Sites on the landscape: Paleoenvironmental context of late Pleistocene archaeological sites from the Lake Victoria basin, equatorial East Africa

C.A. Tryon a,*, J.T. Faith b, D.J. Peppe c, W.F. Keegan d, K.N. Keegan e, K.H. Jenkins f, S. Nightingale g, D. Patterson h, A. VanPlantinga i, S. Driese c, C.R. Johnson j, E.J. Beverly c

aDepartment of Anthropology, Peabody Museum of Archaeology and Ethnology, Harvard University, 11 Divinity Avenue, Cambridge, MA 02138, USA
bSchool of Social Science, The University of Queensland, Brisbane, QLD 4072, Australia
cDepartment of Geology and Geophysics, MS 3115, Texas A&M University, College Station, TX 77843-3115, USA
dHominid Paleobiology Doctoral Program, Center for the Advanced Study of Hominid Paleobiology, Department of Anthropology, The George Washington University, 2110 G Street NW, Washington, DC 20052, USA
eDepartment of Geology, Baylor University, One Bear Place #97354, Waco, TX 76798, USA
fHeritage Consultants, LLC, 877 Main Street, Newington, CT 06111, USA
Department of History, Fairfield University, 1073 North Benson Road, Fairfield, CT 06824, USA
iDepartment of Anthropology, University of Minnesota, 395 Hubert H. Humphrey Center, 301 19th Avenue South, Minneapolis, MN 55455, USA
jDepartment of Anthropology, Graduate School and University Center, City University of New York, 365 Fifth Ave., New York, NY 10016–4309, USA
gDepartment of Geology and Geophysics, MS 3115, Texas A&M University, College Station, TX 77843–3115, USA
dDepartment of Anthropology, University of Connecticut, Box U-2176, Storrs, CT 06269, USA

A R T I C L E   I N F O

Article history:
Available online xxx

A B S T R A C T

Open-air archaeological sites record only a small fraction of the behavioral traces of mobile forager populations. Whereas caves and rockshelters were often occupied at least in part for protection from the elements, the reasons why human foragers occupied other places on the landscape (however briefly) are varied and not always readily recoverable. We develop a framework for interpreting human use of the landscape and modeling occupation of open-air sites using the archaeological and paleoenvironmental record of Middle Stone Age (MSA) sites from Rusinga and Mfangano Islands, located near the eastern margin of Lake Victoria. Paleoenvironmental reconstructions using fossil faunas suggest an arid grassland setting unlike the present. Paleoeccological modeling of the habitats of extant and extinct bovids, combined with GIS-based reconstructions of lake level change, indicate that human occupation of these sites coincided with substantial declines in the level of Lake Victoria. During this time, both Rusinga and Mfangano would have been connected to the mainland and represented local topographic highs within an extensive grassland. Geological, ecological, and ethnobotanical observations suggest that these topographic high points would likely have been important sources of stone raw material, fresh water, and a variety of plant resources for food, fuel, and other purposes. In contrast, the grassy lowland plains were probably exploited primarily as a source of large game, which included numerous species of large gregarious grazers, several of which may have followed now extinct migration routes.

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1. Introduction

In part because they provide shelter from the elements, caves and rockshelters often preserve long archaeological sequences attesting to successive human visitations. In addition to recurrent usage, caves and rockshelters favor longer-term occupations, the material residues of which may sample a wide range of the behavioral repertoire of any given population, and these behavioral traces are often better preserved than in other settings. For these and other reasons, caves and rockshelters have played a central role in Middle Paleolithic/Middle Stone Age (MP/MSA) archaeology, particularly in regions such as Western Europe, the Levant, and southern Africa. However, among mobile groups of human foragers in tropical climates, the majority of daily activities are performed outside of caves and rockshelters, creating a larger, potentially more diffuse and varied archaeological record. The material culture documented at open-air archaeological sites may reflect a range of time spans, from minutes to decades, and result from a number of
possible activities, including habitation, social gatherings, and acquiring stone, plant, or animal resources, among other possibilities. The contribution of open-air MSA sites to our understanding of hominin behavior is particularly important in areas such as eastern Africa where caves and rockshelters are relatively rare.

Key elements in the study of open-air archaeological sites are the natural and cultural factors that led humans to choose to use particular places on past landscapes. For more recent time periods, research has included catchment analyses to examine the spatial relation between sites and available resources (e.g., Jarman et al., 1972), and more formal predictive modeling of site location based on resource distribution and ethnographic or ethnographic behavior of foragers or farmers (e.g., Gaffney and Stancic, 1996; Westcott and Brandon, 2000). These approaches can be difficult to apply to the Paleolithic record, where the modern landscape may bear little resemblance to the ancient one.

Among Early Stone Age sites in eastern Africa, several long-term archaeological projects have examined variation among archaeological sites and reconstructed paleoenvironments within relatively narrow temporal intervals to identify favored places on the landscape (e.g., Potts et al., 1999; Braun et al., 2008; Blumenschine et al., 2012). Comparable landscape-scale reconstructions for MSA sites in eastern Africa have yet to be done, although there have been efforts in this direction (e.g., Barboni et al., 1995; Ambrose, 2001; Yellen et al., 2005; Assfai et al., 2008; Tryon et al., 2010, 2012; Faith et al., 2011; Brown et al., 2012). Here, we begin on these efforts to explore the reasons for open-air site occupation by MSA hominins on the eastern margins of the Lake Victoria basin in Equatorial Africa, drawing on archaeological evidence as well as approaches derived from ecology, geology, historical geography, and ethnobotany.

