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Ditchfield, P, Whitfield, E, Vincent, T, Plummer, T, Braun, D, Deino, A, Hertel, F, Oliver, JS, Louys, J and Bishop, LC

**Geochronology and physical context of Oldowan site formation at Kanjera South, Kenya.**

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### Article

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1 Geochronology and physical context of Oldowan site formation at Kanjera South, Kenya.

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3 Ditchfield, P.<sup>1</sup>

4 Whitfield, E.<sup>2</sup>

5 Vincent, T.<sup>2</sup>

6 Plummer, T.<sup>3</sup>

7 Braun, D.<sup>4</sup>

8 Deino, A.<sup>5</sup>

9 Hertel, F.<sup>6</sup>

10 Oliver, J.S.<sup>7</sup>

11 Louys, J.<sup>8</sup>

12 Bishop, L.C.<sup>2</sup>

13

14

15

16 1. Research Laboratory for Archaeology and the History of Art, School of Archaeology,  
17 University of Oxford, 1 South Parks Road, Oxford, OX1 3QY, UK

18 2. Natural Sciences and Psychology, Liverpool John Moores University, James Parsons  
19 Building, Byrom Street, Liverpool, L3 3AF, UK

20 3. Department of Anthropology, Queens College, CUNY & NYCEP, 65-30 Kissena Blvd,  
21 Flushing, NY 11367 USA

22 4. Department of Anthropology, Columbian College of Arts & Sciences George Washington  
23 University 2110 G St., NW Washington, DC 20052, USA

24 5. Berkeley Geochronology Center, 2455 Ridge Road, Berkeley CA 94709, USA

25 6. Department of Biology, California State University, Northridge CA 91330, USA

26 7. Department of Geosciences, Earth & Mineral Sciences Museum, Pennsylvania State  
27 University, 151 Standing Stone Lane, State College PA16802, USA

28 8. Research Centre in Human Evolution, Environmental Futures Research Institute, Griffith  
29 University, Brisbane, Queensland, 4111, AU

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### **Abstract**

Oldowan sites in primary geologic context are rare in the archaeological record. Here we describe the depositional environment of Oldowan occurrences at Kanjera South, Kenya, based on field descriptions and granulometric analysis. Excavations there have recovered a large Oldowan artefact sample as well as the oldest substantial sample of archaeological fauna. The deposits at Kanjera South consist of 30 m of fluvial, colluvial, and lacustrine sediments. Magneto- and bio-stratigraphy indicate the Kanjera South Member of the Kanjera Formation was deposited between 2.3 and 1.92 million years ago (Ma), with 2.0 Ma being a likely age for the archaeological occurrences. Oldowan artefacts and associated fauna were deposited in the colluvial and alluvial silts and sands of Beds KS-1 to KS-3, in the margins of a lake basin. Field descriptions and granulometric analysis of the sediment fine fraction indicates sediments from within the main archaeological horizon were emplaced as a combination of tractional and hyperconcentrated flows with limited evidence of debris flow deposition. This style of deposition is unlikely to significantly erode or disturb the underlying surface and therefore promotes preservation of surface archaeological accumulations. Hominins were repeatedly attracted to the site locale, and rapid sedimentation, minimal bone weathering, and an absence of bone or artefact rounding further indicate that fossils and artefacts were quickly buried.

## 1. Introduction

The appearance of Oldowan sites by 2.6 million years ago (Ma) reflects an important adaptive shift in hominin evolution. Stone artefact manufacture coupled with large mammal butchery and novel food and lithic transport and discard behaviours led to some of the oldest accumulations of archaeological debris (Potts, 1991; Plummer, 2004). Whereas Oldowan sites are known between ca. 2.6 – 1.7 Ma from East and South Africa and from North Africa and Georgia as well (Plummer, 2004), our understanding of the behavioural complexes leading to site formation remains rudimentary at best. In part this is because very few sites include both sizable artefact samples and well-preserved archaeological fauna. Moreover, it is sometimes unclear to what degree the associated fossil and artefact assemblages reflect on-site hominin activities, mixing of unrelated behavioural traces by geological processes, or palimpsests of activity traces from different taxa (e.g., hominins and carnivores) (Dominguez-Rodrigo, 2009).

