A spring and wooded habitat at FLK Zinj and their relevance to origins of human behavior

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ABSTRACT

The 1959 discovery of the hominin fossil Zinjanthropus boisei brought the world’s attention to the rich records at Olduvai Gorge, Tanzania. Subsequent excavations of archaeological level 22 (FLK Zinj) Bed I uncovered remains of Homo habilis and a high-density collection of fossils and Oldowan stone tools. The occurrence of this unusual collection of bones and tools at this specific location has been controversial for decades. We present paleoecological data that provide new insights into the origin of FLK Zinj. Our recent excavations 200 m north of the site uncovered a 0.5-m-thick tufa mound draped by Tuff IC, in the same stratigraphic horizon as level 22. Stable isotope analyses indicate that the carbonates were deposited by a freshwater spring. Phytolith analysis of the waxy clay under Tuff IC revealed abundant woody dicotyledon and palm phytoliths, indicating that the site was wooded to densely wooded. The time equivalency and close physical proximity of the two environments indicate the two are related. This study has provided the first documented evidence of springs in Bed I and these data have important implications for the interpretation of hominin behavior in meat acquisition and the ongoing debate on scavenging versus hunting.

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Introduction

Mary and Louis Leakey discovered Zinjanthropus boisei (Zinj) at FLK, Olduvai Gorge, Tanzania in 1959, then the oldest hominin fossil (Fig. 1). From the 1960–61 excavation of a 315-m² area of level 22, i.e. the FLK Zinj layer, Leakey reported approximately 2500 Oldowan stone artifacts and 3500 fossil bone specimens including remains of Homo habilis and Zinjanthropus (later renamed Paranthropus boisei) (Leakey, 1971). Subsequent analyses have refined these numbers, but based on Leakey's first report, the site is recognized as one of the prime examples of a localized, high-density co-occurrence of Oldowan tools and fossilized bones. But, why this unique archaeological site occurred at this specific location in the Olduvai Basin has remained a mystery. The “junction area” (confluence of the main and side gorges) of Olduvai Gorge represents only a small portion of the fluvial-lacustrine sedimentary outcrop of the basin, but it contains a large proportion, perhaps as much as 75%, of the hominin paleontology and archaeological sites found in the Gorge (Hay, 1976).

The significance of the site for understanding the origins of sophisticated hominin behavior, such as foraging strategies, is documented by abundant butchered bones and evidence of repeated transport of portions of at least 48 large mammal carcasses (mostly Bovidae) to this location on the paleolandscape (Bunn, 2007; Domínguez-Rodrigo et al., 2007). Since its discovery, the unusually large collection of human-butchered bones at the FLK Zinj, has been debated and interpreted as a “living floor” (Leakey, 1971), a “home base” (Isaac, 1978, 1984; Bunn, 1982, 2007), a “refuge” or “stone-cache” for butchering and marrow-processing activities by hominins (Potts, 1988), and a “central-foraging place” where food-sharing of fleshed carcasses took place (Isaac, 1983; Bunn and Kroll, 1986; Rose and Marshall, 1996; Domínguez-Rodrigo et al., 2007; Domínguez-Rodrigo et al., 2007). These models of early Pleistocene hominin behavior, however, are completely dependent on the paleoenvironmental context. For example, Binford (1981) hypothesized that FLK Zinj was an open space site, and a palimpsest or a time-averaged assemblage where hominin participation was marginal. However, the paucity of arboreal refuge in mudflat would suggest that any visit by hominins must have been brief and limited to the fast processing of some carcass parts (Blumenschine and Masao, 1991). Another model proposed that
Figure 1. Paleogeographic reconstruction of Olduvai Gorge at Bed I time shows location of the Ngorongoro Volcanic Highland, the pyroclastic alluvial fan, proposed regional groundwater flow direction, outline of shorelines during expanded and contracted lake phases, and location of the FLK Zinj archaeological site (star). A–B cross section is shown in Figure 4. The outline of the modern gorge is indicated. Inset map depicts location of Olduvai Gorge in northern Tanzania.
hominins were creating “stone caches” on the lake margin floodplain to process carcasses. The model implies that hominins would be competing with carnivores for resources and thus the environment was not likely extensively wooded (Potts, 1988). In contrast, a closed-vegetation habitat supports models involving more advanced foresight and complex behaviors, such as “central-foraging place,” “homebase” or “resource-defense” models (Isaac, 1983; Domínguez-Rodrigo et al., 2007; Domínguez-Rodrigo et al., 2007). Carnivore competition in wooded habitats is low, thereby enhancing the likelihood of prolonged stay in those places (Domínguez-Rodrigo et al., 2007).

