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Analysis of orientation patterns in Olduvai Bed I assemblages using GIS techniques: Implications for site formation processes

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A B S T R A C T

Mary Leakey's excavations at Olduvai Beds I and II provided an unparalleled wealth of data on the archaeology of the early Pleistocene. We have been able to obtain axial orientations of the Bed I bone and stone tools by applying GIS methods to the site plans contained in the Olduvai Volume 3 monograph (Leakey, 1971). Our analysis indicates that the Bed I assemblages show preferred orientations, probably caused by natural agents such as water disturbance. These results, based on new GIS techniques applied to paleoanthropological studies, have important implications for the understanding of the formative agents of Olduvai sites and the behavioral meaning of the bone and lithic accumulations in Bed I.

Introduction

Archaeological assemblages excavated by Mary Leakey (1971) at Bed I of Olduvai Gorge (Tanzania) are dated to between >1.84 (Tuff IB, Blumenschine et al., 2003) and 1.74 Ma (Manega, 1993; Blumenschine et al., 2003), and are probably the most renowned sites for the entire African Plio-Pleistocene. The archaeological sequence revealed by Leakey formed the foundation for highly influential interpretations of early human behavior (i.e., Isaac, 1978) and also their subsequent critique (e.g., Binford, 1981; Blumenschine, 1986; Potts, 1988). A significant part of the discussion on the behavioral interpretation of Bed I assemblages was due to disagreements about how site formation processes operated at Olduvai. Leakey (1971) proposed that most sites were undisturbed assemblages, either representing living floors (DK Level 3, FLKNN 1 and FLKNN 3, FLK Zinj) or butchering sites (FLK North 6). Although introducing some modifications, Isaac (1978) and Isaac and Crader (1981) broadly agreed with Leakey's interpretation, differentiating between vertically concentrated *in situ* floors and vertically diffuse disturbed assemblages.

These early views were challenged by Binford (1981), who argued that the associations between lithics and fossils resulted from depositional dynamics of stable land surfaces where non-integrated episodes led to the formation of multi-event palimpsests. Whereas Binford (1981) challenged the "vertical dimension" of the alleged Olduvai living floors, Blumenschine and Masao (1991) criticized their horizontal delimitation, proposing that the densities of fossils and artifacts were similar across the Olduvai landscape, and that therefore the concept of delimited and concentrated patches of bones and lithics accumulated by hominins (i.e., living floors) was spurious (Blumenschine and Masao, 1991). Potts (1988) reached different conclusions. He recognized that the depositional history of some of the sites (e.g., FLK North 6, DK) could have been much more complicated than what was considered by Leakey or Isaac, but Potts (1988) still believed that most Bed I sites– apart from FLKNN 2 – yielded clear evidence of human interaction with animal carcasses and that the assemblages were largely undisturbed by post-depositional processes.

de la Torre and Mora (2005a) argued that complex sedimentation processes in Bed I assemblages could have led to the admixture of unmodified rocks and archaeological materials belonging to different depositional events. Based on inconsistencies in the lithic assemblages, de la Torre (2005) also cast doubts on the contextual links between the fossils and stone tools in FLK North 6–3, and the integrity of DK. More recently, this has been supported by new zooarchaeological revisions (Domínguez-Rodrigo et al., 2007), which propose that only FLK Zinj shows systematic manipulation of bones by hominins.

At present, there seems to be a consensus that there were many agents contributing to the formation of the Olduvai Bed I assemblages, including hominins, carnivores and probably also other biotic agents. In recent years, most of the discussion has revolved around the role of carnivores and hominins in the formation of Bed I assemblages (e.g., Bunn and Kroll, 1986; Binford, 1988; Blumenschine, 1995; Capaldo, 1997; Domínguez-Rodrigo et al., 2007), but not so

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much over other natural factors that might affect concentrations of bones and artifacts (Potts, 1988; Petraglia and Potts, 1994; de la Torre and Mora, 2005a). In this paper, we wish to pursue this matter, and in particular through the study of item orientation, to discuss the role of post-depositional disturbance in the formation of the Olduvai assemblages.

Background on the impact of water flow in Olduvai Bed I sites

Despite the relative wealth of studies on fluvial disturbance (Isaac, 1967; Voorhies, 1969; Behrensmeyer, 1975, 1982, 1988; Schick, 1984; Badgley, 1986; Aslan and Behrensmeyer, 1996; Coard, 1999; and others), the application of models derived from experimental data and actualistic research to Olduvai has been rather limited as of yet. This is probably due to the existence of a consensus (arguably unfounded) over the primary position of all Bed I assemblages. Given the fine-grained contexts in which assemblages are located and the largely fresh condition of artifacts and bones, it is widely agreed that sites experienced no major post-depositional disturbance.

However, only Potts (1988) and Petraglia and Potts (1994) discussed systematically the effects of water flow in Bed I. Potts (1988) proposed six indicators that might reveal the effects of fluvial disturbance on the Olduvai sites (sedimentology, paleogeography, artifact size classes, preferred orientations, edge abrasion and bone hydraulic transport groups), but none has provided conclusive results as yet.

