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ORIGINAL ARTICLE

Guano-derived δ^{13}C-based paleo-hydroclimate record from Gaura cu Musca Cave, SW Romania

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Abstract The δ^{13}C values of 23 unevenly spaced guano samples from a 17-cm long clay sediment profile in Gaura cu Muscă Cave (GM), in SW Romania, made it possible to preliminarily characterize the Medieval Warm Period summer hydroclimate regime. The beginning of the sequence (AD 990) was rather wet for more than a century, before becoming progressively drier. After a brief, yet distinct wet period around AD 1170, drier conditions, with a possible shift from C_3 to a mixed C_3-dominated/C_4 type vegetation (2 ‰ lower δ^{13}C values), prevailed for almost half a century before the climate became colder and wetter at the onset of the Little Ice Age, when bats left the cave. The guano-inferred wet and dry intervals from the GM Cave are mirrored by changes in the color and amount of clay accumulated in the cave. They also agree well with reconstructions based on pollen and charcoal from peat bogs and δ^{13}C and δ^{18}O on speleothems from other Romanian sites. Overall, these results indicate that the δ^{13}C of bat guano can provide a sensitive record of the short-term coupling between local/regional climate and the plant–insect–bat–guano system.

Keywords Guano · Cave · Carbon isotopes · Paleoclimate · Romania

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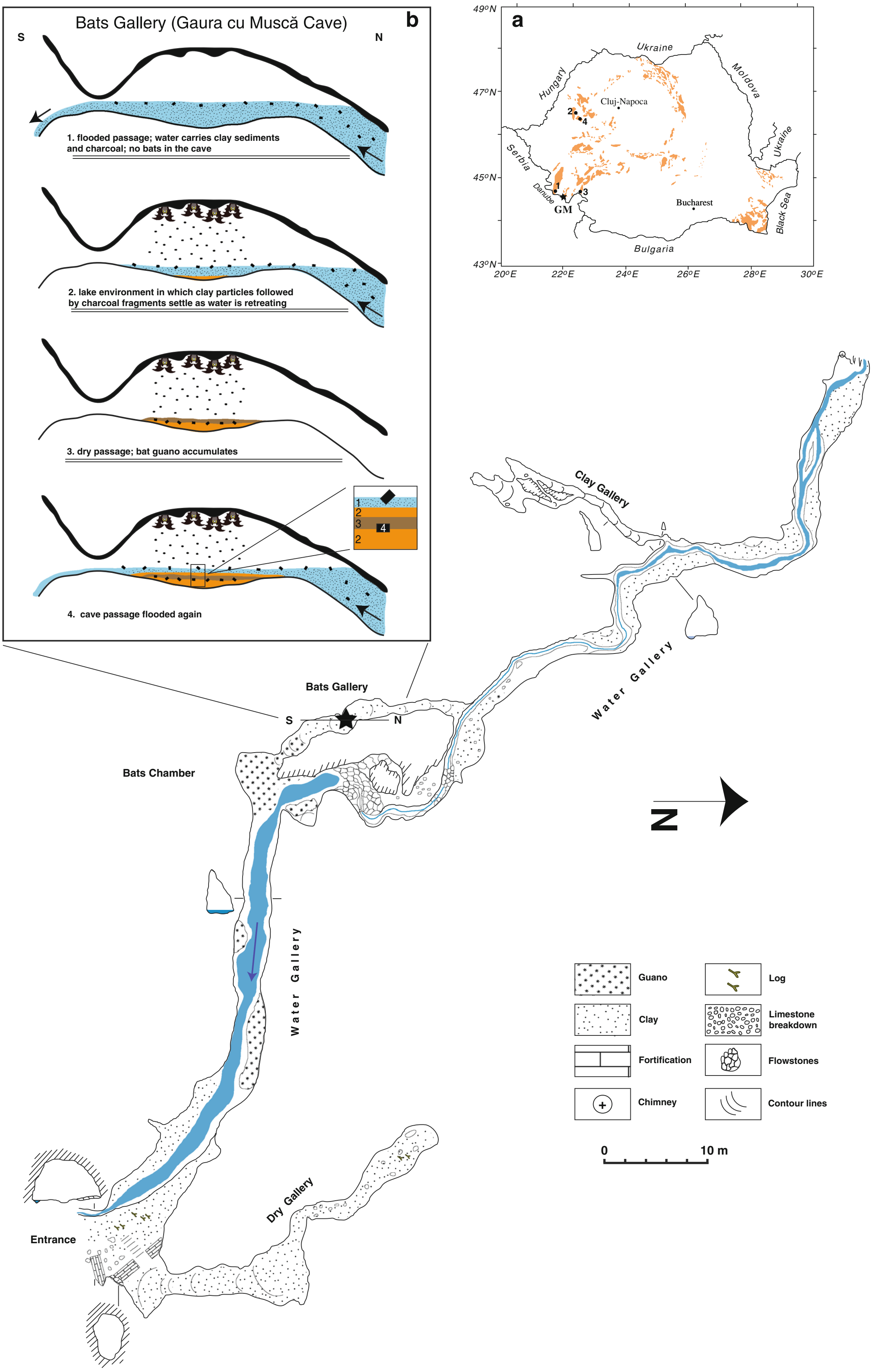
Introduction

