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Increasing contextual information by merging existing archaeological data with state of the art laser scanning in the prehistoric funerary deposit of Pastora Cave, Eastern Spain

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ABSTRACT

In this paper we present a virtual reconstruction of prehistoric funerary practices in Pastora Cave, a collective burial site in Eastern Spain that dates from the Late Neolithic, Chalcolithic and Bronze Age. Modern data of the cave was captured by 3D laser scanning techniques and added to recorded archaeological data and 3D graphic information. The combination of these data sets allowed us to create a hypothetical reconstruction to analyze the material excavated in the 1940s and 50s in greater spatial context. A 3D model of the current cave was created in order to serve as a basis for modeling the relative stratigraphic information available. We present the methodology employed and the results and implications of the analysis for Pastora Cave with particular emphasis on the spatial and chronological data.

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1. Introduction

Recent developments in 3D laser scanning techniques provide a tool to better understand chronological contexts in archaeological sites (Rüther et al., 2009). In this paper we present a virtual reconstruction of prehistoric funerary episodes in Pastora Cave, a collective burial site in Eastern Spain that dates from the Late Neolithic, Chalcolithic and Bronze Age. Pastora Cave has long been regarded as a typical example of collective burials in the region (McClure et al., 2010, 2011; Soler, 2002) and is one of many known mortuary cave deposits. Most of these burial caves, however, were excavated in the early 20th Century AD and share problems of old excavation techniques and documentation. In particular, they often lack detailed contextual information of the finds.

To address these issues of context, we generated a virtual image of what the ancient cave may have looked like by recreating the stratigraphy and representing it in a 3D virtual environment. In

order to do this, modern data of the cave captured by 3D laser scanning techniques was added to recorded archaeological data and 3D graphic information. The combination of these data sets allowed us to create a hypothetical reconstruction to analyze the material excavated in the 1940s and 50s in greater spatial context. This endeavor also highlights the possibilities of recovering accurate plans, sections and isolines from the 3D real mesh of the cave. In the following we present the methodology employed and the results and implications of the analysis for Pastora Cave with particular emphasis on the spatial and chronological data.

2. La Cova de la Pastora

La Cova de la Pastora (Alcoi, Alicante) or Pastora Cave is part of a larger phenomenon that begins from the Late Neolithic onwards (mid IVth millennium cal BC) in Eastern Spain. During this period, collective burials were placed in natural caves. This is a characteristic of the central Mediterranean area of the Iberian Peninsula where the megalithic monuments of the Atlantic facade are absent. The funerary use of caves continues in this region during the Chalcolithic and into the Bronze Age. Approximately 130 caves with collective burials are known from the Valencian region on the

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Mediterranean coast of Spain (Soler, 2002, Fig. 1). Unfortunately, a large part of these sites were excavated in the first half of the 20th century and, as a result, they generally suffer from poor stratigraphic resolution and chronological control.

Pastora Cave is a primary example of this issue. The site is located approximately two miles from Alcoi, a small town in the province of Alicante (Spain). Remains of approximately 59 individuals were discovered in the cave as well as burial objects (McClure et al., 2011). Grave goods include stone tools of local (arrow points) or extra-local production (large blades of flint), personal ornaments of a variety of provenances (lignite, shell, variscite, ivory), worked bone, polished stone tools and pottery (García Puchol et al., 2012). Most of the finds are curated at the Museum of Prehistory in Valencia.

In 2008 we began to analyze this interesting deposit in order to characterize funerary practices and investigate their relationship to the emergence of social inequality on the Iberian Peninsula. As a result we started an integrative program that included systematic fieldwork and analyses, as well as archaeometry studies that have

provided an accurate chronocultural dataset of the burial context (McClure et al., 2010, 2011).

3. Former excavation data

The first reference to the archaeological work in Pastora Cave was published in 1945 by Isidro Ballester, who at the time was the director of the Museum of Prehistory in Valencia. In his paper, Ballester presented the results of the fieldwork carried out by Vicente Pascual and José Alcacer (Ballester Tormo, 1945, 1949).

In 1940 Pascual began the excavation of northern part of the cave, the area with the greatest density of archaeological material. He unearthed impressive quantities of human remains (a minimum of 46 crania) and associated objects interpreted as grave goods (Ballester Tormo, 1945). Pascual, who was not formally trained as an archaeologist, adopted self-studied research methods and recorded all his information in a personal diary. Unfortunately, he started writing these notes sometime after the excavation. As a consequence, the surviving data is certainly incomplete compared to the amount of data he would have reported daily during fieldwork.

Pascual's handwritten diary is an important historic document. It includes information such as excavation plans and the features and position of archaeological remains. He described four main cultural levels from the top to the bottom in a sequence that surpassed 2 m of vertical deposits. The three first levels correspond with several funerary phases of Late Neolithic, Chalcolithic, and finally, Bronze Age. He observed a final level on the top that included several pots and metal objects (including Roman coins) that indicate the use of the cave for ritual practices during the Iron and Roman Age.