The paleoecological setting of the Olduvai Bed I sites has also been used to discuss the importance of meat eating in the earliest representatives of our genus. Models relying on a paleoecological reconstruction of the site which describes FLK Zinj in an open mudflat support scavenging hypotheses in which meat and food sharing were unimportant, given the overall high carnivore competition and the associated predation risks (Binford, 1981; Blumenschine and Masao, 1991). In contrast, models that recreate FLK Zinj in a habitat with dense arboreal component support the idea that meat was the main target in carcass exploitation and that food sharing was a natural result of the food surpluses repeatedly transported to the site (Isaac, 1978, 1983; Bunn, 1982; Bunn and Kroll, 1986; Rose and Marshall, 1996; Bunn, 2007; Domínguez-Rodrigo et al., 2007; Domínguez-Rodrigo et al., 2007). For these models, meat represents a high-quality movable resource that was transported to specific places that offered spatially fixed defensible resources such as fresh water, trees and plant foods and where predation risk was very low (Rose and Marshall, 1996).

In order to test these ecologically based models of early hominin behavior, we carried extensive field work at Olduvai in 2008 and 2009, and opened test trenches both at and in the surroundings of the

Figure 2. Location map within the “junction area” of Olduvai Gorge that depicts modern cultural features (road, trails, and museum), natural features (river and fault) and the interpreted paleoecological features. The interpreted groundwater-fed spring is circle at FLK NN. The interpreted wooded habitat is around the spring at FLK NN and archaeological site FLK Zinj (square), but its spatial extension over the area depicted in this map could not be ascertained by our phytolith data. Data are restricted to FLK Zinj, FLK NN, and FLK NW (Fig. 2).
site as far north as FLK NN (Fig. 2), where a tufa was found in the same stratigraphic position as FLK Zinj archaeological level 22 (Fig. 3). Detailed lithostratigraphic analyses were carried out and this stratigraphic layer systematically sampled for paleobotanical remains. Given the paucity of palynological content in Bed I sediments (Bonnefille and Rolliet, 1980), phytolith analysis of the first few centimeters of the waxy clay below Tuff IC was used to investigate the distribution and density of vegetation in the ca. 2000-m² area encompassing the archaeological site and the newly discovered spring site at FLK NN and Location 45b (Hay, 1976). This paper presents new geological and biological evidence and examines the results of this high-resolution reconstruction of the landscape in terms of its bearing on our understanding of early hominin behaviors.

**Geologic and hydrologic setting**

The Olduvai Gorge cuts across a 50-km-wide rift-platform basin located between Precambrian basement to the west and the Pleistocene Ngorongoro Volcanic Highland to the east (Hay 1976) (Fig. 1). The basin fill is now disrupted by rift-parallel faults and separated into blocks. The sediments are quite thin (100 m) and comprised largely of reworked volcanioclastic sediment and air-fall tuffs deposited in a shallow semiarid fluvial–lacustrine basin (Hay, 1976). The basin was hydrologically closed and astronomically forced climate cycles raised and lowered lake levels on a time scale of 21 ka (Ashley, 2007). The Highland today acts as a rain shadow for the predominantly easterly winds from the Indian Ocean. The modern Ngorongoro Highland receives ~1150 mm/yr (Deocampo, 2004), whereas Olduvai receives only ~550 mm (Hay, 1976). Evaporation in East Africa is estimated to be 2500 mm/yr and very few perennial rivers can persist with this highly negative water budget.

A geological section across the basin reveals a prominent basalt high at the base of Bed I, related to extensional tectonics associated with the East African Rift and to a horst (1.5 km wide, up to 20 m local relief) created by rift parallel faults (Figs. 1 and 4). Hay's detailed stratigraphic reconstruction of Bed I sediments shows thinning of beds over the basalt high in the junction, documenting its presence at the time of deposition of Bed I (Fig. 4) (Hay, 1976). The complex geologic structure would have affected the flow of water moving in the basin.