At ca. 2.0 Ma, the site of Kanjera is particularly significant: Its Oldowan lithic and zoo archaeological assemblages are among the oldest and most substantial known and both record novel behaviours in an open habitat different from other, more wooded Oldowan sites (Table 1; Bishop et al., 2006; Plummer et al., 1999; Plummer & Bishop, 2016; Oliver et al., submitted). Hominins were repeatedly attracted to the site locale and alluvial and colluvial deposition resulted in Oldowan artefact and fossil accumulations in an approximately 3 m thick sequence. In contrast to other Oldowan sites (e.g., FLK-Zinjanthropus, Olduvai Gorge) the Kanjera South assemblages document a suite of hominin behaviours that were not ephemeral, but persisted over time. Here we describe the geochronology and depositional context of the Oldowan site complex at Kanjera South, southwestern Kenya, focusing on the lithology and depositional history of the Kanjera South Member. In particular, new granulometric analyses have refined our previous understanding of the geological processes that formed Kanjera South and document that this Oldowan locality provides a reasonably unaltered record of hominin behaviour.

\*\*\*\*\*INSERT TABLE 1 NEAR HERE\*\*\*\*\*

## 2. Physical setting

The early Pleistocene Oldowan occurrences at Kanjera South (0°20'24" S, 34°32'16" E) are found on the northern margins of the Homa Mountain Carbonatite Complex, Homa Peninsula, southwestern Kenya (Figure 1) (Le Bas, 1977). Homa Mountain is located on the southern shores of the Winam Gulf, a northeastern extension of Lake Victoria that lies in the fault-bounded Nyanza Rift system (Saggerson, 1952). Volcanic activity associated with the mountain began with doming of the central portion of the edifice in the late Miocene and shifted to peripheral vents during the Pliocene and Pleistocene (Le Bas, 1977; Saggerson, 1952). Today, the heavily eroded edifice of Homa Mountain is 1754 m high, approximately 600 m above the level of Lake Victoria. The mountain's lower slopes are incised by a radial drainage system

1 exposing late Miocene through Recent sediments (Kent, 1942; Ditchfield et al., 1999; Pickford,  
2 1984). Evergreen forest and bushes cover portions of the upper slopes undisturbed by human  
3 activity.

4  
5 The history of paleoanthropological research on the peninsula is summarized in Behrensmeyer et  
6 al., (1995), Ditchfield et al., (1999), Pickford, (1984), and Plummer & Potts, (1995).  
7 Fossiliferous deposits outcrop at Kanjera in three areas, termed the Northern, Middle and  
8 Southern Exposures (Figure 1). Initially, deposits in the Northern and Southern Exposures were  
9 thought to be equivalent, though the stratigraphic framework was largely based on observations  
10 made in Kanjera North (Oswald, 1914; Kent, 1942; Pilbeam, 1974; Pickford, 1987). As more  
11 attention was paid to the stratigraphy of the Southern Exposures some differences in composition  
12 between the deposits in the north and south emerged, and separate bed definitions were devised  
13 for each area (Behrensmeyer et al., 1995). Further work (Ditchfield et al., 1999; Plummer et al.,  
14 1999) indicated that no lithostratigraphic correlation existed between the North and South, and  
15 that the Southern Exposures sequence largely or entirely predates deposition in the North.  
16 Deposits in the north and south were provisionally designated Kanjera Formation (N) and  
17 Kanjera Formation (S), respectively (Ditchfield et al., (1999). The Kanjera North exposures  
18 consist of a series of low mounds of less than 3 m vertical relief and include the type site of  
19 *Theropithecus oswaldi* and the discovery site of some controversial anatomically modern human  
20 fossils by L. S. B. Leakey (Leakey, 1935; Behrensmeyer et al., 1995; Plummer & Potts, 1995).  
21 Magneto- and biostratigraphy suggest that deposition of the Kanjera Formation (N) began in the  
22 mid to late early Pleistocene and continued into the middle Pleistocene (Behrensmeyer et al.,  
23 1995). Sediments were deposited at the margin of a small playa or lake, in fluvial, lake flat, and  
24 lacustrine settings.

25  
26 The Kanjera South deposits outcrop approximately 600m south of the Kanjera North location in  
27 a small (50,000 m<sup>2</sup>), eastward-facing amphitheater reaching approximately 14 m above modern  
28 Lake Victoria (Behrensmeyer et al., 1995).

### 30 **3. Geologic context of Oldowan occurrences**

31  
32 The Kanjera Formation is located on the northern flanks of the Homa Mountain massif. The  
33 country rocks of the Homa Peninsula consist of the Bukoben and Nyanzian metavolcanics and  
34 other high-grade metamorphic rocks (Saggerson, 1952; Le Bas, 1977). The emplacement of the  
35 Homa Mountain carbonatite system resulted in extensive fracturing and fenetization of these  
36 country rocks. The Plio-Pleistocene sediments are distributed radially around the Homa  
37 Mountain edifice and unconformably overlie Miocene sediments of the Kanam Formation in  
38 some areas.