Regarding the funerary deposits, Pascual notes three distinct contexts and illustrates the position of crania and other materials (human postcranial bones, faunal remains and objects), often as 'packages'. Pascual marked the location of these items in individual level plans, usually with three coordinates (a depth measurement from the original surface of the cave, as well as X and Y measurements from a marked datum). The "packages" are simple groups of items that he found during excavation in relation with the crania. He numbered some skulls according to when they were discovered and he marked other objects with symbols on the diary to code the type of find. An example is shown in Fig. 2. The circles, numbered and drawn on the plan in Roman numerals, identify the groups of finds together with their depth in the stratigraphy, whereas just below the plan is the symbol legend that depicts the specific items.

In 1945 and 1950, José Alcacer, curator of Museum of Prehistory of Valencia, finished the archaeological excavation inside the cave. In his two short seasons of excavation, he only recovered 6 more crania and other artifacts. In addition, Alcacer and his group of workers screened the backdirt created by Pascual and collected a greater range of artifacts, substantially increasing the assemblage but without clear stratigraphic contexts. It is clear from the diaries that the bulk of the deposit was excavated by Pascual in the summer of 1940.

More than 50 years later we began new fieldwork at the site (García Puchol and McClure, 2008). The main goal was to obtain new data for understanding the sequence, building on the old excavation reports, diaries, and assemblages. This work consisted of locating and analyzing assemblages in museums as well as assessing the integrity and contextual information of these finds through excavation of different areas inside and outside of the cave (Figs. 3 and 4). A close study of the diaries highlighted some incongruities with the assemblages in the museums. For example, the diaries list substantial numbers of postcranial human remains and animal bones, yet few of these were in the museum collections.

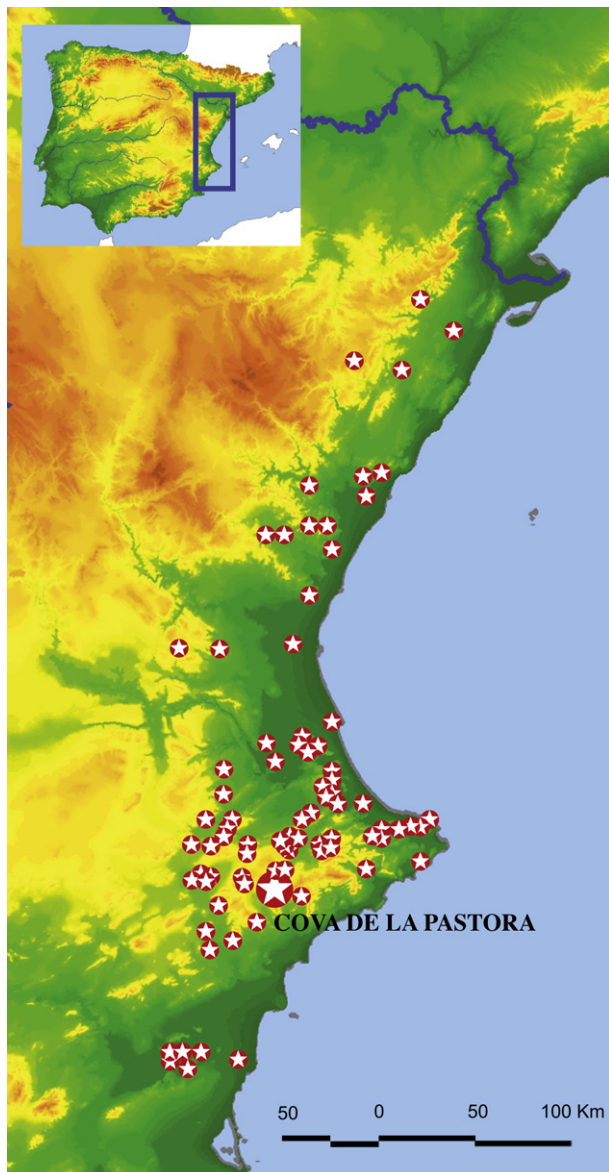


Fig. 1. Location of Pastora Cave and other funerary caves in the region of Valencia, Spain.

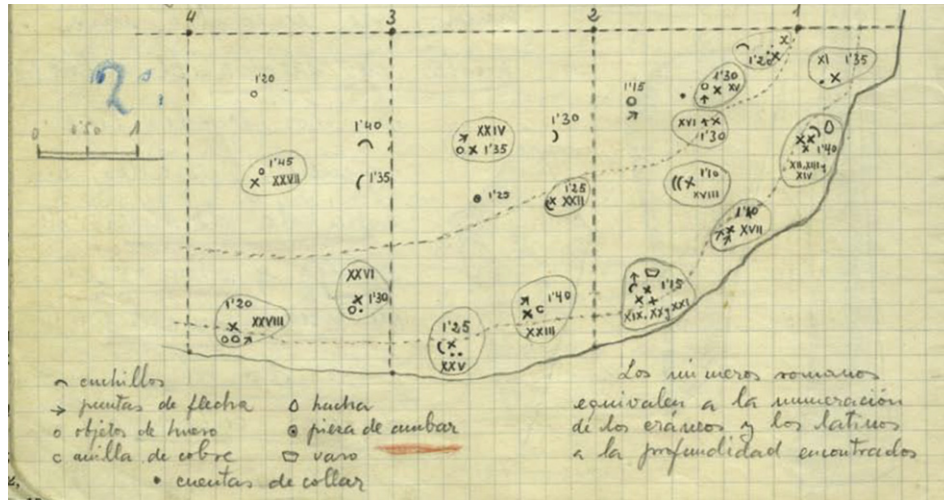


Fig. 2. Page of Pascual's diary showing the plan of a stratigraphic unit with the location of the finds.

