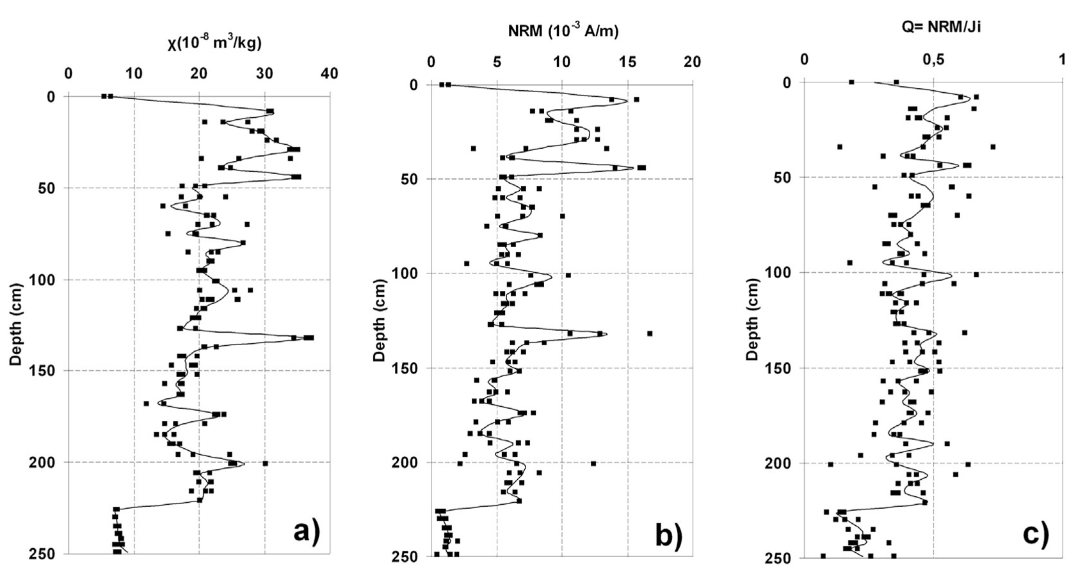

Fig. 6. Variations of rockmagnetic parameters along Section 3: (a) – low-field mass-specific magnetic susceptibility, (b) – natural remanence, (c) – Keonigsberger (NRM/J_i) ratio.