With reference to the sedimentology of the sites, the clay and silt contexts of the Bed I sites (Leakey, 1971) do not automatically mean that the material therein is undisturbed. Schick (1984) points out that archaeological assemblages in clay deposits may have undergone significant disturbance, as fluvial systems may have high-energy competence even if the available sediment to transport is fine grained. With regards to the paleogeography of the Olduvai Bed I sites, Hay (1976) located most of the assemblages in low energy deposits corresponding to the lacustrine floodplain (Hay, 1976), but it has been suggested that some channels existed near DK (Potts, 1988), the FLK broader area (Blumenschine et al., in press), and even across the FLK Zinj excavation surface (Leakey, 1971).

Regarding size classes and edge abrasion of artifacts, both Petraglia and Potts (1994) and de la Torre and Mora (2005b) presented some results, but a systematic and unified assessment of size sorting and rounding of Leakey's stone assemblages is still lacking. A similar picture emerges from the fossil collections. The outstanding number of small bone fragments in sites such as FLK Zinj, where there are about 50,000 bone splinters less than 2 cm (Bunn, 1982), has been considered as the definitive proof of the absence of water sorting over the assemblage. However, several of the other Bed I assemblages such as FLKN levels 3–5, FLKNN levels 2–3 and DK, show fewer small bone fragments than expected (Domínguez-Rodrigo et al., 2007). Bone abrasion indices are also inconclusive. Potts (1988) documents the percentages of abraded fossils consistently above 10%, but the results are contradictory. As he notes, DK, the most water disturbed site on sedimentological grounds, also shows the lowest index of abraded fossils (Potts, 1988).

The application of rounding indices is equivocal in the Olduvai assemblages. In reference to lithics, de la Torre (2005) indicated that it is sometimes difficult to distinguish between water rounding and *in situ* weathering for Olduvai lavas, and the hardness of Olduvai quartzite would require heavy transport for the edges to present significant damage. Potts (1988) showed that abrasion indices for the fossils from Leakey's assemblages were inconclusive. Furthermore, it has also been argued that in clays and silts, precisely the deposits containing Bed I sites, fresh bone edges remain unmodified even after undergoing long distance transport (Fernández-Jalvo and Andrews, 2003).

Bone hydraulic groups and preferred orientations are other proxies proposed by Potts (1988) to determine water disturbance. Although Potts (1988) presented some preliminary results using Voorhies' groups, subsequently no one has applied this methodology systematically to the Olduvai Bed I faunas. Regarding orientation, Potts (1988) commented on the preferred directions of fossils in DK, FLK Zinj and FLKNN 3, but his comments were based on general observations and not on a systematic study of the azimuth of artifacts and bones. Statistics of artifact orientation (i.e., azimuth and inclination) have long been used to assess water flow (e.g., Toots, 1965; Isaac, 1967; Nagle, 1967; Schleiger, 1968; Voorhies, 1969; Schick, 1984; etc.) and is considered today as a powerful proxy to address post-depositional disturbance in archaeological contexts (e.g., Lenoble and Bertran, 2004; Benito-Calvo et al., 2009). However, it has never been systematically investigated at Olduvai because measurement of artifact azimuth and inclination was not common practice in the early 1960's when the major excavations at Bed I took place (Leakey, 1971).

Given the fact that several of the proxies used for the identification of hydraulic disturbance are inconclusive (see above) and that most authors agree on the important significance of artifact orientations to assess post-depositional processes, we have developed a new method to measure and analyze the strike of artifacts in the assemblages excavated by Mary Leakey at Olduvai Bed I. The results of our analysis contribute fresh data to the understanding of the Olduvai assemblages and shed new light on the effect of post-depositional processes at these sites.

Materials and methods

The Olduvai Volume 3 monograph is widely acknowledged for the quality of Leakey's field data recording methods and her accurate excavation plans (e.g., Potts, 1988), which as presented enabled spatial analysis studies (Davis, 1975; Ohel, 1977; Kroll, 1994). Bone and stone tool refit maps (Kroll, 1994) suggest primary access to the original maps with identifications of archaeological items, but these plans have not been available to most researchers, including ourselves. However, the superb mapping of the archaeological items in Leakey's (1971) monograph permits a detailed analysis of the horizontal dimension of artifacts and bones, which has allowed us to study the orientation of items using Geographic Information System (GIS) technology.

Firstly, site plans were scanned in a raster format (tiff format) and georeferenced in a local metric coordinate system using the map scale and the excavation grids ($0.14064 < RMS > 0.00415$). The resulting raster layers were vectorized and each individual item (bone, artifact or other feature) plotted on Leakey's maps were converted into polygon layers. In this process, standard smoothing algorithms were used to remove small fluctuations in the polygon shapes caused by the grid structure of raster data. The polygon shapes were then linked to an attribute table containing a univocal numeric identification for every element, which includes also metric fields related to the size, shape and strike of every element, as well as descriptive data fields. These descriptive fields included a column for the general classification of every polygon shape (bone, artifact, or natural rock), and more specific fields such as lithic tool type, animal group and anatomical part, as rendered in Leakey's plans.

The metric fields added to the attribute table were length (A-axis), width (B-axis), Elongation Index ($I_e = A\text{-axis}/B\text{-axis}$), and strike of every element. These data were not made available by Leakey in the site plans, but given the precision of her maps, such variables can be accurately calculated using GIS techniques. The