

Implications of a new chronology for the interpretation of the Middle and Later Stone Age of the upper Zambezi Valley.

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Abstract

Single grain OSL dating has been used to produce new chronologies for three previously investigated sites in the northern Kalahari basin in western Zambia containing both Middle and Later Stone Age material (Phillipson 1975 a&b). We find that Mode 3 (Middle Stone Age, MSA) assemblages in the Upper Zambezi Valley pre-date the Last Glacial Maximum. The chronology produced here is consistent with age estimates from a handful of dated sites within the wider Kalahari basin. The Mode 3 to Mode 5 (Later Stone Age, LSA) relationship at one site, Chavuma, is unlikely to be a continuous transition as previously thought. Instead we find a significant chronological hiatus between MSA material deposited at 66.5 ± 9.9 ka and LSA material deposited at 16.7 ± 2.6 ka. We consider these dated archaeological finds within the context of current archaeological and palaeoenvironmental records for the region. The results demonstrate the highly variable climate history of the region and the limitations of the existing archaeological record for modelling human responses to habitat change.

1. Introduction

1.1 Palaeolithic Archaeology in the Kalahari basin

The southern African interior possesses a long record of human occupation (Barham, 2000; Burrough, 2016;) that, for the most part, remains poorly investigated. This is despite the richness of available sites reported in the middle of the twentieth century by Van Riet Lowe (1935), Clark (1950) Bond and Summers (1954) and others. Archaeological research has favoured sites that offer good organic preservation, with a strong focus on cave-sites along the South African coast (Backwell et al., 2014; Stewart et al., 2012;) (Figure 1). The interior Kalahari basin however possesses an abundance of Stone Age archaeological sites (see Burrough 2016 for an overview), albeit that many are in open air contexts. While these may often lack associated organic deposits, many are situated in landscape contexts that attest to extreme and repeated water deficits and surpluses (Burrough et al., 2009; Burrough and Thomas, 2013; Thomas et al., 2003; Thomas and Burrough, 2012) that have potentially

vital implications for human population distributions in the Quaternary and today (Brooks, 1984, Barham, 2000).

