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Middle Stone Age archaeology at Olduvai Gorge, Tanzania

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ABSTRACT

This paper describes the motivation, procedures, and results of archaeological and geological field survey of the Ndutu Unit, Olduvai Gorge, conducted in June and July of 2013. Survey focused upon the area of Olduvai Gorge between the second fault and the Obalbal depression, although selective survey occurred in other areas in and around the Gorge. Over 72 archaeological find-spots were recorded, and hundreds of Middle Stone Age (MSA) artifacts were recovered, as was a small sample of fauna. Geological observations provisionally suggest that the Ndutu was formed, in part, from a series of pyroclastic density flow and ash fallout events from neighbouring volcanoes; this contrasts slightly with previous interpretations of the deposits in that at least some of the beds are thought to be in primary stratigraphic context. Our initial field findings are conducive to discussions of a number of issues directly relevant to the MSA in East Africa, and overall we conclude that there is strong potential for Olduvai's Ndutu Unit to shed light on the behavior, adaptations, and evolution of *Homo sapiens* prior to, during, and just after its physical emergence.

> "*Although Olduvai Gorge in northern Tanzania is arguably the world's most famous and best studied Lower Pleistocene locality, remarkably little is known about the archaeology of its late Quaternary deposits.*"
>
> Brandt and Mabulla 1990

> "*Surprisingly, despite investigation since the 1930s and the presence of relevant archaeological material, Olduvai Gorge in Tanzania has played little role in our understanding of MSA sites in eastern Africa…*"
>
> Tryon and Faith 2013

1. Introduction

In order to understand the behavioral adaptations and cultural evolution of *Homo sapiens sapiens* just prior to, during, and immediately after its physical emergence ca. 195,000 years ago (Ingman et al., 2000; Clark et al., 2003; White et al., 2003; Shea et al., 2007; Shea, 2008), research on the African Middle Stone Age (MSA) is of crucial importance (Blome et al., 2012: 563–564; McBrearty and Brooks, 2000; Shea, 2008; Tryon and McBrearty, 2006; Tryon et al., 2008: 662; 2010: 657; Tryon and Faith, 2013). Moreover, the study of Late Pleistocene human dispersals around the globe can also be directly linked to the African MSA, as a number of researchers have recently suggested that research into the African MSA may potentially reveal the origins of adaptive mechanisms — as well as the environmental and demographic contexts in which those mechanisms evolved — that allowed humans to colonize new environments in Asia, Europe, and the Americas between 70,000 and 10,000 years ago (e.g. Ambrose, 1998a; Assefa et al., 2013; Basell, 2008; Beyin, 2013; Blome et al., 2012: 563–564; Brandt et al., 2012: 38–39; Chiotti et al., 2007; Dewar and Stewart, 2012; Rose et al., 2011; Shea, 2008: 480; Stewart et al., 2012; Tryon et al., 2010: 657–658, 2012: 15).

Despite the importance for understanding hominin behavioral evolution that the African MSA may hold, there exist three clear gaps in our knowledge of the period. First, our understanding of the MSA has been overwhelmingly dominated by a geographic focus of South Africa. Conard (2008: 176) asserted that, "no other region in

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Africa provides a comparable wealth of indications of complex behavior", while in a recent volume Dusseldrop (2012: 1) noted that "southern Africa is overrepresented" (see also Lombard, 2012: Appendix). This disproportionate geographic focus naturally leads to questions: How typical across Africa are South African MSA hominin behaviors? Did those behaviors originate in South Africa and transmit northward, were they an isolated occurrence, or were they adopted from elsewhere? If South African MSA hominin behaviors are different from those present in the rest of the continent, how exactly do they differ? What is the temporal "pace" of behavioral evolution in the South African MSA versus other regions?

A natural place to look for comparisons to the South African MSA archaeological record is in the northerly adjacent region of East Africa, but this prompts the second knowledge gap. There are few East African sites from which to glean information from this pivotal time period. Basell (2008) recently estimated there were fewer than 40 MSA sites in all of East Africa with any sort of chronometric control (East Africa = Tanzania, Kenya, Ethiopia, Somalia, Eritrea, Eastern Sudan, Uganda, Rwanda, Burundi). Pleurdeau (2005) has noted in his research on the Ethiopian MSA that "African MSA key sites are rare." Tryon et al. (2005: 200–201) have stated that comparable studies for the African MSA are lacking for most of the African continent, but the problem "is particularly pronounced in eastern Africa" (see also Tryon and Faith, 2013). Ambrose (2001: 22) notes that "in comparison to the LSA, [in East Africa] MSA sites are rare." Others have also recently taken note the dearth of East African MSA sites (Barham and Mitchell, 2008: 279; Cornelissen, 2003: 2; Leplongeon and Pleurdeau, 2011: 213), which is all the more puzzling considering that "compared to other regions of the continent the MSA in East Africa has the longest and most continuous record" (Assefa, 2006: 51), and the data already acquired from the region are quite compelling (e.g. Ambrose, 1998b; Basell, 2008; Dickson and Gang, 2002; Diez-Martin et al., 2009; Eren et al., 2013; Gliganic et al., 2012; Johnson and McBrearty, 2010; Marks and Conard, 2007; McBrearty and Brooks, 2000; Mehlman, 1989; Mercader, 2009; Mercader et al., 2009; Shea, 2011; Shea and Hildebrand, 2010; Tryon and McBrearty, 2002; Tryon and Faith, 2013; Willoughby, 2001, 2009, 2012).

The third knowledge gap in our understanding of the African MSA involves the context in which sites are recovered. As "most MSA sites are caves or rockshelters" (Dusseldrop, 2012: 1; see also Barham and Mitchell, 2008: 279; Assefa et al., 2013; Sahle et al., 2013; Groucutt and Blinkhorn, 2013: 2), there is a relative shortage of dated open-air sites, which means we are missing a substantial component of MSA hominin behavior involving their utilization of the open landscape for hunting, acquiring resources, wayfaring, and habitation (see Tryon and Faith, 2013; Tryon et al., 2013). Recent intensive efforts have successfully begun to rectify this sample bias, especially via Tryon's East African MSA open-air research program (Tryon, 2006, 2010; Tryon et al., 2005, 2008, 2010, 2013; Tryon and Faith, 2013; Tryon and McBrearty, 2002, 2006) and the work of others (e.g. Ambrose, 2001; Clark et al., 2003; Dickson et al., 2004; Johnson and McBrearty, 2012; Kelly and Harris, 1992; Kelly, 1996; Mercader et al., 2008, 2012; Sahle et al., 2013; Shea, 2008; Sisk and Shea, 2008; Yellen et al., 2005; for earlier MSA open-air research projects see; Isaac et al., 1972; Kurashina, 1978; McBrearty, 1981; Wendorf and Schild, 1974; Wendorf et al., 1975; Wendorf and Schild, 1993). However, there is no question that more work in this arena needs to be done given that "among mobile groups of human foragers in tropical climates, the majority of daily activities are performed outside of caves and rockshelters" (Tryon et al., 2013:1).

Thus, (1) to better understand MSA hominin behavior in a geographic location outside of South Africa, (2) to increase the number of East African MSA sites and amount of available comparative data, and (3) to contribute to the growing emphasis on understanding African MSA hominin behavior in open-air contexts, we initiated an archaeological research program in the Ndutu Beds of Olduvai Gorge, Tanzania in June and July of 2013. The primary goal of the pilot field season simply was to assess the potential for future MSA open-air research. Although archaeologists have known about the presence of MSA artifacts at Olduvai Gorge for quite some time (Leakey et al., 1972; Hay, 1976), our fieldwork was the first systematic study to evaluate the extent and density of MSA material present. We report here on the results of this initial fieldwork, which, in light of previous studies on Olduvai's MSA (described below in Section 1.2), suggests that Olduvai Gorge possesses extremely high potential for contributing to the three knowledge gaps identified above, as well as to the study of MSA hominin behavioral adaptation and evolution more generally.

1.1. *Olduvai Gorge, Tanzania*

The East African Rift System (EARS) extends from the Gulf of Aden, through Ethiopia and Kenya, to Northern Tanzania. Rift-associated volcanism began in Ethiopia around 30 Ma, then migrated southwards through Kenya and initiated in northern Tanzania around 8 Ma (Dawson, 2010). The current day topography is characterized by elongate basins filled with volcanic sediments and fresh and saline lakes, as large scale extensional fracturing of the African plate took place as the Somalia Micro-Plate was driven eastwards from the Nubian Plate in response to deep-seated tectonism.

Olduvai Gorge is located within the northern Tanzanian volcanic province about 40 km to the northwest of Ngorongoro caldera. The gorge cuts through sediments in a Pleistocene palaeobasin which formed around 8 Ma during a period of major faulting. The saline Lake Olbalbal has been present in this depression throughout much of the time to present. At around 2 Ma there was a minor episode of faulting that resulted in formation of large basaltic-trachyte shield volcanoes in the nearby crater highlands. Between 1.0 and 1.2 Ma there was a major episode of faulting which gave rise to the modern rift valley topography. Between 0.4 Ma and the present day there was minor faulting on the floor of the rift valley, which was accompanied by volcanism that formed various stratovolcanoes such as Ol Doinyo Lengai. The Olduvai succession is approximately 140 m thick and consists of seven formations that include pyroclastic, fluvial and alluvial input (Hay, 1976): from oldest to youngest these include Beds I–V, and the Masek, Ndutu and Naisiusiu Beds.

1.2. *Previous archaeological research*

To our knowledge, there have been two previous studies of MSA archaeology at Olduvai Gorge. The first was by Leakey et al. (1972), who described 120 lithic specimens. These specimens were collected from two Ndutu localities east of the Second Fault, but unfortunately the localities were not identified (although it seems likely that these localities were 4b and 26, based on Hay, 1976: 159). There is no mention that the collection procedure was either extensive or systematic. The assemblage consisted of a variety of artifacts characteristic of the MSA, including flakes with thick, facetted platforms and discoidal and Levallois cores (Leakey et al., 1972: 332–333). There was an apparent lack of retouched tools (Leakey et al., 1972: 333), a phenomenon recently documented in other open-air MSA contexts (e.g. Shea, 2008: 451, 477; Thompson et al., 2012; Tryon et al., 2008: 658; Tryon et al., 2010: 664; Tryon et al., 2012: 32). Of the collected stone flakes, Leakey et al. (1972: 333) report that “convergent” (triangular) shapes are a significant component, and that a number of flakes show “irregular chipping that appears to be the result of use”. Olivine basalt was described as the predominant raw material ($n = 112$, 93%), but seven specimens were produced on phonolite (6%), and one was on quartz (1%). For the purposes of further examination and description, M.I.E. and A.Z.P.M. attempted to locate this assemblage in the storage facility at the old Leakey Camp located at Olduvai Gorge, but a thorough inspection of the facility was unsuccessful. To our knowledge, the location of this assemblage is currently unknown.