39  
40 The Kanjera Formation is exposed regionally at Kanjera; in the ~~Southern~~, Northern, and Middle  
41 and Southern Exposures (Behrensmeyer et al., 1995; Plummer et al., 1999, Ditchfield et al.,  
42 1999). The oldest units, Beds KS-1 to KS-5, make up the Kanjera South Member and are  
43 exposed at the Kanjera South locality (Figure 1). They have been the subject of extensive  
44 archaeological enquiry (Plummer et al., 1999; Plummer, 2004; Ferraro, 2007; Braun et al.,  
45 2008; 2009; Plummer et al., 2009; Ferraro et al., 2013; Lemorini et al., 2014; Plummer &  
46 Bishop, 2016). These beds are gently dipping to the north and are affected to a minor extent by

1 normal faults down-stepping to the north, and associated minor folding. The Kanjera South  
 2 Member is overlain unconformably by the beds of Kanjera North Member (Beds KN1-KN5),  
 3 which also dip northwards but are more intensively deformed by faulting associated with the  
 4 Winam Gulf graben. These members were previously informally referred to as Kanjera Fm (S)  
 5 and Kanjera Fm (N) (Plummer et al., 1999). Both Kanjera South and Kanjera North Members  
 6 are unconformably overlain by the Kanjera Middle Exposure Member (KME-1 to KME-3),  
 7 which represents a west-to-east directed alluvial fan sequence erosive into both underlying  
 8 members.

### 10 **3.a. Kanjera Bed Descriptions and Granulometric Analysis**

13 The lithological sequence of the Kanjera South Member consists of colluvially and, to a lesser  
 14 extent, alluvially reworked pyroclastic deposits and lacustrine clays, capped by a local volcanic  
 15 sequence related to a late, peripheral, parasitic vent from the Homa Mountain Volcanic Complex.  
 16 It has yielded archaeological occurrences from the top of Bed KS-1 through to the lower part of  
 17 Bed KS-3.

19 The base of the Kanjera South Member, Bed KS-1, is a thick, poorly bedded, pyroclastic deposit.  
 20 This is at least 4m thick and its base has not been reached in any of the excavations or geological  
 21 trenches. The lowest visible part of this bed consists of very poorly sorted agglomerate with clast  
 22 sizes ranging from granule to large boulders (in excess of 1m diameter). These clasts are strongly  
 23 matrix supported in a fine sand to silt grade micaceous matrix and clasts are largely sub-rounded,  
 24 with a tendency for the smaller pebble- to granule-size clasts to be more angular. The clast  
 25 population is dominated by igneous rock types associated with the Homa Mountain volcanic  
 26 complex. These range from coarse-grained ijolites to fine grained carbonatites. The clast  
 27 population also includes a significant proportion of fenitized, fine grained, Nyanzian lavas and  
 28 other pre-Cambrian basement lithologies. This lower part of KS-1 shows little internal  
 29 stratification whereas the upper part is more regularly bedded. This upper part shows discrete  
 30 beds up to 50cm thick, often delineated by pebble to granule stringers at the base of the bed,  
 31 which tend to be planar and weakly erosive into the underlying unit. These upper parts of Bed  
 32 KS-1 show weak to moderate pedogenic alteration of the pyroclastic parent material with  
 33 occasional in situ soil carbonates preserved.

34 The overlying bed, KS-2, has a poorly-defined base and is often gradational from the upper part  
 35 of KS-1. This bed is a moderately pedogenically altered and micaceous clay to gravel deposit  
 36 dominated by silty sand. KS-2 contains common granule to pebble grade clasts of local igneous  
 37 rock frequently arranged as laterally discontinuous stringers, often only a single pebble or  
 38 granule thick and typically extending laterally only a few centimeters. At several horizons in the  
 39 upper part of KS-2 there are thicker pebble conglomerates that form laterally discontinuous  
 40 lenses. These conglomerates are matrix- to weakly clast-supported and dominated by pebble-size  
 41 clasts of local igneous rock types. Pebbles are sub-angular to sub-rounded and show no clear  
 42 imbrication. The conglomerate lenses vary from 5cm to 30cm thick; they lack any real  
 43 channelization and show only very weakly erosive bases or no evidence of erosive bases. Lenses  
 44 occasionally show preferential carbonate cementation relative to the surrounding finer grained  
 45 material. The alluvial architecture of this unit comprises of broad, shallow, weakly defined  
 46 channels, or sheet flood type structures (Blair, 1999). Deposition via hyper-concentrated,

1 tractional and mudflow processes are inferred. Within KS-2 palaeosol development occurs at  
2 several horizons but is spatially discontinuous and shows only moderate to weak development.