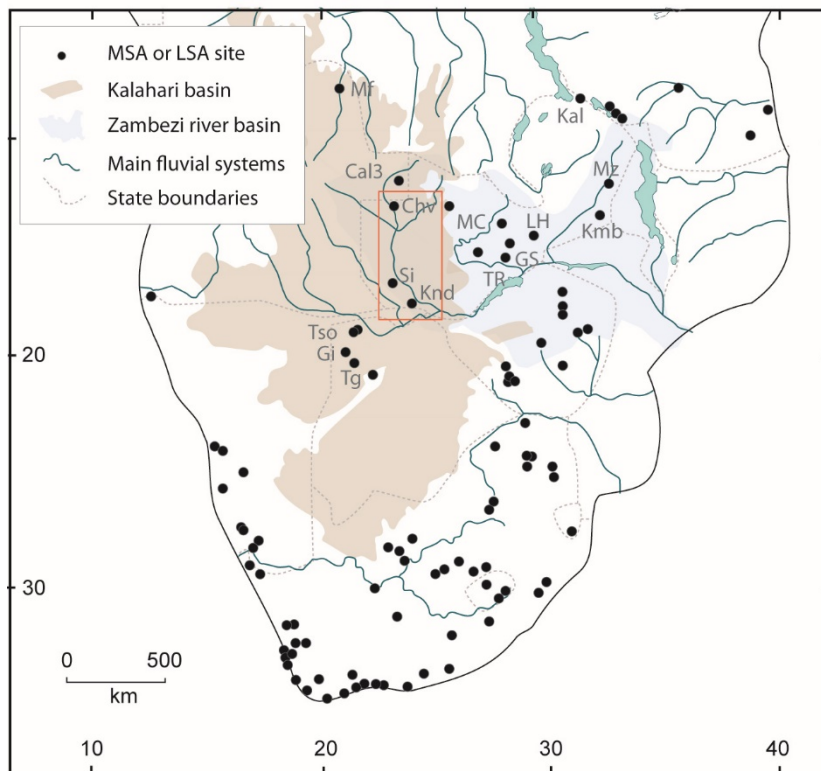


Figure 1: Published MSA and LSA archaeological site locations within southern Africa. The upper Zambezi region is marked with a red box. 1) Congo basin; 2) eastern Namib/western Kalahari rainfall record; 3) Megalake Makgadikgadi; 4) Tswaing Crater; 5) Zambezi Fan; 6) Lake Chilwa; 7) Lake Malawi; 8) Lake Tanganyika; Mf = Mufo; Cal3 = Calunda III; Chv = Chavuma; Si = Sioma M; Knd = Kandanda; Kal = Kalambo Falls; Mz = Manzi River; MC = Mumbwa Caves; GS=Gwisho Springs; TR = Twin Rivers; LH = Leopards Hill Cave; Kmb = Kalembo Rock Shelter; Tso = Tsodilo; Gi = #Gi; Tg = Toteng.

Zambia, which includes the northeastern part of the Kalahari basin, provides key evidence from the Zambezi Valley (Clark, 1950) and high plateau (Clark, 2001; Barham, 2000) that demonstrate marked changes in the content and periodicity of occupation, with gaps in the record tentatively related to records of palaeoenvironmental change (Barham, 2001). Important themes to have emerged include the potential significance of fluvial systems as refugia during regionally dry conditions in the Pleistocene (Avery, 2003; Barham, 2001;). There are however very few chronologically constrained sites (particularly in association with river systems) to test whether this is a real pattern or an artefact of research to date. Nevertheless, the north-south fluvial corridors of the southern African interior (Okavango, Kwando and Zambezi), bringing flood pulses from the tropics, are likely to have

been critical for access to food and water resources. They may also have been important as human migratory corridors during times when wider environmental conditions were dry.

In western Zambia at the northeastern margin of the Kalahari basin, an abundance of Stone Age sites have been reported in the Upper Zambezi Valley (UZV) (Inskeep, 1959; Phillipson, 1975a; Phillipson, 1975b; Phillipson, 1977). However, little archaeological investigation has taken place since the surveys and excavations of Laurel Phillipson (Phillipson, 1975a&b, 1977) who worked at open sites along the Zambezi between the Angolan border and Victoria Falls (Phillipson, 1975a). Middle (MSA) and Later (LSA) Stone Age assemblages were excavated, but remain largely under-cited, perhaps because of the difficulty of proving site chronologies. Radiocarbon was the only absolute dating technique available at the time and not all the sites contained charcoal, with none containing bone. Subsequent dating developments have shown the MSA to be well beyond the range of radiocarbon (Barham and Mitchell, 2008; Wadley, 2015), with the onset of the LSA in southern Africa at its upper limits (Villa et al., 2012). A recent road construction project has destroyed many of the sites that Phillipson investigated, but during palaeoenvironmental fieldwork in 2011 an opportunity arose to revisit three remaining, but imminently threatened, Phillipson sites at Chavuma, Sioma M and Kandanda (Donke gravel pit) to undertake sampling for Optically Stimulated Luminescence (OSL) dating. Here we report the findings of this investigation with the aim of placing the original archaeological data within the chronological context of regional records of palaeolithic and palaeoenvironmental change. We present the sampling and dating for each site, a re-consideration of the archaeological material and a discussion of both the archaeology and their ages in relation to our knowledge of the wider regional archaeological and environmental record.

1.2. Western Zambia

Western Zambia (Figure 1) occupies the eastern margin of the 2.5 million km² Kalahari sedimentary basin (Thomas and Shaw, 1991), and is covered by sand up to 200 m thick (Thomas 1988; Haddon, 1999, 2005). Mean annual rainfall in interior southern Africa decreases from northeast to southwest, controlled principally by the seasonal migration of the tropical rainbelt, decreasing in the UZV from 1,375 mm^a at Mwinilunga (near the source of the river on the Central African Plateau) to 700 mm^a at Sesheke (Fanshawe, 1971). The wet season extends from November to May in the north of the valley, though is several weeks shorter in its southern reaches, near Katima and Livingstone. The Zambezi moves water through the broad Barotse floodplain, which floods up to 30 km in width between December and May, steepening and narrowing below Senanga as it incises into Karoo-age basalts of the sub-Kalahari bedrock, creating a series of rapids. The UZV spans an ecological transition zone from dense *miombo* woodland through woodland-savanna and

edaphic grassland to a much more xeric-savanna system in the south (Burrough and Willis, 2015). Like the Okavango and Kwando rivers, the UZV carries water from the wetter sub-tropics into drier sub-humid areas. Permanent fluvial channels within the Zambezi floodplain and dambos (shallow wetlands) away from the river provide critical dry season water for modern occupants of the UZV (Burrough et al., 2015). That this was also the case in the past may be reflected in the distribution of archaeological sites along channel margins.