Lake Victoria is the largest body of water in Africa and the surrounding area today supports diverse flora, fauna and dense human populations. However, the lake is very sensitive to variation in climate, and multiple lines of evidence indicate Lake Victoria has completely dried up repeatedly during the Pleistocene. As such, the present is often a poor analog for the past. We emphasize here MSA artifacts and fossils from the Kenyan islands of Rusinga and Mfangano that date to one or more of these lake low-stands some time between ~100 ka and ~33 ka. During MSA hominin occupation, Rusinga and Mfangano were likely topographic high points within a grassy plain. In the absence of an adjacent lake margin, hominin use of the area instead may have been driven by the availability of a number of other resources, including fresh water from springs, good quality stone raw material, hunting overlook sites that likely intersected with migratory game paths, and the presence of plant materials not found in the neighboring grasslands.

2. The paleoenvironmental history of the Lake Victoria region

2.1. Evidence from lacustrine deposits

Lake Victoria (Fig. 1) is the largest lake in Africa as measured by surface area (66,400 km²). It started to form ~400 ka when tectonic uplift along the western margins of the Rift Valley caused progressive back-bonding of westward flowing rivers that previously cut across the basin (Bishop and Trendall, 1967; Johnson et al., 1996). Lake Victoria is also very shallow, with a maximum depth of 68 m, and thus modest changes in lake level can result in large increases or decreases in lake surface area. Seismic profiles across the lake show four surfaces that mark former periods of lake desiccation. The uppermost of these desiccation surfaces dates to ~15–18 ka (Stager et al., 2011), whereas the lowermost is likely the pre-lake surface developed on basement rock and Miocene sediments. The remaining two surfaces are undated (Johnson et al., 1996), although Stager and Johnson (2008) suggest a possible Late Pleistocene age of 80 ka for one of these surfaces. Raised beach deposits and wave-cut terraces at +3, +10–12, and +18 m above current water level attest to periods when Lake Victoria expanded, with only the +3 m terrace dated to ~4 ka (Temple, 1967).

Today, Lake Victoria’s water level is primarily controlled by rainfall (Piper et al., 1986; Sene and Plinston, 1994; Broeker et al., 1998), and thus the size and depth of the lake serves as a fairly sensitive rain gauge. Sedimentological, isotopic, and microfossil (pollen and diatom) data from multiple lake cores, as well as historical bathymetric records, confirm that lake level has long been strongly tied to local precipitation. For example, Lake Victoria’s water level declined during the Last Glacial Maximum or LGM (26.5–19/20 ka; Clark et al., 2009), fell rapidly with complete desiccation during Heinrich Event 1 (17–16 ka; Hemming, 2004), and expanded during the peak of the Holocene African Humid Period (15–5 ka; deMenocal et al., 2000), and has varied ±3 m in depth since the 1880s (Kendall, 1969; Nicholson, 1998; Stager et al., 1997, 2002, 2011). Pollen and isotopic data indicate the expansion and contraction of adjacent grasslands with fluctuations in relative aridity (Kendall, 1969; Talbot and Livingstone, 1989; Talbot and Laerdal, 2000, Talbot et al., 2006). These data suggest similar linkages among variability in rainfall, lake level, and the surrounding vegetation throughout the history of Lake Victoria.

2.2. Evidence from terrestrial deposits on Rusinga and Mfangano Islands

Despite good data for the history of Lake Victoria since the LGM, there is little detailed evidence for the pre-LGM history of the lake or the surrounding region. This paucity of evidence exists because sediment cores collected from Lake Victoria do not penetrate beyond the Heinrich Event 1/LGM lowstand surface and few pre-
LGM deposits have been identified or studied. However, artifact-bearing Late Pleistocene terrestrial sediments from Rusinga and Mfangano Islands within Lake Victoria (Fig. 1) provide key complementary information on the pre-LGM natural and cultural history of the region (Tryon et al., 2010, 2012).

Although connected to mainland Kenya by an artificial causeway since the 1980s, Rusinga Island (∼40 km²) was formerly separated from the mainland by a shallow (∼5–10 m) channel, whereas Mfangano Island (64 km²) lies some 10 km from the shore of Lake Victoria (Fig. 1). Maximum elevations above the lake are 297 m for Rusinga Island and 541 m for Mfangano Island, with most of Mfangano dominated by steep lava uplands (Fig. 1). The area today receives ∼800–1000 mm of rainfall per year, and prior to substantial recent human impacts, the islands were likely covered by variably dense woodlands (Andrews, 1973). Both islands are the remnants of deposition related to the eruptive history of the Kisingiri volcano during the Miocene, and share a similar bedrock lithology of Miocene lavas and volcaniclastic rocks (e.g., Van Couvering, 1972; Pickford, 1986; Drake et al., 1988; Peppe et al., 2009). On Rusinga and Mfangano Islands, poorly consolidated Pleistocene sediments accumulated at the base of each island’s central uplands and unconformably overlie Miocene deposits (Fig. 1). These Pleistocene deposits are the Wasiriya Beds on Rusinga Island that crop out over an area of ≤10 km², and the Waware Beds on Mfangano Island that are exposed over an area of ≤4 km² (Whitworth, 1961; Van Couvering, 1972; Pickford, 1986; Tryon et al., 2010, 2012). The Wasiriya and Waware Beds are primarily tuffaceous alluvial and fluviatile sediments and paleosols. Rare tufa deposits in the Wasiriya Beds indicate the former presence of springs at the Nyamita locality on Rusinga Island (Fig. 1). The generally poorly sorted, gravel and pebble-dominated fluviatile sediments are consistent with flashy, high energy, episodic deposition and erosion and suggest seasonal precipitation. The features identified in clay-rich paleosols on Rusinga (Beverly et al., 2012) also indicate precipitation seasonality, as well as seasonal soil moisture deficit (Wilding and Tessier, 1988; Coulombe et al., 1996). The presence of pedogenic slickenside surfaces, wedge-shaped peds, root traces and the abundance of smectic clay identify many of the paleosols as Vertisols (Buol et al., 2003; Southard et al., 2011) that formed when the soil expanded and contracted during repeated wet and dry cycles.

