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Reconstructing the geomorphic history of Liang Bua, Flores, Indonesia: a stratigraphic interpretation of the occupational environment

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ABSTRACT

Liang Bua, in Flores, Indonesia, was formed as a subterranean chamber over 600 ka. From this time to the present, a series of geomorphic events influenced the structure of the cave and cave deposits, creating a complex stratigraphy. Within these deposits, nine main sedimentary units have been identified. The stratigraphic relationships between these units provide the evidence needed to reconstruct the geomorphic history of the cave. This history was dominated by water action, including slope wash processes, channel formation, pooling of water, and flowstone precipitation, which created waterfalls, cut-and-fill stratigraphy, large pools of water, and extensive flowstone cappings. The reconstructed sequence of events over the last 190 k.yr. has been summarized by a series of time slices that demonstrate the nature of the occupational environment in Liang Bua. The earliest artifacts at the site, dated to ~190 ka, testify to hominin presence in the area, but the reconstructions suggest that occupation of the cave itself may not have been possible until after ~100 ka. At ~95 ka, channel erosion of a basal unit, which displays evidence of deposition in a pond environment, created a greater relief on the cave floor, and formed remanent areas of higher ground that later became a focus for hominin occupation from 74–61 ka by the west wall and in the center of the cave, and from ~18–17 ka by the east wall. These zones have been identified according to the sloping nature of the stratigraphy and the distribution of artifacts, and their locations have implications for the archaeological interpretation of the site.

Introduction

Interpretations of site formation processes and the distribution of materials in archaeological sites fundamentally rely on an understanding of karstic and fluvial processes (Glover, 1979), and are limited by the stratigraphic integrity of the deposits and problems associated with establishing a chronology (Gilbertson et al., 2005). Excavations in Liang Bua, a large dissolution chamber situated 16 km from Ruteng in the mountainous Manggarai province of western Flores, have yielded a wealth of palaeoenvironmental, palaeontological, and archaeological evidence (Morwood et al., 2004, 2005, 2009; Westaway, 2006) contained within a complex stratigraphy. This evidence includes stone artifacts, plant and animal remains, pottery, metal items, skeletal remains of *Homo floresiensis* in the Pleistocene deposits, and modern humans in the Holocene (Morwood et al., 2004, 2005, 2009). The present study follows the recommendations of previous analyses of cave sites in this region (e.g., Glover, 1979; Anderson, 1997; Gilbertson et al., 2005) and provides a detailed geomorphological and chronological (Roberts et al., 2009) context for the interpretation of the materials excavated at Liang Bua.

Westaway et al. (2009a) discovered that Liang Bua is part of a much larger cave system, located within an extensive cone and basin topography, situated on the highest alluvial terrace (~30 m above the river) within a flight of at least five uplifted terraces (Westaway, 2006). Rapid uplift dictates the dominant geomorphological processes in this region, such as karst solution, alluvial downcutting, and surface wash erosion, all of which contributed to the formation, exposure, and development of Liang Bua. The influences of these processes can be observed in the cave's stratigraphic record, which contains sedimentary evidence for multiple geomorphological events. Interpreting the archaeological evidence requires an understanding of these processes, such as the mode of transport, the energy of the depositional environment, and an appreciation of their relative timing. In this paper we describe the stratigraphy, and its characteristics and sequential relationships, for

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purposes of establishing a depositional history for the cave and identifying geomorphological events that have influenced the distribution of artifacts and skeletal remains.

Methods

In the field, we cleaned, illustrated, described, and sampled stratigraphic sections revealed by archaeological excavations. Subsequent analysis of a conglomerate deposit at the rear of the cave involved the excavation of small test pits to reveal the extent of deposition in the cave. We later extended an initial excavation, 1 m deep (CP1) and situated directly in front of the conglomerate wall, horizontally towards the center of the cave. We conducted two further excavations (50 cm^2 wide and ~2 m deep) in line with the original trench; one (CP3) located by the small stalagmite mound at the junction between the chambers, and the other (CP2) located between this and the original pit.

In the laboratory, we analyzed the range of particle sizes found in the cave samples using a Malvern Mastersizer 2600 to infer the mode of deposition (e.g., Chivas et al., 2001). The samples were thoroughly dried and sieved to 2000 μm to remove the larger grains, and a representative sample (~0.5 mg) was added until the laser obscuration was within range (between 10% and 20% obscuration). This sample was dispersed by both physical and ultrasonic agitation and the particle size distribution (in % volume) was plotted against particle size (in Phi units). We also analyzed sediment samples using a Philips (PWI 130/90) X-ray diffraction unit to determine the mineral composition of the sediments as an indication of provenance (e.g., Carr et al., 1999). In preparation, we ground the sediment into a fine powder using a pestle and mortar, and placed it into small aluminium trays. We scanned the samples from 4° to 70° (using a scan rate of 2°/min); the peaks were isolated using a peak analysis program, Traces 6 (e.g., Chivas et al., 2001).