Similarly, the diaries are heavily biased toward the funerary deposits and only briefly mention the Bronze Age and Iron Age pottery that were plentiful in the museums' holdings.

The inconsistencies in the diaries and museum collections highlighted the need to return to the cave to investigate the state of preservation, search for intact deposits, and assess the contexts of the materials housed in the museum. Several units were placed in the interior of the cave, one at the entrance, and others in the exterior surroundings. Small soundings inside the cave confirmed that the excavators had indeed captured all of the cultural deposits and only ephemeral remains of archaeological sediments and objects were found in nooks and crannies of the cave wall. In the entrance we excavated a 3 m² unit that contained intact levels from the Iron Age and possibly few remains of the last prehistoric use in

the Bronze Age. The results of the excavation of 4 pits located in the historic backdirt piles at the site were very illuminating. It is here that we found the postcranial human remains and faunal remains mentioned in the diaries, along with a plethora of artifacts (e.g., beads, lithics, ceramics), indicating that the earlier excavators made a selection of materials to deposit in the museum and left a portion of the cultural materials behind.

Laboratory analyses have consisted of detailed studies of different artifact groups (e.g., García Puchol et al., 2012), many of which are ongoing. The human osteological study included analysis of museum holdings (McClure et al., 2010; Roca de Togores and Soler, 2010) and excavated materials are still under analysis. However, one of the most meaningful contributions to date is the construction of a direct chronological framework based on AMS

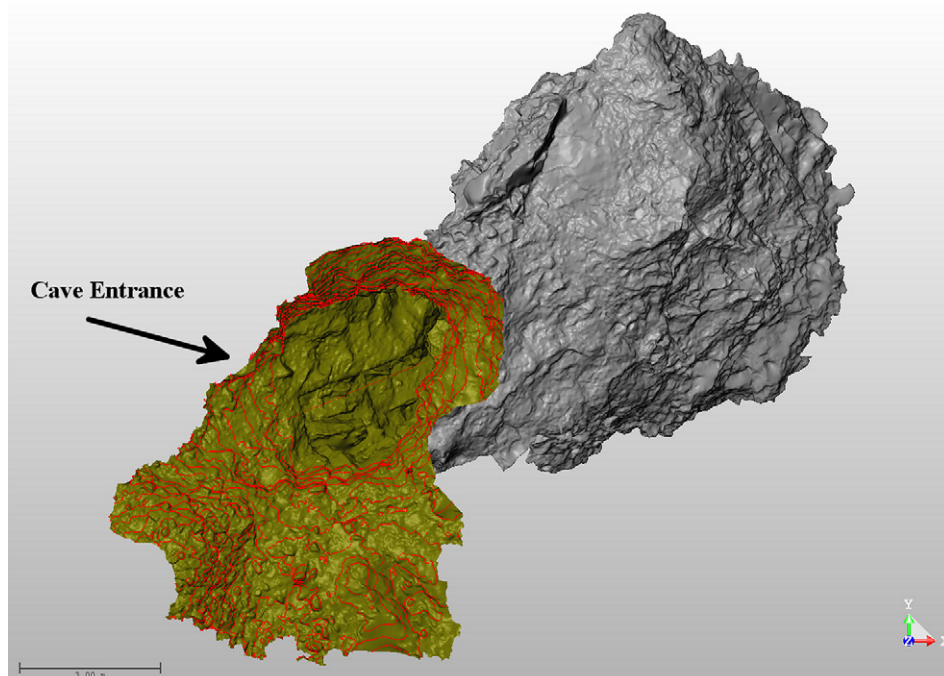


Fig. 3. 3D mesh of Pastora Cave shown in Realworks 6.3. Back-face view of its internal terrain.