The Wasiriya and Waware beds are constrained to approximately 100–33 ka. Geochemical analyses of tephra from the islands suggest derivation from volcanic sources 250 km to the east, from volcanoes in the East African Rift Valley System that began erupting ~100 ka (Tryon et al., 2010). The timing of these eruptions provides a maximum age for the deposits. A suite of calibrated radiocarbon age estimates on the shells of intrusive gastropods (Limiocalaria cf. L. martensiana) from both the Wasiriya and Waware Beds provide minimum ages of ~33–45 ka for the deposits. These age estimates demonstrate the pre-LGM age of the Pleistocene sediments on Rusinga and Mfangano Islands. The position of these sedimentary archives on islands within Lake Victoria make them important pieces of evidence to study changes in the lake margin as a result of expansion or contraction over the last ~100 kyr.

### 2.3. Pleistocene archaeological sites on Rusinga and Mfangano islands

**In situ Stone Age archaeological sites within the Wasiriya Beds and Waware Beds demonstrate hominin occupation of Rusinga Island and Mfangano Island during one or more intervals between ~33 ka and ~100 ka.** A comprehensive survey of all Wasiriya Beds outcrops has shown that artifacts on Rusinga Island are largely concentrated at three localities (Nyamita, Wakondo, and Nyamsingula), with a single locality (Kakrigu) identified during a similarly detailed pedestrian survey of the Waware Beds on Mfangano Island (Fig. 1). As indicated by surface collections and limited test excavations (Table 1), artifacts at these open-air sites are neither abundant (n = 351) nor dense (see Tryon et al., 2010, 2012 for collection methodology). On Rusinga (n = 339) they include typologically Middle Stone Age (MSA) artifacts such as unifacially and bifacially flaked points, recurrent and preferential Levallois cores,

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Artifact counts from 2009 to 2010 field seasons on Rusinga and Mfangano Islands.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locality</td>
<td>Wasiriya Beds, Rusinga Island</td>
</tr>
<tr>
<td>Approximate site size (km²)</td>
<td>0.2</td>
</tr>
<tr>
<td>Area excavated (m²)</td>
<td>4</td>
</tr>
<tr>
<td>Artifact type</td>
<td></td>
</tr>
<tr>
<td>Complete flakes</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Non-Levallois flake</td>
<td>20 (3)</td>
</tr>
<tr>
<td>Blade</td>
<td>0</td>
</tr>
<tr>
<td>Proximal flake fragments</td>
<td></td>
</tr>
<tr>
<td>Levallois/Levallois related</td>
<td>8 (1)</td>
</tr>
<tr>
<td>Non-Levallois flake</td>
<td>17</td>
</tr>
<tr>
<td>Levallois blade</td>
<td>0</td>
</tr>
<tr>
<td>Flaking debris</td>
<td>55 (13)</td>
</tr>
<tr>
<td>Cores and core fragments</td>
<td>2 (1)</td>
</tr>
<tr>
<td>Levallois</td>
<td>0</td>
</tr>
<tr>
<td>Multiple</td>
<td>4</td>
</tr>
<tr>
<td>Casual</td>
<td>2 (1)</td>
</tr>
<tr>
<td>Disconid</td>
<td>5</td>
</tr>
<tr>
<td>Single platform</td>
<td>0</td>
</tr>
<tr>
<td>Indet.</td>
<td>0</td>
</tr>
<tr>
<td>Shaped and retouched pieces</td>
<td></td>
</tr>
<tr>
<td>Biface</td>
<td>0</td>
</tr>
<tr>
<td>Point</td>
<td>3</td>
</tr>
<tr>
<td>Retouched Levallois flake or fragment</td>
<td>1</td>
</tr>
<tr>
<td>Retouched non-Levallois flake or fragment</td>
<td>5</td>
</tr>
</tbody>
</table>

Numbers in parentheses indicate artifacts recovered from excavation.

*Please cite this article in press as: Tryon, C.A., et al., Sites on the landscape: Paleoenvironmental context of late Pleistocene archaeological sites from the Lake Victoria basin, equatorial East Africa, Quaternary International (2013), http://dx.doi.org/10.1016/j.quaint.2013.05.038*
and Levallois flakes, some retouched as scrapers, among other flake, tool, and core types (Fig. 2). The Mfangano collections are smaller \( n = 12 \) and contain bifacial points, but lack evidence for Levallois technology (Fig. 2). The Mfangano sample can likely be attributed to the MSA as well, but a larger sample size would aid attribution.

Stone artifacts co-occur with fossil fauna at all localities on Rusinga and Mfangano Islands, and our surveys suggest that this association is significant, as concentrations of only artifacts or fauna are rare. The association of stones and bones on the landscape may signal the presence of a resource, such as water, that attracted hominins and other animals to these areas. At Wakondo on Rusinga Island, cut-marked fossils demonstrate direct hominin involvement in the taphonomic history of some of the fauna (Tryon et al., 2010; Jenkins et al., 2012).

