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Cave clastic sediments as a tool for refining the study of human occupation of prehistoric sites: insights from the cave site of La Cala (Cilento, southern Italy)

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ABSTRACT: La Cala (southern Italy) is an important prehistoric cave site containing a clastic sedimentary infill recording evidence of an almost constant human occupation from the Mousterian to the Copper Age. However, a cultural gap (estimated to be approx. 10.5–6.2 ka) has been identified between the Evolved Gravettian and the Evolved Epigravettian. This study presents a sedimentological and allostratigraphic study of the cave clastic infill. The succession at La Cala can be subdivided into four allostratigraphic units (CC1–4 in stratigraphic order), each one bounded by major erosional surfaces. The most prominent erosional surface (UN1), which separates unit CC1 from CC2, has a channel-like geometry and is directly overlaid by cross-stratified sediments, suggesting deposition in an underground stream setting. This documents an important hydrological change in the cave drainage with the development of an important phase of sediment erosion. The erosional surface UN1 stratigraphically marks the cultural time-gap revealed by the archaeological excavations, suggesting that this hiatus may be due to the erosion of sediments rather than to a lack in human occupation. This study confirms the importance of cave clastic sediments in archaeological cave sites as a helpful tool for refining the timeframe of human presence.

KEYWORDS: allostratigraphy; cave sediments; Epigravettian; geoarchaeology; Gravettian.

Introduction

Cave clastic deposits have been largely investigated in the framework of geologically orientated studies as they often provide valuable information for the reconstruction of geological, geomorphological and climate evolution of karst areas (Bosch and White, 2004; Sasowsky and Mylroie, 2004; White, 2007; Martini, 2011). In addition, clastic successions within caves and shelters are among the most important archives for documenting the dynamics of human settlement in natural sheltered sites. Surprisingly, these sedimentary records are seldom investigated to refine and/or infer the environmental changes that occurred during human occupations, although some works have recently highlighted the novelty and the potential of applying modern sedimentological and stratigraphic approaches to cave clastic deposits (e.g. Brandy and Scott, 1997; Ghinassi *et al.*, 2009; Hunt *et al.*, 2010). This lack of attention to cave clastic sediments is perhaps due to a combination of factors including: (i) the common adoption of classical lithostratigraphic criteria in the investigation of sedimentary successions within caves, preventing the identification of depositional processes; (ii) anthropogenic or animal disturbance, potentially leading to the obliteration of strata and/or sedimentary structures; (iii) the difficulty of adapting existing depositional models for cave clastic sediments to human-perturbed settings; and (iv) the choice of carrying out environmental reconstruction on the basis of other proxies (e.g. stable isotopes, pollen analyses).

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The aim of this study is to test using the study of cave clastic sediments as a tool to refine the occupation timeframe in the prehistoric cave site of 'La Cala' (Marina di Camerota, southern Italy), which is a key site for the reconstruction of the Upper Palaeolithic in central–southern Italy owing to its detailed and almost complete sequence. The Cala series is particularly suitable for our goals in that past studies and excavations have provided an excellent background for a sedimentological-based study while, at the same time, leaving some open questions that can be answered by investigating the cave-fill clastic succession. From a palaeoanthropological standpoint the key nature of La Cala also relies upon the presence of layers (containing the late Mousterian, Uluzzian and Protoaurignacian technocomplexes) encompassing the so-called Middle to Upper Palaeolithic Transition, namely the phase in which the demise of Neandertal populations and their substitution by anatomically modern humans (*Homo sapiens*) took place. This topic is hotly debated in international circles and is considered one of the most important issues in Prehistory.

A sedimentological and stratigraphic analysis has been carried out which allowed us to subdivide the successions into four allostratigraphic units. Stratigraphic and sedimentological data have been combined and discussed in the context of the occupation timeframe as documented by archaeological findings.

Site presentation and cultural background

The cave site of La Cala is located in southern Campania, close to Marina di Camerota on the coast road to the east of this village, at the foot of a hilly to mountainous landscape characterized by short tablelands 250–500 m a.s.l. La Cala is part of a wider prehistoric complex (including other caves and shelters) opening into the Poggio rock spur near the present-day coastline, a few metres above sea level (Fig. 1A, B). The cavity (Fig. 1C) has an elongated profile and comprises two main chambers connected, about half way, by a short bottleneck due to the presence of a large stalagmite (Moroni *et al.*, 2016).

Earliest excavations at La Cala started in 1966 and were undertaken by A. Palma di Cesnola of the University of Siena (1966–1969). Investigations at this site were later resumed by Paolo Gambassini (1974–2004) and Adriana Moroni (2014–still in progress) of the same University (Fig. 1C). Between 1966 and 1969 Palma di Cesnola opened a test trench of about 10 m^2 and roughly 3 m deep in the middle of the cave, reaching the bottom of the continental series represented by a strongly cemented marine deposit. The sequence brought to light by Palma di Cesnola is known as 'internal series' (Palma di Cesnola, 1971, 2001, see Fig. 1C for the location within the cave and Fig. 2 for the stratigraphy). During Gambassini's investigations (excavations 1974–1994) a new trench about 20 m^2 in area was opened near the entrance of the cave (since then onwards known as 'atrium series'. Figs. 1C and 2). In this area a more articulated sequence of Upper Palaeolithic layers was discovered, some of which contain evidence of the Uluzzian (layer 14) and the Protoaurignacian (layers AU10–13) transitional technocomplexes (Benini *et al.*, 1997; Boscato *et al.*, 1997; Moroni *et al.*, 2013).

Further excavations were carried out by Gambassini until 2004 in the Holocene layers of the 'internal series'. These excavations also included the digging of a test trench (about 2 m^2) in the inner room of the cave which gave no evidence of human occupation.