The deep Kalahari sands of western Zambia are also a challenge for locating archaeological deposits, with the majority of sites described by Phillipson (1975a) exposed in road quarries dug in the 1960s and 70s. The sand cover also limited the exposure of rock outcrops for Stone Age people, potentially making resources for lithic tool manufacture scarce. It is notable that many of the UZV in-situ sites are adjacent to major rapids where bedrock is revealed, with a significant proportion of documented lithics manufactured from poor-quality sandstone and quartzites exposed in these locations, including derived quartzite pebbles (Money, 1972). Fluvial erosion may also affect archaeological visibility in this otherwise sandy landscape, which could contribute bias to site distributions.

1.3 Site locations

The three investigated sites, Chavuma, Sioma M and Kandanda are shown in Figure 2. Locations and conditions of preservation are outlined briefly here with the archaeological content summarised following the presentation of the dating methods and results.

Chavuma (-13.0946°S, 22.68899°E)

Chavuma Falls archaeological site is on the east bank of the Zambezi at a point where the river is ponded behind a rock barrier as it passes through the Chavuma Hills. It is adjacent to a deep pool at the base of Chavuma Falls and located within a 5 m section of a thick sandy bank. The base of the section grades into fluvially-deposited pebbles and gravels that rest on the underlying bedrock. The absence of material suitable for ¹⁴C dating meant Phillipson (1975a & b) was unable to provide a chronology.

Sioma M (-16.61269 °S, 23.507585°E)

Exposed in a quarry pit during road construction in 1965, Sioma M is 1.3 km southwest of the present Zambezi channel and comprises 0.3 m of hard ferricrete on and in which archaeological material is located. This is overlain by 1.2 – 2.5 m of red- yellow sand (Munsell colour 10YR 6/8).

Donke Gravel Pit near Kandanda (-17.4224 °S, 24.19666 °E)

113 Kandanda is adjacent to rapids where the Zambezi has cut through bedrock obstructions, forming
114 three valley-side terraces. Phillipson (1975a, 1977) described the archaeological site as exposed by a
115 large quarry, on the northeast side of the Senanga road between Kandanda village and the
116 Kachekabwe tributary stream. Forty years later, when sampling occurred for this study, the site was
117 again being used as a quarry for road construction, where enlargement had destroyed the majority
118 of Phillipson’s 1969 excavation trenches. A few sections remained, including Donke, on the
119 uppermost terrace, adjacent to survey beacon BM6R. Charcoal fragments within the Kandanda
120 section provided several ^{14}C ages in the original analysis (see section 3.2.3)