3. Modeling past lake conditions using terrestrial fauna and bathymetry

Fossil fauna are both relatively abundant and well preserved on Rusinga Island and to a lesser extent, Mfangano Island (NISP >450), and provide some of the best evidence for past environmental differences. We combine evidence from the fauna for conditions that are drier, more open, and grassland-dominated than the present with detailed bathymetric studies of Lake Victoria to model the effect of increased aridity on lake level to better understand the nature of the landscape available to MSA hominins.

3.1. Faunal evidence for reduced lake levels

The fossil mammals from Rusinga Island and Mfangano Island indicate more arid conditions than the present, and in particular, an expansion of dry grassland habitats during the Late Pleistocene (Faith et al., 2011; Tryon et al., 2012). Alcelaphine bovids dominate all fossil assemblages from Rusinga and Mfangano, indicating the presence of open, dry grasslands (e.g., Vrba, 1980). A grassland ecosystem is further supported by the locally abundant and well-preserved sample of microfauna from Rusinga Island (NISP >50), which includes Tachyoryctes (African Mole Rat) and Otomys (Groove-Toothed Rat), with extant representatives of Tachyoryctes characteristics of open grasslands or thinly treed savannas (Kingdon, 1974; Nowak, 1999). Some extant taxa from Rusinga Island, such as the oryx (Oryx beisa) and Grevy’s zebra (Equus grevyi), are distributed well beyond their modern ranges, suggesting range expansions or shifts during one or more arid intervals of the Pleistocene (Tryon et al., 2010; Faith et al., 2013). In light of the ±3 m variation in lake level since the late 19th century (Nicholson, 1998), the shallow (~5–10 m) and narrow (250 m) channel separating Rusinga Island is unlikely to have served as a long-term barrier to the movement of land animals between the island and the mainland. However, Mfangano is ~10 km from the shore, and separated from it by a ~25-m-deep channel (Fig. 1). Despite this, fossils of several species of large gregarious grazers are present in Mfangano Island’s Pleistocene sediments (Tryon et al., 2012), including plains zebra (Equus quagga), wildebeest (Connochaetes taurinus), and African buffalo (Syncerus caffer), in addition to extinct long-horn buffalo (Syncerus antiquus) and two arid-adapted alcelaphine antelopes (Rusingoryx adarocephran and Damaliscus hyposodoron) (Faith et al., 2011, 2012). The migratory habits of gregarious grazers such as wildebeest – driven by seasonal variations in resource availability – are well-documented (Kingdon, 1997; Skinner and Chimimba, 2005) and similar migrations may have also characterized D. hyposodoron (Faith et al., 2012). It is doubtful that migratory species would establish island populations that are unable to migrate in response to seasonal resource variation. Furthermore, the landmass of Mfangano Island encompasses a mere 64 km², much of which is dominated by the steep topography of Mount Kwitutu, a size insufficient to support viable populations of gregarious migratory game.

Because Lake Victoria is largely rainfall-fed, the presence of arid-adapted species and migratory grazers in the fossil fauna imply a substantial reduction in lake level and precipitation. The Wasiriya Beds and Waware Beds thus preserve evidence of hominin occupation of the area when Lake Victoria was smaller than present, and possibly absent.

3.2. GIS reconstructions

In order to model the effects of lake level reduction on the landscape implied by the fossil fauna, we used geographic information systems (GIS) analysis to reconstruct the bathymetry of Lake Victoria in the vicinity of Rusinga and Mfangano Islands. GIS analysis uses precise data that conform to established mathematical models of the shape of the earth and, where elevation is a concern, to a known zero elevation point. The choices of spheroid (model of the ellipsoid shape of the earth) and datum (model of the elevation irregularities of the earth’s surface) can significantly affect the accuracy of measurements, especially if data from multiple sources using different models are used.

We used three sources of data on the shoreline, islands, and depths of Lake Victoria. (1) The elevation of the current shoreline and nearby features (including islands) is based on scanned and digitized Survey of Kenya (1979) topographic maps of the lake area that have a known spheroid and datum. (2) Topographic and bathymetric data were collected from British Admiralty maps from the early twentieth century (UK Hydrographic Office, 1902–1956, 1911–1956). The spheroid and datum for these maps are also known, with lake surface reported as measured by a tide gauge at Port Florence in Kisumu, Kenya as 3726 ft (1135 m) above LWOS at Mombasa. LWOS refers to “Low Water Ordinary Springs,” an estimate of sea level based on observations taken of low tides during
non-equinoctial periods in the spring (United States Hydrographic Office, 1915). The depth values provided by the Admiralty charts, like most bathymetry prior to the development of global positioning systems (GPS), represent minimum values of a group of soundings, because the primary users of these charts were mariners wishing to avoid running aground (Monmonier, 2008). (3) Additional bathymetric data collected using a hydroacoustic sounder and GPS are derived from the Lake Victoria Fisheries Research Project (LVFRP) described by Silsbe (2003). Although depth recordings are dense (approximately 15 million points), the utility of these data are restricted because the bathymetry points collected by different methods could not be distinguished, the interpolation method, datum, and spheroid used are unknown, and the elevation zero point used is not stated. These uncertainties introduce unknown systematic errors into all elevation calculations, and the LVFRP data set was used to supplement the more accurate and precise bathymetric data from the Admiralty Charts.