The prehistoric human presence at La Cala encompasses a period of about 50 ka, from the late Middle Palaeolithic to the Copper Age. More specifically the cultural evolution of the local Upper Palaeolithic (from the Uluzzian to the Final Epigravettian, around 40–11 ka) is almost completely documented, except for the period corresponding to the Last Glacial Maximum, namely, in cultural terms, to the Final Gravettian and the Early Epigravettian (gap estimated to be approx. 10.5–6.2 ka and corresponding to the interval between units Q and N-O). The entire archaeological series of La Cala has been ^{14}C dated (Fig. 2; Table 1) (for the original ^{14}C dating results and the relevant applied methodology see Azzi *et al.*, 1973 and Hedges *et al.*, 1998) but most of the dates were performed (on charcoal and burned bones) between 1973 and 1998 (Azzi *et al.*, 1973; Martini, 1978, 1981; Hedges *et al.*, 1998) using now outdated techniques. Nevertheless the results obtained for the upper part of the deposit (layers from the Early Gravettian to the Copper Age) are generally consistent with respect to stratigraphic position and cultural evidence. A series of radiometric determinations concerning the lower part of the Upper Palaeolithic sequence (Uluzzian and Protoaurignacian) (Hedges *et al.*, 1998) are, by

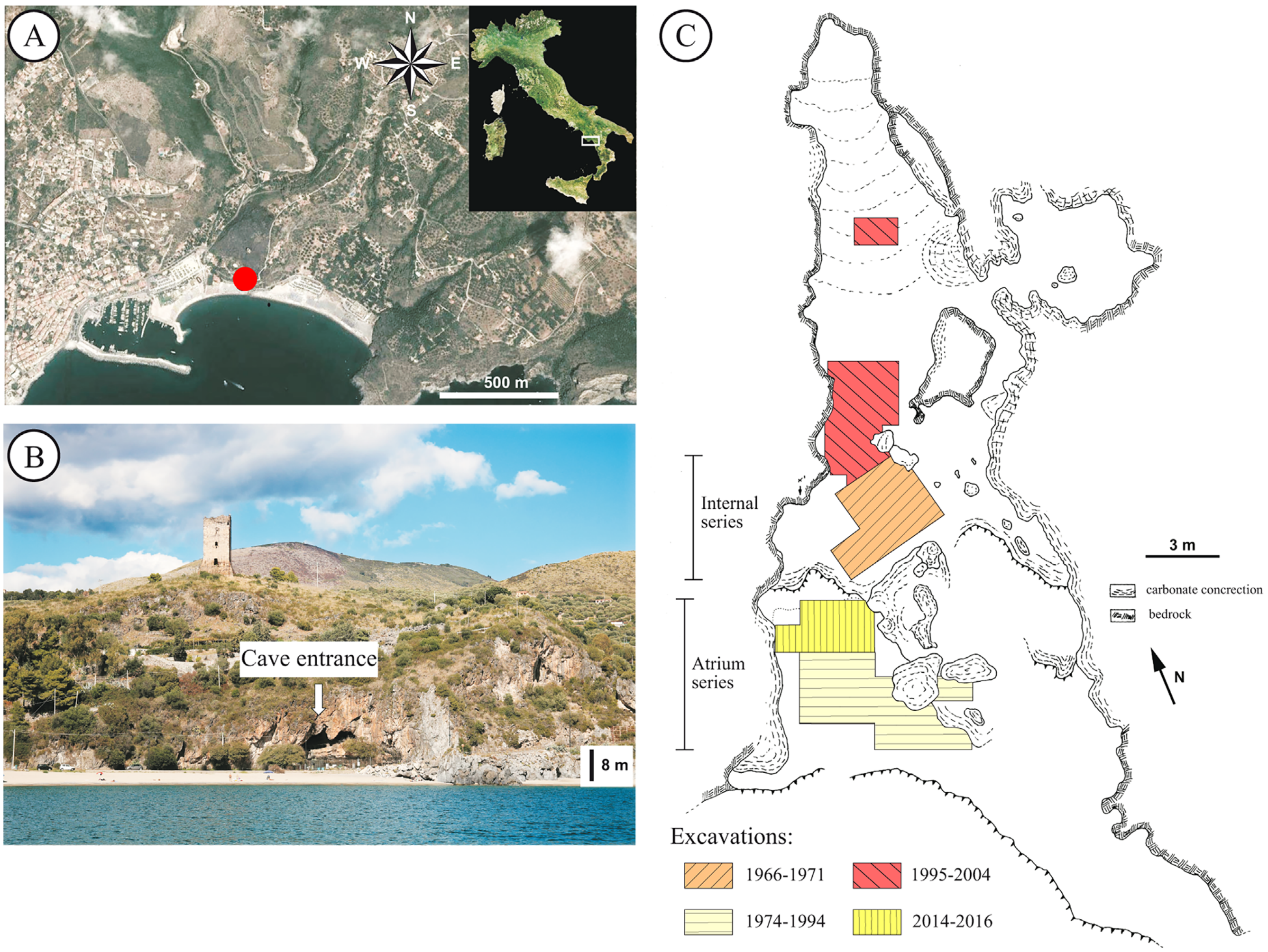

Figure 1. (A) Geographical location of the cave (modified after Moroni *et al.*, 2016). (B) View of the cave from the sea (photo by Stefano Ricci). (C) Planimetry of the cave (modified after Benini *et al.*, 1997) with the excavated areas and the location of the rock exposures investigated in this work.