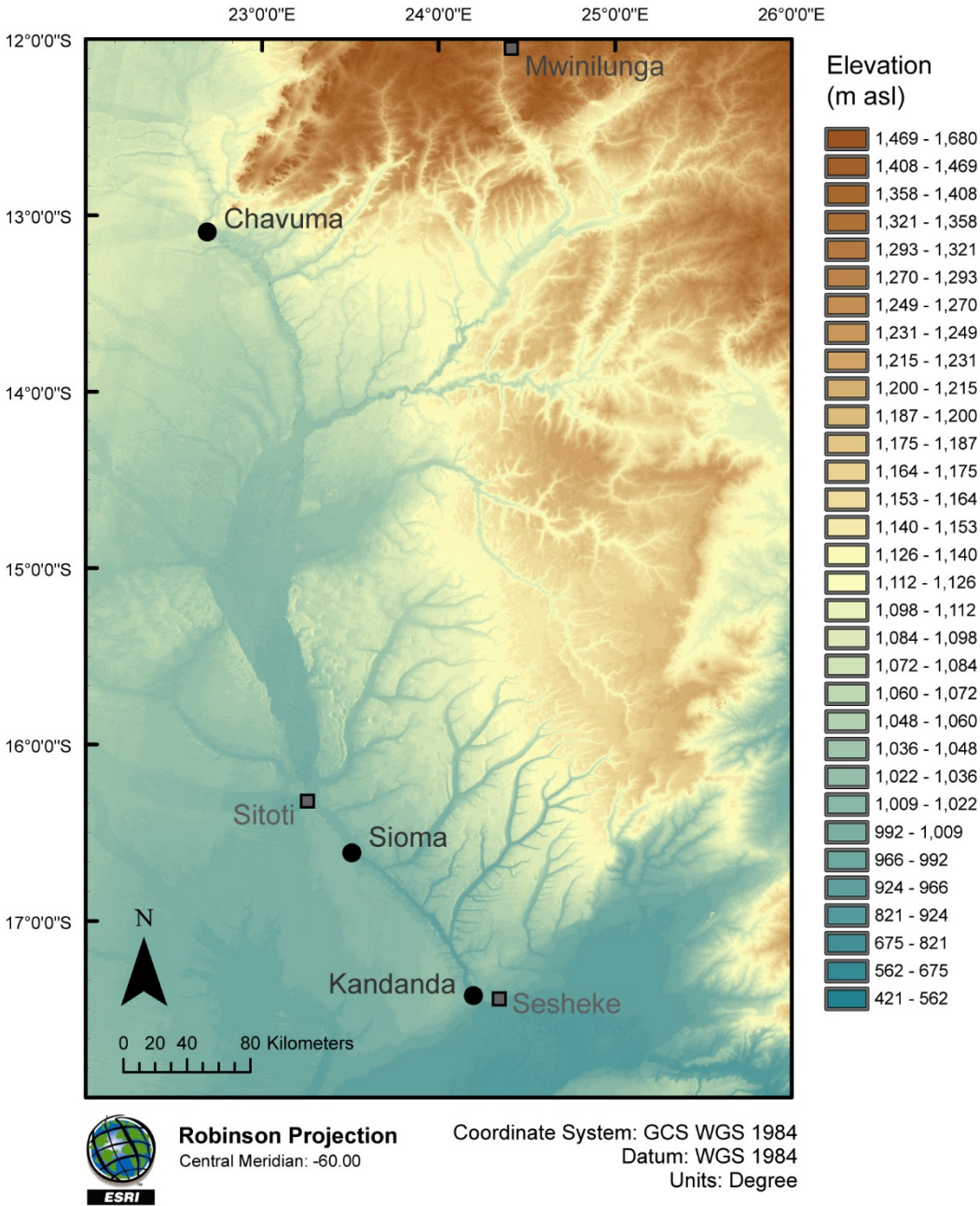


Figure 2: Regional Digital elevation model of the Upper Zambezi Valley (UZV) showing archaeological site locations (filled black circles) investigated in this study. Major settlements discussed in text are also given as grey squares.

2. OSL Dating

Sediments for dating were collected at Chavuma (7 samples; ZAM/11/5) and Sioma M (4 samples; ZAM/11/9) using an auger with a light-tight sampling head. At Donke (Kandanda), Phillipson's 1968 test pit remained open; this was dug out and sampled from a cleaned face (3 samples; ZAM/11/14). Samples for OSL dating were prepared under subdued red light (600 nm) conditions at the Oxford Luminescence Dating Laboratory (OLDLab). The outer material (approximately 60% of an 8 x 15 cm tube) from each sample was separated and later used for dosimetry and sedimentological measurements. The centre of the sample (uncontaminated by light) was processed using standard quartz isolation methods e.g. Burrough et al., (2009). A total of 14 samples were dated for this study.

2.1 Equivalent dose (D_e) Determination

All samples were dated using 800-1000 individual quartz grain D_e measurements per sample. The distribution of D_e measurements from single-grain analysis is advantageous for age determinations from Kalahari sediments. First, multiple grain analysis averages D_e signals in a manner that can mask erroneous data from 'rogue' grains (c.f. Russell and Armitage, 2012) that would otherwise be rejected in a single grain analysis. These averaging errors will most likely produce overestimated ages. Second, single grain analysis provides a D_e distribution that allows a much clearer assessment of depositional and/or post depositional processes, which is critical for informing the choice of age model used to produce the final age. For details on measurement conditions and rejection criteria see supplementary info S1.

