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# Scientific advances in geoarchaeology during the last twenty years

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A B S T R A C T

Advances in areas of archaeological science with a strong geological, sedimentological or pedological component have significantly furthered the understanding of formation processes, improved interpretations and helped develop site preservation over the last twenty years. Here, we examine some of those subject areas and their progress, with a view to charting future directions for this growing body of knowledge.



## 1. Introduction

The last twenty years have seen an enormous growth in the use of earth sciences in archaeology. This type of work has become known *de facto* as geoarchaeology, but there has never been a sense of clear boundaries to the subject area, and a broad spectrum of techniques and approaches are often included. We have selected studies from that spectrum in order to point out the innovations and major growth areas – i.e. to showcase the quality of science rather than to follow a defined a subject area. The lack of boundaries, however, means that those choices often approach other subject domains; so some quite sharp cut-offs inevitably appear in relation to other articles in this special issue of *JAS*. To try and organise the diverse selection of research highlights, we have worked under three main headings – Site Formation Processes, Interpretative Studies, and Taphonomy and Preservation.

## 2. Site formation processes

### 2.1. Cave sediment diagenesis

Probably the most comprehensive advance in our understanding of site formation processes over the last two decades has come about in the study of cave sediments. Caves containing mainly clastic sediments have benefitted from considerably improved understanding, and this is expanded on elsewhere (see Hunt et al., 2015). However, a very different type of cave fill has also been the focus of intense study in the past twenty years, particularly involving micromorphology and FTIR spectroscopy. Owing mainly to reduced throughflow of water, some Mediterranean and tropical caves contain a remarkable suite of sediments primarily modified from biological remains and often deeply stratified. These deposits are mainly introduced by humans, livestock and bats, but also include inputs from rockfall and occasional wild animals.

The major constituents are ash, dung, guano and bones. Ash is formed either from open fires, burnt livestock bedding material or burnt dung. It is made up chiefly of calcium carbonate where trees and shrubs have been the source material, and opaline silica where the fuel was derived from grasses. The calcium carbonate component consists of calcite pseudomorphs of the calcium oxalate crystals that are abundant in the trees and herbs (Fig. 1). The origin of this material was first demonstrated by Folk (1973) and later elucidated by Brochier (1983, 1996; Brochier et al., 1992; Brochier and Thinon, 2003). These papers showed details of the thermally-induced calcium oxalate breakdown, followed by calcium carbonate replacement, either directly (at low-temperatures) or by recarbonation from atmospheric $CO_2$ after higher temperature burning. The siliceous component of ash is mostly morphologically unchanged phytoliths or silica skeletons, except where alkaline salts flux the silica and produce ash melts (Folk and Hoops, 1982; Thy et al., 1995; Canti, 2003; for further details of this material see Dynamics and products of fire, below). Original dung can be found unburnt in some situations (Shahack-Gross, 2011; Brochier, 2002), but it is more typically ashed, in which case the stratigraphy will often end up dominated by faecal spherulites. These are tiny (5–20 μm) radially crystallised bodies of calcium carbonate

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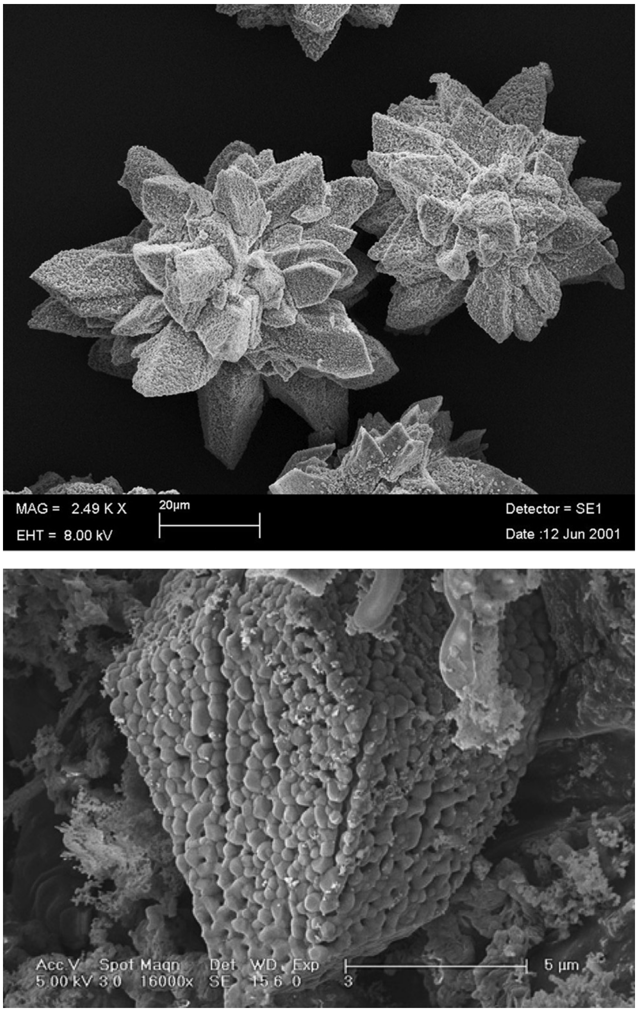