Caves host a variety of clastic, chemical, and organic deposits from which past environmental and climatic information can be recovered (Sasowsky and Mylroie 2007; White 2007). A relatively new, yet untapped, but important repository for paleoclimate information in caves is represented by the accumulation of bat guano (Mizutani et al. 1992a; Bird et al. 2007; Wurster et al. 2008). Such deposits are especially valuable in those karst areas where other environmental archives are either poor, of low quality, or completely missing.

Worldwide, the most significant bat guano deposits are concentrated in caves at low- and mid-latitude (Kunz et al. 2012). When building up large heaps, guano is regarded as a cave sediment that is composed of organic (mainly insect remains) or/and inorganic matter (various phosphate and carbonate minerals, silt, clay, etc.) accumulated in a loose form, similarly to any other unconsolidated sediment. Weathering processes typical of surface environments are minimized in caves, making ideal circumstances for preservation of these materials. In addition, further from the entrance, the cave environment is characterized by constant topoclimatic conditions (temperature, relative humidity, air currents); and therefore, large guano deposits remain undisturbed for long periods of time, preserving their original stratigraphy. The inner structure of guano heaps can potentially be altered by bioturbation, post-deposition diagenetic processes, or if underground streams flow/flood the subterranean passages in which guano accumulated over time.

As early as 1980, Des Marais et al. recognized the paleoecological significance of bat guano, suggesting that there is a connection between its carbon isotopic signature and local climatic conditions. This is because bats are


Bats Gallery (Gaura cu Muscă Cave)
b
S
N
1. flooded passage; water carries clay sediments and charcoal; no bats in the cave
2. lake environment in which clay particles followed by charcoal fragments settle as water is retreating
3. dry passage; bat guano accumulates
4. cave passage flooded again
1
2
3
4
2
a
49°N
47°N
45°N
43°N
20°E
22°E
24°E
26°E
28°E
30°E
Ukraine
Hungary
Moldova
Cluj-Napoca
2
4
Ukraine
Serbia
Danube
1
3
GM
Bucharest
Black Sea
Bulgaria
Clay Gallery
Water Gallery
Bats Gallery
S
N
Bats Chamber
N
Water Gallery
Dry Gallery
Entrance
Guano
Log
Clay
Limestone breakdown
Fortification
Flowstones
Chimney
Contour lines
0
10 m

◀ **Fig. 1** Map of the Gaura cu Muscă Cave (modified after Botoşăneanu et al. 1976) showing the sampling site (*black star*). **a** Location of the Gaura cu Muscă Cave on the karst regions map of Romania; 1 Poleva Cave, 2 Urşilor Cave, 3 Grota Haiducilor Cave, 4 Bihor Mountains peat bogs. **b** Evolutionary stages of the Bats Gallery on a N–S transect