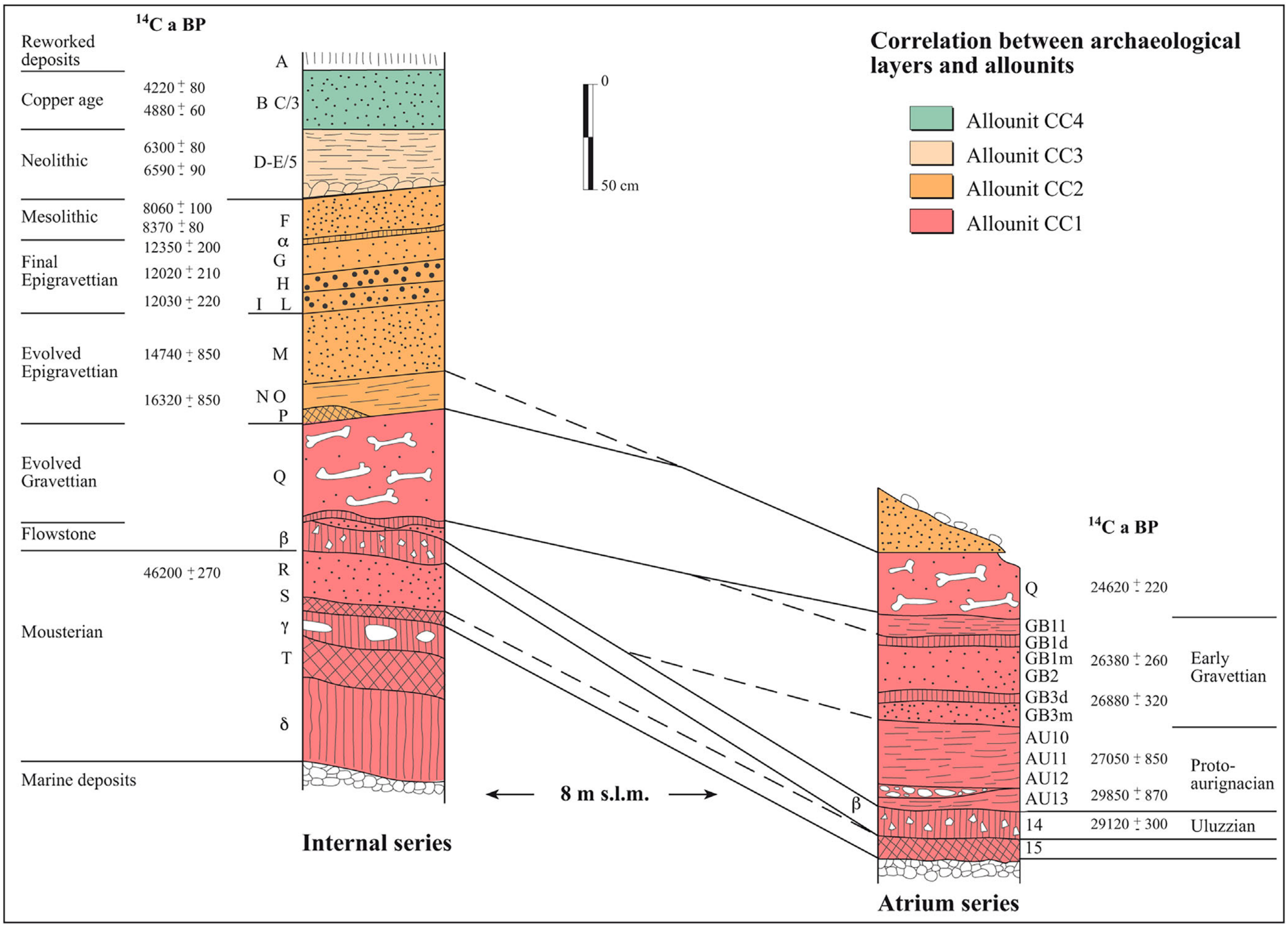

Figure 2. Reference scheme of the internal and atrium series correlating archaeological stratigraphic layers to allostratigraphic units identified in this work (modified from Benini *et al.*, 1997). ^{14}C dates are uncalibrated and are from Benini *et al.* (1997), integrated with data provided by Hedges *et al.* (1998).

contrast, surprisingly unexpected as they are much younger than those commonly accepted for the chronological evolution of the Uluzzian and the Protoaurignacian technocomplexes in southern Italy, whose development is placed before the Campanian Ignimbrite eruption (CI) event dated to approximately 40 ka (Giaccio *et al.*, 2017). A ^{14}C and optically stimulated luminescence re-dating programme of these layers is in progress at Oxford University to obtain a more refined

Table 1. Radiocarbon (after Benini *et al.*, 1997; Hedges *et al.*, 1998) and cultural dating of allostratigraphic units. The dates were calibrated with Oxcal 4.3.2 (Bronk Ramsey, 2010) using the IntCal13 dataset (Reimer *et al.*, 2013).

Allostratigraphic unit	Dated layers	Conventional radiocarbon age (^{14}C a BP)	95.4% probability cal age range (a BP)	Cultural age
CC4	B C/3 (int.)	4220 ± 80	4961–4527	
	B C/3 (int.)	4880 ± 60	5744–5473	Copper Age
CC3	D-E/5 (int.)	6300 ± 80	7419–7010	
	D-E/5 (int.)	6590 ± 90	7620–7317	Neolithic
	F (int.)	8060 ± 100	9263–8636	
	F (int.)	8370 ± 80	9528–9138	Mesolithic
CC2	G (int.)	12 350 ± 200	15 140–13 806	
	H (int.)	12 020 ± 210	14 727–13 433	Final Epigravettian
	IL (int.)	12 030 ± 220	14 793–13 427	
	M (int.)	14 740 ± 850	20 171–15 778	Evolved Epigravettian
	NO (int.)	16 320 ± 850	22 074–17 966	
CC1	Q (atrium)	24 620 ± 220	29 185–28 139	Evolved Gravettian
	GB1m (atrium)	26 380 ± 260	31 069–29 979	Early Gravettian
	GB3d (atrium)	26 880 ± 320	31 405–30 534	
	AU11 (atrium)	27 050 ± 850	33 319–29 517	Proto-Aurignacian
	AU13 (atrium)	29 850 ± 870	35 831–31 893	
	14 (atrium)	29 120 ± 300	33 923–32 548	Uluzzian
	R (int.)	46 200 ± 270	–	Mousterian

radiometric chronological framework based on the use of cutting-edge dating techniques.

In 2014, research at La Cala was resumed (and is still ongoing) with three specific aims: (i) identifying depositional processes according to more recent geoarchaeological perspectives and methodologies; (ii) providing an updated and more reliable chronological framework, especially for the Upper Palaeolithic series; and (iii) investigating the late Mousterian, Uluzzian and Protoaurignacian technocomplexes in light of recent scientific achievements on the Middle to Upper Palaeolithic transition in Europe. This third objective comprises the revision of all past and present-day findings from La Cala using modern methodologies (Oxilia *et al.*, 2015; Arrighi *et al.*, 2016; Duches *et al.*, 2016). To date, although a significant part of the anthropogenic deposit has already been excavated, more than the half of the cave infill, on the eastern part of the cavity, is still uninvestigated and could therefore contain evidence for further cultural phases. All the excavated layers yielded numerous lithics, faunal remains and ornaments, as well as some mobile art objects and several hearth features.

Geological setting

The host rock of the cave is a dolomitic limestone deposited in marine settings in the late Triassic–early Jurassic (Aronne *et al.*, 2014). Karst processes acted mainly along a line of weakness (i.e. a joint) that crosses the vault of the cavity. The cave entrance leads into the first chamber (Fig. 1C), in which most of the past and present excavations have been carried out. The cave is currently dry, but inactive dripwater speleothems are present at several places and especially in the interior part of the cavity.

Clastic sedimentation within the cave starts with marine conglomerate and conglomeratic sandstone, whose deposition is generally attributed to Marine Isotope Stage (MIS) 5e (Esposito *et al.*, 2003; Gambassini, 2003; Moroni *et al.*, 2016), even if an older age for the basal marine deposits cannot be excluded with the available data. Above marine sediments, clastic cave sediments containing archaeological materials occur and they constitute almost the entire present-day floor of the cavity.

This paper focuses on these deposits and a more detailed description is given in the following paragraphs.