The Admiralty and Survey of Kenya maps were georeferenced to the New Arc 60 datum (meters) in ArcGIS 9.3, and the bathymetric and topographic data they contain were digitized as points and lines and converted into meters. The LVFRP bathymetric data were also projected into New Arc 60 in ArcGIS 9.3, using an assumption that its original projection was WGS84; the resulting spatial match between the two data sets was good enough to proceed. We then edited the data set to eliminate land areas and anomalous data points, and rounded all the remaining values to the nearest meter to simplify computation. Because the bathymetric data set was still very large, we imported it into a different GIS program, IDRISI (produced by Clark University, USA), which converted the data from vector format (points) into a raster format, and further examined and edited them for anomalous points and errors. The projected bathymetric data consisted of a set of negative numbers representing distance from the lake surface, to which we added 1135 m to each (negative) bathymetric value using IDRISI’s map algebra function, yielding an elevation relative to the lake surface level. The data were then exported back into ArcGIS as vector point data where the points of the bathymetric data set and the lines of the topographic data set were combined into a single triangulated irregular network (TIN) to permit areal analysis and the display of areas that would be above water at varying lake levels.

Mapping results are shown in Fig. 3, and suggest that a drop in water level of ≤5 m (contour interval 1130 m) is required to connect Rusinga Island to the mainland, a reduction just beyond the ±3 m variation recorded since the late 19th century (Nicholson, 1998). A decline of 25 m (contour interval 1110 m) is sufficient to link Mfangano with the mainland (Fig. 3), providing a landmass of suitable size for large herds of migratory game implied by the observed fossil faunal assemblage. These values represent minimum estimates of lake margin location and lake size during hominin occupation of Rusinga and Mfangano Islands. Whether Lake Victoria was absent or if a reduced version of it was nearby during hominin occupation is presently unknown, but estimates of past rainfall budgets suggest that massive depth declines (e.g., –25 m) would have set in motion a series of feedback mechanisms that could have led to a significantly reduced or even completely desiccated the lake (Broeker et al., 1998; Milly, 1999). Either way, the environment of the area surrounding the present-day islands would have been substantially different from the modern condition.

3.3. A landscape without Lake Victoria: lowlands, uplands, and grazing lawns

Lake level decline or desiccation would have substantially altered the landscape and resources available to hominins in the vicinity of Rusinga and Mfangano Islands. Rather than islands,
Rusinga and Mfangano would have represented one of several topographic high points on the landscape of the Lake Victoria basin. With the reduction of 25 m required to connect Mfangano and Rusinga to the mainland, all of the other islands in Lake Victoria that have published evidence of MSA hominin occupation would also become connected to the mainland (Fig. 4) and similarly represent local topographically high areas. These islands include Lolui, Buvuma/Bugaia, and the Sese Islands in Uganda (Fagan and Lofgren, 1966; Nenquin, 1971; Posnansky et al., 2005). This suggests that (1) models developed for Rusinga and Mfangano may also be applied elsewhere in the Lake Victoria basin, and (2) MSA deposits on these widespread islands near the margin of Lake Victoria around much of its circumference may record the same arid interval represented by Rusinga and Mfangano. Additional fieldwork and chronometric data are needed to test the latter hypothesis.

As shown in Fig. 3, the land near Rusinga and Mfangano Islands exposed with lake level decline is characterized by a shallow topographic gradient. This trend is seen at a larger scale in Fig. 4, which suggests that much of the center of the basin is relatively flat, with the ~60 m isobath spanning an area of >100 km across. As the lake is ~68 m at its deepest, this implies a grade of 0.01% across much of the center of the basin. Although possibly traversed by seasonal slow-flowing streams or rivers when the lake was absent, much of the center of the basin was probably relatively flat lowlands with present-day islands occurring as isolated areas of higher elevation terrain near the basin margin. The central part of the basin was likely a grassland-dominated lowland area during lake desiccation. This is suggested by (1) seismic reflection data that indicates a relatively smooth topography underlying the Heinrich Event 1/LGM desiccation surface that is in places traversed by streams and rivers, (2) the abundance of hypsodont alcelaphine bovids including wildebeest and a variety of extinct forms such as Rusingorux atopocraniun and D. hypsodon from the Wasiriya and Waware Beds on Rusinga and Mfangano Islands, and (3) comparison with data from lake cores dating to the LGM and Holocene suggesting a general trend of increasing grass cover with lake level decline in the vicinity of Lake Victoria (Kendall, 1969; Talbot and Livingstone, 1989; Scholz et al., 1998; Talbot and Laerdal, 2000, Talbot et al., 2006).

Large mammalian herbivores have numerous effects on plant communities. One of the more significant effects of herd-forming grazers (e.g., wildebeest) in African grasslands is the establishment of grazing lawns (McNaughton, 1984; Cromsigt and Olff, 2008), which are intensely grazed patches of grazing-tolerant grass species. Feedback mechanisms result in grazers enhancing both the quality (nutrient content) and quantity (primary productivity) of the grazed vegetation, which in turn promotes grazing lawn formation. Grazing lawns are characteristic of East African grasslands where large gregarious grazers are present (e.g., the Serengeti) (McNaughton, 1985).

Grazing lawns are not ubiquitous across the landscape because the distribution of grazing species is limited by both abiotic and biotic factors. Among abiotic factors, topography plays an important role in mediating the distribution of grazing herbivores (Bell, 1971; Coulson and Coughener, 1991; Bailey et al., 1996; Fowler, 2002), with topographically rugged/steep areas serving as a barrier to large grazers. Grazing lawns cannot be established in such areas of limited grazing pressure, which in turn allows for the development of woody vegetation types. This can be seen here in Fig. 5, which shows the distribution of grazing lawns and woody vegetation in relation to topographic breaks in the greater Serengeti ecosystem (Ngorongoro Conservation Area, Tanzania). There is a clear boundary between the expansive grazing lawns on the flats and the woody vegetation on the topographically steep/rugged highlands formed by the Oldonyo Gof Hills.