The second study of the MSA at Olduvai Gorge was a reconnaissance and test excavations of the Ndutu Unit in 1989–1990 by the Tanzanian Antiquities Department, University of Dar es Salaam, and the University of Florida (Mabulla, 1990a, 1990b; see also; Brandt and Mabulla, 1990). This work discovered a few surface find-spots and sites in “Ndutu-like” deposits which yielded MSA-like artifacts such as “light and heavy duty scrapers, core choppers, and discoidal and biconical cores” (Brandt and Mabulla, 1990: 2–3). However, no sub-surface artifacts were uncovered during excavation (Brandt and Mabulla, 1990:2). The Tanzanian and American teams also excavated test units of Hay’s (1976) geological type site for the Ndutu Unit, locality 26, to a depth of 60 cm (Brandt and Mabulla, 1990: 3). These excavations “revealed a diffuse scatter of *in situ* MSA artifacts, including a bifacial point, fossilized faunal remains composed essentially of large herbivores, and several ostrich egg shell fragments” (Brandt and Mabulla, 1990: 3). Human remains of an anatomically modern human skeleton were also uncovered “a few hundred meters east” of Locality 26, but the age of the skeleton “remains unresolved” (Brandt and Mabulla, 1990: 4).

These two studies clearly demonstrated the existence of MSA archaeology at Olduvai Gorge, and in which deposit that archaeology was to be found. However, because these early projects were somewhat restricted in scope, the density and character of Olduvai’s MSA archaeological record has remained relatively unknown, as has its potential for contributing to broader issues of *H. sapiens*’ behavioral evolution and adaptations. As the opening quotes of this present report suggest (Brandt and Mabulla, 1990; Tryon and Faith, 2013), the ambiguity surrounding the MSA at Olduvai seems acutely odd, especially given the numerous contributions Olduvai Gorge has made to Lower Pleistocene archaeology (e.g. Domínguez-Rodrigo and Barba, 2006, 2007; Dominguez-Rodrigo et al., 2007; Leakey, 1965; Leakey, 1971; Leakey and Roe, 1995; Tobias, 1967, 1991), as well as the influential role Olduvai has played in the history of Paleolithic research and in the public’s awareness and understanding of human evolution (e.g. Bowman-Kruhm, 2010; Cole, 1975; Morell, 1996).

Previous attempts to date the Ndutu and Naisiusiu Beds focused on non-organic matter such as calcretes (Hay, 1976), however, this approach was later considered to be unreliable due to ground water leaching effects (Manega, 1993). Manega (1993) provided the most comprehensive dating effort on the Ndutu Beds and employed a single crystal laser fusion (SCLF) dating technique. This measurement technique applies $^{40}Ar/^{39}Ar$ dating on individual mineral crystals in a population of sediment grains. SCLF dates from Ndutu samples collected from deposits mantling valley sides provided an age range estimate of 0.21–0.45 Ma (bulk weighted mean age of 0.23 ± 0.01 Ma), with two clusters of sediment age around 0.22 ± 0.09 Ma and 0.38 ± 0.02 Ma. Amino acid and atomic mass spectroscopy ^{14}C study of ostrich egg samples collected in the Ndutu provided an age of at least 260 ka, up to a maximum age of 500 ka. In the same work, the Naisiusiu Beds were dated at 0.042 ± 0.01 Ma (using SCLF on biotite crystals) which indicates that there was probably a significant hiatus between deposition of each unit. This contrasts somewhat with more recent work that used electron spin resonance (ESR) to date teeth in the Naisiusiu to around 62 ± 5 ka (see Milliard, 2008; Skinner et al., 2003).

2. Methods

Pedestrian survey of the Ndutu deposit, as well as artifact analysis, was carried out over 21 days during the summer of 2013. We focused our efforts on the geographic area between Olduvai’s Second Fault and the Olbalal, a distance of approximately 4 km (Figs. 1 and 2). This geographic focus was chosen for our pilot field season for several reasons. First, the two MSA archaeological localities, 4b and 26, described by Leakey et al. (1972) and Hay (1976) were located in this area, and our aim was to relocate to relocate these sites. Second, the area in and around the main gorge east of the Second Fault is unique in that “extensive exposures” still remain of the Ndutu unit, whereas west of the second fault the lower unit is represented by “only a few patches” (Hay, 1976: 146). Finally, Hay (1976: 159) noted that isolated MSA artifacts occur widely in the Ndutu Unit, and these are “most common… in sediments deposited adjacent to the main stream east of the second fault.” In addition to this geographic focus between the Second Fault and the Olbalal, we also selectively surveyed locations west of the second fault (Fig. 1, Spots #1, #2, #3).

Pedestrian survey consisted of team members walking along the valley sides, and beside natural sections, of the Ndutu deposit, which is located at the top of the Gorge and therefore just inside the Gorge’s perimeter. Vegetation cover was mostly sparse, and surface visibility was generally clear. Basalt, quartz, and phonolite artifacts were different colors than the Ndutu sediments that contained them, permitting easy identification. As the Ndutu Unit is deposited at the top of the Gorge, any displaced artifact at the elevation of the Ndutu Unit could be confidently attributed to it, especially as most lithic artifacts exhibited characteristics typical of the MSA (see Section 3.2.1 below). There was one exception to this rule. In a few locations we found small chert artifacts, morphologically reminiscent of the East Africa Holocene, resting upon the slopes of the Ndutu Unit. As none of these artifacts were *in situ*, and none appeared morphologically characteristic of the MSA, we initially suspected that they were being transported into the Gorge from Holocene occupations on or near the Gorge’s periphery. Our suspicion was corroborated by two observations. First, above a few select locations where chert artifacts were lying upon the slopes of the Ndutu Unit, we were able to identify the source chert concentrations on the landscape surface outside the Gorge (Fig. 3). Second, we discovered a natural chert ledge at the uppermost section of the Gorge that was capturing chert artifacts before they could fall further to rest upon the slopes of the Ndutu Unit (Fig. 4).

Upon encountering an artifact, either *in situ* within the Ndutu Unit or displaced but still at the same elevation of the Ndutu Unit, forward progress was suspended and focus shifted to recovering a sample of artifacts within the immediate find-spot vicinity. Find-spots were recorded at roughly the center of artifact distributions with a handheld Global Positioning System (GPS) accurate to ±3 m. Artifact samples were collected and bagged according to their find-spot.

Artifacts were classified according to generalized morphological categories (Table 1), and basic measurements and raw material type were recorded. Mass (g), length (mm), width (mm), and thickness (mm) were recorded on all specimens. From lithic specimens possessing a striking platform, platform type, platform depth (mm), and platform width (mm) were also recorded.

Table 1
General morphological classes of artifacts recovered during survey of the Ndutu Formation. The sum totals in the bottom row were calculated from the 'general category' counts. The "Core/hammerstone" category consisted of specimens with peck marks that appeared to be from use as a knapping percussor, but also exhibited flake removals.

General Category	Sub-category	*n*	Total mass (g)	Basalt *n* (mass)	Quartz *n* (mass)	Phonolite *n* (mass)	Unidentified *n* (mass)
Cores		75	22,057	39 (15,971)	35 (5888)	1 (198)	0
	Levallois	18	11,754	18 (11,754)	0	0	0
	Discoidal	28	5662	10 (1638)	17 (3826)	1 (198)	0
	Angular	7	1169	3 (518)	4 (651)	0	0
	Unidirectional	4	838	2 (702)	2 (136)	0	0
	Bipolar	6	350	2 (166)	4 (184)	0	0
	Core/hammerstone	6	895	0	6 (895)	0	0
	Not classified	6	1389	4 (1193)	2 (196)	0	0
Flakes and debris		431	13,500	226 (8981)	174 (2991)	27 (1213)	4 (313)
	Debitage (including possible Levallois flakes)	427	13,253	223 (8853)	173 (2872)	27 (1213)	4 (313)
	Possible retouched specimens	4	247	3 (128)	1 (119)	0	0
Triangular specimens		10	500	7 (406)	2 (57)	1 (37)	0
Miscellaneous items		5	2332	4 (2188)	1 (144)	0	0
	Hammerstone	2	355	1 (211)	1 (144)	0	0
	Biface	1	488	1 (488)	0	0	0
	Flaked cobble	2	1489	2 (1489)	0	0	0
Sum totals		521	38,389	276 (27,546)	212 (9082)	29 (1448)	4 (313)

3. Results

3.1. Stratigraphic reconnaissance survey of the Ndutu Formation

The Ndutu Formation overlies the distinctive red-brown beds of the Masek formation and is present as an almost continuous series of beds in the upper section of Olduvai Gorge, which can be found in the East Gorge in sections from the Second Fault to Olbalbal Basin (Fig. 5, upper). According to Hay (1976), the Ndutu is sub-divided into the Lower Ndutu and Upper Ndutu units, discriminated by the presence of coarse conglomeritic layers in the lower unit (Fig. 5, lower). The Upper Ndutu unit was found in places to mantle pre-existing topography (Fig. 5, upper). Furthermore, at some localities a distinctive whitish tuff bed is present (referred to as the "Marker Tuff" by Hay, 1976) (Fig. 5, middle).