Methods and terminology

This study has been carried out with bed-by-bed sedimentological logging and architecture line-drawings of two sections excellently exposed as a result of archaeological excavations (i.e. the internal and the atrium series). The sedimentological analysis is based on the facies association concept. Facies associations consist of assemblages of spatially and genetically related facies that are the expression of different sedimentary environments (Walker and James, 1992). The descriptive sedimentological terminology used is from Harms *et al.* (1975, 1982) and Collinson *et al.* (2006). The terms 'autochthonous' and 'allochthonous' are used following Iacoviello and Martini (2012, 2013). Autochthonous is used to indicate sediments derived within the cave and possibly moved inside the same cavity (e.g. collapsed blocks). Allochthonous is used to indicate sediments transported into the cave (e.g. alluvial gravel).

Stratigraphic analysis was performed according to allostratigraphic concepts (NACSN, 2005). Among the several discontinuity surfaces usable for defining allounits (Walker, 1990; Bhattacharya and Walker, 1991), unconformities were chosen as bounding surfaces of alloformations because they are readily recognizable and laterally traceable.

Sedimentology and facies analysis

The application of a facies model to the deposits of the cave site of La Cala is not easy because intense human activity has greatly altered the original sedimentary features. Human activity is an important cause of post-depositional alteration, as human trampling and digging usually disturb and obliterate the primary structure of both fine- and coarse-grained deposits (Karkanas *et al.*, 2007). Some beds can also represent episodes during which deposition was not controlled by natural processes, but rather by the phenomena of human accumulation of archeological remains (e.g. bones and lithics) and other materials (i.e. 'anthropogenic deposits' *sensu* Lafferty *et al.*, 2006). In addition, cave deposits may also be affected by several post-depositional alteration processes, which can obliterate the primary depositional processes. The most important of these is the interstitial infiltration of fine sediment particles by percolating waters (Mandel and Simmons, 1997; Woodward and Goldberg, 2001; Karkanas *et al.*, 2007), where fine sediments derive from superficial soils and are introduced into karst systems by percolation and infiltration processes. On the basis of these considerations, the investigated deposits have been subdivided into five facies associations.

Anthropogenic deposits (AN)

These deposits consist of a poorly sorted mixture of sand and granules, containing abundant bones, stone tools, continental and marine molluscs, abundant charcoal detritus and uncommon rounded to sub-rounded pebbles (Fig. 3A,B). A crude layering is commonly observed, although the layers are lacking in internal stratification or grain-size grading. Isolated and angular blocks made of the same limestone forming the cave vault occur locally.

The features of these deposits and the large amount of bones and archaeological material indicates that they accumulated during phases in which deposition was not controlled by natural processes, but was dominated by human activity (i.e. 'anthropogenic deposits' *sensu* Lafferty *et al.*, 2006). In these contexts, the origin of isolated blocks of limestone was due to the occasional fall of blocks from the cave vault (cf. Ghinassi *et al.*, 2009; Martini, 2011).

Channel-fill deposits (CH)

These deposits consist of lenticular bodies of gravelly sandstone (allochthonous sediments), up to 20 cm thick and 1–2 m wide, characterized by an erosional concave-upward base and a flat top (Fig. 3C). Internally, these deposits show a fining-upward trend and a weak low-angle cross lamination, highlighted by stringers of granules and/or small pebbles.

The lens-shaped geometry, the erosional base and the sedimentological feature of this facies indicate deposition in a stream channel-like setting, in which these sediments are the expression of an active tractional infill (Ghinassi *et al.*, 2009). The low depth/width ratio of the palaeochannels and the fine grain size of facies CH indicate a poorly confined stream flow (cf. Ghinassi *et al.*, 2009).

Rockfall deposits (RD)

These deposits are expressed by centimetres- to decimetre-thick beds of clast-supported and unsorted pebble to boulder gravels (Fig. 4A), composed almost exclusively by angular