feeding on insects whose dietary preferences reflect the local vegetation of which distribution is controlled by the local/regional climate. Plants use one of three different photosynthetic pathways (C_3, C_4, or the Crassulacean acid metabolism, CAM; Smith and Epstein 1971; Osmond et al. 1973; Kennedy and Laetsch 1974; O'Leary 1981), each type producing a characteristic range of $\delta^{13}C$ values. Typically, C_4 type plants have a mean of 12.5 ± 1.1 ‰ whereas the $\delta^{13}C$ values for C_3 vegetation averages 26.7 ± 2.3 ‰ (O'Leary 1981; Cerling et al. 1997; error represents 1σ standard deviation); CAM plants typically show $\delta^{13}C$ values between these two endmembers. As the carbon isotopic composition of insect tissue such as chitin reflects the isotopic composition of their diet, and as the $\delta^{13}C$ of plants is highly specific to the photosynthetic pathway, changes in the isotopic composition of guano should also reflect changes in the $\delta^{13}C$ values of vegetation consumed by the insects. Thus, the $\delta^{13}C$ values of bulk guano or chitin recovered from guano deposits represents a weighted average of insect diet before being consumed by bats, and can therefore be considered an implicit proxy for paleovegetation in the investigated region (Des Marais et al. 1980; Wurster et al. 2007).

The first report on the isotopic composition, fractionation, and mixing processes in the plant–insect–bat–guano system was published by Des Marais et al. (1980). The authors investigated the carbon isotopes of individual hydrocarbons in bat guano and estimated the abundance of C_3, C_4, and CAM plants in the Carlsbad region (New Mexico, USA). Mizutani et al. (1992a, b) extended the studies based on carbon isotopes, adding $\delta^{15}N$ to reconstruct the paleo-food web and better constrain the paleoenvironmental information. Over the last decade, similar studies have incorporated measurements of C:N ratio, $\delta^{13}C$, $\delta^{2}H$, and $\delta^{15}N$ in bulk guano or beetles chitin recovered from bat guano deposits to reconstruct paleoclimate and paleoenvironmental change through the Late Pleistocene and Holocene of USA, southeast Asia, Australia, and Jamaica (McFarlane et al. 2002; Forbes and Bestland 2006; Bird et al. 2007; Wurster et al. 2008, 2010).

Climate-driven changes in the ecosystem impact insect population, although, there is a flexible adaptation of them to different diets (Waldbauer and Friedman 1991). Bats consume different insects in the foraging range, which is commonly up to almost 9 km (Zahn et al. 2005). One of the main difficulties in interpreting the $\delta^{13}C$ signal recovered from guano deposits derives from the fact that there is no detailed information about the isotope fractionation along the plant–insect–bat–guano system (Des Marais et al. 1980). Depending on the diet, the $\delta^{13}C$ values of insect bodies is assumed to be enriched by about 1 ‰ relative to the plants they consumed (DeNiro and Epstein 1978). However, little detailed study of individual and species-specific variation in the trophic fractionation involved in the plant–insect–bat–guano continuum has been completed (however, see Boecklen et al. 2011 for a review of trophic fractionation). Other paleoenvironmental proxies derived from bat guano include pollen, charcoal, faunal remains, sediments, and atmospheric ^{36}Cl (Pons and Quézel 1958; Harris 1979; Coles et al. 1989; Bui-Thi and Girard 2000; McFarlane et al. 2002; Gilbertson et al. 2005; Carrión et al. 2006; Leroy and Simms 2006; Maher 2006; Dykes 2007; Johnston et al. 2010).

Although mineralogical investigations on guano-derived cave phosphates have been abundant from Romanian cave deposits (Onac and Bengeanu 1992; Diaconu and Dumitraş 2000; Onac and Vereş 2003; Marincea et al. 2004; Onac et al. 2006), no isotopic studies have been published. Three other studies of guano deposits from Romania have been published including work on the chronology of the guano accumulation in the Adam Cave (Carbonnel et al. 1999) as well as the $^{36}Cl/Cl$ content and pollen stratigraphy of the 800-year-old guano heap in Măgurici Cave (Johnston et al. 2010; Geantă et al. 2012).

With this paper, the authors attempt to use, for the first time in Romania, and to our knowledge elsewhere in Europe, the $\delta^{13}C$ of guano from a cave in south-western Romania to reconstruct shifts in the local to regional environment and climate. Only limited information is currently available on paleoclimate and paleoenvironmental change from terrestrial sites on this part of Romania. Most of the present data derives from pollen studies from sediments in the Danube Gorge caves. However, their utility is significantly reduced due to lack of chronology (Boşcaiu and Lupşa 1967a, b; Pop et al. 1970; Boşcaiu et al. 1971). One study does present a speleothem isotope-based paleoclimate reconstruction; however, the temporal resolution of its Late Holocene part is relatively poor (Constantin et al. 2001).