2.2 Dose rate (D') determination

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was used to measure the isotope concentrations (^{232}Th , ^{238}U and ^{40}K) that determine sample dose rates. For two samples (ZAM/11/5/4 and ZAM/11/5/5), up to 10 small (~1g) subsamples of bulk sediment were separated for additional ICP measurements to attempt to capture any variability within the sediment. In addition, one sample (ZAM/11/5/4) was density-separated to obtain both heavy mineral and feldspar fractions. The latter was too small by mass to undertake analyses but U, Th and K concentrations in quartz and heavy mineral fractions were measured independently to assess within-sample micro-dosimetry variability. Field gamma spectrometry measurements were also taken for samples ZAM/11/9/2; 9/3;

9/4 and ZAM/11/14/3 to check that direct radiation measurements returned within-error estimates of the sedimentary gamma dose. Conversion to external beta and gamma components (to account for grain-size, HF etching and moisture content) used the dose-rate conversion and beta attenuation factors of Guerin et al., (2011) and Mejdahl (1979), assuming radioactive equilibrium in the ^{238}U and ^{232}Th series. Sample moisture contents during burial were estimated at 10-18 % (Table 1) based on 'as found' values. An absolute internal alpha dose uncertainty of 0.012 Gy/ky (Vandenberghe et al., 2008) was added in quadrature to the total dose rate error. Cumulative cosmic dose during the burial period was iteratively modelled based on the overlying depositional history (Burrough et al., 2007). Total dose rate uncertainties were calculated using Monte Carlo methods.

3. Results and Discussion

3.1 Equivalent Dose distribution

Dose rate data, D_e estimates and ages are given in Table 1 and 2. D_e distributions were consistently broad. Overdispersion (statistical distribution) values, ranging from 43% to 120% (Figure S1), lie within the upper end of the range of overdispersion values typical for single grain measurements. In all samples 2-4% of measured grains had natural signals which far exceeded the growth curve. All accepted D_e 's were below 86% of saturation ($2 \cdot D_0$) (Wintle and Murray, 2006). Multiple subsample aliquots for ZAM/11/5/4 and ZAM/11/5/5 suggested bulk dose rate variability of ~20% (subsequently factored into the uncertainty of all sample radioisotope concentrations). Sediments were typically quartz-dominated with a small heavy mineral proportion (0.3-1% by mass). Heavy minerals create very different dose rates at the inter-grain scale (Figure 3b), with implications for age model selection. These data suggest a proportion of the observed sample overdispersion can be attributed to dose rate variability at the single grain scale (see supplementary info S2 for details).

Table 1: Radioisotope concentrations and estimated sediment dose rates for each sample.

Site Name	Sample ID	Radioisotope Concentrations ^a				Sediment dose rates (Gy/ka)			
		K (%)	Th (ppm)	U (ppm)	Moisture content (%) ^b	Beta	Gamma	Cosmic ^d	Total dose rate (Gy/ka)
Chavuma	ZAM/11/5/1	0.05	1.64	0.38	0.10	0.11	0.12	0.21	0.43 ± 0.06
	ZAM/11/5/2	0.05	1.47	0.36	0.10	0.10	0.11	0.20	0.41 ± 0.06
	ZAM/11/5/3	0.07	1.86	0.45	0.10	0.13	0.14	0.20	0.47 ± 0.07
	ZAM/11/5/4	0.03	1.44	0.39	0.10	0.09	0.11	0.19	0.39 ± 0.06
	ZAM/11/5/5	0.04	1.41	0.43	0.15	0.09	0.10	0.18	0.37 ± 0.05
	ZAM/11/5/6	0.05	2.10	0.47	0.18	0.11	0.13	0.16	0.40 ± 0.06
	ZAM/11/5/7	0.05	1.40	0.40	0.18	0.09	0.10	0.16	0.35 ± 0.06

Sioma M	ZAM/11/9/1	0.07	1.40	1.75	0.10	0.26	0.25	0.22	0.73 ± 0.12
	ZAM/11/9/2	0.07	1.16	0.68	0.10	0.14	0.11 ^c	0.21	0.49 ± 0.06
	ZAM/11/9/3	0.08	1.54	1.00	0.10	0.19	0.15 ^c	0.20	0.57 ± 0.08
	ZAM/11/9/4	0.07	1.63	1.60	0.10	0.25	0.23 ^c	0.20	0.69 ± 0.10
Donke	ZAM/11/14/1	0.35	1.36	0.36	0.10	0.29	0.17	0.23	0.69 ± 0.06
	ZAM/11/14/2	0.36	1.60	0.37	0.10	0.31	0.18	0.23	0.72 ± 0.07
	ZAM/11/14/3	0.43	1.62	0.47	0.12	0.36	0.20 ^c	0.22	0.79 ± 0.08

^a Error on K, Th and U estimated at 20% based on repeat (n=10) sub-sample ICPMS measurements for samples ZAM/11/5/4 and ZAM/11/5/5

^b Average moisture content during burial period estimated from present day water content ± 20%

^c Measurements made using in situ gamma spectrometry.