**Materials and methods**

In order to identify the origin of carbonates deposited at FLK NN, we selected sixteen samples from ten locations within the tufa mound and analyzed them for C and O at the Stable Isotope Laboratory at Rutgers University on a Micromass Optima Mass Spectrometer. Samples were loaded into a Multi-Prep peripheral and reacted in phosphoric acid at 90 °C for 13 min. The δ13C and δ18O values are reported relative to V-PDB through the analysis of an internal laboratory standard which is routinely checked vs. NBS-19 (Coplen et al., 1983). The deviations of the internal lab standard from NBS-19 are 0.10 and 0.04‰ for δ13C and δ18O, respectively. The 1-sigma deviations of the lab standards analyzed during the sample analyses are 0.05 and 0.08‰ for δ13C and δ18O, respectively.

Samples for phytolith analyses were collected in archaeological trenches and localities in the FLK and FLK NN areas of Olduvai Gorge (Fig. 2, Table 1). All samples are from the same olive-brown waxy clay layer beneath Tuff IC, equivalent to archaeological level 22. At each sampling spot, three to four sub-samples were excavated less than 5 cm below Tuff IC and less than 1 m apart, and placed together into a clean polyethylene ziplock bag.

Samples were prepared for phytolith analyses by treatment of 8–10 g of sediments with pure HCl (33%) in Pyrex beakers for 4 h to remove carbonates, and then with pure H2O2 (30%) at 70 °C to remove organic matter. H2O2 was changed daily until reaction ceased. Clays were deflocculated using a solution of sodium polyphosphate (NaPO3) at pH 7, and removed by decantation and centrifugation until supernatant was clear. Separation of organic silica from the mineral fraction and concentration of phytoliths was achieved using ZnBr2 heavy liquid at a concentration of 20–30% and then with pure H2O2 at 70 °C to remove organic matter. H2O2 was changed daily until reaction ceased. Slides were prepared using a small amount of dry residue mixed with glycerin as mounting medium to allow rotation of the phytoliths during microscope observations. Slides were observed at 500× magnification. Phytoliths micrographs were taken on extra slides prepared with Canada balsam. All particles that were black under crossed-polarizers were described, drawn, and counted separately. Phytoliths were classified according to their three-dimensional morphology and size, and only later were given (or not) some taxonomic attribution (Appendix 1). Counting was carried out until reaching 200 phytoliths, except for samples DB08-geo15 (material exhausted) and samples DB08-geo18a and DB08-19, which were found sterile (Table 1).

**Results**

**Geological and geochemical evidence for a persistent freshwater spring**

Geological excavation at FLK NN (200 m north of FLK Zinj) uncovered a thick persistent carbonate deposit (tufa) (Fig. 5A). The tufa is blanketed by Tuff IC air fall and thus is equivalent to the level 22 archaeological horizon at FLK (Fig. 5B). Tuff IC cannot be physically

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**Figure 3.** Stratigraphic columns of Bed I at FLK Zinj site and FLK NN, located 200 m to the north. Ages of Tuff IB and Tuff IIC (Blumenschine et al., 2003); Age of Tuff IF (Hay and Kyser, 2001). Archaeological level 22 occurs immediately beneath Tuff IC and is stratigraphically equivalent with the tufa at FLK NN.
Figure 4. Geologic cross section (A–B) of the junction area depicting Olduvai Beds I–IV. Dashed lines represent geologic sections. FLK (Zinj and NN sites) (solid star) are located in Bed I and depicted here adjacent to the FLK fault and above the basalt. The Bed I basalt which is relatively impermeable forms a local high in the junction compared to adjacent areas. This basalt high may have focused groundwater flowing from the Ngorongoro Volcanic Highland to the surface creating freshwater seeps and springs in the junction area (Fig. 6B).

Table 1

Phytolith samples and phytolith counts summarized.