3  
4 Bed KS-3 varies from a silt-rich, fine-grained sand to medium sand, with an often strongly  
5 bioturbated base. The bioturbation is frequently accompanied by preserved large mammal  
6 footprints and, along with other soft sediment deformation features, points to a wetter  
7 environment of deposition. KS-3 also shows moderate- to well-developed palaeosols with in situ  
8 carbonate rhizoliths as well as other pedogenic carbonate nodules. At Excavation 2, towards the  
9 northern part of the Kanjera South exposures, a channel facies of KS-3 is exposed. This displays  
10 clear cross bedding with mean flow directions to the north in a moderately sized (at least 3m  
11 width) asymmetric channel, the base of which is marked by a thin, discontinuous pebble lag  
12 marking an erosive surface into the underlying KS-2.

13  
14 Bed KS-4 is a massively bedded grey to brown, plastic, poorly sorted clayey silt with occasional  
15 pedogenically altered horizons with weak carbonate nodule formation and root marks. It contains  
16 very few terrestrial fossils, but fish teeth, otoliths, and fresh water gastropods are relatively  
17 common. No archaeological materials have been recovered from bed KS-4.

18  
19 Bed KS-5 consists of beds of red brown, poorly sorted silty clay showing signs of moderate  
20 pedogenesis alternating with bands of clast-supported pebble conglomerates up to 30 cm thick. It  
21 has a gradational base and its top has not been observed at Kanjera South. In the southern part of  
22 the outcrop the conglomerate beds become more restricted within steep sided channel features up  
23 to 1 m thick and 2.5 m wide. These channels are filled with a strongly matrix-supported, well-  
24 cemented, pebble conglomerate dominated by clasts fine grained carbonatite lavas and scoria.  
25 These channel features are laterally traceable to the south where they are seen to pass into  
26 bedded agglomerates associated with a local carbonatite vent sequence (see below).

27  
28 In the southern part of the Kanjera South exposures the sedimentary sequence is overlain by  
29 pyroclastic deposits and minor carbonatite lavas from a local, late stage, peripheral vent  
30 associated with the Homa Mountain volcanic complex. These include several feeder dykes to this  
31 vent. These dykes cross cut the Kanjera South Formation (beds KS-2 to KS-4) below the main  
32 outcrop of the volcanic sequence. The agglomerate beds associated with this vent interdigitate  
33 with the conglomerates of KS-5 to the west of Excavation 1.

34  
35 In the northern part of the Kanjera South exposures the sequence is truncated by an erosive  
36 unconformity, which is overlain by the conglomerates of the Middle Exposures Member. Figure  
37 3 is a fence diagram showing representative logs of the above lithological units from geological  
38 trenches and archaeological excavations in the Kanjera South area.

#### 40 **4. Granulometric analysis**

41  
42 Particle size analysis (PSA) has long been an established technique in reconstructing the,  
43 transport processes, depositional mechanisms and depositional environments of sediments (Liu  
44 et al., 2014; Clarke et al., 2014; Amireh, 2015; Hassan, 1978; Friedman, 1979; Le Roux & Rojas,  
45 2007). Due to the ubiquitous nature of sediments, the application of PSA spans an array of  
46 environmental settings (de Haas et al., 2014; Dill & Ludwig, 2008; Dinakaran & Krishnayya,

1 2011; Bement et al., 2007; Guan et al., 2016) and time periods (Amit et al., 2007; Yin et al.,  
2 2011; Wang et al., 2015; Schillereff et al., 2015; Lekach et al., 1998; Houben, 2007; Gillies et  
3 al., 1996). PSA has aided the current research by providing insights into the sedimentary  
4 environments and palaeohydrology at Kanjera South, allowing existing palaeoenvironmental  
5 reconstructions to be refined.  
6

#### 7 **4.1. Methodology**

8 53 spot samples were taken in excavations and geological trenches from beds KS1 to 5. Samples  
9 were subject to chemical pre-treatment outlined by (Konert & Vandenberghe 1997) to isolate  
10 discrete particles and provide evenly dispersed suspension (Liu et al. 2014). Carbonates were not  
11 removed using hydrochloric acid, as these were suspected to make up a large proportion of the  
12 samples and be part of the original deposition. Analysis of samples was undertaken using laser  
13 diffraction, with each sample run 5 times to ensure reproducibility. Laser diffraction is limited to  
14 the analysis of the fine fraction (<2mm); this fraction will be discussed herein. A detailed  
15 overview of the use of laser diffraction is given by Blott et al. (2004). The software package  
16 'GradiStat' was used to analyse the results from particle size analysis, as well as to calculate  
17 textural parameters in phi units. A detailed overview of the package and its uses is provided by  
18 (Blott & Pye 2001).  
19