Study site, bats, and sample description

The Gaura cu Muscă Cave (hereafter GM; meaning the Cave with Flies) is located at the southeastern end of the Locvei Mountains (Southern Carpathians), part of the Reşiţa-Moldova Nouă karst plateau (Fig. 1a). This geomorphic unit is characterized by low elevations near GM cave, ending with some spectacular limestone cliffs facing the Danube River. Given its proximity to the Danube and especially because of the large entrance and the presence of a natural “window” (suspended entrance), the cave was known and inhabited at least since the time of the Hallstatt Culture. The cave was fortified, several times since the fourteenth century, with stone walls that are still visible (Boroneanţ 2000).

The climate in the cave region is temperate continental with significant sub-mediterranean influences. The mean annual temperature is between 10 and 11 °C and the amount of annual precipitation ranges between 700 and 800 mm (mean 750 mm), with most rainfall occurring during summer (Munteanu and Bălănescu 1999; Sandu et al. 2008). The vegetation around the cave consists of thermophylous low shrubs, pastures, and deciduous C_3-type mixed forests of *Fagus sylvatica* with *Quercus ceris* and *Q. petrea*, or *Fagus* with *Carpinus betulus* (Matacă 2003). The plant community in this region also includes C_4-type xerophytic shrubs (Boşcaiu and Resmeriţă 1969); however, the exact ratio between C_3 and C_4 plants is not assessed. Summer precipitations are important for forbs, grasses, and shrubs that emerge and flower from mid-April to late July (growing season). This interval overlaps a significant part of the foraging period when bats are most active.

The cave opens on the left bank of the Danube Gorge, 3 km downstream the village of Coronini (Caraş-Severin County, SW Romania) at 92 m above sea level (Botoşăneanu et al. 1967). It is a short cave (254 m in length) consisting of a main Water Gallery, two short side passages, one near the entrance and the other one at the far end of the cave, respectively (Dry and Clay galleries). At 55 m from the entrance, opens the largest room in the cave, Bats Chamber (6 × 4 m) that continues with the Bats Gallery, a short and rather low height (<1.5 m) corridor that bypasses a lake along the stream passage (Fig. 1).

The cave air temperature (yearly average) measured during several visits between 1962 and 2013 (covering all seasons) is fairly constant (~13.7 °C), whereas the relative humidity is 93–96 %, except for the Dry Gallery where it always stays below 90 % (Negrea and Negrea 1979).

The most commonly reported bat species in GM Cave are *Myotis myotis*, *M. capaccinii*, *M. oxygnathus*, *M. emarginatus*, *Miniopterus schreibersii*, *Rhinolophus ferrum-equinum*, *R. euryale*, and *R. blasii* (Dumitrescu et al. 1962–1963; Decu et al. 2003; Coroiu pers. comm.). The diet of these species consists of small to medium size insects (beetles, spiders, flies, crickets, cranefly, etc.). They forage between April and October in a wide variety of different habitats, including waterways, open woodlands, pastures, and shrubs all available in the cave vicinity.

All faunal observations available from this cave mention the presence of either maternity or hibernation roosts of tens to several hundreds bats (Méhely 1900; Dumitrescu et al. 1962–1963; Negrea and Negrea 1979; Coroiu pers. comm.). Apart from these assemblies, small colonies and isolated individuals were also noticed along the Water Passageway, Bats Gallery, and Clay Gallery. The largest nursery roost for *Myotis capacinii* (and consequently guano deposit underneath) is in the ceiling of the Bats Chamber. Unfortunately, the underground stream is constantly flooding and removing part of the guano from this location, hence not a proper site for sampling.