<table>
<thead>
<tr>
<th>Localities/a sampled under Tuff IC / Sample #</th>
<th>FLK Zinj</th>
<th>FLK NN</th>
<th>FLK NW</th>
</tr>
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<tbody>
<tr>
<td>FLK Zinj (°S)</td>
<td>2°59′22.48″</td>
<td>2°59′13.1″</td>
<td>2°59′21″</td>
</tr>
<tr>
<td>FLK Zinj (°E)</td>
<td>35°20′55.7″</td>
<td>35°20′53″</td>
<td>35°20′54.9″</td>
</tr>
<tr>
<td>FLK Zinj (m)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>FLK Zinj distance to trench FLK-03 (m)</td>
<td>~10</td>
<td>~25</td>
<td>~10</td>
</tr>
<tr>
<td>Phytolith categories/ typesb</td>
<td>Taxonomy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Globular granulate FI</td>
<td>28</td>
<td>78</td>
<td>115</td>
</tr>
<tr>
<td>Globular echinate Palm</td>
<td>20</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Globular echinate/micro-echinate/ridges</td>
<td>13</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Globular tuberculate/faceted/smooth</td>
<td>35</td>
<td>37</td>
<td>30</td>
</tr>
<tr>
<td>Striated/onion-like bodies</td>
<td>7</td>
<td>8</td>
<td>13</td>
</tr>
<tr>
<td>Plates (other)</td>
<td>3</td>
<td>19</td>
<td>4</td>
</tr>
<tr>
<td>Plates (Grass)</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Plates (FI)</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sclereids</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Elongate (others)</td>
<td>18</td>
<td>19</td>
<td>22</td>
</tr>
<tr>
<td>Elongate (FI)</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Blocky bodies (FI)</td>
<td>30</td>
<td>29</td>
<td>17</td>
</tr>
<tr>
<td>Blocky bodies (others)</td>
<td>7</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Acicular hair cells</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan-shaped bulliform cells</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grass silica short cells</td>
<td>38</td>
<td>26</td>
<td>4</td>
</tr>
<tr>
<td>Dubious</td>
<td>34</td>
<td>11</td>
<td>1.5</td>
</tr>
<tr>
<td>SUM Phytoliths</td>
<td>216</td>
<td>233</td>
<td>204.5</td>
</tr>
<tr>
<td>D°/P index</td>
<td>2.2</td>
<td>7.4</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Fl: forest indicators, Mar/Cos?: tentatively assigned to Maranthaceae/Costaceae.

D°/P index: ratio of globular granulate/echinate/tuberculate/smooth phytoliths over grass silica short cells.

After Hay (1976).

Detailed counts of phytolith types are in Appendix 1.
traced from FLK Zinj to FLK NN because of gulley (korongo) erosion down to basalt between the outcrops. But, Tuff IC appears in both FLK Zinj and FLK NN detailed stratigraphic sections (Leakey, 1971). It is described as a medium- to coarse-grained vitric tuff of trachyte composition, and is depicted in stratigraphic sections of FLK Zinj and FLK NN; FLK Zinj being the type section (Hay, 1976). The tuff was characterized geochemically from samples collected throughout the Gorge (McHenry, 2004, 2005) and dated 1.839±0.005 Ma from samples collected at the OH65 archeological site on the western side of the basin (Blumenschine et al., 2003). Level 22 is a 20-cm-thick green to olive-brown silty clay layer in and on which Oldowan stone tools and fossilized bones co-occur (Leakey, 1971)( Figs. 3 and 5B). Green smectitic clays with varying amounts of silt are intercalated with tuffs throughout Bed I. Interpreted to be lacustrine in origin (Hay, 1976), the green clays were deposited during high lake levels when water flooded onto the lake margin, and then modified by pedogenic processes and turning them brown during times of lower lake levels (Sikes and Ashley, 2007).

The tufa occurs in a mound-like form and is at least 35 m by 10 m and ~0.5 m thick (Fig. 5A). It is chalky and friable, white, when pure, but mixed with underlying sediment in places. We interpret the admixing of the lithologies as bioturbation similar to that which occurs at modern watering holes (Behrensmeyer and Laporte, 1981; Ashley and Liutkus, 2002).

