Quaternary Science Reviews xxx (2015) 1–14

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

# A Late Holocene environmental history of a bat guano deposit from Romania: an isotopic, pollen and microcharcoal study

Ferenc L. Forray [a,*], Bogdan P. Onac [b,a], Ioan Tanţău [a], Jonathan G. Wynn [b], Tudor Tămaş [a], Ioan Coroiu [c], Alexandra M. Giurgiu [a]

[a] Department of Geology, Babeş-Bolyai University, Kogălniceanu 1, 400084 Cluj-Napoca, Romania
[b] School of Geosciences, University of South Florida, 4202 E. Fowler Ave., NES 107, Tampa, 33620, USA
[c] Department of Taxonomy and Ecology, Babeş-Bolyai University, Clinicilor 5, 400006, Cluj-Napoca, Romania

ARTICLE INFO

*Article history:*
Received 28 January 2015
Received in revised form
18 May 2015
Accepted 19 May 2015
Available online xxx

*Keywords:*
Cave guano
Carbon isotopes
Pollen
Microcharcoal
Environmental history
Late Holocene
Little Ice Age
Romania

ABSTRACT

A 1.5-m-long core from a bat guano deposit in Zidită Cave (western Romania) has provided a 900-year record of environmental change. Shifts in $\delta^{13}C$ values of bulk guano (between −22.6 and −27.5‰) combined with guano-sourced pollen and microcharcoal information show significant changes in the structure of vegetation and plant biomass. Cave guano $\delta^{13}C$ values reflect the dietary preferences of bats which are controlled by local vegetation dynamics, which in turn depend on local climatic conditions. Neither $\delta^{13}C$ values nor pollen association in guano changed strikingly over the Medieval Warm Period (MWP) and Little Ice Age (LIA) transition. Instead, an overall decreasing trend of $\delta^{13}C$ values between *ca.* AD 1200 and 1870–1900 defines the duration of LIA. A shift toward cooler and wetter conditions *at ca.* AD 1500 noticed in the pollen record by an increase in *Fagus sylvatica* and *Alnus* and the decrease of *Carpinus betulus*, may indicate the first major change at the beginning of the LIA. Evidence for two major cold spells occurring around AD 1500 and *ca.* AD 1870 comes from both $\delta^{13}C$ and pollen record. In between these events, the cave region experienced a warmer and drier climate but colder and wetter than the MWP, favouring the expansion of *Quercus*, *Fraxinus* and *Tilia* simultaneously with the decrease of *F. sylvatica* and Poaceae. Human impact in the studied area is mainly related to agriculture, grazing and deforestation. The effects are most pronounced after AD 1845 when the pollen of cereals increases and *Zea* is recorded (AD 1845). Higher percentages of microcharcoal particles in the guano sequence are generally correlated with agricultural activities like land cleaning via controlled fires.



## 1. Introduction

Human-induced climate change is already affecting Earth's ecosystems and society in trends that are likely to continue for generations to come (Hulme et al., 1999; Parmesan and Yohe, 2003; Macdonald et al., 2005; Holmes et al., 2011). Understanding the complex drivers behind Earth's past climate changes may help predict the likelihood, extent and patterns of future changes. Developing this understanding requires high resolution paleoclimate records like those archived in ice cores, lake and marine sediments, peat bogs, tree rings, or cave deposits (Stuiver et al., 1995; Helmens, 2014; Bradley, 2015). Cave deposits in particular are of special interest because caves provide somewhat isolated environments that are physically and chemically more stable on short time scales (less than 1 Ma) than at Earth's surface (Lauritzen, 1993), allowing for a better preservation of deposits that archive environmental conditions (speleothems, guano, sediments, etc.). This feature makes caves important in areas where other paleoclimatic data are lacking (Onac et al., 2014). Key aspects of climate variability have been most extensively and successfully reconstructed from a range of speleothem proxy parameters (*e.g.*, $\delta^{18}O$, $\delta^{13}C$, trace elements, growth rate, $^{87}Sr/^{86}Sr$, $\delta^{34}S$, biomarkers, etc.; Fairchild and Baker, 2012; Bradley, 2015).