The Ndutu type section was re-visited at waypoint 78 of the current study (locality 26 of Hay, 1976). The Upper Ndutu (Fig. 6) consists of ~6 distinct beds, which may also be subdivided based on textures such as bioturbation (Fig. 7) or stratification (Fig. 8) structures. The upper bed of the Upper Ndutu can be broken into 3

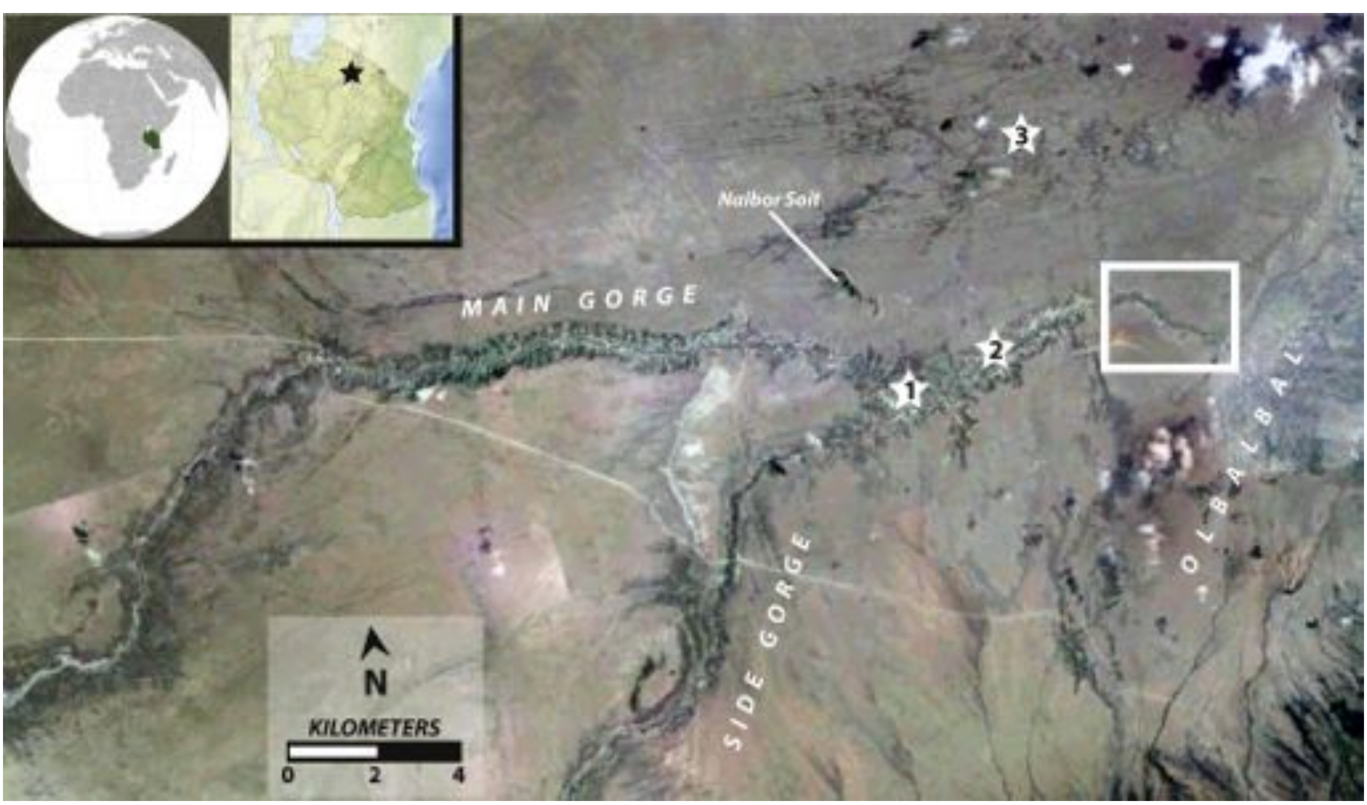

Fig. 1. Olduvai Gorge, Tanzania. The principal area of the 2013 Ndutu Formation field survey was within the rectangle area east of the second fault, but points #1, #2, and #3 also yielded MSA find spots. Point #1 was the R.A.C. locality, which yielded a significant number of artifacts.

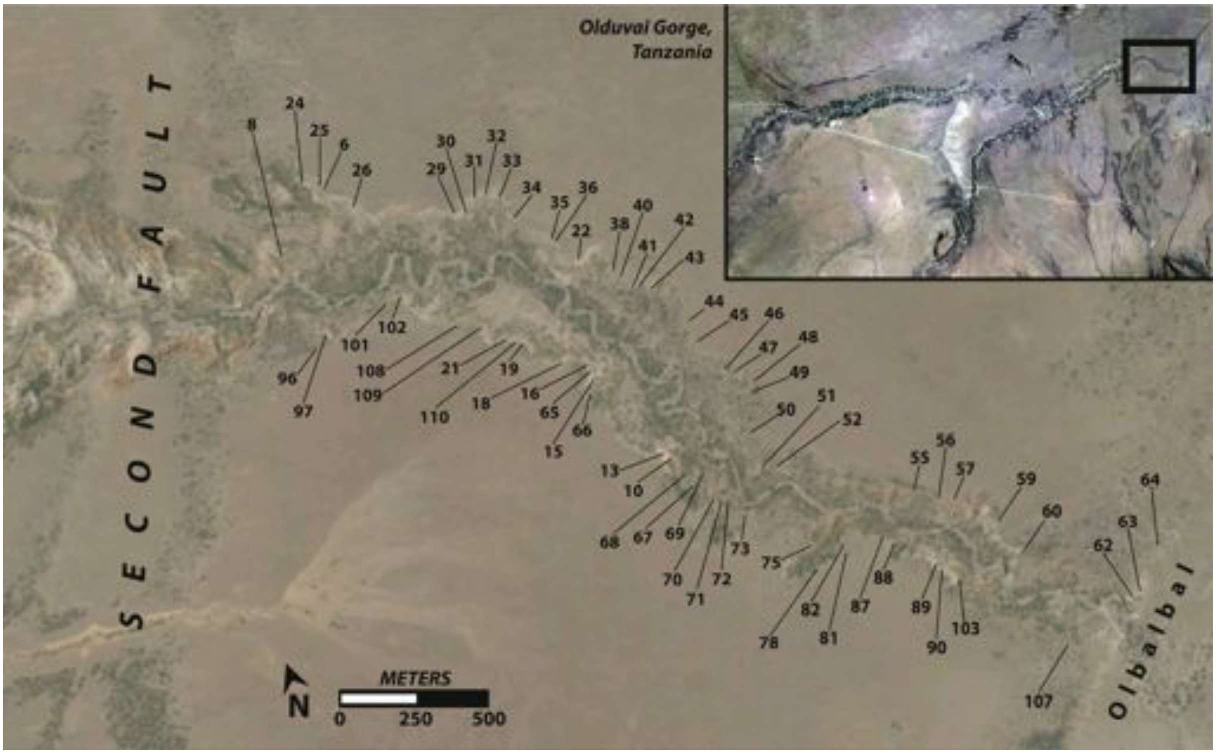

Fig. 2. A close-up view of the chief Ndutu survey area, east of Olduvai's second fault. A total of 69 MSA find-spots were recorded.

sub-units based on the presence of continuous root mould horizons (Figs. 6 and 7), which indicate hiatuses between depositional events. Furthermore, observations of trace fossil animal tracks support hiatuses, and suggest that there was wet sediment present at the surface at times (Fig. 9). Artefacts were found *in situ* in the beds towards the top of sections in the Upper Ndutu (Fig. 10). Frequently, artefacts were collocated with snail shells, possibly *Limicolaria*, which were collected for dating.

At present, vegetation dominated by *Acacia* is established in tributary gullies and on the slopes of the gorge, which can persist through dry periods due to the ability to tap sub-surface water in stratigraphic units under the Serengeti Plain sourced from surrounding topographic highs on either side of the Rift Valley (Fig. 11). There is abundant evidence that trees were also present in areas of the gorge at the time of deposition of the Ndutu beds. At several Ndutu outcrops, tree fossil moulds were observed in tuff

Fig. 3. An example of presumably recent (i.e. Holocene) chert artifacts on the surface of the Serengeti Plain, just outside of Olduvai Gorge.

Fig. 4. This natural ledge presumably caught recent (i.e. Holocene) chert artifacts before they could wash further into the Gorge and rest on the Ndutu surface.

sub-units (Fig. 12): in the majority of cases, the tree moulds were oriented horizontally, while at one locality (WP60) *in situ* fossil tree stump casts were found (Figs. 13 and 14).

These observations suggest that the trees were standing upright in place during the depositional event, and were located in and around the gorge. At some point in time, an eruption from one of the neighbouring volcanoes took place that generated ash fallout and pyroclastic density currents. As evidenced by ignimbrite deposits at the mouth of the gorge, pyroclastic density currents on occasion travelled into the gorge from neighbouring volcanoes. The highly destructive force of these flows is well documented and may explain the horizontal tree limb casts and stumps found in the Upper Ndutu. Ash fallout tends to coat surfaces and would have created deposits on the leaves and branches of the trees and, given the high density of volcanic ash, may have caused branches and/or leaves to break off and fall to the ground.

Taking these observations together, it is proposed that the Upper Ndutu was formed, in part, from a series of pyroclastic density flow and ash fallout events from neighbouring volcanoes; this contrasts slightly with previous interpretations of the deposits in that at least some of the beds are thought to be in primary stratigraphic context. Pyroclastic flows originating from volcanoes around the Ngorongoro complex would have inundated the gorge and formed deposits of the order of 10–30 cm, according to the pre-existing topography. Furthermore, ash fallout also occurred at times, for example, which generated the distinctive “marker tuff” horizons. In some cases, extremely biotite-rich beds were found (Fig. 15), which is a characteristic of tephras erupted from Ol Doinyo Lengai. Subsequent post-depositional re-working resulted in discontinuous layers preserved in pre-existing topographic lows.

3.2. *Middle Stone Age archaeology and fauna*

In total, we recorded 72 MSA archaeological find-spots, and recovered 521 MSA flaked stone specimens (Table 2), as well as a small sample of fauna. The pedestrian survey between the second fault and the Olbalbal Lake yielded 69 find-spots (Fig. 2). Find-spot 107 (M.K.E. locality), yielded a high concentration of lithic specimens ($n = 91$) and appeared to be a tool-production site. The interval between find-spots 29–36 (N.S.E. locality) also yielded a high concentration of lithic specimens ($n = 99$). Other find-spots produced either small numbers of artifacts or isolates, either on the surface, or *in situ* (Fig. 10). We found only small samples of artifacts in the vicinity of Leakey et al.'s (1972) and Hay's (1976) localities 4b and 26 (see Hay, 1976: 2–3, Fig. 3). We did not see any remnants of the excavations conducted by the Tanzanian and American team in 1990 at locality 26, but as that work consisted of only three 1 by 2 m test squares (Brandt and Mabulla, 1990: 3), this was not surprising.

Table 2
The lithic specimens count and mass of lithic specimens per find-spot.