The δ18O and δ13C signatures of tufa record the geochemistry of the water and carbonate-precipitating environment (Pentecost, 2005). δ18O reflects the original signature inherited from precipitation plus any fractionation that occurred during the precipitation of carbonate and thus considered a faithful record of the paleoenvironment. The δ13C signature is less straightforward as contributions of carbon are made from weathered rock and soil that the groundwater has moved through, as well as diffusion of carbon from the atmosphere.

The tufa has a robust “freshwater” isotopic signature. δ18O values range from −5.0‰ to −1.0‰ (Fig. 6A), which indicates a groundwater-fed water source (Cerling and Quade, 1993). Compared to the δ18O average value of −4.0‰ for modern regional rainfall, δ18O values of the newly discovered tufa indicate a meteoric source for the water as well as a fractionation toward more positive values, as found under evaporative conditions when groundwater discharges onto the surface (Cerling et al., 1993). Compared to the carbonate record of a
freshwater wetland in lowermost Bed II, where phreatic rhizoliths formed during both rising and falling lake levels (Liutkus et al., 2005), the $\delta^{18}O$ and $\delta^{13}C$ are slightly more positive for the Bed I tufa suggesting evaporative conditions and more atmospheric exchange, consistent with an interpretation of subaerial groundwater discharge. The oxygen signature of Bed I tufa is more positive than the Bed II samples, which attest to the presence of trees and/or shrubs or bushes. Hence, the paleoenvironmental context at FLK Zinj appears to offer a spring-fed watering hole and wooded to densely wooded habitat

Botanical evidence for wooded to densely wooded environment

We identified 84 different phytolith types in the eight productive samples of clay that were collected immediately below Tuff IC (Appendix 1). Types were grouped into several main categories (Table 1). Phytoliths with unknown taxonomical origin represent 4% to 36% of the total assemblages, and phytoliths with dubious 3D-morphology that could not be classified in a definite category are relatively abundant (>10% in several samples) and represent up to 30% in sample DB08-geo18b at FLK NN tufa locality (Fig. 7).

Grass silica short cells (GSSCs) are rare in all samples (2% to 18%), while forest indicator phytoliths are abundant (43% to 71%) (Fig. 7), which argues for abundant woody plants such as trees and/or shrubs or bushes in the paleo-vegetation. Among the grass phytoliths, the only categories we observed were Bilobate, Pyramidal, Rondel (diameter <15 μm), and Trapeziform short cells (Fig. 8, Appendix 1). Forest indicator phytoliths (FI) include the globular granulate type (Fig. 8), which occurs mainly in tropical woody dicotyledons (e.g., Geis, 1973) and which relative abundance in soils increases with increasing density of broadleaved trees and shrubs at low and middle elevations (Bremond et al., 2005, 2008; Barbón et al., 2007). FI phytoliths also include the globular echninate and micro-echinate types produced by palms (Arecaeae) (Tomlinson, 1961), and the globular echinate bodies with more or less marked ridges (Glo-18, -19, -23, and -24, Appendix 1) that strongly resemble phytoliths produced by some forest species of the Marantaceae and Costaceae families (Strömbärg, 2003). Some types among the categories Striated/onion-like bodies, Plate, Sclereid, Elongate, and Blocky bodies are also associated to woody plants and are, thus, considered forest indicators (Barbón et al., 2010).

$D^{16}/P$ phytolith index, which is the ratio of woody dicotyledon and palm phytoliths over grass phytoliths is another way to measure the relative importance of woody plants over grasses in a vegetation. Values $>1$ are typical for sites in African wet evergreen forests, while $D^{16}/P$ values $<1$ are typical for savannas where trees and shrubs are scarce (Alexandre et al., 1997; Bremond et al., 2005). In the clay samples we studied here, $D^{16}/P$ values range from 2 to $>36$ (Table 1), which clearly suggest a wooded to densely wooded paleo-vegetation.

There are no major differences in the phytolith assemblages among the samples, except that the highest amount of palm phytoliths is found in sample GA-Old-114-07 from Trench FLK Zinj 04, a sample taken few centimeters below sample GA-Old-113-07.