Similar vegetation heterogeneity would have also characterized the late Pleistocene ecosystems in the vicinity of Rusinga and Mfangano Islands, and the fossil bovid assemblages of Rusinga and Mfangano are very similar to extant bovid communities from the Serengeti (Tryon et al., 2010, 2012). The dominance of grazing ungulates (14 species in Tryon et al., 2012) suggests abundant grassland habitats, and the presence of gregarious species such as wildebeest, zebra, and buffalo would have contributed to the establishment of expansive grazing lawns in the flats. At the same time, however, the numerous topographically steep volcanic cones in the region (Pickford, 1972; see also Fig. 3) and parts of Rusinga and Mfangano Islands likely supported densely vegetated woody habitats, perhaps similar to those in Fig. 5. The combined evidence suggests that what are now Rusinga and Mfangano Islands were during the Late Pleistocene local topographic high points that were more densely vegetated than an adjacent grassy plain. The Pleistocene Wasiriya Beds and Waware Beds sample sediments near the foot of these upland areas.

**3.4. Implications for hominin mobility, group size, and landscape use**

Ethnographic observations demonstrate that environmental factors, namely resource predictability and density, play a central role in the socio-territorial organization of hunter-gatherers (e.g., Dyson-Hudson and Smith, 1978; Ambrose and Lorenz, 1990; Kelly, 1995; Marean, 1997). These observations provide a framework for predicting broader patterns of MSA hominin mobility, group size, and landscape use during the Late Pleistocene within the Lake Victoria basin.

Multiple lines of evidence suggest that the landscapes exploited by MSA hominins would have been characterized by highly seasonal...
arid or semi-arid grasslands that were seasonally populated by herds of large migratory game, including zebras, wildebeest, and several extinct species. Such nomadic herds of gregarious game represent high-density resource patches, but their daily movements together with seasonal migrations render them unpredictable in space and time. The ethnographic record suggests that the combination of dense but unpredictable resource patches should promote an adaptive strategy characterized by large home ranges lacking fixed boundaries, with high residential mobility and opportunistic site relocation (Ambrose and Lorenz, 1990). Human population density should vary from low to moderate, depending on terrestrial primary productivity. The presence of arid-adapted ungulates on Rusinga and Mfangano may signal the presence of arid grasslands (<500 mm annual rainfall), in which case both terrestrial productivity and human population densities would be quite low. However, this conflicts with the impressive diversity of the fossil ungulate community (24 species) from Rusinga and Mfangano Islands, which may signal a more productive semi-arid grassland (>500 mm annual rainfall) (Faith, 2013) and perhaps moderate human population densities.

From an archaeological perspective, highly mobile and wide-ranging MSA hominin populations at low-to-moderate population densities should be associated with a diffuse archaeological record reflecting ephemeral and low-intensity occupation. Following Ambrose and Lorenz (1990), in terms of raw material exploitation, this adaptive strategy should be associated with the use of both local and exotic raw material sources.

4. Resource magnets on Rusinga and Mfangano

One or more natural resources served as ‘magnets’ to repeatedly draw hominins to Rusinga and Mfangano Islands and thus produce the recovered archaeological evidence. The presence of spring deposits on Rusinga suggests that water was one. Topographic effects provided several others. Topography plays a key role in the distribution of grazing lawns noted above, and, like Blumenschine et al. (2012), we emphasize the effects that even modest topographic change can have on site suitability for hominin use. The higher elevation parts of both islands would have provided (1) good visibility of nearby animal migration corridors, (2) high-quality stone for tool manufacture, and (3) access to a variety of vegetation types not found in nearby grassy lowlands.

4.1. Springs and fresh water sources

Tufas are sedimentary deposits formed by the precipitation of calcium carbonate minerals. In cool water systems, tufas typically contain the remains of microphytes, macrophytes, invertebrates, and bacteria that form in a persistent aqueous environment (Pedley, 1990; Ford and Pedley, 1996; Pedley et al., 2003). At Nyamita, on Rusinga Island (Fig. 1), multiple tufa deposits include a large fluvial barrage (Fig. 6A) and in situ stromatolites (Fig. 6B). These deposits indicate the presence of a ~2 km² spring-fed fresh water marsh and affiliated fresh water stream system. The tufa deposits are interbedded with tephra that identify them as contemporary with the fossil- and artifact-bearing strata at Nyamita and other localities on the island. Tufa fragments are present in Waware Beds conglomerates of Mfangano Island, but no in situ deposits were identified. The Nyamita spring deposits are adjacent to modern spring deposits, suggesting the long-term persistence of fresh water at this locality. Conglomerates and channels in the Wasiriya Beds (at Nyamita, Nyamsingula, and Wakondo) and the Waware Beds (at Kakrigu) indicate the presence of at least seasonally available water at each of these localities. Particularly during periods of increased aridity and/or lake margin retreat, a fresh water source would have been a key resource for human and non-human foragers.