Find-spot	Number of lithic specimens (In situ)	Mass of lithic specimens (In situ)	Find-spot	Number of lithic specimens (In situ)	Mass of lithic specimens (In situ)	Find-spot	Number of lithic specimens (In situ)	Mass of lithic specimens (In situ)
#1 (115–116)	163 (3)	11,936 (769)	38	2	78	67	1	52
#2 (DK)	2	71	40	2	52	68	2	58
#3 (93–94)	2 (1)	28 (10)	41	1	47	69	6	390
6	2	446	42	1	2	70	3	160
8	2 (2)	1890	43	1	7	71	1	25
10	1	39	44	1	16	72	1	68
13	1	6	45	2	128	73	6	5586
15	3	359	46	3	23	75	1	54
16	4	141	47	1	36	78	4 (1)	113 (6)
18	1	27	48	4	123	81	3	56
19	5	38	49	1	6	82	1	179
21	1	28	50	1	19	87	1	23
22	9	80	51	2	143	88	8	82
24	3	22	52	1	283	89	1	10
25	9	370	55	1	68	90	3 (2)	122 (78)
26	2	72	56	1	450	96	3 (1)	37 (9)
29	2	99	57	1	25	97	2 (1)	47 (30)
30	38 (4)	995 (75)	59	8 (3)	408 (262)	101	1	203
31	4	39	60	6	2442	102	1 (1)	18 (18)
32	13	1129	62	1	9	103	1	16
33	19	1932	63	1	364	107	91	4625
34	2	74	64	2	275	108	8	355
35	11	200	65	11	199	109	2	16
36	10	669	66	1	26	110	5 (2)	175 (147)

We located three find-spots west of the second fault (Fig. 1). Of these, find-spot #1 (R.A.C. locality) appeared to be a major site, yielding 163 lithic specimens, including three *in situ* (Fig. 16).

Taphonomically, we perceived that there might be a possible correlation between MSA find-spots and animal entry points into the Gorge (Fig. 17). While future research should examine this connection further as a potentially productive way to discover sites, we are currently hypothesizing that constant animal foot traffic at entry points erodes and horizontally “deflates” the Ndutu deposit, exposing collections of artifacts.

3.2.1. *Lithic technology*

Following Tryon et al. (2012: 24), here we treat our recovered Olduvai sample in aggregate. Although we acknowledge that aggregate surface collections have limited resolution for answering some questions, they are appropriate for answering other questions, as well as for providing a foundation for formulating new hypotheses. The frequency, masses, and raw material types of different artifact classes is summarized in Tables 1 and 2, and descriptive measurements and other aspects of the assemblage are available in Tables 3–7.

Table 3
Sample size (n), mean ($\bar{x}$), median (Med), and standard deviation (s) of descriptive core measurements per core category, and for all cores. Mass was measured in grams (g), and length, width, thickness were measured in millimeters (mm). Length was measured as the maximum dimension between the farthest two points on the core. Width was recorded as the maximum dimension at the midpoint of, and perpendicular to, the length measurement. Thickness was measured orthogonally to width.

Core category	n	Mass (g)			Length (mm)			Width (mm)			Thickness (mm)		
		$\bar{x}$	Med	s	$\bar{x}$	Med	s	$\bar{x}$	Med	s	$\bar{x}$	Med	s
Levallois	18	653.0	243.5	1057.4	8.9	7.2	6.0	6.6	6.4	3.7	4.0	3.1	2.7
Discoidal	28	202.2	118.0	274.3	6.5	6.1	2.6	5.2	4.7	2.0	3.4	2.7	1.7
Angular	7	167.0	126.0	107.3	7.4	6.9	3.0	4.8	4.8	0.7	3.1	3.0	0.7
Unidirectional	4	209.5	215.5	164.0	7.3	7.3	2.7	5.0	4.6	1.3	3.3	3.4	1.4
Bipolar	6	58.3	60.0	24.4	4.6	4.4	1.1	3.5	3.4	0.6	2.4	2.4	0.6
Core/hammerstone	6	149.2	133.0	71.9	5.6	5.8	0.7	4.6	4.4	0.8	3.8	3.2	1.1
Not classified	6	231.5	191.0	143.2	7.5	7.8	2.3	5.2	5.5	1.0	3.9	4.0	1.0
ALL CORES	75	294.1	123.0	575.4	7.1	6.0	3.7	5.3	4.7	2.4	3.5	3.0	1.8

Table 4
Platform depth, width, and type recorded from all flakes and debris possessing a striking platform.

Raw material category	n	Platform depth (mm)			Platform width (mm)			Platform type (n, %)				
		$\bar{x}$	Med	s	$\bar{x}$	Med	s	Plain	Dihedral	Facetted	Cortical	Concave
Basalt	124	0.9	0.9	0.5	2.6	2.4	1.2	57	34	29	2	2
Quartz	68	0.7	0.7	0.4	1.7	1.4	1.0	44	11	6	7	0
Phonolite	11	0.7	0.5	0.5	1.7	1.7	1.1	7	1	3	0	0
Unidentified	2	1.6	1.6	2.1	3.25	3.25	3.46	2	0	0	0	0
All flakes and debris	205	0.9	0.8	0.5	2.3	2.2	1.2	110 (54%)	46 (22%)	38 (19%)	9 (5%)	2 (1%)

Table 5
Descriptive data of pointed, triangular specimens. See Figs. 24 and 25 for images. Pointed specimens are either naturally triangular or unifacially retouched into triangular shape. No bifacially flaked pointed specimens were found.

Waypoint	Raw material	Mass (g)	Length (mm)	Width (mm)	Thickness (mm)	Platform depth (mm)	Platform width (mm)	Platform type
107	Basalt	27	4.2	3.3	1.0	1.3	2.9	Dihedral
116	Quartz	48	5.8	3.5	1.5	1.4	4.7	Dihedral
116	Phonolite	37	4.9 (Proximal segment)	4.2	1.1	1.3	4.5	Facetted
115	Basalt	89	8.9	5.2	1.4	1.2	3.0	Plain
29	Basalt	75	5.9 (Proximal segment)	4.6	1.3	1.9	4.1	Dihedral
32	Basalt	146	10.1	5.5	2.3	1.5	3.0	Facetted
35	Basalt	35	6.0	4.2	0.7	0.9	2.9	Facetted
44	Basalt	16	3.5 (Proximal segment)	2.5	0.8	0.7	2.3	Dihedral
46	Quartz	9	3.5	2.2	0.6	0.2	0.7	Dihedral
108	Basalt	18	3.1 (Proximal segment)	3.2	1.1	0.6	3.5	Facetted

Table 6
The relationship between stone raw material and core category. "% per core category" represents the core specimens of a specific core category and stone raw material as a percentage of all specimens in that same core category. For example, there are 10 basalt discoidal cores, and these encompass 36% of all discoidal cores (10/28 = 0.36). "% per all basalt/quartz/phonolite cores" represents the core specimens of a specific core category and stone raw material as a percentage of all specimens in that same raw material category. For example, the 10 basalt discoidal cores encompass 29% of all basalt cores (10/39 = 0.26). Note that all Levallois cores are on basalt, whereas quartz dominates nearly all other core categories. This patterning results in a nearly 50–50 split between basalt and quartz across all cores.

Core category	**Basalt**			**Quartz**			**Phonolite**		
	n	% per core category	% per all basalt cores	n	% per core category	% per all quartz cores	n	% per core category	% per all phonolite cores
Levallois (n = 18)	18	100%	47%	0	0%	0%	0	0%	0%
Discoidal (n = 28)	10	36%	26%	17	61%	48%	1	4%	100%
Angular (n = 7)	3	43%	18%	4	57%	11%	0	0%	0%
Unidirectional (n = 4)	2	50%	5%	2	50%	6%	0	0%	0%
Bipolar (n = 6)	2	33%	5%	4	66%	11%	0	0%	0%
Core/hammerstone (n = 6)	0	0%	0%	6	100%	17%	0	0%	0%
Not classified (n = 6)	4	66%	10%	2	100%	6%	0	0%	0%
All cores (n = 75)	39	52%	100%	35	47%	100%	1	1%	100%

Table 7
Basic descriptive metric data on stone flakes and debris, in total, and per raw material category.

Raw material category	n	Mass (g)			Length (mm)			Width (mm)			Thickness (mm)		
		$\bar{x}$	Med	s	$\bar{x}$	Med	s	$\bar{x}$	Med	s	$\bar{x}$	Med	s
Basalt	226	39.9	23.0	53.0	4.4	4.0	1.6	3.4	3.3	1.5	1.1	1.1	0.4
Quartz	174	17.2	12.0	16.6	3.3	3.1	1.1	2.4	2.4	1.0	1.0	1.0	0.5
Phonolite	27	44.9	11.0	150.6	4.2	3.6	2.3	3.2	2.8	1.6	0.9	0.9	0.5
Unidentified	4	78.2	52	81.8	4.6	4.7	1.1	4.3	4.2	2.6	1.9	1.7	0.9
All flakes and debris	431	31.3	16	56.1	3.9	3.6	1.5	3.0	2.7	1.4	1.1	1.0	0.5

Fig. 5. Overview of Ndutu Formation stratigraphic section. (Upper) Ndutu ash section at WP6 overlying the red Masak beds. The arrow indicates bedding seen mantling proto-topography; (middle) Ndutu ash section at WP 10; the arrow identifies a prominent white discontinuous ash layer found mid-section in places along the walls of the gorge (referred to as the "Marker Tuff" by Hay, 1976); (lower) Ndutu beds lying unconformably on older sediments at WP13; at this locality a coarse conglomerate marks the base of the Ndutu.

Cores morphologically characteristic of the MSA, such as Levallois and discoidal cores, comprise the majority of the "cores" category (Table 3, Figs. 18–21). The overall dearth of bipolar cores is consistent with the early dates of the Ndutu provided by Manega (1993), and support the hypothesis that the *regular* use of bipolar technology by hominins is predominately an Early Stone Age or Late Stone Age phenomenon (Mehlman, 1989; Diez-Martin et al., 2011; Eren et al., 2013; Tryon and Faith, 2013; Gurtov and Eren, 2014). Three of the recovered cores were much larger than the others (Figs. 19–21). The first, one of the very few artifacts exhibiting edge rounding from either water and/or wind transport and/or exposure, was a preferential Levallois core with a final flake removal covering over 50% of its ventral (upper) surface (Fig. 19). We categorized the other two large cores as Levallois given their hierarchical flaking, but they possessed elongated, pointed morphologies reminiscent of the Sangoan (Figs. 20–21, Cooke, 1962; McBrearty, 1988; Rots and Van Peer, 2006). If Manega's (1993) early dates of the Ndutu are correct, the presence of Sangoan-like artifacts at Olduvai should not come as a surprise given the Sangoan's age elsewhere in East Africa and on the African continent more generally (Tryon and McBrearty, 2002; Barham and Mitchell, 2008: 234–237). The discovery of a small, crudely knapped biface (Fig. 22) from the Ndutu Unit fits with this early context (see Shea, 2008: 480).