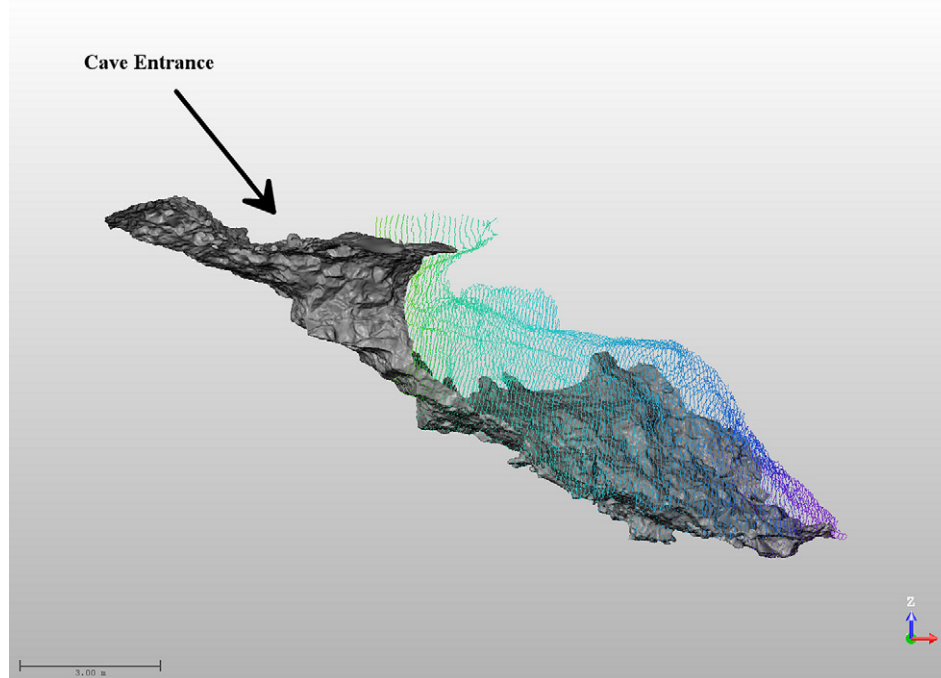


Fig. 4. 3D mesh of Pastora Cave in Realworks 6.3, showing the upper side of the cave as contour lines.

radiocarbon dates of human remains that allow us to redefine the temporal episodes of burials (McClure et al., 2010). In short, burials long thought to date to a very short interval during the Late Neolithic/Chalcolithic were instead spread over a much larger time span – ranging from the Late Neolithic to the Bronze Age – with distinct phases of burial practice in each period. The chronology is described in greater detail below. This finding led to the need to address the issues of stratigraphy and context in a more methodical manner, to try to glean more information from the diaries than basic data points. For this reason, we decided to test a computer simulation to represent the original stratigraphy of the cave.

Data from the diaries, particularly from Pascual, were used to recreate the sequence. In particular, Pascual's diary used the same system of measurement in three dimensions, so information between distinct layers or 'packages' was comparable. The current base of the cave was used as a datum, assuming that it is more or less intact and represents the 'red sterile level' that Pascual described as the base of the deposit. Since the exact position is not apparent, it is necessary to assume some margin of error for the reconstruction. Nevertheless, thanks to new computer science technologies, we were able to produce a general picture of how and where Pascual discovered the human remains and artifacts.

4. Methodology

Recent advances in 3D imaging technology provide us with an excellent tool to document different kinds of archaeological sites (architecture, natural landscapes) with a high spatial resolution as well as some artifacts for a micro-scale analysis (e.g., Grosman et al., 2008). Clearly, this technology presents a number of advantages regarding the preservation and dissemination of cultural heritage. The application of this technique to archaeological cave contexts (Rüther et al., 2009) has an increasing number of examples, mainly dealing with the documentation of prehistoric rock art (Díaz-Andreu et al., 2006; Lerma et al., 2010; Robson Brown et al., 2001). Our goal here instead is to apply this methodology to

obtain a virtual reconstruction of the episodes of cave use based on old excavation data and a new C14 chronology.

The site of Pastora Cave was scanned digitally using a 3D Laser Scanner PHOTON 120 by FARO®. In brief, the machine pivots 360° around a fixed point, emitting and sweeping a diverging laser beam through its x-axis. Additionally, with the technology of 3D LS used, it captures 85 RGB images of 2 MP. The result is the generation of a 3D point cloud composed by thousands or, often, millions of points according to the spatial resolution previously arranged. In this case, with an average distance among the points of 4 mm.

Every point represents real physical information of the objects, stored on a local coordinate system set up by the 3D LS. However, knowing the real geographic coordinates of three points of the point cloud, it is possible to georeference the entire point cloud (Fig. 5). To better digitize 3D objects of real space and to record their backfaces it would be necessary to acquire two or more point clouds, especially when the objects present irregular shapes as in this case. Later, during data processing, the different point clouds need to be joined together to identify common points as well as clean unnecessary objects and noise.

Finally, the point cloud is converted into a mesh with a mathematical triangulation, consisting of connecting each set of points with lines. The mesh works similarly to a fabric wrapping underneath the point cloud. In the end, the mesh represents the real object in a 3D digital format, with an elevated spatial resolution. Furthermore, the 3D mesh may have the original colors of the objects, as the software is able to interpolate the points with their positions on the pixels of the raster images previously captured. Consequently the color of each polygon of the mesh matches its relative points. Pastora Cave was analyzed in this same manner using LIDAR data with the aim of generating a 3D mesh representing the real archaeological site.