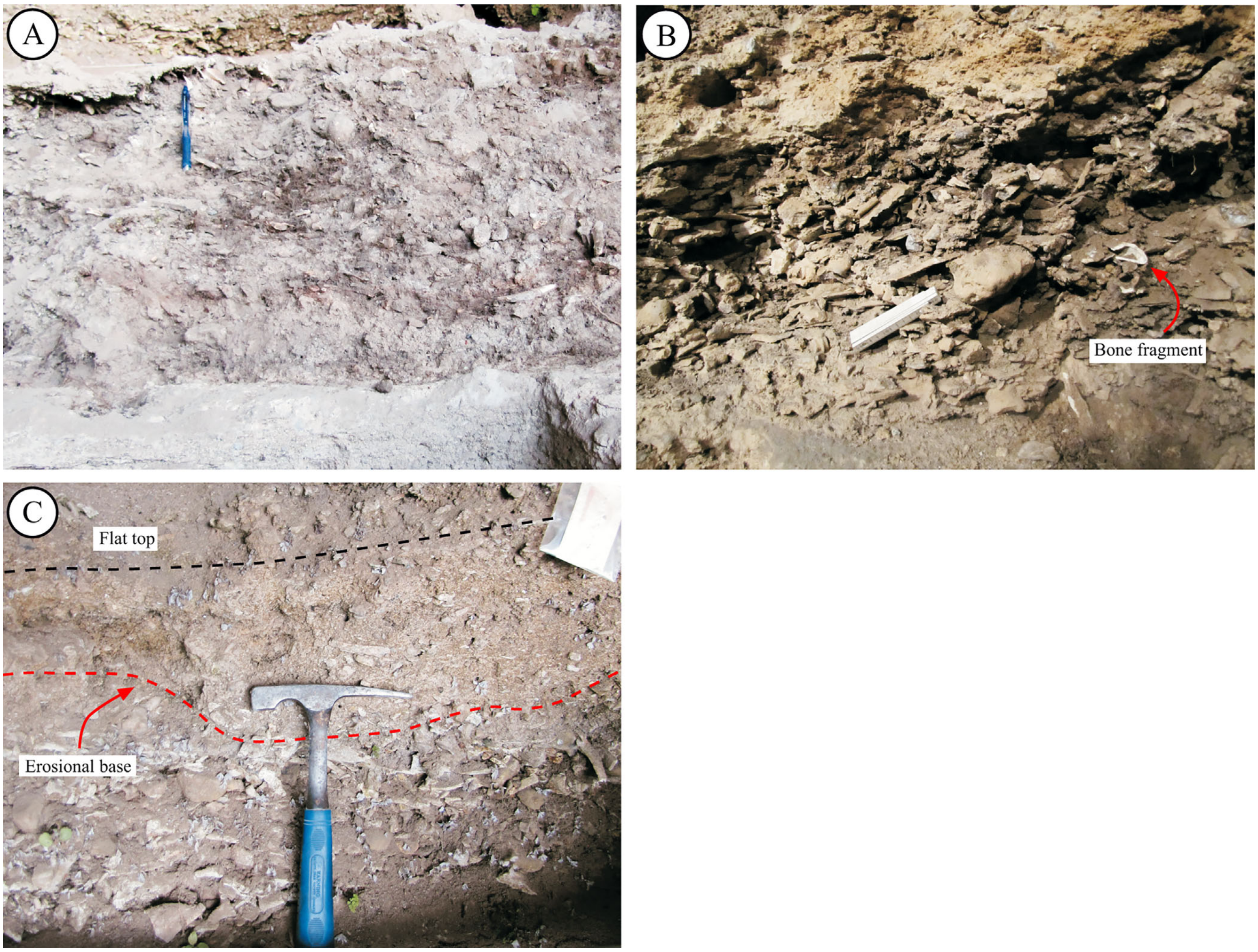

Figure 3. (A) Anthropogenic deposits (AN) expressed by a disorganized mixture of bones, rounded and angular clasts and infiltrated fine-grained sediments. Darker layers include abundant charcoal remains, at places so concentrated as to indicate *in situ* fireplaces. (B) Openwork (i.e. matrix-free) anthropogenic deposits (AN). Stick for scale is 10 cm long. (C) Channel-fill deposits (CH) erosionally overlying anthropogenic deposits.

debris whose surfaces are either slightly, or not at all, weathered. The debris consists exclusively of the limestone that forms the cave vault. Beds of facies BD are commonly openwork (i.e. without interstitial matrix) even if sometimes the primary openwork texture is obliterated by a secondary, infiltrated silty–sandy matrix (Fig. 4A). Scattered boulders of this facies are also present within beds of other facies associations (Fig. 4B).

The sedimentological features of these deposits indicate deposition by rockfall processes from the ceiling of the cave (cf. Blikra and Nemec, 1998; Nemec and Kazanci, 1999; Fornós *et al.*, 2009; Ghinassi *et al.*, 2009; Martini *et al.*, 2014). These processes are widely recognized in cave settings, especially during the air-filled and vadose stages of cave life (Hill, 1999), until forming a thick sedimentary succession commonly referred to by the term ‘breakdown deposits’ (cf. White, 2007, and references therein). These types of deposits are considered autochthonous sediments, even if secondarily infiltrated silty and sandy matrix commonly has an allochthonous origin.

Fine-grained infiltrated deposits (FO)

These deposits consist of sandy silt, sometimes containing scattered granules and small pebbles, forming tabular beds up to 50 cm thick (Fig. 4C). FO deposits are generally structureless or more rarely wake plane-parallel laminated.

These features suggest deposition due to infiltration processes, where fine-grained materials derived from surficial soils infiltrate through fractures and/or joints into the caves where they settle and accumulate (Bosch and White, 2004; Iacoviello and Martini, 2012). As a consequence, these beds are deposited during stages characterized by low supply of coarse-grained sediment.

Flowstone (FD)

These deposits consist of centimetre-thick sheet-like beds of calcium carbonate (calcite) in places containing siliciclastic materials (such as granules, small clasts and debris, Fig. 4D). Flowstone beds are interbedded with clastic deposits and show a pervasive plane-parallel lamination that drapes intervening siliciclastic clasts. The two thickest flowstone beds of the succession have been named in the past as ‘Alpha’ (α) and ‘Beta’ (β) (Fig. 2) and they are key beds for stratigraphic correlations in the internal series (Fig. 5A,B).

These features indicate that these beds formed via the degassing of vadose and carbonate-rich percolation waters, until forming almost continuous calcite drapes and layers commonly referred to by the term ‘flowstone’ (Dreybrodt, 1980; Frisia *et al.*, 2000). The low content of siliciclastic particles within flowstone beds indicates that deposition occurred during stages of limited siliciclastic sediment input (Martini and Capezzuoli, 2014).