Striking platform classes also are consistent with the MSA character of the assemblage. Of the 205 debitage specimens possessing a platform, 84 (41%, Table 4) exhibited a platform that was either dihedral or facetted. A number of flakes possessed the morphology and characteristics consistent with that of preferential Levallois flakes, such as multiple flake scars on the dorsal face; thick, prepared platforms; and a relatively robust thickness evenly distributed across surface area (Fig. 23, Eren and Lycett, 2012). We also recovered ten triangular flakes that *might* have served as weapon tips or cutting implements (Figs. 24 and 25, Table 5), although the function of these items is not definite (see Tryon et al., 2012: 28; Tryon and Faith, 2013). While one triangular flake appeared to be unifacially retouched into shape (Fig. 24b), there were no bifacial points recovered. Nine of ten triangular flakes possessed either a dihedral or facetted platform (Table 5), which is again consistent with MSA stone tool production. There have not yet been any raw material provenience studies of the MSA artifact toolstones at Olduvai, and thus we cannot know whether hominins preferred to manufacture their points on non-local raw materials as Tryon et al. (2012: 28) documented on Rusinga Island, Kenya. It is also important to consider the possibility (likelihood?) that some of the triangular flakes may have been produced incidentally and were never used as tools, especially as no Levallois point cores were recovered.

The overall raw material distribution of our recovered assemblage differs from that of Leakey et al. (1972), who stated that MSA raw material at Olduvai "generally consists of olivine basalt." While our more systematic collection does suggest basalt to be the majority toolstone used by MSA hominins (53% of assemblage count, 72% of assemblage mass), our results also show quartz to comprise a consequential role in the assemblage (40% of assemblage count, 24% of assemblage mass) (Tables 6 and 7). It is interesting to note, however, that in both assemblages Levallois cores are exclusively made on basalt, whereas other core classes in our assemblage show relatively large numbers of specimens made on quartz (Table 6). Given the difficult and unpredictable nature of the locally available Naibor Soit quartz for stone tool production, this pattern may potentially be a case of raw material influencing MSA hominins' implementation of specific reduction strategies. This notion should be further explored in the future via experimental archaeology (e.g. Braun et al., 2009; Eren et al., 2011; Bar-Yosef et al., 2012).

Similarly to other locations in East Africa, and supporting Leakey et al.'s (1972) observations, retouched or "formal" tools are rare in MSA contexts at Olduvai Gorge (Leakey et al., 1972: 333; Shea, 2008: 451, 477; Thompson et al., 2012; Tryon et al., 2008: 658; Tryon et al., 2010: 664; Tryon et al., 2012: 32; for examples of this situation in North Africa: see Dibble et al., 2013; Olszewski et al., 2005, 2010). We recovered only four artifacts possibly exhibiting retouch (in addition to the unequivocally retouched triangular flake noted above and shown in Fig. 24b). However, given the presence of modern animal herds and people in and around Olduvai Gorge, it seems likely this "retouch" is merely the result of trampling (e.g.

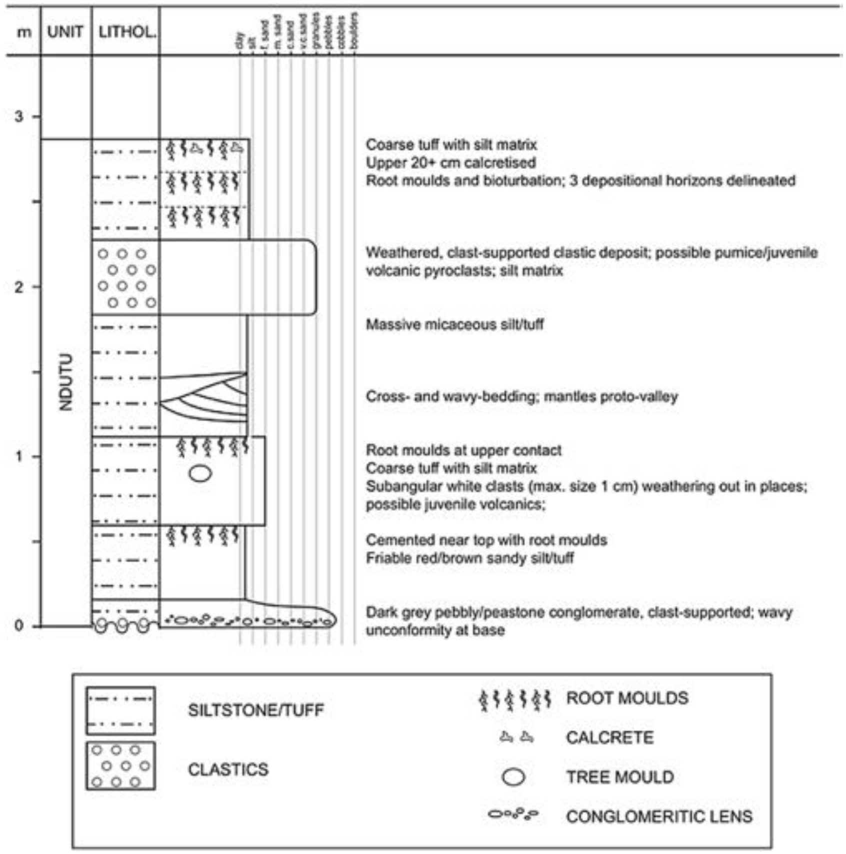

Fig. 6. Type section of the Ndutu Formation at locality 78 (Hay (1976) locality 26).

McBrearty et al., 1998; Eren et al., 2010). The lack of retouched tools at Olduvai might be explained by the preponderance of basalt and quartz toolstone, or, to put it another way, by the absence of more siliceous toolstones like chert (see Tryon et al., 2008: 660–661). Although more experimental testing is necessary, it is reasonable to hypothesize that the edges of basalt, quartz, phonolite, and chert flakes possess different mechanical properties (e.g. Braun et al., 2009; Tryon et al., 2008: 661). If chert flakes "have edges that dull faster, fracture more readily, and leave more abundant macro- and microscopic traces" (Tryon et al., 2008: 661) relative to basalt and quartz flakes, than it should be expected that MSA assemblages composed of basalt and quartz lack retouched tools.

3.2.2. Ndutu fauna

Faunal specimens are few in number: a total of 37 specimens were recovered, of which 25 could be identified minimally to skeletal element or element type. Eleven specimens were unidentifiable except as belonging mainly to large animals. Preservation states vary widely, with both fossil and sub-fossil specimens, as was also noted by C. Marean in his analysis of the assemblage collected by Mabulla (1990a: Appendix 3; 1990b). In the 2013 collection, six specimens had excellent cortical preservation, while the remainder variously showed weathering and flaking of the cortical surface, polishing and rolling of the surface and edges, diagenetic fragmentation, and/or concretions that obscured bone surfaces. The diversity of preservation states suggests distinct site formation processes at distinct find-spots, though much larger sample sizes will be needed in order to elucidate taphonomic histories.

Despite the small sample, a wide range of fauna is represented (Table 8). Most specimens come from large mammals, including a minimum of one zebra, one rhinoceros, one eland, one probable buffalo, and two smaller bovids. The equid specimen, a proximal femur, is of a size suggesting Grevy's rather than Burchell's zebra, an observation also made by Marean for the earlier collection, where he also noted possible giant Cape zebra (*Equus capensis*). If additional finds confirm the presence of Grevy's zebra, this would contribute to an increasing number of Middle-Late Pleistocene fossils in areas far beyond this animal's historic range, a fact that has been linked to greater aridity and expanded grasslands at that time (Faith et al., 2013). Other fauna associated with Grevy's zebra in the Pleistocene fossil record, according to Faith et al. (2013), are white rhinoceros (*Ceratotherium simum*) and the giant long-horn buffalo (*Syncerus antiquus*). While our current sample is far too small and fragmented to permit identification of these taxa, it is notable that a complete metacarpal of a rhinoceros was identified in the 2013 collection, and three compact bones were attributed to either rhinoceros or hippopotamus. Additionally, a small fragment of horncore was found with the appropriate morphology for buffalo. Smaller bovids are also represented but could not be identified to tribe level: one is the size of a topi or kongoni, another the size of a Thomson's gazelle. The only tooth recovered belongs to a medium-sized rodent that is similar in size to giant pouched rat (*Cricetomys gambianus*). Non-mammalian specimens include fragments of carapace, plastron and vertebra from a large land tortoise (family Testudinidae).

Table 8
Fauna specimens recovered during survey of the Ndutu Unit.

Taxon	NISP	MNI	NID
Class Mammalia			
Order Perissodactyla			
Equus cf. *grevyi* (Grevy's zebra)	1	1	
Mammal Size 4 Cf. *Equus* sp. (zebra)	1	–	
Rhinocerotidae (rhinoceros)	1	1	

Table 8 (*continued*)

Taxon	NISP	MNI	NID
Order Artiodactyla			
Bovid Size 2 (Thomson's gazelle sized)	2	1	
Bovid Size 3 (topi/kongoni sized)	4	1	
Taurotragus sp. (eland)	1	1	
Bovid Size 4, Cf. *Syncerus caffer* (buffalo)	1	1	
Order Rodentia			
Medium-sized rodent	1	1	
Indeterminate Mammal			
Mammal Size 2	2	–	
Mammal Size 2–3	1	–	
Mammal Size 3	1	–	
Mammal Size 4	3	–	
Mammal Size 4 Cf. Rhinocerotidae or *Hippopotamus*	3	–	
Class Reptilia			
Testudinidae (tortoise)	3	1	
Indeterminate			
Indeterminate large (size 3–4) animal			11
Indeterminate			1
Total	25	8	12

NISP = Number of Identified Specimens; MNI = Minimum Number of Individuals; NID = Nonidentifiable Specimens

Carnivore tooth marks, observed by Marean in the previous collection, were not noted on any specimens. Three specimens had a series of short, parallel marks strongly resembling cut marks, which were located in places suggestive of disarticulation: an eland proximal metatarsal, zebra proximal femur, and rhinoceros proximal metacarpal all bore such marks. However these marks were so eroded as to make their identity ambiguous.