**Fig. 1.** Druse (upper) and prismatic (lower) forms of calcium carbonate pseudomorphs after calcium oxalate. Both these oxalate crystal forms are very common in trees and shrubs throughout the world, and the pseudomorphs form a major component of ash. Photos – upper from Canti (2003) and lower from Shahack-Gross and Ayalon (2013).

formed in the gut of many animals, but especially herbivores. They were discovered and identified by Brochier (1983, 1996) and Brochier et al. (1992), then subsequently studied in detail by Canti (1997, 1998, 1999) and Shahack-Gross et al. (2003). Further details of spherulites appear under Dynamics and products of fire, below.

From a chemical standpoint, both the faecal spherulites and pseudomorphs of oxalate are simply fine-grained calcium carbonate. Since many of the caves are also made of limestone, there is a preponderance of calcium carbonate ready for reaction with other chemical inputs to the system.

These reactions were first examined at et-Tabun cave by Goldberg and Nathan (1975) who noted the formation of dahllite (carbonated Ca phosphate) where solutions containing bone dissolved by uric and humic acids or bat guano come into contact with calcite. Crandallite (Ca, Al phosphate) and montgomeryite (Ca, Mg, Al phosphate) were formed where the calcite was restricted. A similar understanding of bone dissolution was used by Weiner et al. (1993) to develop a model for which parts of the Kebara Cave were likely to have lost their original bone content and which were not. This was based on mapping the mineral phases present in the sediments using portable FTIR, and comparing the results with the bone condition and distribution.

Further examination led to a more detailed understanding the mineral types, including those occurring in similar suites in Theopetra cave (Karkanas et al., 1999) and siliceous residues in Hayonim (Schiegl et al., 1996). A landmark theoretical analysis of the authigenic minerals in caves was produced by Karkanas et al. (2000), showing the reaction cascades produced on the rims of carbonate rock fragments, and the potential they have for determining past conditions. Stiner et al. (2001) showed a good correlation in Hayonim cave between bone weight recovered and intact calcite and dahllite. Areas of poorly preserved wood ash and lower bone content correlated with higher siliceous components, montgomeryite and leucophosphite (K, Fe phosphate). However, the areas of low bone content also contained some individual well preserved bone, explained as the result of bioturbation.

A significant step forward came when Karkanas et al. (2002) demonstrated that the presence of newberyite (hydrated $MgHPO_4$) could be directly related to past guano deposits in Grotte XVI, Dordogne. Newberyite is an in situ transformation product of struvite, (hydrated $NH_4MgPO_4$), which is a primary component of fresh bat guano. Once deposition ceases and ammonia levels produced by the fresh guano drop, the transformation of struvite to newberyite is automatic.

Shahack-Gross et al. (2004) took the examination of bat guano diagenesis to a greater level of detail in six different Israeli caves. They found that insectivorous bat guano is both more acidic and also richer in phosphate than fruit bat guano. Particular diagenetic pathways tend to occur in micro-environments often localised within caves rather than being universal. The locations of these micro-environments are decided by precise factors such as the presence of bat roosts above the sediment, or the exact path of water through it. This means that intimate knowledge of the diagenetic pathways has to be applied individually to determine the completeness of the archaeological record in any given cave. Echoing this point in a discussion of Hayonim cave, Weiner et al. (2002) said "*Although each cave is unique, sufficient knowledge from different caves in diverse environments is now available that shows that many of the underlying processes observed in Hayonim Cave are common to other cave environments.*"

Since the blossoming of FTIR-based cave diagenesis studies in the late 1990s and early 2000s, further minerals have been discovered, particularly the more soluble (and thus rarer) species e.g. gypsum and nitratite ($NaNO_3$) in Cova des Pas on Minorca (Cabanes and Albert, 2011) and Diepkloof Rock shelter, South Africa (Miller et al., 2013). This latter site also contained sveite (a hydrated K, Al nitrate) and nitre ($KNO_3$) as identified by XRD. Research has continued into other important chemical and morphological aspects of cave fills. Efforts to provide a clearer distinction between ash $CaCO_3$ and cave wall limestone first involved the comparison of different calcite peaks produced by infrared analysis where recrystallisation had not occurred (Regev et al., 2010), and later the use of C and O isotopes because of the differences in the original isotopic composition of the plant matter, air and limestone which form the inputs. The study led to the discovery that the ash itself has different isotopic compositions (Shahack-Gross et al., 2008a), arising from the different fractionations associated with high or low temperature transformation of calcium oxalate into calcium carbonate. The isotopic composition of archaeological ash can thus be shown to reflect mixing lines involving the original plant matter, as well as atmospheric and geological inputs (Shahack-Gross and Ayalon, 2013).

The refined understanding of site formation represented by these studies has led to further developments in methodology and interpretation. The mineralogical distinctions were put to use by Mercier et al. (2007) to refine the TL dating of heated flints from the Mousterian layers of Hayonim. A detailed examination was