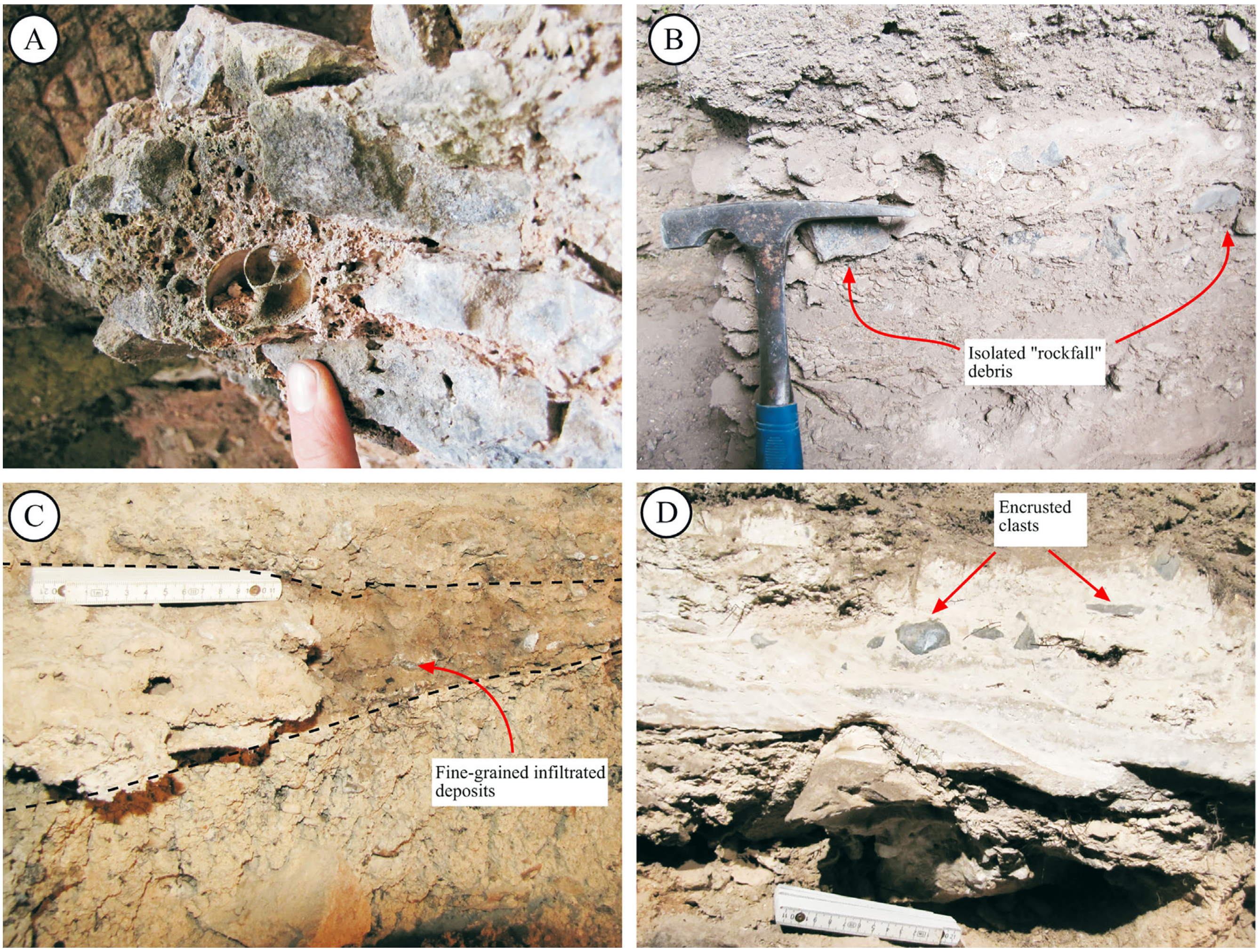

Figure 4. (A) Angular clasts and debris that typifies rockfall deposits (RD). Matrix is composed of coarse-grained sand, at places including remains of gastropods. (B) Isolated angular clasts of RD facies association dispersed within other sediments. (C) Silty sediments of the fine-grained infiltrated deposits (FO). Stick for scale is 10 cm long. (D) Flowstone deposits (FD), containing encrusted clasts. Stick for scale is 10 cm long.

Stratigraphic analysis

The sedimentary succession exposed at La Cala has been divided into four allostratigraphic units (labelled CC1 to CC4 in stratigraphic order). The geological interpretations of the bounding unconformities and the depositional history recorded by each allounit are addressed below, while radiocarbon and cultural dating of each allounit is reported in Table 1.

Allostratigraphic unit CC1

This unit is well exposed in both sections investigated (Figs 5A and 6A) and its thickness is about 1.6 m in the internal series and 1.8 m in the atrium series. The lower boundary corresponds to the beginning of cave sedimentation above marine deposits, while the upper boundary corresponds to an erosional surface (hereafter UN1) the significance of which will be further discussed in below. The surface UN1 is expressed by a high-relief erosional surface (Figs 5A–C and 6A) that, in the atrium sections, marks the base of a channellized body that is a few metres wide and 30–40 cm thick (Fig. 6A).

Allounit CC1 consists predominantly of anthropogenic (AN), flowstone (FD) and rockfall (RD) deposits, while channel-fill deposits are limited to a single and thin bed (up to 5 cm thick and 1 m wide). The attitude of beds is towards S-SW (i.e. towards the entrance of the cave), with an inclination ranging between 16 and 20° in the interior part of the cave and between 2 and 5° in the atrium.

Allostratigraphic unit CC2

Deposits of this unit overlie those of CC1 above a sharp erosional boundary, *i.e.* the aforementioned UN1, that defines a channelized feature over which channel-fill deposits (CH) occur (Figs 5A,B,C and 6A,B). The upper boundary of the unit corresponds to another important erosional surface (hereafter UN2). The unit is of variable thickness, ranging from 1.2 m (internal series) to 1.6 m (atrium series).

Unit CC2 consists invariantly of channel-fill deposits (CH, coincident with the archaeological layer ‘P’) at the base, passing upward to anthropogenic (AN) and rockfall (RF) deposits with subordinated flowstone layers (FD). The attitude of beds of the AN and RF deposits is towards W-SW (i.e. towards the cave wall), with an inclination ranging between 10 and 14° in the interior part of the cave (Fig. 5A,B) and between 20 and 30° in the atrium (Fig. 6A,B).

Noteworthy is that the larger speleothems of the cave (i.e. stalagmites and columns) grow above the basal erosional surface of allounit CC2, or above the channel-fill deposit resting above this surface. Overlying deposits of allounits CC2 to CC4 onlap these vertical speleothems (i.e. accumulated around the standing flowstone).