4. Summary and discussion

The results of the first intensive, systematic field survey of Olduvai Gorge's Ndutu Unit suggested that there is tremendous promise for the site to significantly contribute to our understanding of African MSA behavioral evolution and adaptation. Our work – which did not include *any* excavation – and which essentially encompassed a linear (2-D) distance of only 8 km around the perimeter of the small section of the Gorge east of the Second Fault, yielded hundreds of MSA artifacts, a variety of find-spots and sites of drastically different densities and raw material compositions, *in situ* artifacts, preserved fauna, and potentially important geological and paleoenvironmental findings.

Fig. 7. Examples of bioturbation and root structures found in the Ndutu beds. (upper) Section at locality 26; prominent whitish tuff layer found mid-section indicated by the arrow; (upper right) base of the whitish tuff layer overlying friable unit containing intricate root casts; (lower left) modern soil horizon colonised by plants with extensive tubular root networks; (lower right) bioturbated horizons in the Upper Ndutu beds; these surfaces were previously colonised and the pre-existing plant roots left hollow tubular structures in the beds.

Fig. 8. The Upper Ndutu found at locality 15; (left) the section near the top of the gorge; (right) detail of upper massive tuff with cross-bedding (to the left of the hammer).

While these findings should only represent the beginning of renewed research on Olduvai Gorge's Ndutu beds, and may be significantly revised by future research by ourselves or others our initial results allow us to touch upon a number of broader issues in East African MSA studies including the possible impact of volcanism upon *Homo sapiens* and their ecosystems; regional patterns of lithic core size; and the significance of Levallois flake production in contexts where retouch potential may not have necessarily been be a motivating factor for hominins. All of these topics will require further research, and as such any conclusions drawn in the following discussion should be considered as tentative, preliminary ideas for future testing.

4.1. Volcanic impacts on ecosystems and human behavior

The presence of *in situ* artefacts within the Ndutu beds supports the notion that hominin populations were actively utilising the landscape at the time the Ndutu was deposited. Furthermore, the presence of tree stump fossil casts and moulds indicates that the area was vegetated, at least in part, which would have provided habitat both for hominin populations, as well as game for hunting. The animal trace fossil tracks suggest that parts of the landscape were wet, indicating that there would have been a water supply available.

While all of the ingredients for sustaining hominin populations appear to have been available at the time of the Ndutu, volcanic activity produced substantial volcanic deposits within the Gorge itself throughout this period. This key observation indicates that at times, conditions in Olduvai Gorge and surrounds would have been detrimental to hominin survival. There is evidence that pyroclastic density currents travelled into the gorge; these would have been highly destructive and probably killed any animals present. Ash fallout would have presented immediate respiratory health hazards, digestive tract irritation, inundated vegetated ecosystems and fluvial systems, and contaminated drinking water through leaching of toxic compounds. This interpretation supports a major evolutionary forcing on hominin populations at the time of these volcanic events (Basell, 2008). In contrary to some hypotheses, the region would have been highly unstable at the time of volcanic eruptions.

However, the massive tuffs towards the top of the Upper Ndutu section contain a series of bioturbated horizons, which indicates deposition was punctuated by enough time to fully establish mature vegetation. The eruption of Mount St. Helens in 1980

Fig. 9. Trace fossils in fine tuff left by a multi-legged walking animal. The preservation indicates the bed was wet when the creature walked over the surface.

Fig. 10. Examples of artefacts and shells found in the Upper Ndutu at locality 30; (upper left) the section at locality 30; (upper right) a quartize artefact found *in situ*; (middle left) an angular phonolite artefact found *in situ*; (middle right) a shell found collocated in the bed containing the artefacts (possibly *Limicolaria*); (lower) detail of the shell once removed from the bed for dating purposes.

Fig. 11. Geomorphological constraints on vegetation in Olduvai Gorge and on the Serengeti Plain. (left) View across the Main Gorge from locality 1, looking south; here vegetation is dominated by Acacia trees which have extensive root networks, allowing the plant to persist through extremely arid conditions; (right) View northwest from the summit of Engelosin across the Serengeti Plain; Acacia tree colonies are geologically-bounded and follow fault structures which permit the vegetation to tap into subsurface water supplies.

Fig. 12. Tree moulds found at location 65; (upper left) large (diameter 15 cm) tree mould in upper section of the Ndutu beds; (right) tree mould found on top of section; grey coloration (~1 cm thickness) follows the form of the mould; (lower left) ripple marks in laminae found at the base of this sub-section.

Fig. 13. *In situ* tree stump fossils found at locality 65. (lower) 4 tree stump moulds were identified; (upper left) the area enclosed by the white box; (upper right) detail of the largest fossil tree stump mould; the centre is hollow.

Fig. 14. *In situ* tree stump fossils found at locality 65. (upper) cluster of fossil tree stump casts found in a roughly linear distribution; (lower) detail of area enclosed by the white box in the upper image; the arrows indicate the locations of 3 prominent large tree stump casts (with hollow centres), while there are numerous smaller casts clumped around; the distribution is suggestive of modern day *Acacia* trees.

provided insights into ecological recovery: in regions exposed to pyroclastic density currents, almost no organisms or vegetation survived. Plants and animals that remained underground during depositional events had a better chance of survival. Overall, the thickness of the deposit and the mode of emplacement (fall versus flow) determined the likely ecological consequences (Dale et al., 2005). For example, in the case of the Novarupta eruption (Katmai) in 1912, satellite-based surveys in 2000 and 2002 indicated that after ~90 years only ~5% of the pyroclastic flow and fallout deposits had been revegetated in regions where the deposit was 2 m thick or greater. Conversely at greater distance from source where the ash deposit was thinner about 70% of the region showed signs of revegetation (Jorgenson et al., 2012). Between the potentially destructive volcanic depositional events, ecosystems had time to re-establish and stabilise, and would have again become attractive to hominin populations.

The observations presented here are consistent with the idea of a "push/pull" effect on the migration of hominin populations due to volcanism in the region (Basell, 2008; see also; Bailey et al., 1993, 2000; King and Bailey, 2006). During times of high volcanic activity, hominins not caught up in the direct impacts would have been inclined to migrate away from the gorge, while in more stable

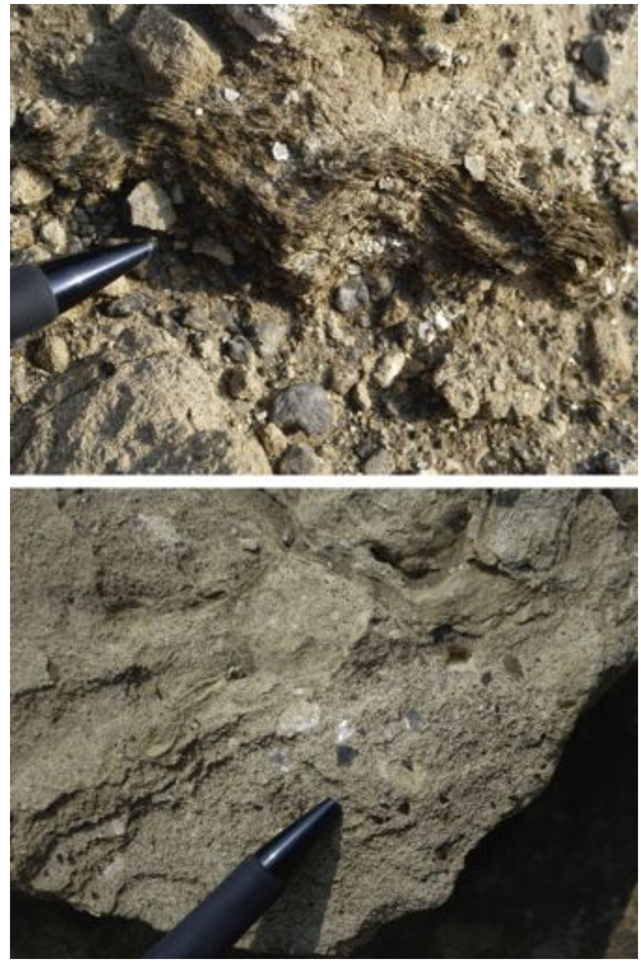

Fig. 15. Large biotite flakes preserved in the Ndutu tuff beds. Ol Doinyo Lengai characteristically erupts tephras rich in biotite.

periods the opposite would be true. The extent of migration would be linked to the magnitude of the eruption, with smaller events causing more localised migrations (e.g., to different parts of the Rift Valley), whereas larger events may have lead to large scale mass migrations on sub-continent scales.

4.2. Core size and distance from the rift valley

Tryon et al. (2008: 660; see also Toth, 1985) documented two intriguing relationships between maximum lava core size versus site distance to the Rift Valley margin (reproduced here, Fig. 26). First, as distance increases, core size decreases; and second, as distance increases, core size variability decreases. As such, we can predict that the Olduvai Gorge Ndutu Unit, which is located in the Rift Valley itself, should possess relatively larger mean core size and greater core size variability than other localities. The basalt maximum core size data collected from Olduvai are entirely consistent with these predictions (Fig. 26).

Tryon et al. (2008: 660) suggested that this pattern "is unlikely to reflect intensive reduction due to raw material conservation during transport... as local sources were used for even the smallest size assemblages from the Kibish Formation." Instead, "the pattern appears to reflect downstream reduction of fluvial clast size with increased transport distance" and thus "geological rather than behavioral factors likely explain most of the interassemblage

Fig. 16. Find-spot #1, the R.A.C. locality. 163 lithic specimens were collected on the slope, presumably having eroded out from the area indicated by the upper arrow, which is where three *in situ* artifacts were discovered. And example of an *in situ* phonolite stone flake is pictured in the lower left.