#### 20 **4.2. Results**

21 Particle size distributions are presented as size class divisions, due to the occurrence of  
22 polymodal sediments (Figure 4); bed contacts are excluded from this representation. In KS1,  
23 samples are composed of clayey silts with subordinate very fine sands. They are characterised by  
24 a fine skew and poor/very poor sorting, with almost all of the sediment belonging to the  
25 suspension load (Visher 1969). In KS2 there is a coarsening of sediments to silty sands, which  
26 are noticeably more poorly sorted than adjacent beds. Samples are very poorly sorted and fine  
27 skewed, with higher percentages of coarse sand, suggestive of a more significant saltation load  
28 during this period of deposition. Samples are also increasingly polymodal. KS3 sees a fining  
29 trend from KS2, with sediments consisting of silty sand and sandy silts more likely to have been  
30 transported through suspension. Poor to very poor sorting and a fine skew continue to define  
31 sediments in KS3. Sediments continue to follow a fining trend into KS4 with very poorly sorted  
32 and fine skewed clayey silts. The fine fraction of KS5 shows similar characteristics, with the  
33 exception of some samples that are composed of silty clays as well as clayey silts. Sediments  
34 remain poorly/very poorly sorted. With the reduction of coarser grain sizes in this fine grained  
35 units of this bed, some samples lack any skew, whilst some maintain a fine skew.  
36

37 \*\*\*\*\*INSERT FIGURE 4 DISPLAYING PARTICLE SIZE DISTRIBUTIONS HERE\*\*\*\*\*  
38

### 39 **5. Environmental interpretation**

40  
41 The sedimentology and lithology of the Kanjera South Formation provide a record of the  
42 palaeoenvironments of its deposition. Previous interpretations of the Kanjera depositional  
43 environments are shown in Table 2. The analysis presented below draws upon these previous  
44 studies and adds further field and laboratory analysis, including the previously discussed  
45 granulometric analysis of the matrix sediment (see Table 2 and Figure 4).  
46



1  
2 \*\*\*\*\*INSERT TABLE 2 NEAR HERE\*\*\*\*\*  
3

4 The lower part of KS-1 possibly represents the deposits of one or more relatively large flows of  
5 remobilized pyroclastic material, likely as lahars (volcanic debris flows) based on the abundance  
6 of clays and silts, as well as its very poor sorting and fine skew, in addition to the presence of  
7 large clasts and boulders of a wide variety of Homa Mountain igneous lithologies. These most  
8 probably moved from the Homa Mountain complex in the south towards a depositional center in  
9 the north related to the Winam Gulf graben. These lower parts of KS-1 show little internal  
10 stratification and no pedogenic development and likely represent rapid deposition. The upper  
11 parts of KS-1, which lacks the coarse conglomerate component (boulder-grade material), and  
12 includes weak pedogenic development, represents intermittent reworking of the pyroclastic flow  
13 deposits probably by ephemeral streams running across the landscape. KS-2 further develops this  
14 latter style of deposition with more widespread and better-developed pedogenesis, indicating  
15 wider temporal spacing between depositional events. Unconfined channel structures (with weak  
16 erosive, weakly developed channel base structures) very poor sorting of the <2mm fraction  
17 (poorly sorted grain size assemblages in the >2mm fraction), multi-modality and fine-skew  
18 indicates deposition is likely to have been dominated by intermittent hyperconcentrated-to-  
19 mudflow events of an unconfined nature (Pierson, 2005). Such flow events would have been  
20 separated by periods of landscape stability with periods of pedogenic development, characteristic  
21 of alluvial fan and pediment/slope environments. This is important to the interpretation of  
22 archaeological remains deposited in KS-2, as this style of deposition is less likely to erode the  
23 underlying surface, due to the relatively viscous nature and low shear stress bases (Pierson,  
24 2005). This promotes preservation of surface archaeological accumulation, as surface objects are  
25 buried rather than eroded (de la Torre et al., 2017; Stanistreet et al., 2018). In addition to this,  
26 flow hiatuses may have been characterised by aeolian deposition and reworking of sediment,  
27 which may have been subsequently reworked. Such reworking may account for the abundance of  
28 fine sediment, as well as the multimodal nature of grain size distributions (Vandenberghet al.,  
29 2013). Overall, the depositional environment of KS-2 is compatible with an alluvial plain setting.

