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Lahar inundated, modified, and preserved 1.88 Ma early hominin (OH24 and OH56) Olduvai DK site

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ABSTRACT

Archaeological excavations at the DK site in the eastern Olduvai Basin, Tanzania, age-bracketed between ~1.88 Ma (Bed I Basalt) and ~1.85 Ma (Tuff IB), record the oldest lahar inundation, modification, and preservation of a hominin "occupation" site yet identified. Our landscape approach reconstructs environments and processes at high resolution to explain the distribution and final preservation of archaeological materials at the DK site, where an early hominin (likely *Homo habilis*) assemblage of stone tools and bones, found close to hominin specimens OH24 and OH56, developed on an uneven heterogeneous surface that was rapidly inundated by a lahar and buried to a depth of 0.4–1.2 m (originally ~1.0–2.4 m pre-compaction). The incoming intermediate to high viscosity mudflow selectively modified the original accumulation of "occupation debris," so that it is no longer confined to the original surface. A dispersive debris "halo" was identified within the lahar deposit: debris is densest immediately above the site, but tails off until not present >150 m laterally. Voorhies indices and metrics derived from limb bones are used to define this dispersive halo spatially and might indicate a possible second assemblage to the east that is now eroded away. Based upon our new data and prior descriptions, two possibilities for the OH24 skull are suggested: it was either entrained by the mudflow from the DK surface and floated due to lower density toward its top, or it was deposited upon the solid top surface after its consolidation. Matrix adhering to material found in association with the parietals indicates that OH56 at least was relocated by the mudflow.

1. Introduction

1.1. Lahar initiation and flow processes

Tephras from explosive volcanic eruptions are known to preserve a variety of important archaeological sites, e.g., historical Pompeii (Mastrolorenzo et al., 2001), Herculaneum (Luongo et al., 2003), and Bronze Age Akrotiri (Doumas, 1983). Volcanically sourced mudflows, cohesive and non-cohesive debris flows, or lahars (Macías et al., 1982; Naranjo et al., 1986) result from mobilization of unconsolidated tephra. They are as dangerous as the directly volcano-derived pyroclastics in terms of their volumes, sedimentation rates, and quick burial capacity, and can cause major losses of life. Their high potential to preserve entire landscapes is profound. At 5600 BP, the major Osceola lahar issuing from Mt Rainier (Vallance and Scott, 1997) covered and preserved an Amerindian archaeological site (Harris, 2000). More recently, lahars from El Chichón volcano (Macías et al., 1982), and from Nevado del Ruiz volcano, Colombia, 1985, (Naranjo et al., 1986) rapidly and tragically buried entire settlements. However, to date there has

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been no recognition of the role that laharic mudflows play in the preservation of and effects on early Pleistocene archaeological sites. Much more numerous are empirical and experimental studies and appreciations of disruption of assemblages by the fluidal flows of rivers (Voorhies, 1969; Leakey, 1971; Behrensmeyer, 1978; Schick, 1986, 1991; Pante and Blumenschine, 2010). Toward resolving that discrepancy, this paper describes the inundation, preservation, and modification of the classic DK hominin assemblage by a lahar sourced from adjacent Ngorongoro volcano.

Weathering and hydrothermal alteration of lavas and tephra of volcanic cones tend to produce clay-rich mixes of soil and sediment, which when triggered transport large volumes of sediment and water together. The resulting mudflows travel preferentially down existing drainage systems as lahars to be deposited within valleys, but also spread across and cover neighboring dissected plains to considerable depth. The fluidity of lahars is controlled by the proportions of entrained grains/fragments, clay, and water, the last provided variously by (1) water contained in (phreatomagmatic) eruptives that incorporate enormous quantities of expelled groundwater, (2) melting ice and snow caps of volcanic cones (Naranjo et al., 1986), (3) exceptional rainfall, including typhoon superstorms (Paguican et al., 2009), (4) collapses of caldera or crater lakes, (5) collapses of volcanically dammed lakes (Macías et al., 1982), or combinations of any of the above. Once triggered, lahars can travel downslope at prodigious speeds, as high as 50–100 m s^{-1} (Plafker and Ericksen, 1978; Voight et al., 1983), but with a common downstream velocity gradient. For example, during the 1980 Mount St. Helens eruption, flow velocities ranged from <1.5 m s‾1 downstream to >40 m s‾1 near the cone (Janda et al., 1981). Mobilized volumes can be extremely high, with the Mount St. Helens-related North Fork lahar reaching 140 million m^3 (Fairchild, 1987). Lahars can be highly erosive if they maintain fluidity as non-cohesive debris or hyperconcentrated flows (Pierson and Costa, 1987; Smith and Lowe, 1991; Svendsen et al., 2003), but can less disruptively cover the landscape if they are more viscous because shear stress is then dispersed through the flow and not solely concentrated at the base, as in less viscous flows (Lowe, 1982).