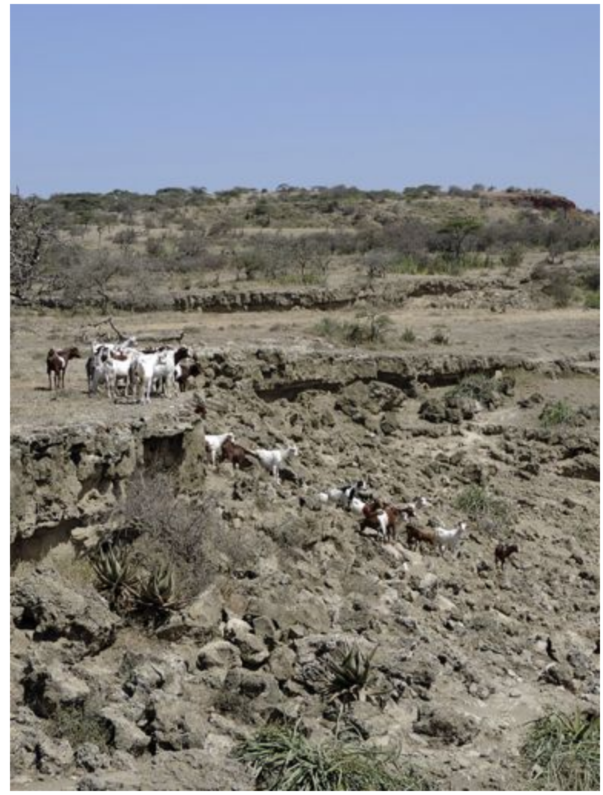

Fig. 17. An example of an animal entry point into Olduvai Gorge.

variation related to artifact size due to the dimensions of available raw material ‘packages’ and the proximity of Rift Valley-margin sources” (Tryon et al., 2008: 660). While we agree in part, we propose that this pattern still holds behavioral implications for East African MSA foragers. A number of sub-Saharan MSA studies have suggested that MSA foragers, at least occasionally, procured toolstone over long distances (McBrearty, 1981, 1988; Merrick and Brown, 1984; Mehlman, 1989; Merrick et al., 1994; Negash et al., 2011). Indeed, Nash et al. (2013) recently documented that MSA foragers at White Paintings Rockshelter procured the majority of their toolstone (silcrete) from a source 220 km away. When we consider the pattern exhibited in Fig. 26 in light of findings that MSA foragers were quite capable of transporting toolstone long distances, we can ask a more behaviorally-grounded question of our data, namely “why did MSA foragers *choose* not to transport

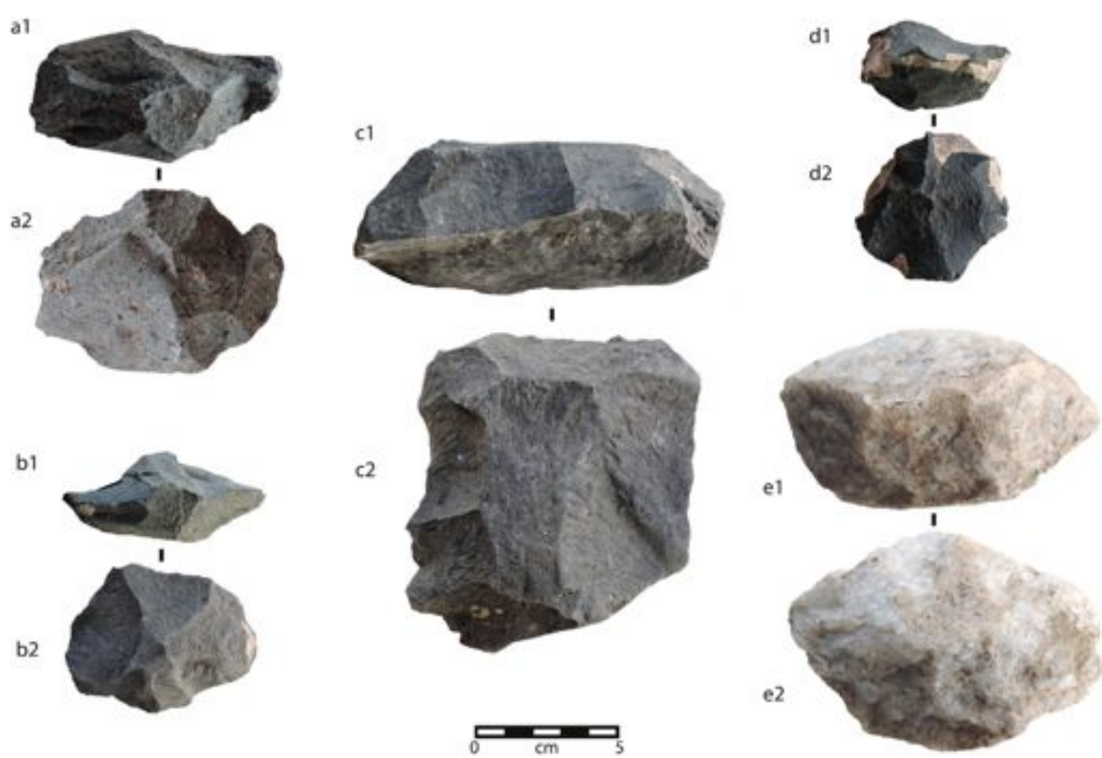

Fig. 18. Examples of MSA cores: a phonolite discoid core (side, a1; face a2); basalt discoid cores (side, b1, c1, d1; face b2, c2, d2); a quartz discoid core (side, e1; face e2).

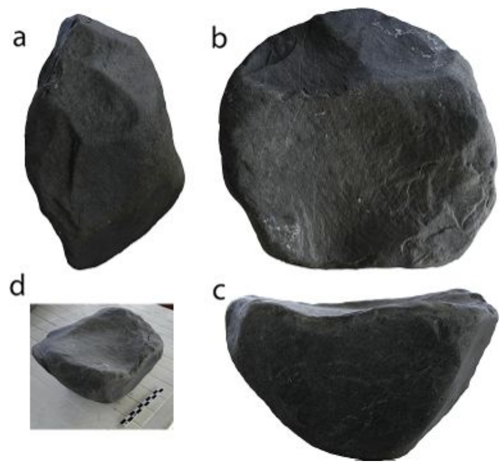

Fig. 19. A large preferential Levallois core made on basalt. Maximum length is 18.0 cm, maximum width is 17.0 cm, and thickness is 9.0 cm.

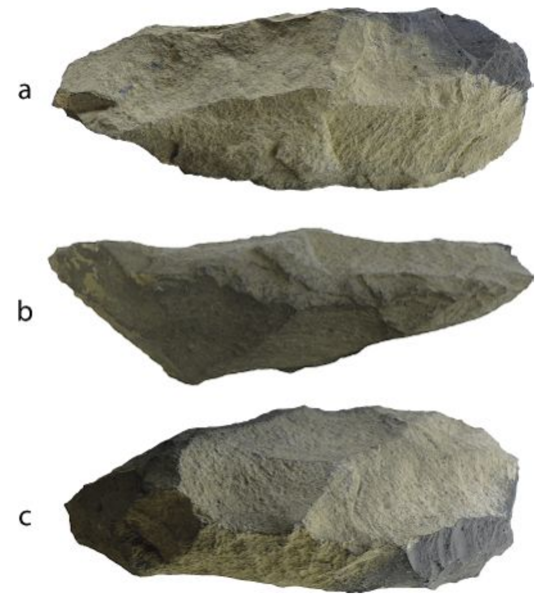

Fig. 21. A large, hierarchically-organized core, possibly Sangoan. Maximum length is 20.0 cm, maximum width is 11.2 cm, and thickness is 7.9 cm.

lava cores in East Africa?" While any number of behavioral factors (gearing up, expediency, etc.) can be tested for, our purpose is not to answer that question here, but to emphasize that geological factors should not be automatically given explanatory primacy for patterns that are the result of hominin-environment *interaction*.

4.3. Levallois core reduction and the lack of retouched tools

Levallois cores, as well as flakes possessing morphologies consistent with preferential Levallois flake production, are common at Olduvai Gorge and other East African MSA localities (e.g. Shea, 2008; Tryon et al., 2008, 2010, 2012). Recent mathematical and experimental analyses have empirically demonstrated several utilitarian advantages of preferential Levallois reduction that could have potentially served as motivating factors for hominins' adoption of the strategy (Brantingham and Kuhn, 2001; Eren et al., 2011; Eren and Lycett, 2012; Lycett and Eren, 2013a,b). One proposed motivating factor for the adoption of Levallois reduction is the production of flakes that have greater potential for retouch and re-use, given that preferential Levallois flakes possess morphologies in which flake thickness is evenly distributed over flake surface area (see Eren and Lycett, 2012: 8; Turq, 1992: 77).

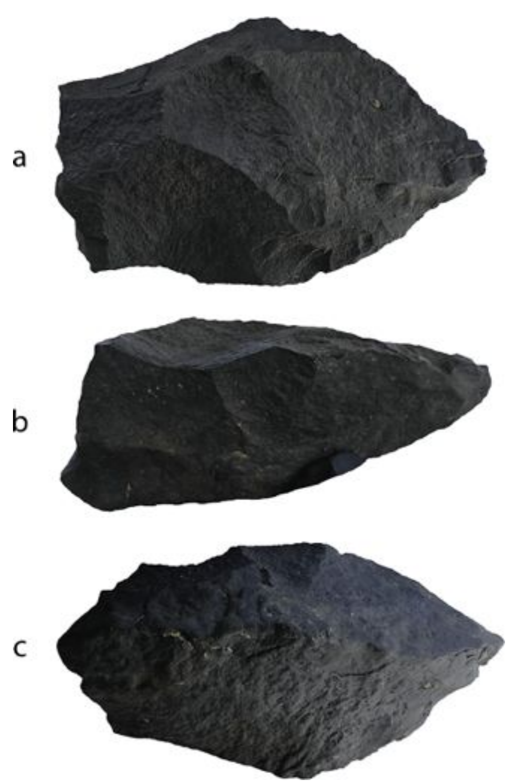

Fig. 20. A large, hierarchically-organized core, possibly Sangoan. Maximum length is 24.0 cm, maximum width is 9.4 cm, and thickness is 7.3 cm.

However, as already noted above, retouched or "formal" tools are rare in MSA contexts at Olduvai Gorge, a phenomenon documented at several other East African MSA localities (Shea, 2008: 451, 477; Thompson et al., 2012; Tryon et al., 2008: 658; Tryon et al., 2010: 664; Tryon et al., 2012: 32). As such, while the specific reason(s) why East African MSA foragers adopted Levallois reduction have not yet been identified, by integrating the results of approaches that possess high internal validity (mathematical models, experiments) and high external validity (fieldwork, studies of the archaeological record) (see Lycett and Eren, 2013b), we *can* reasonably infer that the adoption of Levallois reduction by East African MSA foragers was *not* motivated by "retouch potential." Thus, future examinations of this question in East Africa might more profitably focus on factors such as core reduction economy (Brantingham and Kuhn, 2001; Lycett and Eren, 2013a), functional efficiency and ergonomic considerations (Eren and Lycett, 2012), or the Levallois reduction strategy's adaptability to toolstones of significantly contrasting characteristics (Eren et al., 2011). We feel it important to emphasize, however, that our negative inference for the adoption of Levallois in the East African MSA does *not* preclude "retouch potential" as a motivating factor for the adoption of Levallois in other geographic or temporal contexts.