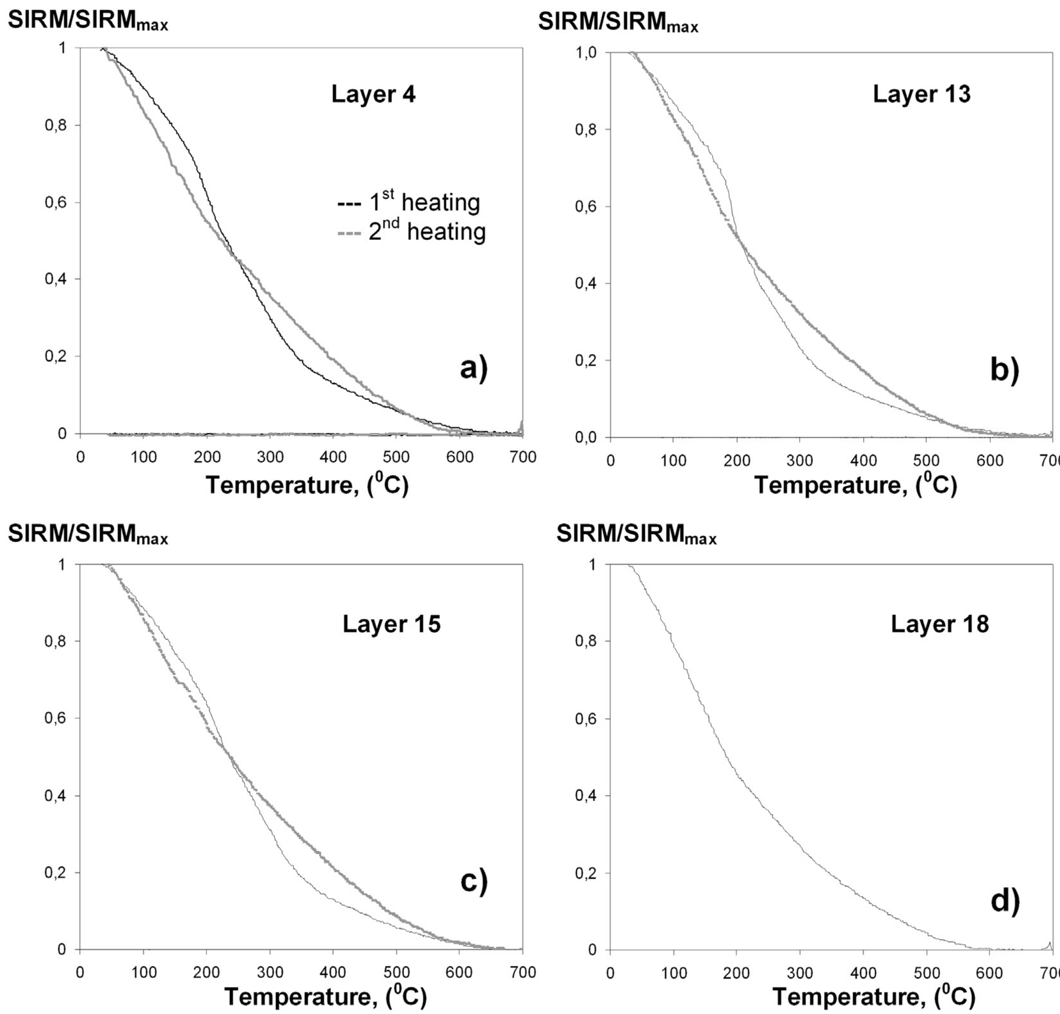

Fig. 7. SIRM (T) decay curves for Section 3: (a) Unit S4, (b) Unit S13, (c) Unit S15, (d) Unit S18.

(Crimea, Ukraine) (Bondar and Ridush, 2009). Unit S1 on the top of Section 3 contains a younger declination paleosecular feature dated to 1 ka BP (Daly and Le Goff, 1996).

The cave served as a hyena den during Late Pleistocene (MIS-3) (Trapeznyi Chamber and adjacent galleries) and a brown bear dwelling during the Early Holocene (MIS-1) (Dry Chamber). Brown bears (*U. arctos*) dwelled on the surface of sandy loam (Unit S18), formed by temporal water-flows during one of the anomalous geomagnetic polarity intervals. Containing coprolites and bone fragments, Unit S18 in the Dry Chamber probably correlates with Unit T2 in the Trapeznyi Chamber.

One of the entrances to the cave was exposed in the Mid Holocene, indicated by the presence of *M. bobac* remains in Unit S13 (Section 3) (Fig. 4C).

Presumably at the beginning of Holocene, the top of gypsum strata was perforated, and the material from upper stratigraphic layers began to fill the Dry Chamber. This process stopped about 1 ka BP, and the Dry Chamber remained dry till now.

6. Conclusions

The rockmagnetic, palaeomagnetic and paleontological studies of clastic unconsolidated sediments of the Bukovynka Cave indicate the following conclusions:

1. Three sections of clastic sediments studied in the Bukovynka Cave contain fluvial and aeolian deposits of Late Pleistocene/Holocene age. The sequence of Section 3 in the Dry Chamber covers almost all the Holocene, from ~11 ka to ~1 ka BP. The age of deposits is confirmed by two ^{14}C dates.
2. The material transported into the cave by wind or temporary water flows has significantly lower scalar magnetic characteristics than fluvial sediments derived from inside the massif.
3. In Section 3, maghemite is the main magnetic mineral in fluvial deposits of type 1. Sandy loam from the lowest Unit S18 (Late Pleistocene) contains a small amount of magnetite.
4. The eastern peak of declination observed in Unit S12 is the most intensive declination palaeosecular feature and correlates with the Etrussia excursion, dated 2.8 ka BP.
5. The cave entrances were exposed during Late Pleistocene and most of the Holocene and were closed by slope failure at the end of the Holocene.
6. Unconsolidated sediments from Bukovynka Cave contain paleofaunistic, paleomagnetic and some other kinds of records (palynological, granulometric), and are important paleoarchives, which could be used for regional paleogeographical and paleoclimate reconstructions of Late Pleistocene–Holocene time.