The presence of at least seasonally available water at the spring (and perhaps stream channels) is consistent with elements of the faunal assemblages such as reedbuck (Redunca redunca or R. fulvorufula), kob or southern reedbuck (Kobus kob or R. arundinum), and hippo (Hippopotamus cf. amphibius), each of which indicates the presence of standing water. Although much of the fauna indicates a general dry grassland environment, the combined evidence suggests that the archaeological and paleontological sites

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investigated here are probably wetter, more densely vegetated areas within this setting. Rare megafoossil leaves (Fig. 6C) further support the presence of more dense vegetation. These include at least three species of relatively large dicot angiosperm leaves that demonstrate the presence of trees and/or shrubs surrounding the spring. Additionally, monocot fossil leaves, which are mostly likely a species of *Typha*, are clear indications of a wetland habitat with at least periodic standing water. Together, the paleobotanical evidence, though relatively sparse, suggests the tufa deposits at Nyamita were likely areas with standing water surrounded by a potentially dense stand of trees and/or shrubs, an interpretation also supported by preliminary isotopic analyses of soil carbonates and bulk organics that indicate the presence of relatively closed C3-dominated vegetation at Nyamita and other Rusinga and Mfangano localities (Garrett et al., 2010; Peppe et al., 2011).

The artifact density at the Nyamita spring and other sites is low, in apparent contradiction to the inferred importance of fresh water in a relatively dry landscape. However, this pattern is consistent with our expectations of ephemeral and low-intensity site occupations in general, and specifically for springs, where the danger of carnivore competition or the possibility of scaring away game is high (Brooks, 1978; Sampson, 2001). Although cores and core-trimming elements have been recovered (Fig. 2), extensive refitting efforts suggest that complete or extensive reduction sequences are not present at any of the sites. This is seen most clearly in the diversity of stone raw materials. Although only 339 stone artifacts have been recovered from Rusinga Island’s Wasiriya Beds, >30 different raw material types are present. These data suggest that the sites we study are locations of artifact use and discard rather than places of tool manufacture. Whereas the reduction of even a single cobble can produce hundreds of flakes in matter of minutes, sites where primarily finished tools are used and occasionally discarded will have a low artifact density regardless of the frequency of its use by hominins (e.g., Roebroeks, 1988).

4.2. Game visibility and acquisition

Their position as topographic high points overlooking grassy lowlands would have made both Rusinga and Mfangano Islands natural vantage points for tracking herds of migratory game, many species of which are found among the recovered fauna. A similar argument has been made for MSA sites at Porc Epic Cave in Ethiopia (Clark, 2001), Nasera rockshelter in Tanzania (Mehlman, 1989), and Lukenya Hill in Kenya (Marean, 1992, 1997).
Streams draining the highlands on Rusinga and Mfangano may have also provided terrain suitable for driving, corralling, or hunting game, as has been argued for GvJm-46 at Lukenya Hill (Miller, 1979; Marean, 1997). At Wakondo on Rusinga, our ongoing research focuses on an apparent mass-death assemblage of the extinct wildebeest-like Rusingoryx atopuscranion. The fossils occur in one or more related high-energy, shallow stream channels at the base of the uplands. The assemblage includes multiple cut- and chop-marked specimens and an unusual large blade-based stone tool assemblage (Jenkins et al., 2012), but whether this represents opportunistic scavenging or specialized tactical hunting (sensu Marean, 1997) is currently under investigation.

4.3. Stone raw material availability

Despite the diversity of raw material types, the lithic assemblages from Rusinga Island and Mfangano Island are dominated by locally available raw materials. From Rusinga, where sample size is larger, the majority of artifacts are made of lava (65%) and chert (29%) (Tryon et al., 2012). Of the lava artifacts, 52% are made of Lunene Lava (Tryon et al., 2012), a fine-grained nepheline that is part of a series of Miocene lava flows that cap the Miocene volcaniclastic sedimentary rocks and create prominent topographic highs in the center of the island (Shackleton, 1950; Van Couvering, 1972). Other raw material types (many represented by only a single artifact) such as quartz, quartzite, and some varieties of lava and chert, have no known source on the island, and imply the use of more distant sources indicated by our models of hominin land use. The presence of obsidian (n = 1) from sources >200 km away in particular suggests contact with distant regions either through extensive seasonal or annual territorial movement, direct procurement, or trade with other hominin groups (Tryon et al., 2012). Further support for the acquisition of resources further afield can be seen in the sample of points from Rusinga and Mfangano, the majority of which (5/6) are of raw materials not found on either island, suggesting that artifact deposition on the islands represents the end of use cycles that began elsewhere.

Several varieties of lava as well as chert are available from primary deposits (outcrops) or secondary deposits (as stream clasts) on Rusinga Island, Mfangano Island or the mainland to the east. Sampling of Pleistocene stream deposits at multiple outcrops across Rusinga Island has demonstrated that average maximum dimension of clasts for all raw materials is <7 cm. While lava represents between 55% and 83% of the clasts available in these deposits, many of these are significantly weathered and thus highly friable, making them unsuitable as material for stone tools. Furthermore, the complete absence of chert clasts in the sampled deposits strongly suggest that most if not all of the chert artifacts must have been quarried from the local outcrop or transported from sources further afield. These observations suggest that lava and chert outcrops (rather than stream gravels) may have served as a further resource that attracted hominins to Rusinga and Mfangano, with initial raw material acquisition and reduction occurring closer to the outcrops rather than from the sites currently under study.

The importance of the lava and chert outcrops on Rusinga and Mfangano is underscored by the rarity of high quality stone raw materials elsewhere in the Lake Victoria basin, particularly west of the islands. The deposits from the Miocene Kisingiri Volcano that form the bedrock of Rusinga, Mfangano, and parts of the mainland are the easternmost source of lava suitable for stone tool production in the immediate vicinity. The surrounding bedrock, and that which probably underlies most of Lake Victoria, is metamorphosed coarsely crystalline bedrock (Schlüter, 2008), generally poorly suited for tool manufacture. Archaeological sites on Lolui and Buvuma Islands in Uganda (Fig. 4) indicate that quartz is available in some areas (e.g., Van Noten, 1971; Posnansky et al., 2005). The abundance of quartz outcrops in the central part of the basin is unknown, but may have been sparse if buried by alluvium, old lacustrine sediments, or soil developed on either of these. Although inselbergs of basement rock in the central part of the basin may have provided stone raw materials when lake level was reduced, few are observed in the seismic survey data of the lake basin (Scholz et al., 1998), suggesting limited availability to hominins.