The seasonal activity of bats, i.e., active during summer and entering a torpid state (hibernation) in winter is well reflected by the guano heap underneath colonies. Fresh guano continuously accumulates during late-spring and summer; however, when bats enter the hibernation period or move away from a particular cave site, it begins to desiccate (if cave microclimate allows). A new layer of guano will be laid down when bats resume their activities. Therefore, the presence of massive guano deposits or thinner layers interbedded within other cave sediments is always related to the period between April and early October when bats are most active. The volume/thickness of guano in a given cave location largely depends on whether that is a permanent maternity roost and on its size. However, the amount of guano accumulated does not always reflect the size and/or permanency of the bat colony; natural (water, gravitation) or anthropic (small to large scale guano mining) factors are responsible for this situation.

A 25-cm deep excavation was dug in the clayey floor of the Bats Gallery below a section of the ceiling easily distinguishable as bat roost by dark ceiling stains (hydroxylapatite coatings) and some guano accumulation on the floor (Fig. 1, black star). The opened profile was carefully cleaned and a 20 × 7 × 25 cm (width × depth × height) rectangular slice was extracted, photographed, documented, and described (stratigraphy, color, sedimentology) in the cave. The recovered sediment sequence consists of two distinct types of clays [yellow in the upper 7.6 cm (Munsell color system: 10YR 7/6) and brownish yellow (10YR 6/6) between 7.6 and the bottom of the profile] in which very dark brown (7.5YR 2.5/2) guano layers or lenses are interbedded (Fig. 2a). The thickest of these guano horizons is between 14 and 15.6 cm below the surface. One other thick horizon appears between (6.5 and 7.6 cm), followed upward by three more, each under 1 cm in thickness. Millimeter-size black shiny fragments of charcoals are scattered throughout the entire profile. As the lower 8 cm of the profile contains no guano, the present study focuses on its upper 17 cm.

The particular stratigraphy of this profile (alternations of guano and clay, with or without charcoal fragments) suggests that over the accumulation period, the southern end of the Bats Gallery repeatedly acted as a dam behind which clay sediments settled on top of guano deposits (Fig. 1b, stages 1 and 4). The charcoal fragments are very light; thus, they floated at the surface of the ponding water until the dam completely dried up. At this point, the charcoal was laid down on top of the freshly accumulated clay sediments (Fig. 1b, stages 2 and 3). The reason for the modest amount (thickness) of organic matter in the sequence is twofold: (i) part of the guano might have been removed when the gallery flooded; or (ii) the size of the nursery roost was small (plausible hypothesis considering the overall space available).

Materials and methods

Carbon isotopic composition

For the analysis of carbon isotopic composition, each guano horizon or lens at 4 mm intervals were sampled, except for the thin layers from which only one sample was recovered. In addition to the 23 guano samples, nine charcoal fragments were extracted from clay and guano layers. The guano samples were prepared for isotopic analysis using a modified method of Wurster et al. (2007). To avoid contaminations from organic materials (e.g., plastics) glass vials and watch glasses were used throughout the entire procedure. The organic material was dried for 3 h at 40 °C, a temperature that is lower than the bats maximum body temperature (Hock 1951), thus preventing any loss of organic material. The dried samples were ground in an agate mortar, homogenized and weighed. Half the quantity of each sample was mixed with 300 µl distilled water and 1 ml HCl (10 %) and left for 3 h at 25 °C to remove any carbonate minerals. No visible bubbles resulted from these reactions. After drying at 40 °C overnight, the organic material was ground and homogenized again. Both the acid treated and non-treated samples were analyzed. The Student's *t* test indicated that at the significance level of 0.01, there is no major difference between the carbon isotopic compositions of the two sample populations, thus confirming that the samples were free of carbonates.

The carbon isotopic composition was measured in the Stable Isotope Laboratory of the Babeş-Bolyai University (Cluj, Romania), using the Combustion Module-Cavity Ring Down Spectroscopy (CM-CRDS) technique (Busch and Busch 1999; Brand et al. 2009). The combustion module designed by Costech Analytical Technologies Inc. delivers the CO_2 to the CRDS analyzer (Picarro G2101-i type), which was used with the default factory calibration. Corrections were carried out on each sample measurement batch, using two-point calibration with internal standards (atropine and acetanilide) and a control standard (B2151) for consistency verification. The internal standard was calibrated against ANU Sucrose and two organic analytical standard reference materials, B2155 Protein (Casein) and B2151 high organic sediment (Elemental Microanalysis, Ltd), respectively. All δ^{13}C values are expressed relative to the VPDB standard, where:

$$\delta^{13}C = \left(\frac{\left({}^{13}C/{}^{12}C\right)_{\text{sample}}}{\left({}^{13}C/{}^{12}C\right)_{\text{std}}} \right) \times 1{,}000\%$$

For each sample, three (in case of charcoal) or four (in case of guano) measurements were carried out and the average reported. Precision is estimated to be better than ± 0.06 ‰ (1σ) based on replicate internal standards in each run. The reproducibility between replicate standards in each run was better than ± 0.1 ‰ (1σ).