Geochemical studies of cave guano, including studies using stable isotopes in particular, can provide paleoecological (relative abundance of $C_3$-, $C_4$- or CAM-type plants, vegetation changes, feeding behaviour of bats) and paleoclimate (precipitation) records (Des Marais et al., 1980; Mizutani et al., 1992a; McFarlane et al., 2002; Bird et al., 2007; Wurster et al., 2007; Onac et al., 2014, 2015). This work on cave paleoclimatic studies, builds on previous

* Corresponding author.
*E-mail address:* ferenc.forray@ubbcluj.ro (F.L. Forray).

http://dx.doi.org/10.1016/j.quascirev.2015.05.022
0277-3791/

paleoenvironmental and paleoclimatic reconstructions using carbon isotopic composition of insect chitin in non-cave settings (Schimmelmann and DeNiro, 1986; Schimmelmann et al., 1986; Miller, 1991; Gröcke et al., 2006). Other guano-based studies have obtained meaningful complementary climatic and environmental information using hydrogen and nitrogen isotopes (proxies for local precipitation and changes in the trophic level, respectively), as well as carbon:nitrogen (C:N) ratios (Mizutani et al., 1992b; Bird et al., 2007; Wurster et al., 2007, 2008).

Guano deposits also contain a variety of pollen grains, which link bats and their dung with the vegetation composition nearby the cave (Navarro et al., 2001). The mechanisms by which pollen is incorporated into guano are: i) trapping in bat skin and hair; ii) digestion of insects, and iii) wind transport (Leroy and Simms, 2006). Pollen grains recovered from radiocarbon-dated cave bat guano deposits have been used extensively to reconstruct changes of local to regional past vegetation, using similar methods to records provided by lake sediments and peat (Carrión et al., 2006; Maher, 2006; Batina and Reese, 2011; Geantă et al., 2012; Onac et al., 2015).

Similarly to peat and lake sediments, the organic (guano) and inorganic (clay) cave sediments may contain charred particles (Onac et al., 2014). Charcoal is carried in caves by water, wind or bats. Because charcoal is a proxy for fire, it can be used along with pollen to examine the link between vegetation, fire history, climate, and sometimes anthropogenic activities (Whitlock and Larsen, 2001; Mooney and Tinner, 2011; Feurdean et al., 2013a; Onac et al., 2015).

The aim of the present study is to reconstruct a 900-year record of environmental change and anthropogenic impacts in western Romania using multi-proxy data ($\delta^{13}C$, pollen and microcharcoal) derived from a precisely $^{14}C$-dated bat guano core recovered from Zidită Cave.

## 2. Guano $\delta^{13}C$ as proxy for past environments and climates

Bulk organic sediments (such as guano) are chemically heterogeneous mixtures of amino acids, sugars, and other compounds, each with a range of different carbon isotopic compositions. According to Schimmelmann and DeNiro (1986), variation in the abundance of these different organic compounds will introduce an "isotopic noise", with the impact suggestion that isolated compounds should be used for isotopic measurements rather than bulk material. However, bat guano contains mainly insect chitin, a long-chain polymer of a N-acetyl-D-glucosamine, which is a very insoluble organic compound (Miller, 1991; Pillai et al., 2009). Wurster et al. (2010) directly compared the carbon isotopic composition of insect cuticles extracted from guano with the values of bulk guano and based on their overall similarity suggested that carbon isotopes from bulk guano can be used reliably for paleoenvironment and paleoclimate studies.