30  
31 KS-3 sees the transition to a wetter depositional environment reflected in the style of pedogenic  
32 alteration and preservation of soft sediment deformation features (especially large mammal  
33 pedoturbation), as well as the abundance of clays/silts and a very fine skew in the sediment.  
34 There is evidence of at least one channel in the area, as seen from the sequence at Excavation 2.  
35 This channel was at least 1 m deep and 3 m wide and preserved the partial skeleton of a  
36 hippopotamid associated with artefacts. KS-4 represents a continuation of this wetting trend as  
37 lake margin deposits transgressed from north to south over the area. Despite this, the lake system  
38 was at least periodically dry enough for minor palaeosol development to take place within at  
39 least two horizons in this unit.

40  
41 Bed KS-5 represents a return to terrestrial conditions following regression of the lake, possibly  
42 mediated by local uplift associated with the activity of the nearby Kanjera South volcanic vent  
43 system.

44  
45 The lahar deposit that defines the lowermost known extent of KS-1 would have been significant  
46 in the local area and perhaps beyond. Because the main unstratified body of the flow is at least

1 3m thick, it likely destroyed all standing vegetation in its path and modified some aspects of  
 2 local topography. The main archaeological horizon concentrated in KS-2 and uppermost KS-1  
 3 accumulated during the interval following the emplacement of the lahar deposits at the base of  
 4 bed KS-1 and before the lake margin transgression across the area at the base of bed KS-4.  
 5 Stable isotopic analysis of pedogenic carbonates from these archaeological strata at Kanjera  
 6 South show a uniformly C4 grass-dominated signal that is further supported by the taxonomic  
 7 and isotopic analyses of the numerous mammalian fossil remains recovered from the site  
 8 (Plummer et al., 1999; Plummer et al., 2009). Kanjera South thus may have been a particularly  
 9 attractive locality for hominin activity during that time, with lake margin grassland on at least  
 10 seasonally moist soils supporting an abundant local fauna, and ephemeral streams supporting  
 11 patches of plants producing underground storage organs (Lemorini et al., 2014).

## 12 13 **6. Geochronology**

14  
15 A precise geochronology for the Kanjera South deposits is somewhat difficult to construct, due  
 16 in part to the resistance to known dating techniques of the igneous material recovered so far.  
 17 Repeated attempts to date overlying volcanics using Ar-Ar methods have been unsuccessful.  
 18 However, a combination of palaeomagnetic and biostratigraphic studies using the abundant  
 19 mammalian fauna allow us to delimit the age of the archaeological deposits. The proboscidean  
 20 *Deinotherium* sp., the suids *Metridiochoerus modestus* and *M. andrewsi*, as well as the extant  
 21 genus of equid *Equus* have all been recovered. The earliest African appearance of *Equus* dates  
 22 to 2.3 Ma as does the First Appearance Datum (FAD) for *M. modestus* (Cooke, 2007). *M.*  
 23 *andrewsi* is known from 3.36 Ma – 1.7 Ma elsewhere in Africa and *Deinotherium* sp. is known  
 24 from deposits older than 1.5 Ma. These taxa indicate that archaeological materials were  
 25 deposited between 2.3 -1.7 Ma. Moreover, the Olduvai Subchron (1.922 – 1.775 Ma, Singer  
 26 2014) has been detected in the sediments of Beds KS-4 and KS-5 (Ditchfield et al., 1999). In  
 27 Ditchfield et al. (1999: 141) the Olduvai Subchron was mistakenly identified as beginning in KS-  
 28 5, as the label for KS-4 was missing from Fig. 8. This figure should have shown Bed KS-4  
 29 extending from just below paleomag sample KJS 51 to about 20 cm above paleomag sample KJS  
 30 45. Thus, normal polarity paleomag samples KJS 45-56 are from KS-4, demonstrating that the  
 31 Olduvai Subchron extended from KS-4 across its contact with basal KS-5. The underlying  
 32 archaeological occurrences in Beds KS-1 to KS-3 must therefore predate the base of the Olduvai  
 33 subchron at 1.92 Ma, yielding a date of between 2.3 and 1.92 Ma for hominin activity. Given the  
 34 rapidity of deposition, it seems likely that the archaeological occurrences are closer to the  
 35 younger end of this time interval, with an approximate age of ~2 Ma.