1.2. Olduvai Bed I volcanism, fan-deltas, and paleoenvironments

Olduvai Gorge in northern Tanzania is incised into the southeastern margin of the Serengeti Plain (Fig. 1), exposing a >90 m thick Pleistocene sequence of lacustrine, alluvial, and aeolian deposits with interleaved lavas and tuff beds. It is world-famous for its paleoanthropological assemblages, including the remains of *Paranthropus boisei*, *Homo habilis*, and *Homo erectus* in association with other vertebrate fossils and stone artifacts (Leakey, 1971). The Olduvai stratigraphic framework (Fig. 2) is based upon integrated magnetostratigraphy (Hay, 1976; Tamrat et al., 1995; Hay and Kyser, 2001) and tephrostratigraphy (Hay, 1976; Deino, 2012; McHenry, 2012), with various tuffs fingerprinted by their mineral assemblages, whole rock and single-grain geochemistry (McHenry, 2005; McHenry et al., 2013), and dated by $^{40}Ar/^{39}Ar$ analysis (Deino, 2012). The DK site, which is the focus of this study, is located in the eastern part of the Olduvai Basin, ~2.5 km east of the "junction area" where the Main Gorge and Side Gorge join (Fig. 1), and encompasses Hay's (1976) geological Locality 13. Artifacts and bones at DK occur in the interval (Fig. 2) between the Bed I basalt lava and Tuff IB, well constrained by $^{40}Ar/^{39}Ar$ dating at 1.877 ± 0.013 to 1.848 ± 0.003 Ma (Deino, 2012).

During deposition of Bed I, lahars from the Ngorongoro Volcanic Highlands were deposited on mixed debris flow and braided fluvial fan-deltas (cf Stanistreet, 2012; Fig. 1) that entered Paleolake Olduvai (Hay, 1976; Ashley and Hay, 2002; Stanistreet, 2012). Lahars produced diamictite beds, thick massive volcaniclastic units rich in clay matrix, supporting boulder- to pebble-sized clasts, which are interbedded with river gravels and sandstones, and preferentially accumulated east of the synsedimentary west-dipping Long K Fault (Stollhofen and Stanistreet, 2012). Substantial supply of primary Olmoti Volcano material had not yet initiated during the period between the Bed I Basalt lava and Tuff IB (Fig. 2; McHenry et al., 2008; McHenry, 2012; Mollel and Swisher, 2012), and the fan-delta system was sourced predominantly from Ngorongoro Volcano (Fig. 1) and its adjacent highlands toward the southeast of Paleolake Olduvai (Habermann et al., 2016a). Basinal stratigraphic profiles (Hay, 1976) show that the maximum lake shoreline at that time extended ENE to WSW (Figs. 1 and 3).

1.3. The DK site and sequence

The DK "occupation" floor was discovered (Leakey, 1971; Leakey et al., 1971) when a level of exposed lithic artifacts and bones was excavated in a series of trenches: MK, Trial, IC, DKI, DKIA, and DKIB. The DK main site was interpreted as an "occupation floor" (Leakey, 1971) with a "stone circle" (Fig. 3), originally speculated to represent an early hominin-constructed shelter, although alternatives have been proposed, such as that the arrangement of stones may have resulted from typically radially distributed tree roots breaking up an underlying lava layer (Potts, 1984; Njau, 2012). The lithic artifacts were reportedly dominated by basalt (Leakey, 1971), unlike younger Oldowan cultural sites in the Olduvai area (e.g., FLK, FLK N, HWK, FLK NN; Leakey, 1971), presumably reflecting the local accessibility of natural basalt scatter. However, this estimate is only by weight and when absolute frequencies of artifacts are considered, quartzite lithics (e.g. Leakey, 1971; Reti, 2016), particularly as flakes, represent the dominant raw material (Masao et al., 2013). The assemblage sat partly upon a volcaniclastic sandstone, previously termed "tuff" (Leakey, 1971), but lapped onto a neighboring basalt lava ridge. The partial *H. habilis* skull OH24 was discovered slightly higher within the interval at DK E, 300 m to the east of the original site (Leakey et al., 1971). OH56 skull fragments were discovered at DK in 1977 (Doumas, 1983) and, from our own observations, fossil bones excavated from the level of OH56 still have sandy diamictite matrix within and adhering to them.

2. Methods and materials

2.1. New and re-exhumed trenching

In 2010 and 2011, the Olduvai Landscape and Paleoanthropology Project (OLAPP) excavated new Trenches (152, 153, and 154) adjacent to the main Leakey DK trenches (DKI, DKIA, and DKIB) and re-exhumed trenches ("near Trial Trench", DK trench 9, DK Trench 3, and Taliwawa Hill Trench 2) toward MK (Masao et al., 2013) along a NE-SW trending line (Profile 1 in Fig. 3). The resulting stratigraphic profile revealed their sedimentary facies and time-rock correlation in a novel, sequence stratigraphic context (Fig. 4). Trenches 160, 161, 164, and 166 were excavated in 2012 to provide (Profile 2 in Fig. 3) a NW-SE cross-section (Fig. 5), orthogonal to the previous profile.

2.2. Survey and sampling techniques

Trench positions were located by GPS, and the elevation of the underlying Bed I lava surface was surveyed with a total station working at 5 mm-scale accuracy. Excavated sections were examined and logged (n = 12) to mm-scale accuracy to reconstruct sedimentary processes and paleoenvironments at high resolution. Representative samples were collected from each of the lithofacies