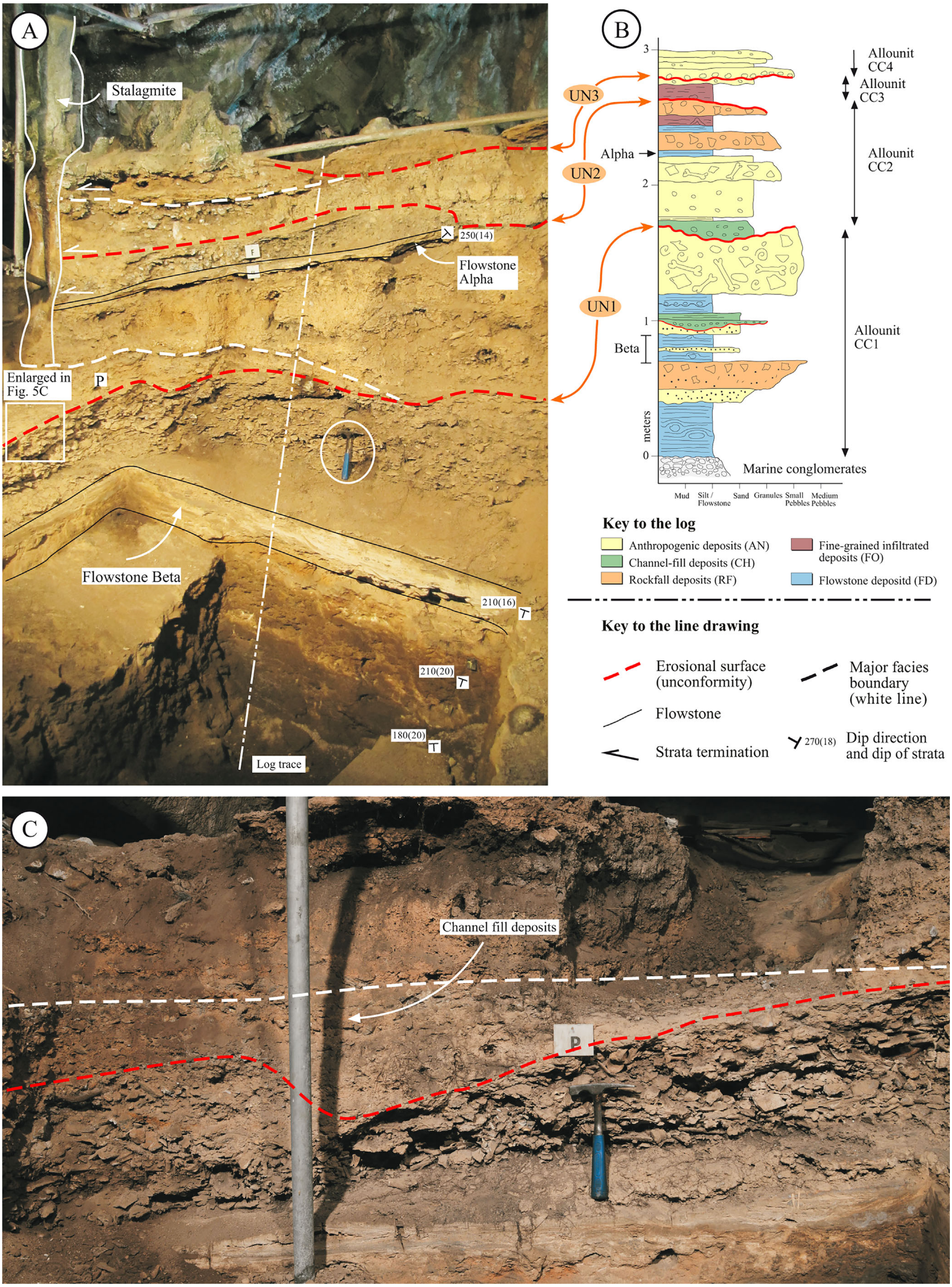

Figure 5. (A) Panoramic view of the Internal series. Hammer for scale is about 28 cm long, and the entire succession is about 3 m thick. (B) Sedimentary log of the clastic succession exposed in A, with reported major erosional surfaces corresponding to the boundaries of allounits. (C) Close-up view of the channel-fill deposits (CH) corresponding to the archaeological layer P in the Internal series.

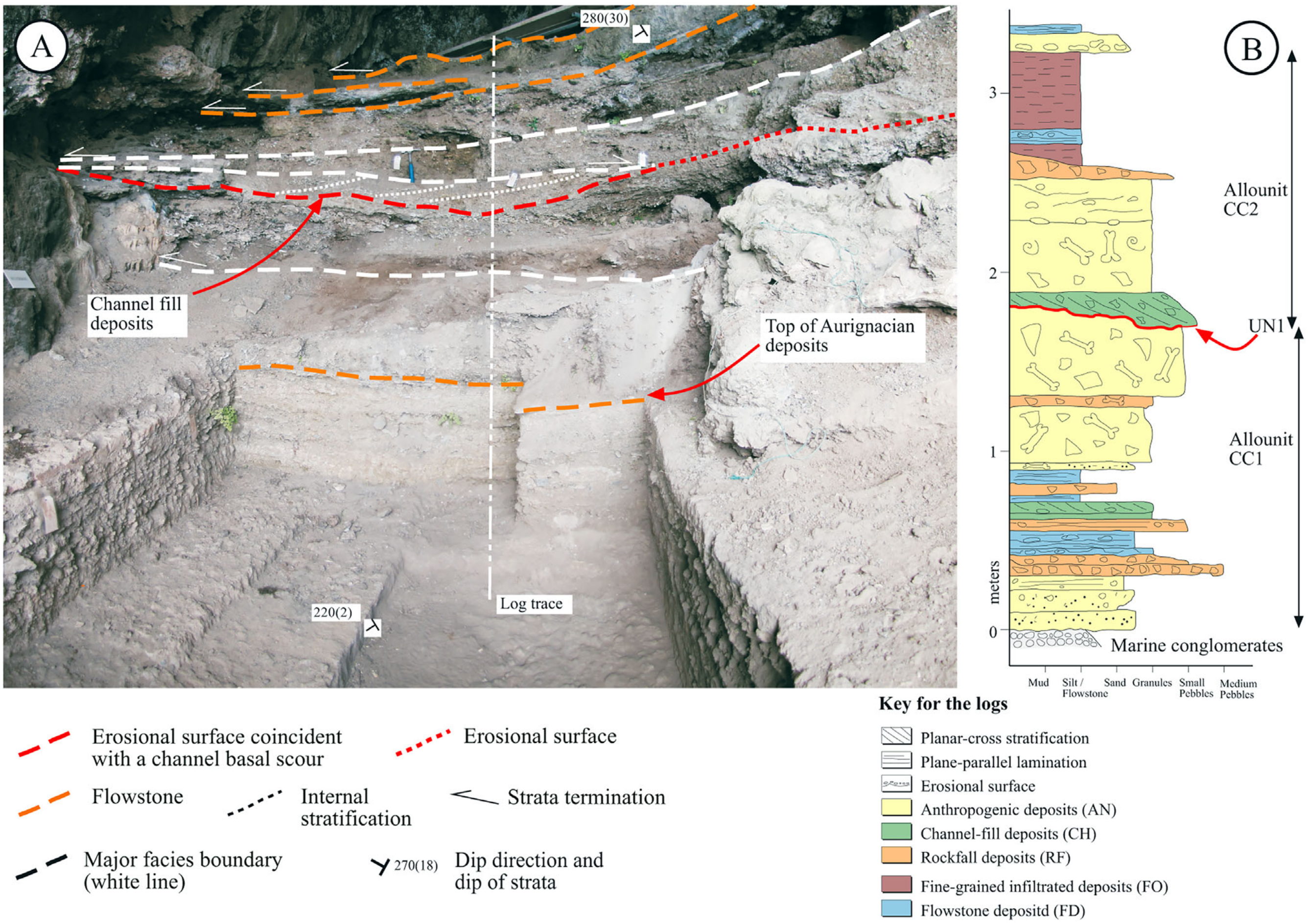

Figure 6. (A) Panoramic view of the Atrium series. Hammer for scale is about 28 cm long, and the exposed succession is about 3.5 m thick. (B) Sedimentary log of the clastic succession exposed in A, with reported major erosional surfaces corresponding to the boundaries of the allounits.

Allostratigraphic unit CC3

The lower boundary of unit CC3 corresponds to the surface UN2, while the upper boundary corresponds to a gently scoured erosional surface (UN3). Deposits of this unit are exposed only in the internal series and display limited thicknesses, of the order of 10–40 cm. Unit CC3 consists almost entirely of fine-grained infiltrated deposits (FO), with subordinate rockfall (RF) and flowstone (FD) deposits.

Allostratigraphic unit CC4

Unit CC4 is bounded by surface UN3 at the base and by the present-day floor of the cave at its top. Deposits of this unit dominantly consist of anthropogenic deposits (AN), with subordinate flowstone layers (FD). The unit ranges between 10 and 15 cm thick in the internal series, but is missing in the atrium.