^d Mean cosmic dose rates, (cumulative modelled total cosmic dose (Gy) / age (ka)).

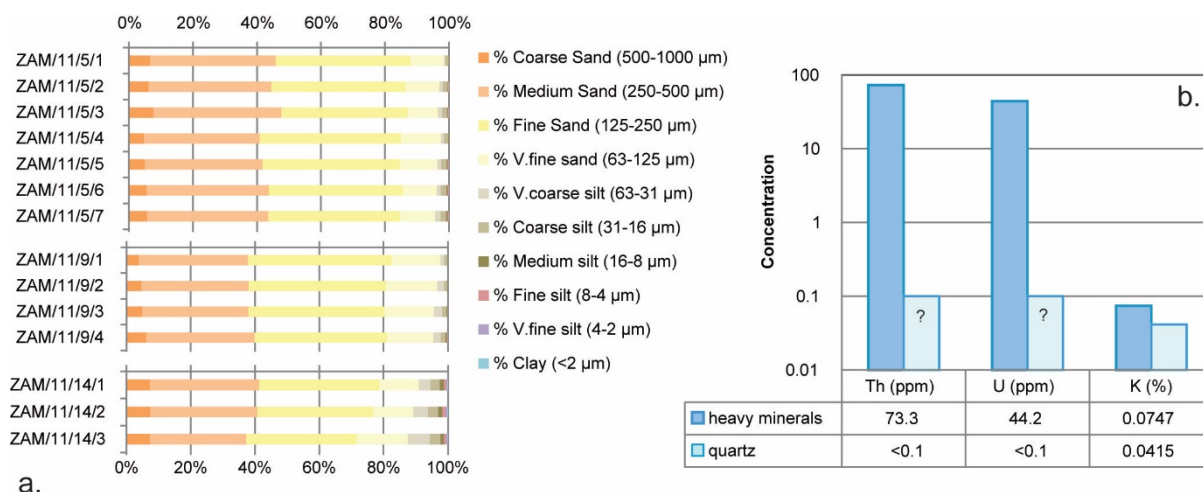


Figure 3: a) Grain size distribution for each site and b) Separated heavy mineral and quartz fraction radioisotope concentrations from sample ZAM/11/5/5 (question marks indicate measurements below detection limits (<0.1 ppm)).

Table 2: Equivalent dose distribution characteristics and OSL age estimates.

Sample ID	Depth (m)	n ^a	Equivalent Dose ^b (Gy)	Overdispersion (%)	Central Age (ka)	FMM Age (ka)	Wgt Mean Age (ka)
ZAM/11/5/1	1.00	115/800	1.63 ± 0.1	114%	5.19 ± 0.76	2.85 ± 0.33	3.77 ± 0.41
ZAM/11/5/2	1.50	127/800	2.72 ± 0.39	94%	9.64 ± 1.76	6.42 ± 1.03	6.66 ± 1.59
ZAM/11/5/3	2.00	121/800	3.50 ± 0.35	81%	9.60 ± 1.26	6.81 ± 1.09	7.55 ± 1.43
ZAM/11/5/4	2.30	105/800	3.27 ± 0.31	66%	10.44 ± 1.91	8.40 ± 1.31	8.29 ± 1.67
ZAM/11/5/5	3.00	233/800	6.99 ± 0.63	81%	25.64 ± 4.19	16.66 ± 2.60	18.82 ± 3.55
ZAM/11/5/6	3.50	250/900	11.03 ± 0.60	67%	34.48 ± 5.25	65.51 ± 9.93	26.69 ± 4.14
ZAM/11/5/7	4.00	155/900	14.00 ± 1.1	64%	51.23 ± 8.11	75.73 ± 16.61	39.76 ± 6.86