Sedimentation and stratigraphy

The sediments in the cave can be divided into two areas: the rear chamber, comprising mainly of *in situ* and modified conglomerate and slope wash deposits, and the front chamber, consisting of deeply stratified and complex interbedded deposits (Fig. 1), with a ~10 m difference in height between the floor of the rear and front chambers (Westaway et al., 2009a). Excavations in Sectors I, III, and IV, near the center of the cave, and Sectors VII and XI, close to the easterly cave wall, revealed the structure of the deposits in the front chamber, which Morwood et al. (2009) describe in more detail, and reference will be made throughout to their four main stratigraphic figures (Morwood et al., 2009: Figures 10–12, 14). Further small-scale excavations also determined comparable information for the rear chamber using a series of small test pits, as described in the methods section.

Results

Correlation of the front and rear chambers produces a composite stratigraphy of nine main sedimentary units. In stratigraphic order, they consist of: 1) a conglomerate, 2) basal units, 3) collapse material, 4) an occupation level capped by flowstone, 5) channel deposits by the east wall of the cave, 6) a reworked and eroded conglomerate, 7) an occupation level containing the skeleton, 8) volcanic sediments, and 9) a younger occupational level and modern slope wash deposits (Fig. 2). The extent and elevation of these units are illustrated in the cross sectional profile of the cave (Fig. 3), while the sedimentary characteristics (Table 1) and photographs (Fig. 4) of each unit have also been included. Not all of these units are found in each sector but, when chronologically combined, they reveal a sequence of geomorphological and sedimentological events that influenced the cave environment and its history of occupation.

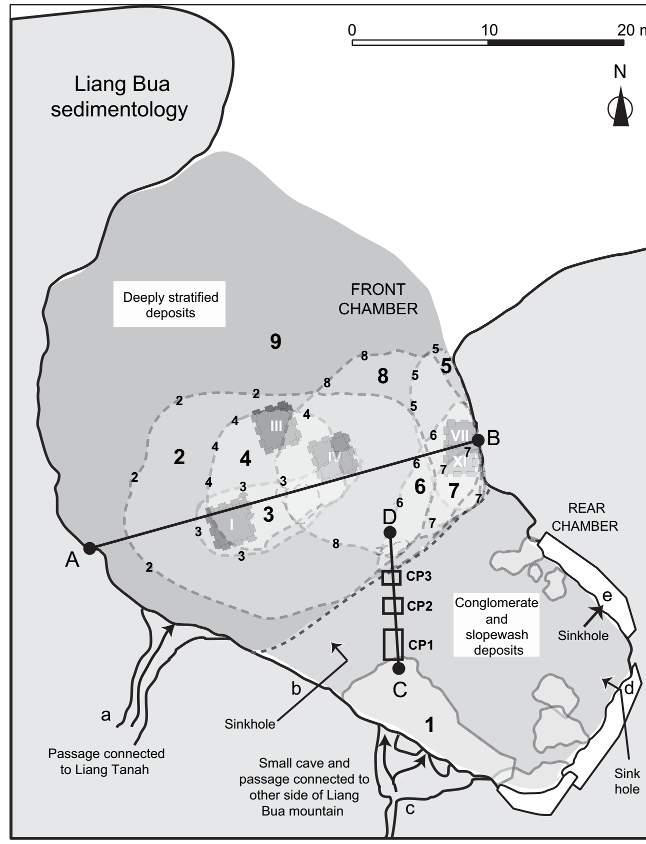

Figure 1. The structure and sedimentology of Liang Bua, showing the division of the cave into a rear and front chamber containing predominantly conglomerate and slope wash deposits, and deeply stratified deposits, respectively. The locations of the main excavations have been marked with dashed boxes (I, III, IV, VII, XI) and the smaller excavations (CP1, CP2, CP3) marked with solid boxes. The estimated extent of the main sedimentary units have been marked using dashed circles and numbered (1–9). A number of passages, sinkholes, and caves provide entry points into Liang Bua (a-e), and two transects running west to east (A–B) and south to north (C–D) provide the locations for the cross sections illustrated in Figs. 3 and 6, respectively.

Unit 1, conglomerate deposit

The structure, composition, and extent of the alluvial deposits at the rear of Liang Bua have been discussed in detail in Westaway et al. (2007, 2009a) so we include only a brief summary.

The Wae Racang River is, at present, ~30 m below and ~200 m from the cave entrance. However, the river previously occupied a similar elevation (~492 m.a.m.s.l.), as evidenced by a densely packed clast-supported conglomerate representing the river's first high-energy entry into the cave (Fig. 4a). In addition to this information, particle-size analysis of these deposits (Table 2 and Fig. 5) reveals a coarse matrix of silty sand that also indicates deposition by high-energy moving water. The combined clast and matrix size make this deposit one of the coarsest sedimentary units found in the cave. Lithological analysis of the dense framework of clasts reveals a predominantly volcanic composition of andesite, basalt, latite, trachytite, and dacite with occasional limestone, chert, and calcite clasts (Fig. 4a). This composition reflects the lithology of the bedrock throughout the course of the river, similar to the present composition of the Wae Racang riverbed. Both the extent of the