**Discussion**

The isotopic signature of the tufa coeval to the FLK Zinj archaeological level 22 that we uncovered at FLK NN by our recent excavations at Olduvai Gorge indicates that less than 200 m away from the high-density patch of stone tools and butchered bones observed at FLK Zinj, a fresh water source was available to hominins. In the area surrounding FLK Zinj itself, including FLK NN where the spring was found, abundant plant silica bodies (phytoliths) from woody dicotyledons and palms were found, which attest to the presence of trees and/or shrubs or bushes. Hence, the paleoenvironmental context at FLK Zinj appears to offer a spring-fed watering hole and wooded to densely wooded habitat that would have provided a location relatively safe from carnivores for hominins to butcher animals.

Despite considerable recent advances in the field of phytolith research, which now allow for the identification of some important crops in fossil sediments (bananas, bottle-gourd, squash, maize, rice; e.g., Piperno, 2006), silica bodies, in general, can only relate to broad ecological groups or plant types (e.g., woody dicots, palms, and grasses). Even within the phytolith-rich Poaceae family, it is rarely possible to identify types that are diagnostic to the species-, genus-, or even sub-family level (e.g., Barbón and Bremond, 2009). Recent work on the modern miombo flora of Mozambique showed that few arboreal taxa, such as *Uapaca nitida* and *Podocarpus falcatus* produce unique diagnostic phytoliths, but in such low numbers compared to other phytoliths typical for woody dicotyledons that their detection is most unlikely unless extremely high total phytolith counts are carried out (Mercader et al., 2009). In the clay samples we studied here, despite the fact that forest indicator phytoliths are diverse and most abundant (>40%) compared to grass silica short cells ($D^{16}/P$ ratio $>1$), we cannot identify if their abundance reflects the abundance of trees, shrubs, or bushes, or all three plant types in the paleo-vegetation.
Figure 7. Relative abundance of phytoliths indicators of grasses, grasses and/or sedges, and of forest taxa, including Maranthaceae/Costaceae?, Arecaceae (palms), and undifferentiated woody dicotyledons observed in the samples collected from 10 sites from the green silty clay layer under Tuff IC. Totals would reach 100% if the relative abundance of phytoliths with unknown taxonomical origin and dubious 3D-morphology would be null. See Appendix 1 for taxonomic attribution of phytolith types.

<table>
<thead>
<tr>
<th>Locality</th>
<th>Phytolith Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLK Zinj</td>
<td>Grass/Grass</td>
</tr>
<tr>
<td>FLK NN</td>
<td>Grass/Grass</td>
</tr>
<tr>
<td>FLK NW</td>
<td>Grass/Grass</td>
</tr>
</tbody>
</table>

Figure 8. Optical micrographs of woody dicots, palm, and grass phytoliths from archaeological level 22 (FLK Zinj) (see Appendix 1 for detailed taxonomic attributions). A–D, phytoliths of the type Globular granulate (Glo-3, 4); E–G, phytoliths of the type Globular echinate (Glo-10); H, spherical phytolith with concentric striations (Str-3); I, globular phytolith micro-echinate oblong (Glo-32); J, dubious body made of imbricated cubes (Unid-9); K, trapeziform short cell phytolith (GSSC-42); L, Discoidal/spheroidal psilate phytolith, vaguely fan-shaped (Blo-7); M, Thin silicified plate, edge or surface lacunate (Pla-3); N, Elongate cylindrical phytolith, surface lacunate (El-10); O, vaguely key-stone phytolith with concentric striations (Str-2).
Palms (Arecales), which are big producers of phytoliths (Hodson et al., 2005) were most likely scattered because the relative abundance of globular echinate phytoliths is <10% in average in our fossil samples. For comparison, the percent of globular echinate phytoliths is a swamp dominated by Raphia palms is ~68% (Bremont et al., 2005). It is most likely that there were few open spaces between the woody plants because grasses which are ubiquitous and big phytolith producers contributed few silica bodies and types in all samples (Fig. 7, Table 1).