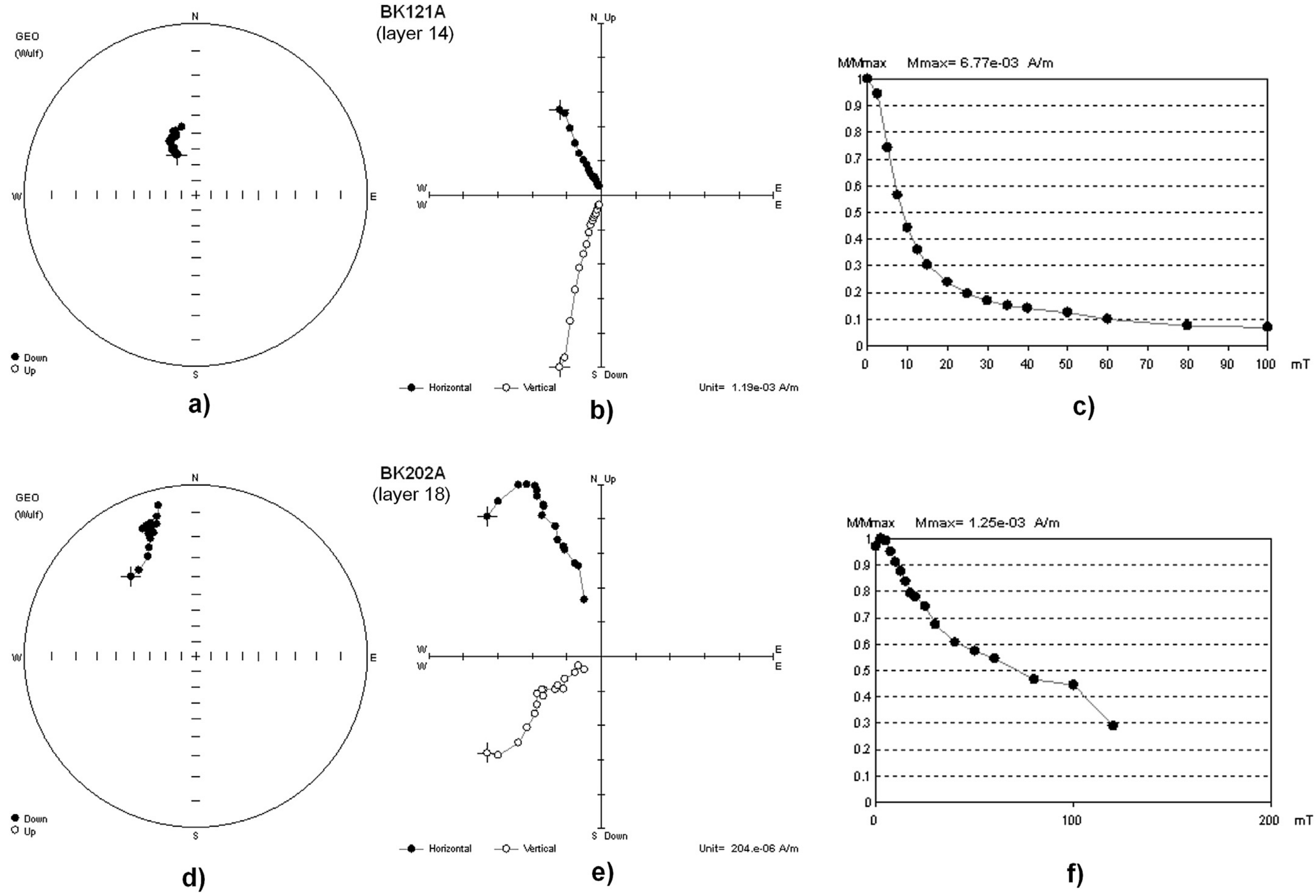

Fig. 8. Examples of AF-demagnetization of specimens from Section 3: (a) – stereograms of RM vectors positions during demagnetization, (b) – Zijderveld diagrams of RM components, (c) – normalized intensity of RM during AF demagnetization. Numbers of units from which the specimens have been taken are marked in the figures.

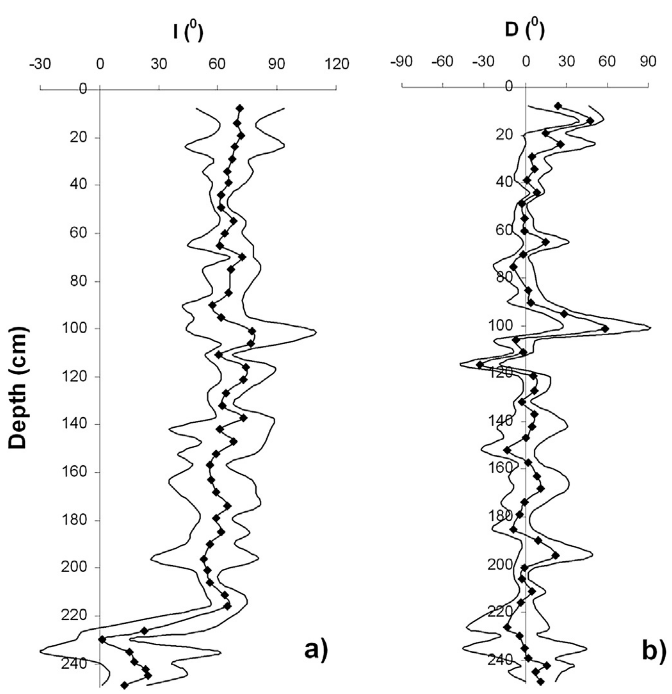

Fig. 9. Stacked curves of inclination (a) and declination (b) of ChRM along the Section 3. Values are calculated as averaged values from individual specimens in the limits of 95 percent confidence interval.

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