## 36 **7. Analysis of site formation**

37  
38 In any discussion of archaeological site formation the central question to be addressed is the  
 39 extent to which artefacts and fossils are in primary depositional context. The answer to this  
 40 question determines the types of behavioural inferences that can be drawn from study of the  
 41 archaeological material. At Kanjera South it is impossible to determine whether the sedimentary  
 42 matrices were deposited primarily by alluvial and/or colluvial action given the lack of  
 43 sedimentary structures in uppermost KS2. Field sedimentological observations coupled with  
 44 granulometric analyses of the matrix indicate the most likely environment of formation for KS-2  
 45 is an alluvial fan/pediment. Deposition is characterized by hyper-concentrated (ss. Pierson, 2005;  
 46 de la Torre et al., 2017) and tractional, unconfined flow events (Blair, 1999). It is possible given

1 the fine-grained nature, fine-skew and multi-modality that sediments were partly deposited via  
2 aeolian processes (Vandenberghe et al., 2013). Sedimentary structures are absent due in part to  
3 in situ breakdown of volcanic materials from the Homa Mountain complex, which are altering  
4 into clays. Where bedding structures are present and not obliterated by subsequent pedogenesis  
5 they lack significant channelisation and thus tend to point more towards unconfined sheet flow-  
6 like processes. The planar to undulating, unchannelised nature of pebbly lags at the base of some  
7 beds also supports this interpretation. Within the archaeological strata, most of the artefacts and  
8 bones are outsized clasts compared to the enclosing sediment (Plummer et al., 1999). The  
9 general low energy/fine-grained nature of the facies, coupled with evidence of mudflow to  
10 hyperconcentrated flow and hyper-concentrated flows (notwithstanding minor conglomeratic  
11 lenses in KS-2), indicates that depositional processes buried an in situ accumulation of artefacts  
12 and fossils. The general state of the archaeological materials, which show little weathering or  
13 rounding, preserve good surface and edge detail, and include bones with a range of hydraulic  
14 potentials strongly supports this interpretation (Plummer et al., 1999; Ferraro et al., 2013;  
15 Lemorini et al., 2014). Finally, the presence of thousands of non-identifiable bone fragments  
16 less than 2 cm in length (Ferraro, 2007), which would likely have been winnowed away under a  
17 high energy flow regime, also argues against the bone and artefact assemblages being formed  
18 through hydraulic activity. That these small fragments are not being transported from elsewhere  
19 is indicated by their frequent association with larger bones bearing evidence of hammerstone  
20 percussion. Given the above and taking into account the vertical distribution of materials, deposit  
21 depths, and estimated rates of sedimentation, deposition likely occurred over a period of decades  
22 to centuries per bed burying stone tools and faunal remains at or very near their place of discard.  
23

## 24 **8. Conclusions**

25  
26 In summary, this paper presents the geological setting and lithostratigraphic descriptions of the  
27 herein designated Kanjera South Member of the Kanjera Formation. Archaeological traces of  
28 Oldowan hominin behaviour have been recovered primarily from the upper part of Bed KS-1  
29 through to the lower part of Bed KS-3, with a significant concentration in unit KS-2. Analysis of  
30 the sedimentary facies sequence and stable isotopic analysis of pedogenic carbonates within the  
31 archaeological sequence, point to a grass-dominated relatively low-slope environment, which  
32 formed relatively rapidly on top of earlier lahar deposits. There is a wetting trend from KS-1 to  
33 KS-4, possibly indicating that the lake margin was moving progressively closer through time.  
34 Traces of hominin activity in the area cease as lake facies transgressed from north to south across  
35 the site as seen in Bed KS-4. Although there are weak soil horizons within the lake deposits in  
36 KS-4 indicating at least periodic retreat of the lake, these have yielded no archaeological  
37 materials. Granulometric analyses of the sediments indicate a sedimentary regime of  
38 hyperconcentrated flows with subordinate mudflows, which would not have significantly eroded  
39 or altered the surface on which they were deposited (Pierson, 2005; de la Torre et al., 2017). It is  
40 notable that a similar depositional environment was recognized in Bed I Olduvai Gorge,  
41 Tanzania where this interpretation has also been applied (Stanistreet, 2012). The sedimentology  
42 and site formation processes of the archaeological strata at Kanjera South support the  
43 interpretation that the Oldowan assemblages represent a primary context accumulation from  
44 which behavioural inferences can be reliably drawn.  
45  
46