The paleoenvironment would have been a wooded lake margin setting with low-relief hummocks (undulating surface) created by sediment blanketing the irregular surface of the underlying basalt. The spring was in a depression 1–2 m lower than the FLK Zinj. Although the water table was likely high on the lake margin, the slight difference in local relief (i.e., hummocks) may have produced a better drained area at FLK Zinj, and thus a site near to the spring sought for meat consumption. The spring deposit is located a scant 50 m from the FLK Fault (Figs. 2 and 4) and groundwater likely flowed from the fault or related fractures associated with the extensional faulting prevalent in the Olduvai basin. However, the underlying geology needed to verify this pathway is not exposed.

The likely source for the fresh water at FLK NN was groundwater recharged by precipitation on the 3000-m-high Ngornogoro Volcanic Highland that lay to south and east (Ashley et al., 2008). Groundwater flow (and surface runoff) would have been northwestward from the Highland toward the Olduvai basin (Figs. 1 and 6b). The basin high in the junction area was relatively impermeable compared to the overlying tuffs and sediments, and likely focused groundwater to the surface by restricting flow (Fig. 4).

The taphonomic analysis of level 22 revealed that the site was predominantly anthropogenic in origin with carnivores playing a minor role (Dominguez-Rodrigo et al., 2007). The spring would have provided an attraction and the woodland a temporary respite of safety for multipurpose activities of hominins producing tools and consuming animals (Dunnell and Dancey, 1983).

Even though the reconstruction of the site includes abundant evidence of hominin activity the context of the site has been problematic because prior reconstructions emphasize the location of the site on an exposed lake-margin flat. Lake Olduvai was a saline-alkaline playa, not a freshwater lake (Hay and Kyser, 2001; Hover and Ashley, 2003; Deocampo et al., 2009). During wetter periods the water flooded across the lake margin (Hay and Kyser, 2001) and during drier periods the lake withdrew to the west exposing a wide lake margin and the potential freshwater sources supplied from the highlands to the east (Ashley and Hay, 2002) (Fig. 3). FLK Zinj is found within this general paleoenvironmental scenario.

Tuff IC blanketed Olduvai basin at 1.839 ± 0.005 Ma, covering the Olduvai basin at or marshland (Hay, 1990). Mud at a depression 100 cm wide and 40 cm deep) incised into the FLK Zinj clay layer on the edge of excavation. This narrow steep-sided incision is more in keeping with the scale of a hippopotamus trail than a river channel (Ashley and Liitkus, 2002; Deocampo, 2002).

Our descriptive model of the paleoenvironment of the FLK Zinj site including the newly discovered evidence for a freshwater source (Figs. 2, 5A, 6) is consistent with the phytoliths reported in this study and a range of independently collected data from the site in the past 40 years. No pollen data from FLK Zinj level 22 or a stratigraphically equivalent layer are available (Bonnefille and Rirollet, 1980); however, stable isotopes (Sikes, 1994), faunal data (bovids) (Kappelman, 1984; Potts, 1988), abundant remains of the Acacia rat Thallomys (Jaeger, 1976; Gentry and Gentry, 1978), freshwater snails and urocyclid slugs (Hay, 1973) have provided abundant evidence for woody C3 floral habitats, like Acacia woodland or gallery forests.

Palaenvironnal analyses of faunas, in particular rodents, from mid-Bed I indicate a very rich closed woodland environment (Fernandez-Jalvo et al., 1998). A recent analysis of bovid taxa excavated from the FLK Zinj horizon indicates animals with a mixed grazing and browsing diet and also suggests a significant presence of C3 plants in the area (Plummer et al., 2009). Paleoenvironmental proxies, including our phytolith results from the archaeological site itself, point to a closed habitat made of undefined woody trees and/or shrubs or bushes and palms at the FLK Zinj site.

Our recent excavations have exposed a sharp difference in density of archaeological materials in most of the ca. 2000-m² area between FLK Zinj locality and the surroundings, including the FLK NN spring locality (Fig. 2). The high density patch at FLK Zinj contains the highest diversity of stone tool types and more completely butchered animal bones than the surrounding lower density samples (Dominguez-Rodrigo et al., 2010). Very few quartz and quartzite artefacts and flakes were found outside FLK Zinj, and cutmarked bones occur only at the FLK Zinj itself. None have been documented in our excavations of the surrounding landscape (Dominguez-Rodrigo et al., 2010). Carcass butchering activities were thus restricted to FLK Zinj site.