4.1. Working on the point clouds

Nine point clouds were recorded in the cave. The large amount of points is due to the irregular shape of the cave, the large number



Fig. 5. One of the point clouds captured showing the interior of Pastora Cave in RGB. Point cloud composed of approximately 28,000,000 points.

of stones inside it, and the cave's marked slope that limits the recording process. Once all the point clouds were captured, they were refined and processed in the laboratory as described above. First, they were georeferenced in SCENE[®] software provided by FARO[®]. Subsequently, they were exported to FOTOGIFLE[®]. The point clouds showed noise, given the spatial resolution of the 3D LS, recording fractions of millimeters and also taking into account the internal environment of the cave presenting dust as well. The scan of the cave entrance included unnecessary vegetation and objects, and all these were removed since they are irrelevant in the analysis.

Furthermore, using the software FOTOGIFLE[®], the unified point cloud was transformed into a HD RGB mesh which needed to be refined as well to eliminate unnecessary imagery but keep the relevant data in the 3D object and converted into polygons. The final mesh contains more than 4,300,000 polygons. Finally, using the compatible format OBJ, able to store textures and mapping information, it was exported to other software specialized in managing 3D data (Fig. 6).

4.2. Data processing in Realworks and modeling in BLENDER

The primary software employed for the metrical information was Realworks[®]. Specifically, the mesh was used to generate plans, sections and contour lines; data required to analyze the stratigraphy of the prehistoric cave. In contrast to other 3D software, the open-source BLENDER requires a reduced amount of polygons in the scene to work properly and without crashing, particularly when the objective is an animation or when there is a considerable number of objects in the scene. In the case of Pastora Cave, the scene was populated with a visual representation of the finds discovered by Vicent Pascual including skulls, rests of pots, bones, stone-tools, and ornaments. The skulls were recovered from LIDAR data of previous projects due to the complexity of their shapes, whilst the other objects were simply modeled by means of the Vicent Pascual's drawings.

The spatial resolution of the 3D mesh of the cave and the 3D skulls was much higher in comparison with the rest of the 3D

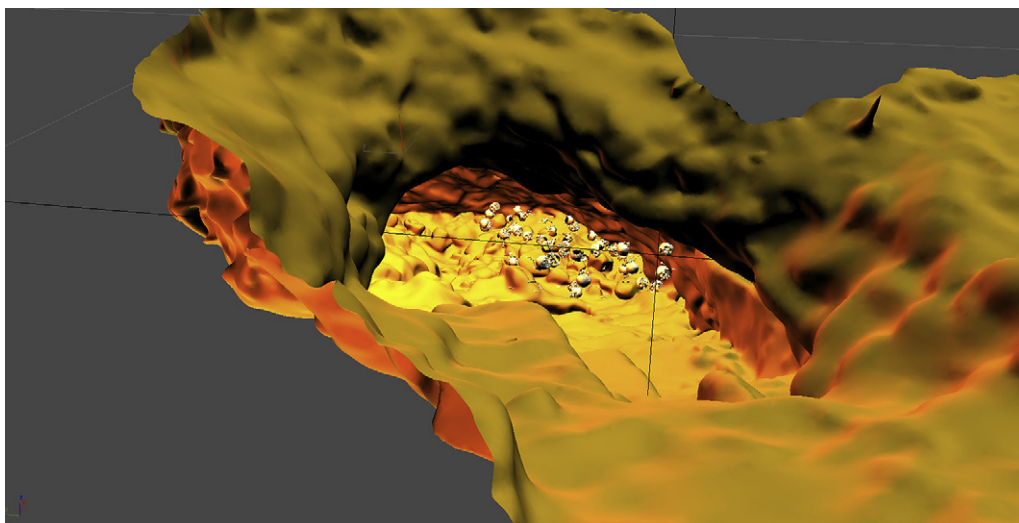


Fig. 6. Internal view of the cave captured from the entrance, with the groups of finds positioned in the stratigraphic units according to the interpretation of Pascual's diary.

objects. Furthermore, the final rendered images were single and static view shots, avoiding too much calculation of light and textures. As a result, only the meshes of the cave and the skulls needed to be optimized. Specifically, the cave was optimized directly in FOTOGIFLE and prior to the introduction into BLENDER it was mathematically reduced to approximately 400,000 polygons, certainly introducing loss of information. However, the main aims are to recreate the work carried out by Pascual and represent visually the data recorded in his diary (Fig. 2), more than a spatial analysis of the surfaces of the cave. Initially, the modeling focused on the 3D reconstruction of the stratigraphic units and trying to understand the idiosyncrasies in the recording and measurement systems he adopted. A second step was to recreate the “packages” of finds along with their stratigraphic position (Fig. 7).

5. Discussion: chronological and cultural contexts and 3D spatial information

The three funerary episodes described by Pascual include a total of 44 crania, and a group of 5 more “packages” with indications of objects but lacking human remains. Artifacts were made of local and extra-local raw materials such as ivory, variscite, amber, metal and certain cherts and metamorphic rocks (Table 1). Several ceramic pots and faunal remains suggest the likelihood of ceremonial practices that include food offerings. This context shows affinities to other Late Neolithic and Chalcolithic burials known in the Western Mediterranean region as the Los Millares culture (Chapman, 2008; Cámara and Molina, 2006). Nevertheless, revision of old excavation data concludes that the last level of burials present some features (and many ceramic vessels) that place them within a Bronze Age chronology (2002). As we have seen from Pastora Cave, the AMS chronology further supports this chronological attribution of some of the burials (McClure et al., 2010, 2011).