Sequence chronology

The dating control of the upper 17 cm sediment sequence in GM Cave is based on three accelerator mass spectrometry radiocarbon measurements performed on a twig charcoal fragment (GM3 A) and two pre-treated carbonate-free guano samples (GM3 A–B and GM3 B) at the Poznan Radiocarbon Laboratory and ^{14}Chrono Center, Queens University Belfast, respectively. Radiocarbon dates were calibrated using OxCal 4.1 and the INTCAL09 dataset of Reimer et al. (2009) and are reported as calibrated years AD. Because the dated sequence is highly peculiar (i.e., unevenly spaced layers of guano or charcoal pieces within clays), constructing an age-depth model is not suitable for this site.

Results and discussion

^{14}C dates

Results from the radiocarbon measurements reveal that all three ages (AD 1280, AD 1170, and AD 990) are in stratigraphic order (Table 1). The two calibrated radiocarbon ages at the top and bottom of the profile are likely to be AD 1280 and AD 990, respectively, thus constraining the Medieval Warm Period.

One could argue that this youngest age obtained on charcoal may carry an "inbuilt" error, defined as the amount of time elapsed from the death of the tree to its burn (McFadgen 1982). It has been abundantly documented that if this is the case the inbuilt age always biases ^{14}C ages to be older (up to hundreds of years) than the time of the fire (Waterbolk 1983; Gavin 2001). Therefore, the inbuilt-age error impacts the authors' ability to safely distinguish, using ^{14}C dating of charcoal, the minimum interval between two fires. In this case, dating any of the charcoal fragments in the upper 7 cm of the profile,

Table 1 Guano and charcoal samples submitted for radiocarbon dating

Sample name	Lab no.	Depth below surface (cm)	Material dated	Age ^{14}C	Calibrated age range (AD) at both 1σ and 2σ	Date used
GM3A	Poz-51866	0.5	Charcoal	795 ± 30	AD 1222–1261 (100 %) 1σ AD 1186–1201 (3.54 %) 2σ AD 1206–1277 (96.46 %) 2σ	AD 1280
GM3x	UBA-21559	6.7	Guano	875 ± 30	AD 1058–1073 (11.13 %) 1σ AD 1155–1215 (88.87 %) 1σ AD 1043–1105 (23.80 %) 2σ AD 1118–1224 (76.20 %) 2σ	AD 1170
GM3B	Poz-51867	16.5	Guano	990 ± 30	AD 999–1002 (1.7 %) 1σ AD 1013–1045 (63.26 %) 1σ AD 1095–1120 (28.16 %) 1σ AD 1141–1147 (6.83 %) 1σ AD 989–1053 (60.09 %) 2σ AD 1079–1153 (39.91 %) 2σ	AD 990

spanning ~106 years, would have produced similar ^{14}C ages, but definitely older than the other two available. In addition, however, the authors' upper two ages were obtained on different materials, a piece of burned twig (known to be significantly less affected by inbuilt error; McFadgen 1982) and bulk guano, respectively. Considering this and the age-stratigraphy of the sediment sequence, an inbuilt error was excluded for the top age of the profile.