It appears that hominins were not simply using this as arboreal habitat as a refuge, otherwise, following the behaviours of modern non-human primates (Dominguez-Rodrigo et al., 2007), FLK Zinj would exhibit a much lower density of materials. The palaeoenvironmental evidence presented in this work refute all previous interpretations on the behavioral nature of the Olduvai sites based on observations made in the spring. Palaeoenvironmental analyses of faunas in particular rodents, from mid-Bed I indicate a very rich closed woodland environment (Fernandez-Jalvo et al., 1998). FLK Zinj horizon indicates animals with a mixed grazing and browsing diet and also suggests a significant presence of C3 plants in the area (Plummer et al., 2009). Paleoenvironmental proxies, including our phytolith results from the archaeological site itself, point to a closed habitat made of undefined woody trees and/or shrubs or bushes and palms at the FLK Zinj site.

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Modern foragers transport carcasses across long distances. In marked contrast, the high concentration of select parts at FLK Zinj suggests a different behaviour pattern (Faith et al., 2009). The presence of a nearby spring (the only documented source of fresh water in that part of the basin) would have been a magnet for herbivores during the dry season. Hence, hominins could have obtained carcasses at the nearby spring (FLK NN) and transported them a short distance (200 m) to FLK Zinj. Carcass availability and their exploitation in a low competition environment probably was one of the major appeals of the spring and woodland to hominins.

The dynamics of carcass acquisition and carcass transport are complex, and short-distance transport by hominins from the spring to FLK Zinj is one working hypothesis among several alternatives. For example, modern felids, such as lions and leopards, are known ambush hunters and kill their prey essentially on the spot. If similar felids were killing their prey near the spring at FLK NN, then it follows that hominins scavenging from such feld kills would face only a short transport distance. However, the bovid mortality profiles from FLK Zinj do not indicate that ambush hunting by felids was the predominant source of the bovid carcasses, and the bovid mortality

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profiles call into question any form of scavenging or persistence hunting by hominins (Bunn and Pickering, this issue).

An alternative working hypothesis is that hominins themselves were ambush hunters. Ambush hunting by modern Hadza foragers (a local tribe near Lake Eyasi) using long bows and poison-tipped arrows usually does not yield on-the-spot kills, except for the rare, paralyzing shot to the spine. Large Hadza prey animals commonly run long distances before death and must be tracked by the hunters for distances ranging up to 5 km prior to field butchery and transport (Bunn et al., 1988). If hominins were hunting large animals near the spring, they lacked such sophisticated weaponry, acquiring them and transporting portions to FLK may have involved considerable effort. This latter interpretation will have to be experimentally verified.

In summary, the spectacular high concentration of life in “the junction” appears to be caused by the interplay of rift valley-related tectonics and astronomically-controlled climate fluctuations that created localized freshwater environments in the Olduvai basin between ca 1.85–1.75 Ma (Ashley and Hay, 2002; Ashley, 2007). The consistent attraction of this site for hominins and animals from both the Ngorongoro Volcanic Highland and Serengeti grasslands was most likely the availability of fresh water at a time of increasing dryness and climate instability in Africa that coincided with early migrations out of the continent (deMenocal, 1995; Gabunia et al., 2000; Ashley et al., 2008; Ashley, 2009).

Conclusions

Field observations, isotopic analyses of the tufa found at FLK NN, in the same stratigraphic position as archaeological level 22 at FLK Zinj, and micro-botanical analyses of biogenic silica particles (phytoliths) attest to the presence of a freshwater source and a closed wooded vegetation (forest, shrub- or bushland). We conclude that the localized, high-density co-occurrence of stone tools and fossilized bones at FLK Zinj, was located approximately 200 m from a freshwater source in a wooded to densely wooded habitat. This new reconstruction suggests a site highly attractive to hominins, in stark contrast to the current consensus model of a lake margin flat with non-potable saline-alkaline water. Our study suggests that hominins selected this site for carcass transport, accumulation and processing. Future reconstructions of early Pleistocene hominin behavior will need to be tested against the taphonomic information retrieved from FLK Zinj (Fernandez-Jalvo et al., 1998), together with the new palaeoenvironmental evidence provided by this present study.

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