5. Conclusion and future research

Our overall findings suggest that Olduvai Gorge possesses an astonishing amount of archaeology directly relevant to MSA open-

Fig. 22. A bifacially-flaked implement.

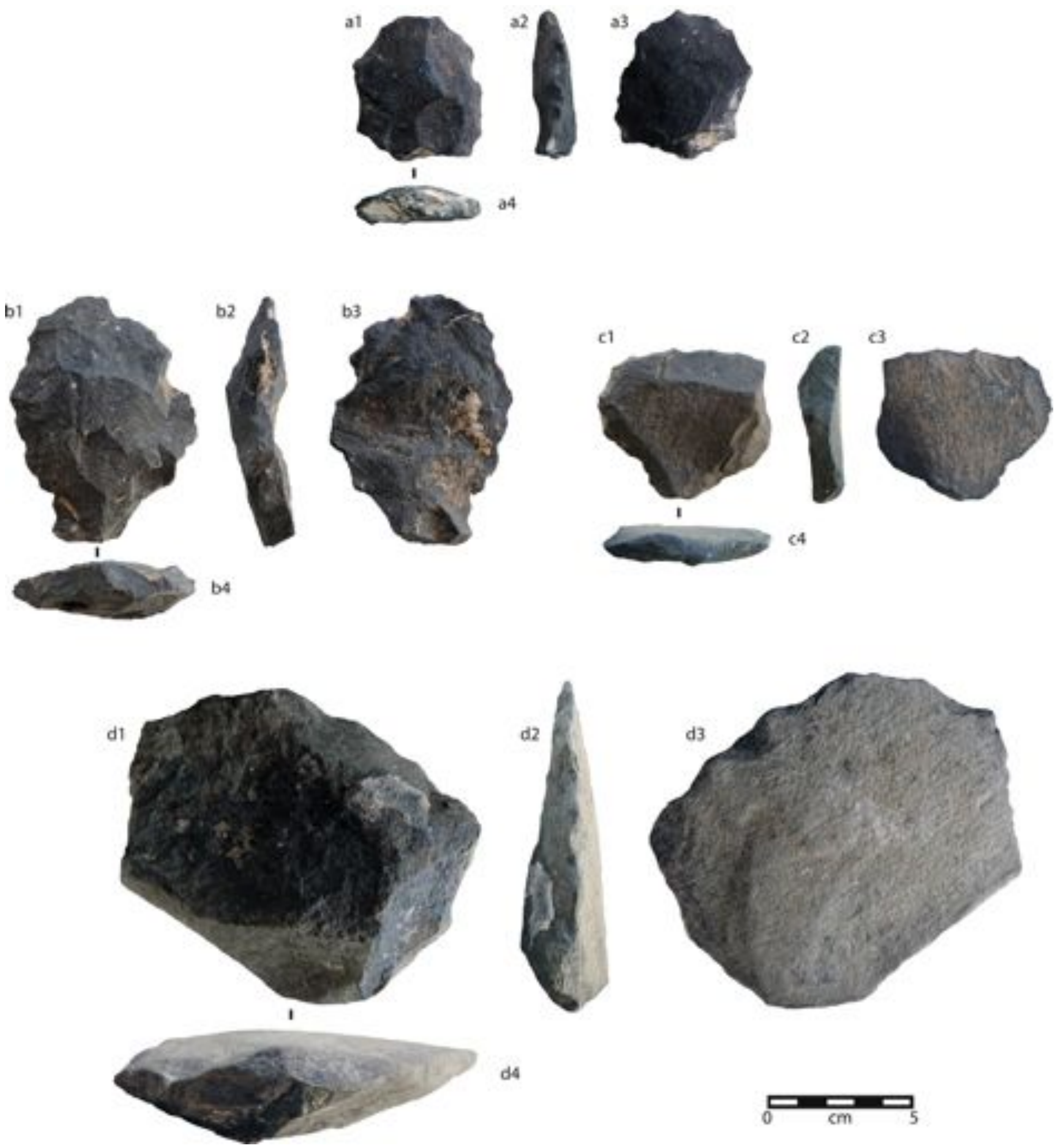

Fig. 23. Flakes possessing attributes characteristic of preferential Levallois flakes. All flakes shown here were made on basalt.

Fig. 24. Triangular flakes that were possibly used as points or knives. The middle point is unifacially retouched. All flakes shown here were made on basalt.

air site behavior and adaptation prior to, during, and just after the physical emergence of *H. sapiens*. Future research questions and fieldwork will certainly attempt to address issues involving the depositional date or dates of the Ndutu deposit. Given the presence of unequivocal Levallois technology in the Ndutu deposit, as well as the deposit's possible early dates, Olduvai may have a significant part to play with regard to the earliest emergence of this important stone tool reduction strategy (see Tryon, 2006; Morgan and Renne, 2008; Moncel et al., 2011). Thus, future dating studies, especially in conjunction with documentation of *in situ* artifacts, are a must.

Settlement patterns, mobility studies, and land use should also be a central focus (e.g. Ambrose, 2001), and tightly integrated with raw material provenance studies (e.g. Nash et al., 2013). Paleoenvironmental reconstruction will play a major role in understanding why Olduvai was attractive to MSA foragers (e.g. Tryon et al., 2013), and volcanism studies should in part explain why

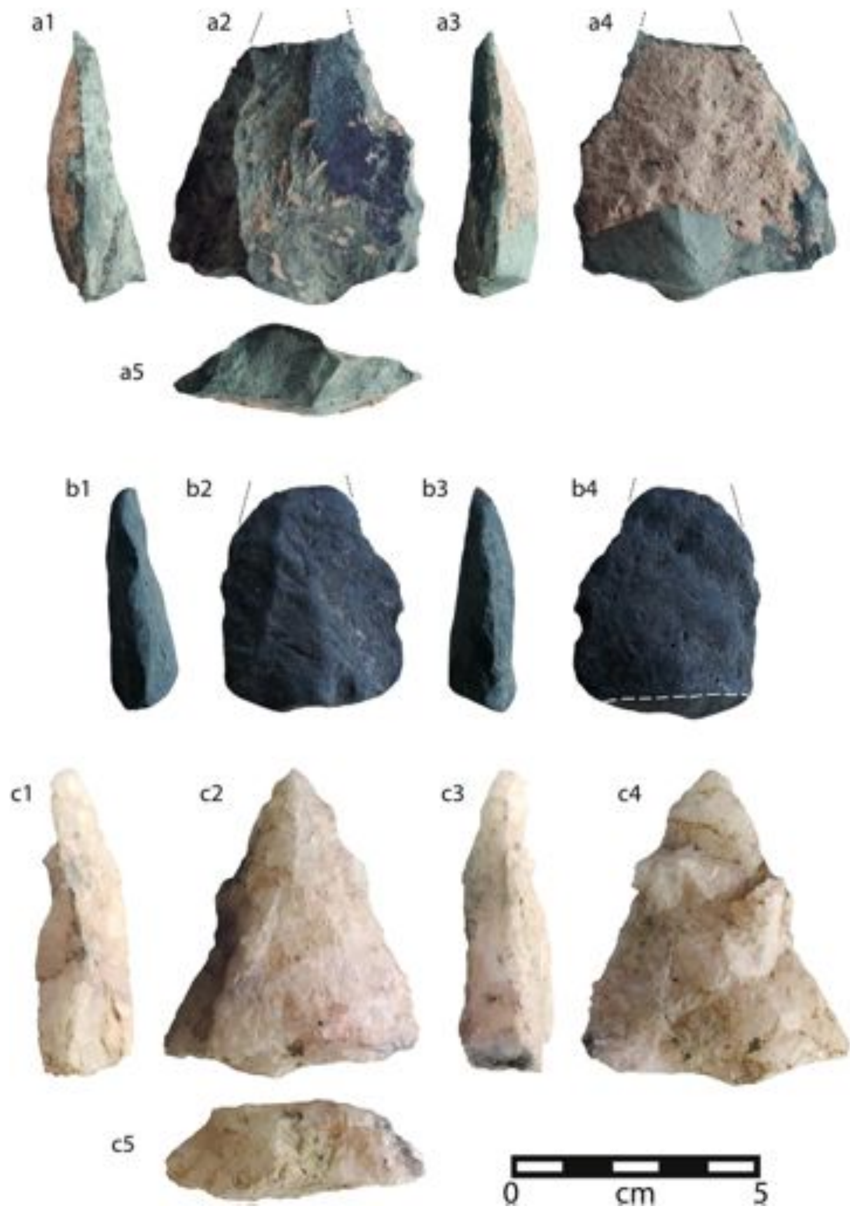

Fig. 25. Triangular flakes that were possibly used as points or knives. The top flake was made on phonolite; the middle flake on basalt; the bottom flake on quartz.

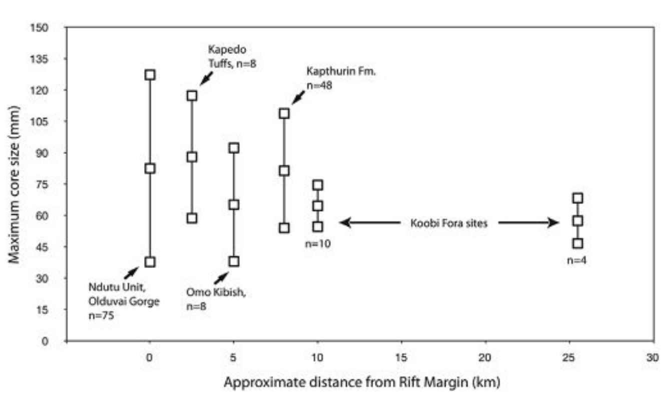

Fig. 26. Tryon et al. (2008) uncovered a pattern between maximum core size and approximate distance from the Rift Valley margin, namely that as distance increases, core size and core size variability decreases. The core size data from the Ndutu Unit at Olduvai Gorge are entirely consistent with this overall pattern.

the area might have been at times abandoned (e.g. Basell, 2008). Olduvai's artifact assemblage diversity and frequency should positively contribute towards calls for inter- and intra-regional comparisons of MSA archaeology (Tryon et al., 2005), and shed further light on human behavioral variability throughout Africa and beyond (McBrearty and Brooks, 2000; Shea, 2011; Tryon and Faith, 2013).

In conclusion, the research possibilities contained within Olduvai's Ndutu deposit appear to be quite promising, and we are hopeful that this long-ignored chapter of human evolution at Olduvai Gorge will remain open to scores of researchers for scientific exploration, analysis, and scrutiny for years to come.

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