Archaeological site interpretation using experimental quantitative and qualitative data: a response to Magnani *et al.* (2019)

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The evidence reported in Holen *et al.* (2017) for hominin activity at the Cerutti Mastodon site is being intensively critiqued by many of our colleagues, but often with little regard for the cumulative meaning or the contextual data that support our interpretation of cultural bone and stone modification at the site. Magnani *et al.* (2019) characterise our bone-breakage experiments as pilot studies, or first-generation experiments, and as such, argue them to be insufficient in their own right to overturn previous research on hominin migration. While we acknowledge the limits imposed by qualitative data and the potential gains offered by quantitative, laboratory experimentation, much has been learned from these field experiments—including insights into processes used in the past and phenomena worthy of further investigation.

We (Holen *et al.* 2017: supplementary information) state that the aim of the actualistic experiments was to replicate the process by which hominins, for at least 1.5 million years, used hammerstones to break fresh proboscidean limb bone to harvest and quarry bone for nutritive value and for tool manufacture. Actualistic experimental methods, in contrast to laboratory experimentation, are used to "test out hypothetical scenarios using potentially authentic materials and conditions" (Outram 2008: 2). Previously reported scientific principles predicting the characteristics of fresh bone breakage described by Johnson (1985) were the basis for our actualistic studies (Holen *et al.* 2017: supplementary information 4). Our hypothesis that hammerstone percussion of fresh bone results in characteristic fractures and flaking was developed prior to the opportunities that we had to obtain a limited number of modern elephant limb bones for use as a proxy for mammoth and mastodon bone. Two actualistic bone-breakage experiments were subsequently conducted on this modern elephant bone. We stated clearly that the first experiment was designed to replicate the fracture patterns and anvil use at the La Sena Mammoth site ~21 000 BP (Holen *et al.* 2017: supplementary information 4). This experiment was conducted in 2006—two years before our initial analysis of the Cerutti Mastodon site collection.

The second experiment was designed to replicate the Cerutti Mastodon site evidence using fresh limb bones from a second modern elephant. Initial bone breakage was conducted using a 14.7kg granite hammer, selected because it was approximately the same weight as the

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pegmatite (granite) hammer—including refits—found in concentration 1 at the Cerutti Mastodon site. The elephant femur was broken on a large cobble anvil, similar to the one found at the site. Bone flaking was then conducted using smaller hammerstones.

By using an actualistic experimental method, "where unpredictable phenomena are given more opportunity to act" (Outram 2008: 2), we expanded our first-hand knowledge of fresh bone breakage on large-prey animal bones. We found, for example, that modern elephant femora were difficult to break near the proximal end, where thinner cortical bone covers spongy cancellous bone, and easier to break where the cortical bone is thickest. Even the use of the hafted granite hammer in the second experiment provided useful insight by demonstrating how hammerstones can be fractured when they slip off the bone and hit the anvil.

Despite diverse environmental factors, differences in hammerstone weights and sizes and in the choice of anvil material (e.g. wood *vs* stone), the process of hammerstone percussion on fresh bone produced the characteristic fractures, cone flakes and notches (Johnson 1985; Lyman 1994) created by other researchers (Stanford *et al.* 1981a) and found at archaeological sites (e.g. Stanford *et al.* 1981b; Holen 2006, 2007; Pobiner *et al.* 2008; Espigares *et al.* 2013; Domínguez-Rodrigo *et al.* 2014; Hannus 2018). Comparable findings at the Cerutti Mastodon site are interpreted as evidence of fresh bone breakage by percussion, as their features are qualitatively analogous to those from experiments such as ours, the extensive body of taphonomic literature and to evidence from other archaeological sites.

Although not performed specifically to replicate Cerutti Mastodon site bone-breakage patterns, we reported on the experimental breakage of cattle bone (Holen *et al.* 2017) because it demonstrated that, despite the differences in species and bone size, fresh bone-breakage patterns are similar. This again supports the hypothesis that the bones at the Cerutti Mastodon site were broken by percussion while fresh.

Magnani *et al.* (2019) state that the kangaroo-bone breakage experiment was inconsistent with the other three experiments. We agree, in that it was not a taphonomic experiment and was not reported as such. Rather, it was an experiment intended to produce use-wear patterns on a hammerstone. Magnani *et al.* (2019) also claim that we have not experimentally ruled out other causative agents. The elimination of alternative causation, however, is best achieved by examination of the context in which the Cerutti Mastodon site was found, along with the associated taphonomic evidence. Context and taphonomic evidence are discussed at length in Holen *et al.* (2017: supplementary information 1–2, 4 & 6).

The Cerutti Mastodon site yielded a very small number of impact notches, cone flakes and incipient cone flakes. Similarly, the hammer and anvil stones had few—although distinct—impact marks and lithic use-wear features consistent with being used for breaking bone. The isolated location of these features on the stones, their rarity and their encrustation are important. A small area of the upper surface of andesite cobble CM-281, for example, exhibits impact marks resulting from stone-on-stone impact—presumably from when the hammer has missed the bone and struck the anvil—forming jagged scars and abrasion that are typical of anvils used in bone-breaking experiments (e.g. de la Torre *et al.* 2013). In contrast, the lower surface of CM-281 has no impact marks or use-wear features, indicating that the lower, broad surface of this cobble, which was facing down when excavated, has only been subjected to natural weathering processes. This pattern of features supports our interpretation of the deliberate placement of CM-281 in its most stable position and use of its upper surface,

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on which bones were held in place and struck with a hammer. Pegmatite cobble CM-423 has a concentrated area of impact-induced, macroscopically visible pitting and cracks, although it is mostly encrusted with carbonate. The carbonate encrustation has preserved the underlying features and also rules out damage from modern machinery because the carbonate crust formed thousands of years ago. As the number of features diagnostic of percussion technology are too few for valid statistical analyses, we chose not to attempt such quantitative measures. Instead, we turned to qualitative analyses, using analogy and supporting arguments as an appropriate archaeological method for interpretation (Kosso 2001; Outram 2008: 5). At the Cerutti Mastodon site, features produced on fresh bone by percussion are only one component of the multiple lines of evidence that point to the processing of the mastodon bones by hominins.

Magnani *et al.* (2019) call for controlled scientific experiments with quantitative results to support or disprove our claims, and we applaud their enthusiasm in this regard. We fully agree that laboratory experimentation, which includes controls and larger samples, will be helpful. Other researchers are encouraged to take up that challenge after first examining the relevant research (e.g. Krasinski 2010) and recognising that even quantitative results must be interpreted contextually. Further study of the lithic use-wear is in progress. We acknowledge the value of qualitative and quantitative data, and the limitations of both when interpreting past human behaviour. We encourage formulation of testable hypotheses that account for the bone and stone breakage in the context of this unique site.

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