To better understand the link between bulk guano carbon isotopic composition and climate, one needs to track the isotope fractionation along the atmospheric $CO_2$–plant–insect–bat–guano pathway. Present-day atmospheric $CO_2$ has a lower $^{13}C/^{12}C$ ratio than that of prior centuries, a fact attributed to fossil fuels combustion (Keeling et al., 1979). The additional anthropogenic carbon has resulted in a present day $\delta^{13}C$ value of *ca.* −8.24‰, as compared to the pre-industrial value of *ca.* −6.35‰ (Francey et al., 1999; McCarroll and Loader, 2004; Keeling et al., 2005; Scripps, 2015). Plants use three major photosynthetic mechanisms to fix carbon from the atmosphere: $C_3$ (Calvin), $C_4$ (Hatch-Slack), and crassulacean acid metabolism (CAM) (Smith and Epstein, 1971; Osmond et al., 1973; Kennedy and Laetsch, 1974; O'Leary, 1981) each resulting in a different range of carbon isotopic fractionation due to differences in biochemistry and physiology of each pathway. Because $C_3$ plants are most adapted to cool growing seasons, native vegetation in our study area of Romania exclusively belongs to the $C_3$ type, and we consider only the fractionation associated with $C_3$ photosynthesis here. In addition, most of the cultivated plants in the region (wheat, barley, oats, etc.) also use $C_3$ photosynthetic pathway, except maize (*Zea mays*) which is a $C_4$ type, having an average $\delta^{13}C$ value of $-12.5 \pm 1.1$‰ (mean ± standard deviation; Cerling et al., 1997). $C_3$ photosynthesis involves a large fractionation (~−18‰) compared to the other pathways, resulting in $C_3$ biomass with $\delta^{13}C$ value of $-26.7 \pm 2.3$‰ (Cerling et al., 1997). Significant variation of the photosynthetic fractionation occurs within the $C_3$ pathway due to differences in water-use efficiency (WUE), light-use, canopy recycling of $CO_2$, and other environmental factors (Lambers et al., 2008a), but $\delta^{13}C$ variations cannot always be attributed to change in WUE (Tang et al., 2014). Intrinsic WUE is influenced by atmospheric $CO_2$ concentration (Silva et al., 2013) as well as environmental variables such as precipitation (Silva and Horwath, 2013).

The chitin of herbivorous insects will have $\delta^{13}C$ values reflecting that of their diet ($C_3$, $C_4$ or CAM), with an additional whole-body $^{13}C$-enrichment of ~1‰ relative to the diet (intra species variation in this $^{13}C$-enrichment can be as high as 2‰; Potapov et al. (2014)).

Furthermore, different mammalian species such as bats feeding on the same diet have similar isotopic relationships between whole-body $\delta^{13}C$ values and their diets (DeNiro and Epstein, 1978). Environmental changes affect insect ecology (reproduction, development, dispersal, mortality, etc.) modifying the insect community and subsequently the diet of insectivorous bats. Ultimately, these processes will reflect broad-scale environmental controls in the $\delta^{13}C$ values of bulk guano. There are also slight seasonal variations in $\delta^{13}C$ values of some insects, but age-related (larval, subadult, and adult stages) changes in isotopic composition may be comparatively small (Potapov et al., 2014). According to Des Marais et al. (1980) animal faeces are usually 0.8‰ enriched in $^{13}C$ relative to their diet.

## 3. Study site

### 3.1. Zidită Cave

A 1.5 m long core was extracted from a bat guano deposit in the Zidită (Walled) Cave (Lat/Long: N46.00746°, E23.12869°), located in Pleşa Mare Hill near Mada Village (Hunedoara County, Romania) in the southern part of the Apuseni Mountains (Fig. 1A, B). The cave is located at 410 m a.s.l. in a small karst area (2.8 × 1.4 km) cut by Geoagiu River through limestone. The river formed the Mada Gorge, which separates Pleşa Mare (712 m) and Dosu (684 m) hills, respectively (Borcoş et al., 1981; Cocean, 1988).

Zidită Cave (hereafter ZC) develops in Late Jurassic limestones (Fig. 1B), has a total length of 547 m, and no water flows along its passages. Shortly beyond the cave entrance (Fig. 1C), a rectangular maze of small, descending phreatic tubes lead to The Great Hall. This room formed at the intersection of passages developed N–S and SE–NW and is partly filled with breakdown blocks. From here, a horizontal large gallery (The Great Passage) oriented SE–NW, connects The Great Hall with the dome-shaped Bat Room (10 × 15 m). Beyond the Bat Room, the main cave passage turns S and continues for 30 m.

The cave fill consists of breakdown blocks, fine detrital sediments and several guano deposits (Fig. 1C). Common calcite speleothems, such as flowstones, stalactites, stalagmites calcite rafts, and gours occur through the cave. Large guano deposits are present in the Great Hall, Bats Room and in the Great Passage (Fig. 1C). The core investigated in this study comes from a guano mound (1.5 m in