ZAM/11/9/1	0.50	105/700	1.88 ± 0.10	73%	2.78 ± 0.41	2.63 ± 0.34	2.59 ± 0.35
ZAM/11/9/2	1.20	174/700	2.41 ± 0.7	86%	5.93 ± 0.96	4.61 ± 0.62	4.97 ± 0.68
ZAM/11/9/3	1.70	145/700	8.49 ± 0.21	60%	16.78 ± 2.58	15.02 ± 2.01	14.95 ± 2.07
ZAM/11/9/4	2.10	188/700	9.94 ± 0.29	80%	21.83 ± 3.73	16.47 ± 2.44	14.14 ± 2.17
ZAM/11/14/1	0.32	112/800	1.80 ± 0.05	66%	3.18 ± 0.29	3.09 ± 0.25	2.63 ± 0.18
ZAM/11/14/2	0.55	102/800	3.27 ± 0.8	43%	4.65 ± 0.48	4.48 ± 0.49	4.61 ± 0.41
ZAM/11/14/3	0.80	107/700	4.74 ± 0.11	59%	6.96 ± 0.83	6.39 ± 0.74	6.16 ± 0.56

^a Number of accepted OSL signals / total number of grains measured.

^b Weighted mean $D_e \pm 1\sigma$

3.2 Age model selection

It is unknown whether the highly overdispersed D_e s are a common or anomalous feature of the region: despite a long history of Kalahari OSL applications (c.f. Thomas and Burrough, 2013) very few studies have utilised the single grain methodology. It is vital therefore to consider this further.

There are three possible reasons for a large D_e distributional spread: i) partial bleaching, whereby grains were insufficiently exposed to sunlight prior to deposition, leaving some with a residual dose from a previous depositional cycle; ii) bioturbation, with grains of different depositional ages moved or mixed by biological processes after deposition; and iii) beta dose rate heterogeneity, whereby grains of the same age were exposed to different dose rates within the sediment. In each case, a different statistical age model can be used to derive an accurate estimate of the specific targeted depositional event associated with the archaeological material. In this case the wide D_e distributions likely result from a combination of both beta heterogeneity (see supplementary info S2) and a degree of post-depositional mixing. We assume the latter because of the biologically productive nature of the UZV savanna region (Burrough and Willis, 2015). Zero dose D_e values on modern Zambezi fluvial deposits indicate that residual doses from any incomplete bleaching are minimal and unlikely to impact the equivalent dose distributions (Figure S2).

The central age model (CAM: Galbraith et al., 1999) and finite mixture model (FMM: Roberts et al., 2000) were fitted using the Luminescence R package (Kreutzer et al., 2012, 2017). Representative D_e estimates were derived assuming overdispersion was caused by dose rate heterogeneity and biological mixing (see S3 for model specification). In addition to CAM and FMM we also calculated weighted mean D_e s for each sample. This age model is appropriate where overdispersion can be entirely attributed to between-grain dose rate variability and where radioisotope concentrations, estimated from homogenised bulk sediment sub-samples, will provide *average* sediment dose rates.

Comparative age/depth relationships for each model are shown in Figures 4 a-c for each archaeological site. Based on the radio-isotope characteristics of the sediment and observations of sediment mixing within this region, we use a Finite Mixture Model (prescribed with overdispersion, σ_b -values, of between 0.3-0.8 as expected from natural/dose-driven grain-to-grain variability) in the final calculation of depositional ages.