Since the discovery of Pastora Cave in the 1940s, the main interest of researchers has focused on bioarchaeological or anthropological analyses of the large number of human remains, in particular regarding trepanations (Campillo, 1976, 2007; Fregeiro, 2005; Rincón de Arellano and Fenollosa, 1949; Riquet, 1953). For this reason, several studies have been published providing interesting data about physical features, paleopathological analysis, description of skull trepanation, and recently dietary analysis of C and N stables isotopes (McClure et al., 2011). The chronological sequence was only recently confirmed with the publication of 12 AMS C14 dates of human remains (McClure et al., 2010; Soler et al., 2010).

Fig. 8 presents the radiocarbon dataset currently available from the site. Due to several preservation and conservation issues, it was not possible to directly date many of the crania in the Valencia Museum of Prehistory. This was unfortunate because most of the crania depicted in Pascual's diary were thus unavailable for dating. Fortunately a number of other human remains from Pastora Cave are housed in the Archaeological Museum of Alcoi, including numerous mandibles that had been separated from the crania. Ten of these mandibles were AMS dated. In addition, a recent study of prehistoric trepanations included two C14 dates from Pastora Cave (Roca de Togores and Soler, 2010), totaling 12 AMS dates. The recent analysis of the human remains has resulted in a minimum number of 59 individuals (McClure et al., 2010). Consequently 20% of the total sample of burials has been directly dated.

The majority of the crania from the uppermost level at Pastora Cave are housed in the Valencia museum with their mandibles, suggesting that the dated samples come largely from levels 2 and 3 of Pascual's excavation. The radiocarbon dates support this. The sequence shown in Figs. 7 and 9 is based in the plans in Pascual's diary and combine the cultural information with the chronological data. For this we consider the likelihood of the existence of two close burial events (Chalcolithic and Bell Beaker) together with different funerary episodes that span a greater period of time (Late Neolithic to Bronze Age). A more extensive AMS C14 dating program will further delineate these phases. For now the combination of 3D modeling, AMS radiocarbon dates, and excavation documentation allows us to recognize three major phases or events during the 2000-year span of burial practices in the cave.

The first phase is probably the most intensive use of the cavity as a burial location. A total of 13 crania are documented in Pascual's plan, located in the deepest part of the cave (Fig. 9, in yellow). The reconstruction suggests that the first burials were located mainly by the northern and western walls of the cave. The descriptions detailed in the diary explain the general disturbance and movement of the human bone and objects. Consequently, no articulated human skeletons were noted. The five AMS dates are very close to each other, even statistically identical in some cases (McClure et al., 2010). Furthermore, the artifacts, such as bifacial points, some geometrics and large bladed knives made of chert are chronologically consistent and often found together (García Puchol et al., 2012). Based on the spatial, contextual, and chronological data, we suggest that this phase was relatively short and intensive, and previous burials were moved or disturbed as new skeletons were interred.

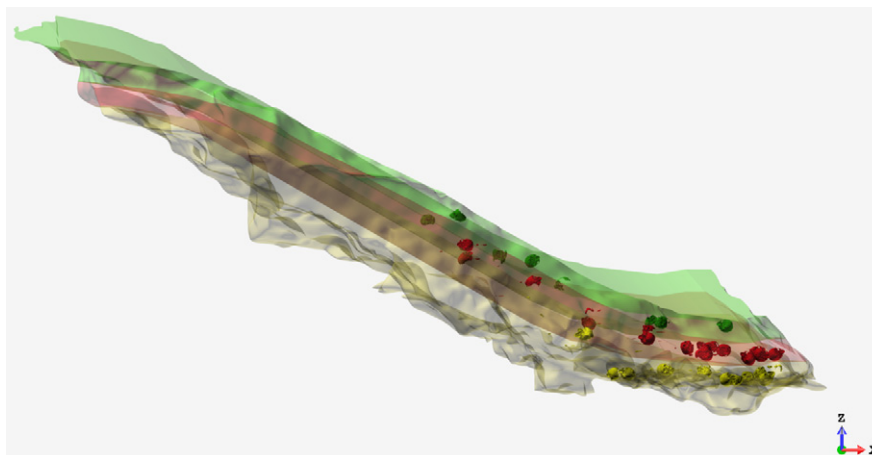


Fig. 7. Lateral view of the cave in transparency with the groups of finds floating inside of it. Hypothesis of the stratigraphy units according to the interpretation of Pascual's diary.

Table 1

Record of the objects recovered by Pascual at Pastora Cave. Pottery remains are not included in the list.