In addition to the probable rarity of outcrops of suitable stone raw materials west of Rusinga and Mfangano, secondary deposits were also likely absent in the central part of the Lake Victoria basin. Channel gradients suggest that streams draining the mainland or island highlands would not have transported suitably sized rock clasts far beyond Rusinga or Mfangano. As noted above, in the absence of Lake Victoria, any rivers crossing the central part of the basin would have traversed a shallow gradient, meaning low competence and the transport of small (i.e. sand sized and smaller) clasts. Thus, for any hominin groups operating further west toward the center of the Lake Victoria basin, Rusinga and Mfangano would have been important areas for raw material acquisition and stone tool production.

4.4. Plant resources

As discussed above, the effects of topography and foraging preferences of grazing ungulate herds play an important role in shaping the vegetation of eastern African savannas. In contrast to the grassy lowlands, the topographically high and rough areas, such as Rusinga and Mfangano Islands, would have been avoided by grazers and are likely to have supported a variety of plant resources including shrubs and trees. Such a flora would have provided several resources for hominins that may have been more predictably available than mobile or migratory game (see comparable discussion in Marean, 1997). Multiple ethnobotanical studies of modern populations in arid eastern African savanna environments indicate that these plant resources are important sources of food, medicine, fuel, and for tool construction and other purposes (see below). Although adjacent grazing lawns provided excellent fodder for migratory game herds, vegetation on the uplands on Rusinga Island, Mfangano Island, and on the present day mainland may have been particularly important to hominin foragers.

Different parts of various shrubs and trees are useful for a number of purposes. Woody parts would have been important fuel for making fire, hafting tools, and making digging sticks or hunting weapons. Some woody stems are chewed for water content, and stems, leaves, piths, roots, bark, and fruits are commonly used as food and medicine (Ichikawa, 1987; Maundu and Berger, 2001; Bussman, 2006; Bussman et al., 2006). In eastern African savannas, wooded patches are likely to occur in topographically rough areas and in areas with higher moisture availability, conditions found in the uplands of Rusinga and Mfangano and at each of the archaeological and paleontological sites discussed here. The presence of at least some tree cover is implied by the fossil leaves from Nyamita (Fig. 6C). Direct evidence of the use of plants by hominins is presently lacking. However, the ethnobotanical data emphasize the importance of shrubs and woody vegetation, and the role they likely played in shaping hominin foraging decisions and settlement locations.

5. Discussion and conclusions

The Lake Victoria basin is a dynamic environment. Although the largest lake in Africa today in terms of surface area, this important body of water expanded and contracted in response to climatic

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changes, in particular moisture availability. The history of the changes in Lake Victoria’s shape, size, and surrounding plant and animal communities, including early populations of Homo sapiens, remains largely unknown beyond the Last Glacial Maximum. Terrestrial sediments dated to ~300 ka from the near-shore islands of Rusinga and Mfangano record one or more pre-LGM arid intervals, as indicated by a suite of arid-adapted extinct and extant ungulate taxa.

During arid intervals, including the period of hominin occupation studied here, lake level dropped at least 25 m (based on our bathymetric reconstructions) and grasslands expanded. Under these conditions, Rusinga and Mfangano likely represented densely vegetated local topographic highpoints on the landscape, overlooking grassy lowlands. These topographic high points would have been important to hominin foragers for several reasons: (1) they provided vantage points to observe migratory game, (2) they contained outcrops of high quality raw material, and (3) they included a range of potentially useful plants not found in the lowlands, and (4) water, probably rare in the surrounding environment, was available at a spring or in seasonal streams. The archaeological record of Rusinga and Mfangano Islands is sparse, but lithic raw material diversity in particular suggests repeated visits to these locales.

The effects of even minor changes in topography can have important impacts in savanna environments in eastern Africa. We have modeled some of these for the eastern margin of Lake Victoria, but similar factors likely explain hominin use of other open air sites, as has already been suggested for Oldowan sites at Olduva Gorge, Tanzania (Blumenschine et al., 2012). We will continue to refine and test the hypotheses presented here through our ongoing fieldwork on Pleistocene sediments on Rusinga and Mfangano Islands as well as the adjacent mainland.

Acknowledgments

Research presented here was conducted under research permit NCS/5/002/R/576 issued to Tryon by the government of the Republic of Kenya and an Exploration and Excavation License issued by the National Museums of Kenya. Funding was provided by the National Science Foundation (BCS-0841530, BCS-1013199, and BCS-1013108), the National Geographic Society’s Committee for Research and Exploration (8762-10), the Leakey Foundation, the Geological Society of America, New York University, Baylor University, and the University of Queensland. We thank Drs. Emma Mbuia, Kieran McNulty, William Harcourt-Smith, Holly Dunsworth, and Albert, R.M., Njau, J.K., Prassack, K.A., 2012. Landscape distribution of Oldowan stone artifact assemblages across the fault compartments of the eastern Olduvai Lake Basin during early lowermost Bed II times. Journal of Human Evolution 63, 384–394.

References


Faith, J.T., 2013. Ungulate diversity and precipitation history since the Last Glacial Maximum in the Western Cape, South Africa. Quaternary Science Reviews 68, 191–199.