Mean annual precipitation reconstruction from carbon isotopic composition

In a recent paper, Kohn (2010) presented the following equation to estimate the mean δ^{13}C value of C_3 plants ($\delta^{13}C_{C3}$) using the altitude, absolute latitude, and the mean annual precipitation of a given region:

$$\begin{aligned}\delta^{13}\mathrm{C}\,(‰;\ \mathrm{VPDB}) = {} & -10.29 + 1.90\times10^{-4}\,\mathrm{Altitude}\ (\mathrm{m}) \\ & - 5.61\,\log_{10}(\mathrm{MAP}+300,\ \mathrm{mm/yr.}) \\ & - 0.0124\ \mathrm{Abs}\ (\mathrm{latitude},^{\circ})\end{aligned}$$

where MAP stands for the mean annual precipitation. Substituting altitude, MAP and latitude terms pertaining to the GM Cave (102 m; 800 mm/year; 44.66472º) the authors estimate that the mean $\delta^{13}C_{C3}$ in the region should be −27.89 ‰. This is within the analytical error of the mean value of −27.85 ‰ obtained on terrestrial grasses and leaves from trees and bushes collected nearby the cave (Onac et al. unpubl. data). The difference between the calculated (and present-day) $\delta^{13}C_{C3}$ and the δ^{13}C value of fresh guano in GM Cave (−26.63 ‰) is 1.26 ‰. This value may be used as an estimation of the fractionation along the plant–insect–guano path, comprising a difference in δ^{13}C values for two trophic levels (plant–insect and insect–bat, DeNiro and Epstein 1978). Having tested the Kohn (2010) equation that relates $\delta^{13}C_{C3}$ to environment, the authors rearranged it and reconstructed paleoprecipitation (MAP) based on the measured δ^{13}C of guano through the Medieval Warm Period (MWP) (Fig. 2b).

Isotope data interpretation

The δ^{13}C values of guano from GM cave range from 27.1 to 25.2 ‰ for bulk guano, and from 27.4 to 24.5 ‰ in charcoal, and is 26.63 ‰ in modern guano collected at the surface of the site (Fig. 2b). Beneath 0.4 cm, the δ^{13}C value of the guano increases rapidly to 25.2 ‰ at 3 cm before decreasing to almost 27 ‰ at 6.7 cm. Within the next 0.7 cm, the δ^{13}C values are once again increasing to 25.8 ‰, then drop to 27.1 ‰. Between 11 cm and the base of the profile, the δ^{13}C values only change about 0.15 ‰ on both sides of 27 ‰. In order to understand the paleoclimatic signal encoded in the δ^{13}C values of the GM Cave guano, the authors attempted to compare this time series with those available in SW Romania for this period.

Overall, the trend of guano and charcoal δ^{13}C values parallel each other, bearing similarity to the δ^{18}O trend in the PP9 stalagmite from Poleva Cave situated within a few kilometers from the GM Cave (Fig. 1a, site 1). Constantin et al. (2007) interpreted this record to reflect swings from cold to warm climates. In particular, for the time frame investigated in this study, the variation in δ^{18}O values from Poleva Cave suggest a rapid warming at the transition from the Dark Ages to the MWP. The climate remained warm until the cooling associated with the LIA begun. On the other hand, the δ^{13}C isotope record from PP-9 (despite the