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Bed	Description	Palaeoenvironmental Interpretation
KS-1	Grey-brown silty, gravelly sand and sandy silt, with layers of hard CaCO <sub>3</sub> nodules. These preserve fine horizontal lamination and indicate post-depositional calcification. Clasts including granite, grey and red chert, some volcanic material and large biotites present in gravel associated with coarser sand. Some thin clayey silt beds in upper 1m. Bimodal grain size distribution of medium-grained sand and fine silt-clay	Deposition initially began as a flow of pyroclastic material from the Homa Mountain complex towards depocenter Nyanza Rift graben in the north. These deposits reworked by ephemeral streams running across the fan of the original pyroclastic flows. Possibly a near-shore lacustrine or wet floodplain environment
KS-2	~1.3m of orange and yellow-grey gravelly sand, with a thin patchy conglomerate. Contains fresh biotites, angular and rounded volcanic and basement clasts. Cross-stratification orientated 150-155° (southeast). Variable cementation, locally very mottled with irregular limonitic staining	Fluvial channel fill, with deposition by anastomosing channels flowing with intermittent, diffuse, generally low energy flow regimes
KS-3	~60cm of homogeneous and massive light orange to yellow-grey sandy silt with some tuffaceous silt. Some horizontal orange mottling. Includes partial Hippopotamus skeleton. Ostracods and fish scales also present	Continuation of KS2, with a transition to a wetter depositional environment. Small channel present with more stable land surfaces
KS-4	~3.2m thick grey-green and brown clay, with some silty clay and occasional sandy clay in lower bed. Clays generally dense, homogeneous, calcareous and mottled, with occasional slickensides and soft patches of CaCO <sub>3</sub> . Sandy clay channel feature 1.5m above the base, with root traces and reworked clay clasts. Irregular bedding contacts within the clays suggest pedobioturbation. Increased CaCO <sub>3</sub> in upper half of unit; this occurs as vertical patches and small nodules. Pedogenesis evidenced by vertical cracking, decreased homogeneity of clay, and abundant nodules. Ostracods and fish debris in lower parts of bed	Very-low energy lacustrine or swamp deposition. Periodic sub-aerial exposure with some sub-aqueous deposition. Clays deposited either during the transgression of a lake or during the formation of a wetland system
KS-5	~2-2.5m of brown clayey sandy gravel, with matrix-supported grains and pebbles. Some resistant CaCO <sub>3</sub> layers interbedded; abundant volcanic gravel and cobbles present in some of these. One limestone bed has plant stem and root moulds, whereas others are massive and caliche-like. Clayey sand and gravel beds generally massive and bimodal, with some grain-supported gravel lenses and abundant small CaCO <sub>3</sub> nodules throughout	Fluvial deposition with a variable energy regime combined with pedogenesis and stable landsurface development
KS-6	2m of brown clay, grading upward to light-grey mottled gravelly clay and capped by an irregular, massive CaCO <sub>3</sub> bed up to 40cm in thickness. Lower part has fewer CaCO <sub>3</sub> nodules than KS-5. Upper part of bed has patches of gravelly and sandy clay, which are dark grey and have yellow streaks and mottling. Relatively pure clay with no coarser clast components	Continuation of KS5. Wet conditions, possibly near a spring or other source of calcium-saturated water

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Table 2. Summary of bed descriptions and environmental interpretations for the Kanjera South area based on observations in this study and previously published descriptions from Behrensmeyer et al., (1995), Ditchfield et al., (1999), and Plummer et al., (2009).

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Bed	Total NISP	Macro-mammal NISP	Macro-mammal MNI	Principal fauna (%NISP, %MNI)	Artefacts
KS-1	982	975 (525)	25	Bovid (92.4, 72.0), Equid (4.4, 8.0), Suid (1.5, 8.0), Hippo (0.2, 4.0)	179
KS-2	2190	2153 (886)	40	Bovid (82.6, 67.5), Equid (11.6, 10.0), Suid (0.9, 5.0), Hippo (1.0, 2.5)	2533
KS-3	491	470 (172)	16	Bovid (77.9, 68.8), Equid (4.7, 6.3), Suid (0.6, 6.3), Hippo (14.0, 12.5)	171

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Table 1: Excavated materials from Kanjera South. These samples were recovered predominantly from Excavation 1. ‘Total NISP’ refers to specimens that were collected with coordinate data. Thousands of non-identifiable bone fragments <2cm are not included in these counts, nor are fossils from the conglomeratic facies (CP levels of Plummer et al. 1999). Macro-mammals refers to animals weighing more than 5 kg. Macro-mammal NISP values are total sums, followed by the sum of specimens identified beyond Linnean class in parentheses. After Ferraro et al., 2013, Table 1.