Discussion

In the more than 3-m-thick stratigraphic sequence of La Cala, human presence appears to be generally constant from the late Mousterian to the Copper Age (Fig. 2). Nevertheless, a gap in the cultural sequence is detectable between the anthropogenic deposits of layer Q and the overlying channel-fill deposits of layer P (Figs 5,2A,B and 6A,B, Table 1). According to the cultural sequence and the ^{14}C results this hiatus corresponds to a time interval of about 10.5–6.2 ka [i.e. the interval between 24 620 ± 220 ^{14}C a BP of layer Q and 16 320 ± 850 ^{14}C a BP of layer N, coinciding with the Last Glacial Maximum (LGM)]. There are several possibilities that can explain this pattern: (i) a period in which the cave was abandoned by humans; (ii) sediments deposited in the Late Gravettian–Early Epigravettian time-span were eroded; and (iii) lack of deposition and no production of anthropogenic deposits.

Understanding which hypothesis is the most plausible is nearly impossible by adopting classical lithostratigraphic criteria, as no dramatic sedimentological changes are recorded between strata just below and above the break in the succession (cf. Sala, 1983). Further complications in the study of this succession are due to the severe human-induced disturbance of sediments that, at places, led to the complete obliteration of the original sedimentological features. As a consequence, sediments only occasionally provide helpful elements for reconstructing the evolutionary history of the cave. In this regard, more information has been provided by the allostratigraphic approach to the cave succession.

The data highlight that at least three important erosional surfaces developed during deposition of the cave succession and that these define four allostratigraphic units (Figs 5B and 6B). Erosional surfaces in cave environments are typically connected to the restoration of stream flows (Ghinassi *et al.*, 2009; Martini, 2011; Zhornyak *et al.*, 2011). Hydrological changes in cave drainage usually occur because of variations in the general availability of rainwater (i.e. directly controlled by regional climate), even if the underground runoff can also be influenced by local factors (e.g. cave-vault collapse). In caves with an entrance located close to the shoreline, such erosional surfaces could also originate by the action of waves during major storm events, eroding previously deposited sediments (Waterstrat *et al.*, 2010). However, at La Cala, the occurrence of channelized and cross-stratified deposits indicates that erosional surfaces were generated by water flows instead of marine waves.

The most important surface, in terms of lateral and vertical extension, is UN1 that displays a classical channelized shape and defines the base of archaeological layer P. Moreover, sedimentological features of layer P indicate channel-fill deposition. These data highlight the instauration of runoff settings within the cave (with the associated possibility of occasional flood events), but which did not prevent humans from living in the cave, as corroborated by the occurrence of archaeological findings (including an undisturbed hearth) within archaeological layer P (Palma di Cesnola, 1978). The change in cave environment is also confirmed by the stalagmites that grow over surface UN1 and layer P, because speleothem formation is likely to have taken place during the warm/humid phases when permanent rainwater guaranteed constant dripwater from the cave ceiling.

The erosional event associated with the origin of surface UN1 also triggered an important change in stratigraphic patterns and dip attitude of the cave sediments. Beds of allounit CC1 are inclined towards the cave entrance, suggesting that they form a cone with an *apex* in the interior part of the cave and the distal part close to the cave entrance. Conversely, the dip of beds of allounits CC2–4 is mainly towards the west wall and at places towards the north, *i.e.* towards the interior part of the cave. This is because the development of a stream channel close to the west wall (coincident with surface UN1) modified the cave physiography, which in turn greatly influenced sedimentation. Indeed, erosional surface UN1 mainly eroded CC1 deposits close to the west wall (Fig. 1C), producing a 'depressed area' in the western sector of the cave where the space available for the following sediment accumulation (i.e. accommodation space) is greater compared with other zones of the cave. This influenced the depositional patterns of beds of allounits CC2–4, as well documented in the atrium series, where beds display marked changes in thickness (i.e. thinner in the eastern part and thicker in the western part; Fig. 6A,B) and in the angle of dip (higher in the stratigraphically lower beds and lower in the upper beds) that document the progressive infilling of the depression.

This sedimentological and stratigraphic evidence suggests that surface UN1 marked an important erosional phase connected with the restoration of a stream within the cave. Although it is not possible to estimate the amount of sediment eroded, nor understand the time-interval when the stream was active, the evidence as a whole allows us to consider that the apparent gap in the human presence could be due to the erosion of sediments deposited during the Late Gravettian and Early Epigravettian. According to this model traces of Late Gravettian and/or Early Epigravettian occupations could perhaps be preserved in the undisturbed eastern part of the cave, which has not yet been excavated.

Conclusions

The sedimentological and allostratigraphic study of the clastic succession of the cave site of La Cala enabled us to identify a wide range of sedimentary facies forming a sedimentary succession more than 3 m thick. This succession can be subdivided into four allostratigraphic units (CC1–4 in stratigraphic order), each one bounded at its base and top by major erosional surfaces (UN1–3). The most important of these surfaces (UN1) has a channelized shape and coincides with an apparent hiatus in human occupation of about 10.5–6.2 ka, as testified by our archaeological investigations. Sedimentological features of sediments immediately above surface UN1 (archaeological layer P) indicate that deposition occurred in an underground stream setting. Major stalagmites grew directly above surface UN1 and sediments of level P, while younger sediments onlap these speleothems.

This sedimentological and stratigraphic evidence provides helpful data to understand the reasons for the apparent gap in human occupation within the cave in the interval corresponding to the Late Gravettian–Early Epigravettian. Sedimentological and stratigraphic data indicate a marked increase in the intensity of water runoff in the cave (probably associated with a period of increased rainwater) during the period in which surface UN1 was generated and sediments of layer P as well as the main speleothems were deposited. This caused a strong erosion of the previously deposited sediments, with the subsequent removal from the cave environment of sediments and of possibly associated archaeological remains. As a consequence, the archaeological and chronological gap identified from excavations carried out so far can be realistically connected to the above described erosional processes, although other reasons cannot be excluded, at least until investigations are carried out in the *in situ* deposits located in the eastern part of the cave. In fact, the severe climatic conditions of the LGM may have led to a general contraction of the Final Gravettian and Early Epigravettian human groups over Italy as a whole, seemingly marked by the depopulation of entire regions as emphasized by the paucity of archaeological records even in areas considered possible refugia (Palma di Cesnola, 2001). However, the erosional processes associated with climate change at the end of the LGM may be an important confounding factor, a sort of 'background noise', as they could have obliterated part of the archeological evidence, partially altering the data and over-emphasizing the depopulation phenomenon. Restoration of an underground stream and the presence of continuous percolating waters made the cave less hospitable to human settlement at the onset of the Evolved Epigravettian occupation, but not sufficiently to prevent Palaeolithic people from inhabiting the cave as indicated by the findings in layer P.

This study confirms that cave-fill deposits may be used as an important tool for refining the timeframe of human presence in caves. Moreover, the combination of sedimentological and allostratigraphic investigations can provide helpful data in deposits that have been strongly homogenized due to human activity.

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