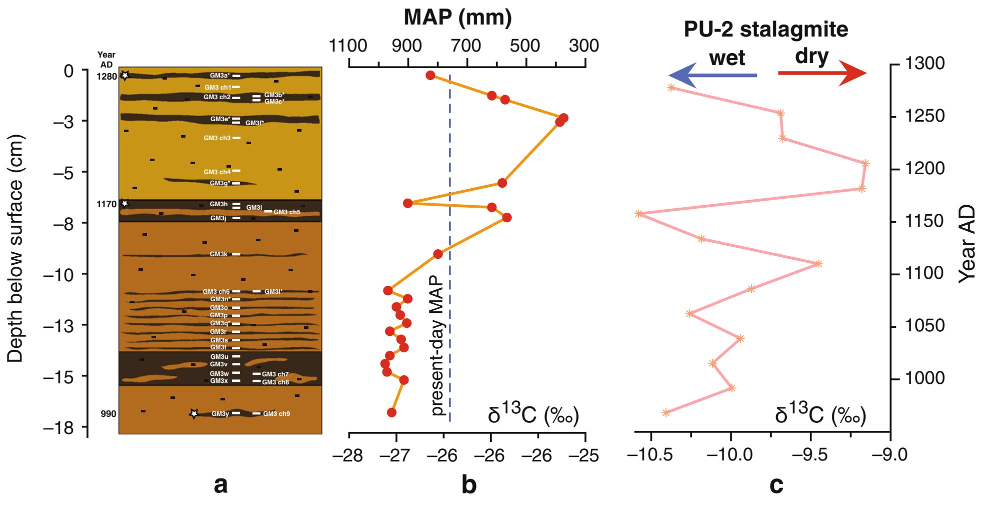


Fig. 2 **a** Synthetic profile of the sediment (*yellow and brownish yellow*)/guano (*black layers*) deposit within the Bats Gallery. The location of the radiocarbon (*empty starts*), guano (*white rectangles*), and charcoal (*black rectangles*) samples is also shown. **b** Carbon-isotope composition of the guano samples and the MAP reconstruction (*upper X-axis*) based on Kohn's (2010) equation (see text for explanations) **c** The Medieval Warm Period δ^{13}C profile for stalagmites PU-2 from Urşilor Cave (Onac unpubl. data)

low resolution data set) is thought to document shifts from wetter to drier conditions (Constantin, unpubl. data). Furthermore, comparing the δ^{13}C records from GM Cave and Urşilor Cave PU-2 stalagmite from NW Romanian (Fig. 1a, site 2; Onac et al. 2002; Onac et al. in prep.), the authors noticed the two profiles overlap each other (within data uncertainty) very well. Individual spikes of ^{13}C-depleted δ^{13}C values were interpreted as indicative of periods of heavy rainfall, based on the speleothem calcite fabric changes (Onac et al. 2002). Corroborating the above observations, the authors are tempted to conclude that the more positive/negative δ^{13}C values in both bulk guano and charcoal from the GM Cave, document dry/wet periods. Thus, the 17-cm isotopic profile reveals a shift from wetter summer conditions in the first half of the MWP towards more drier over the last century of it. These major hydroclimatically different intervals are also mirrored by changes in the color (from yellowish during the dry period to dark brown when wet conditions prevailed) and amount of clay accumulated in the Bats Passage.

Conclusions

The time interval identified in this sequence is short (<300 years) and bracketed by two cold periods know as the Dark Ages and LIA, respectively. Paleorecords of this period from SW Romania are not only scant but either completely lacking chronology or originate from high altitude locations (e.g., Boşcaiu and Lupşa 1967a, b; Pop et al. 1970; Rösch and Fischer 2000). Under these circumstances, little information is available for evaluation and comparison purposes. Although accumulated at uneven sedimentation rates, the organic layers/lenses or fragments preserved within the clay sequence at GM Cave allowed to tentatively unravel the summer hydroclimatic changes using the δ^{13}C signal in bulk guano, in addition to being used as a proxy for paleovegetation in the investigated region.

Though ^{14}C ages can be useful in establishing the chronology of guano deposits, given the distinctiveness of this site, the temporal precision is rather coarse. Therefore, the radiocarbon dating of GM Cave guano and charcoal primarily constrains the cave occupancy by bats and document flood events, respectively. The ages suggest bats dwelt in the cave during both wet and arid periods; however, apparently, the production of guano was higher at the beginning of the MWP. Around AD 1170, the δ^{13}C values in the GM Cave guano record a short-lived (few years) wet period also seen in the PU-2 stalagmite and known from many other locations throughout Europe (Marusek 2010). Towards the upper part of the profile, corresponding to the demise of MWP, the guano layers are thinner and completely vanish at the onset of the LIA.

The alternating dry/wet periods is further supported by the pollen assemblage (older-middle to younger Subatlantic Period) described from nearby Grota Haiducilor Cave sediments (Fig. 1a, site 3) by Boşcaiu and Lupşa (1967b). A regional charcoal study (concentration and rate of accumulation) conducted by Feurdean et al. (2012), shows a general rise over the MWP followed by a drop in the LIA, suggesting biomass burning was modulated by climate. The wet/dry spells inferred from the δ^{13}C record in GM Cave agrees well with the charcoal concentration in two of the investigated sites (Molhaşul Mare and Călineasa, Bihor Mountains; Fig. 1a, site 4). The MWP summer hydroclimatic variations in SW Romania inferred from the δ^{13}C of bat guano, also correlate well with the tree ring-based reconstructed summer precipitations totals of Central Europe (Büntgen et al. 2011).

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