Chert blade	Chert point	Bone punch	Bone needle	Bone idols	Stone idols	Bone pendant	Shell pendant	Ivory	Amber	Lignite bead	Variscite bead	Teeth bead	Other beads	Metal objects
61	125	5	16	34	1	13	195	2	2	846	81	24	43	6

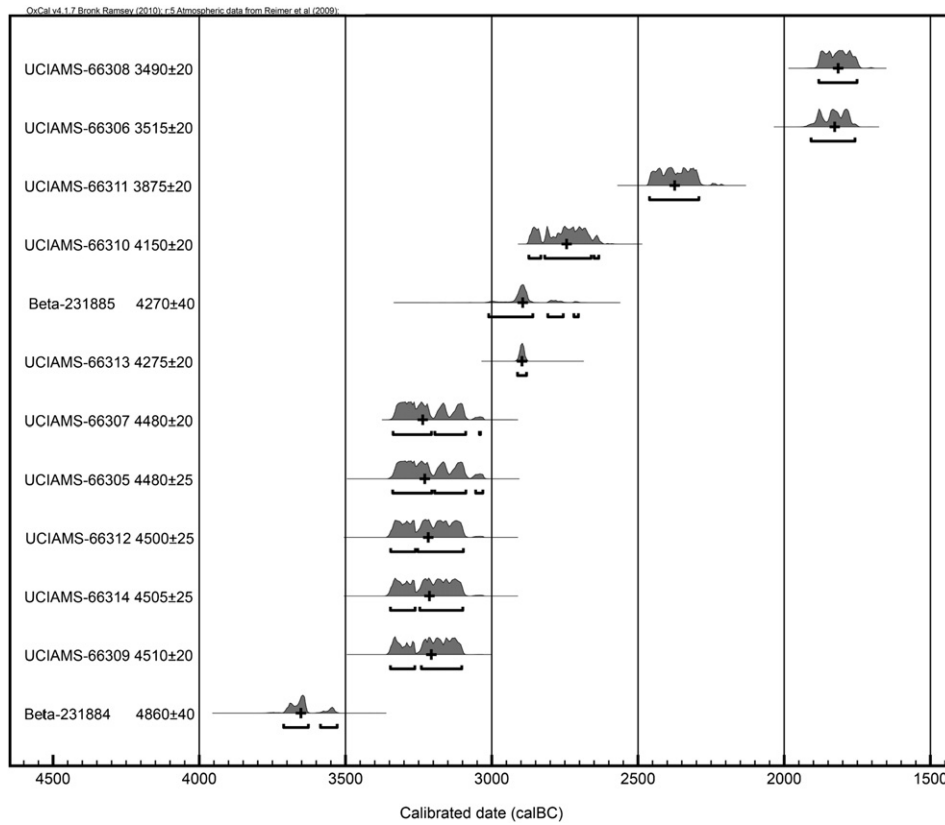


Fig. 8. Radiocarbon data from Pastora Cave calibrated with Oxcal 4.1 (Bronk Ramsey, 2009) using the Intcal09 calibration curve (Reimer et al., 2009).

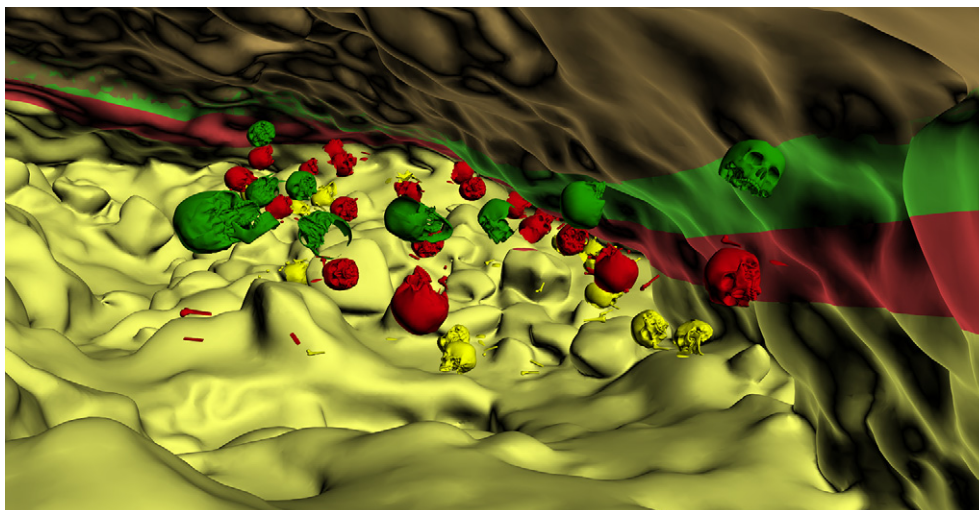


Fig. 9. Internal view of the cave showing the groups of finds positioned and colored in association with their specific stratigraphic units. Hypothesis elaborated according to the interpretation of Pascual's diary. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

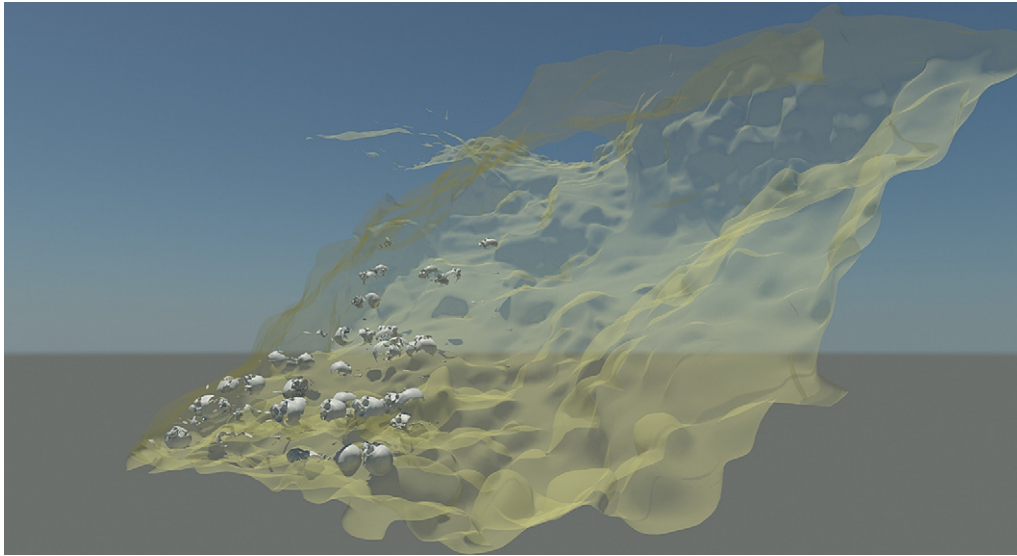


Fig. 10. Front view of Pastora Cave in transparency, with the groups of finds internally visible.

A second phase with a smaller number of C14 dates corresponds at least in part with Pascual's second level. Nineteen crania were excavated and documented in the diary (Fig. 9, in red), and Pascual noted the presence of different objects similar to those described in the first level. It is likely that this level reflects a longer-term, more sporadic funerary use during the Chalcolithic and Bell Beaker transition periods. Among the artifacts is a metal bifacial point, known as a palmela point, that is typical of the Bell Beaker. This is interesting because there are no other clear Bell Beaker materials in the cave, despite the presence of Bell Beaker sites in the area. Bell Beaker is an interesting social and political phenomenon in the region and it is striking that this point is the only clear artifact in the cave for this period in addition to the C14 dates. During this period the treatment of the dead was not uniform in the region, and there are many examples where a range of practices were combined, such as the appearance at individual pit tombs in some open air sites such as La Vital (Gandía, Valencia) (García Puchol and Gómez, 2011). In this case, the presence of metal artifacts and Beaker pots in a few single burial contexts can be interpreted as part of specific ceremonial practices related to emerging elites that show strong similarities to other European contexts (Salanova and Tcheremissnoff, 2011; Thomas, 2005).

Finally, the third phase of burial corresponds to the Bronze Age (Fig. 9, in green). Two radiocarbon dates are statistically identical (McClure et al., 2010) and support the hypothesis of a more closed and episodic funerary use at this time. Pascual drew a plan with the position of 14 crania and only scarce objects associated with the burials. Among these are a few bifacial chert points and the remains of ceramic pots. An Argaric vessel typical of the Bronze Age, is described in the diary. It was found close to an almost complete skeleton. The combination of chronological, spatial, and artifactual data suggests that this cave was likely used intensively for a short amount of time during the Bronze Age.

6. Summary and implications

The combination of 3D laser scanning techniques, AMS radiocarbon dating, and detailed analysis of field notes in a virtual reconstruction has been essential for exploring the complexities of the depositional history of the burial cave. This combination can be applied to a range of other kinds of archaeological sites and is

particularly useful in cases where a considerable lack of information from old excavations limits the interpretive potential of assemblages. At Pastora Cave this approach has allowed us to combine distinct datasets with differing resolutions to build a reconstruction of funerary episodes in a spatial manner. The utilization of 3D laser scanning techniques to analyze and visualize the ancient environment has certainly increased the accuracy of the results and the relationships of finds and burials to one another (Fig. 10). On the other hand, the visual representation elaborated in BLENDER should be considered more as an educational or evaluation tool for appreciating the original nature of the archaeological site and for interpreting Pascual's sequence. This representation could be further developed by adding new information, such as the 3D mesh of some of the original finds still preserved in the museum.

The study of Pastora Cave is part of a larger integrative approach to socioecological dynamics in long term prehistory of the western Mediterranean region. Several research teams in Spain and the USA have conducted projects that include archaeological survey and systematic excavations in the central Valencian region (e.g., Barton et al., 2004, 2012; Bernabeu et al., 2006; García Puchol et al., 2009; McClure et al., 2008, 2009). The development of a 3D spatial approach as exemplified at Pastora Cave will help shape future projects by integrating new technologies in this archaeological research. Through this approach, we can better understand the spatial, chronological, and cultural contexts of archaeological sites on varying scales by combining data sets with different degrees of resolution.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.jas.2012.10.015>.

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