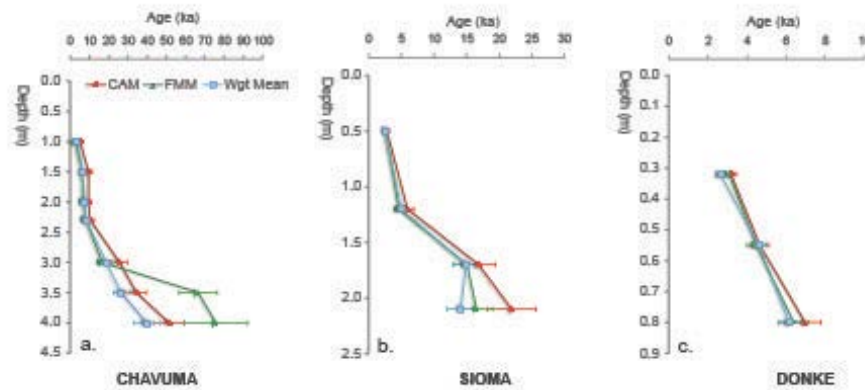


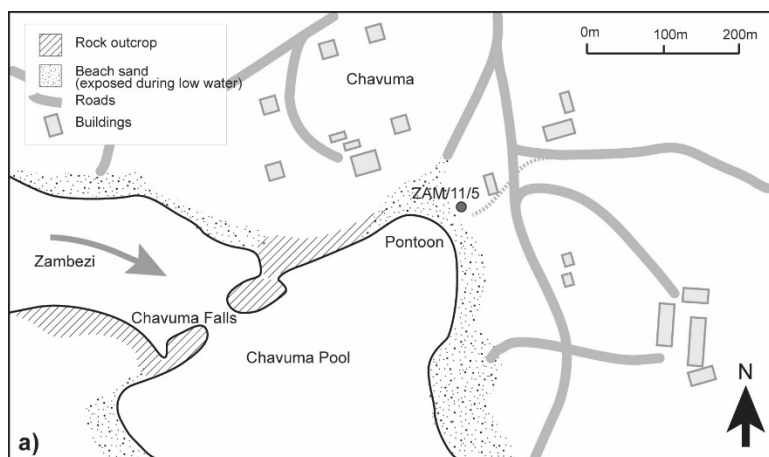
Figure 4: Comparative age depth relationships for each site using three age models – The Central Age Model (CAM), the Finite Mixture Model (FMM) and the Weighted Mean (Wgt Mean).

3.3 Site archaeology and age

4.3.1 Chavuma

Phillipson's (1975a,b) excavation at Chavuma Falls was undertaken in a 3.7 m high sand body (interpreted as an aeolian dune) above the 'land surface' or 'rubble horizon', which slopes down 1.5 m to the modern flood season Zambezi water level. The 1968 excavation occurred in the exposed lower ~1.2 m of the sand unit, and was carried out in 15 cm spits down to the 'rubble horizon'. Spits were integrated into separate 'levels' based on similarities in selected artefact categories and to a lesser extent in raw material use.

Artefacts were described as comprising sandstones and mudstones with rare quartz and chalcedony, probably sourced from water-polished cobbles on the edge of the Chavuma pool (Figure 5). None of the upper level artefacts were heavily weathered and some pieces showed signs of utilisation. A few artefacts resting on the land surface were heavily abraded but most were moderately fresh in condition. Some older, very abraded pieces were reworked for the production of more recent artefacts (cortex flakes). Phillipson found no consistent statistically-significant differences between assemblages from adjacent spits. One pot sherd was found in Level 1 and one in Level 2; they were regarded as intrusive given their small size and rarity.



2. OSL dating 2011

1. Phillipson 1968 Excavation

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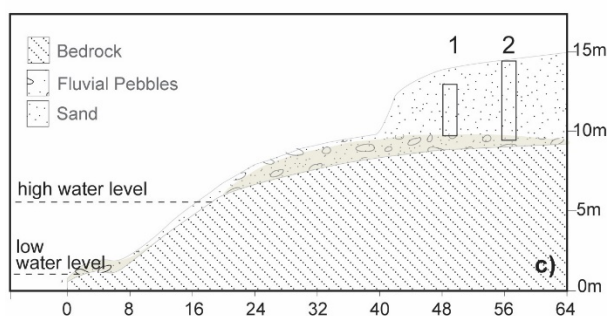
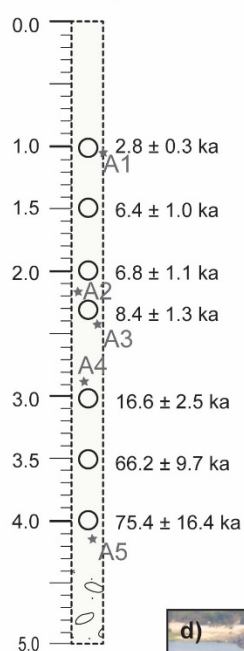
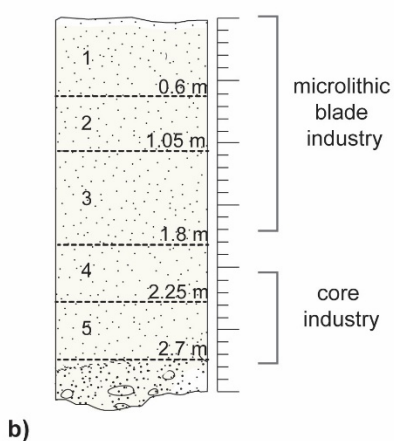
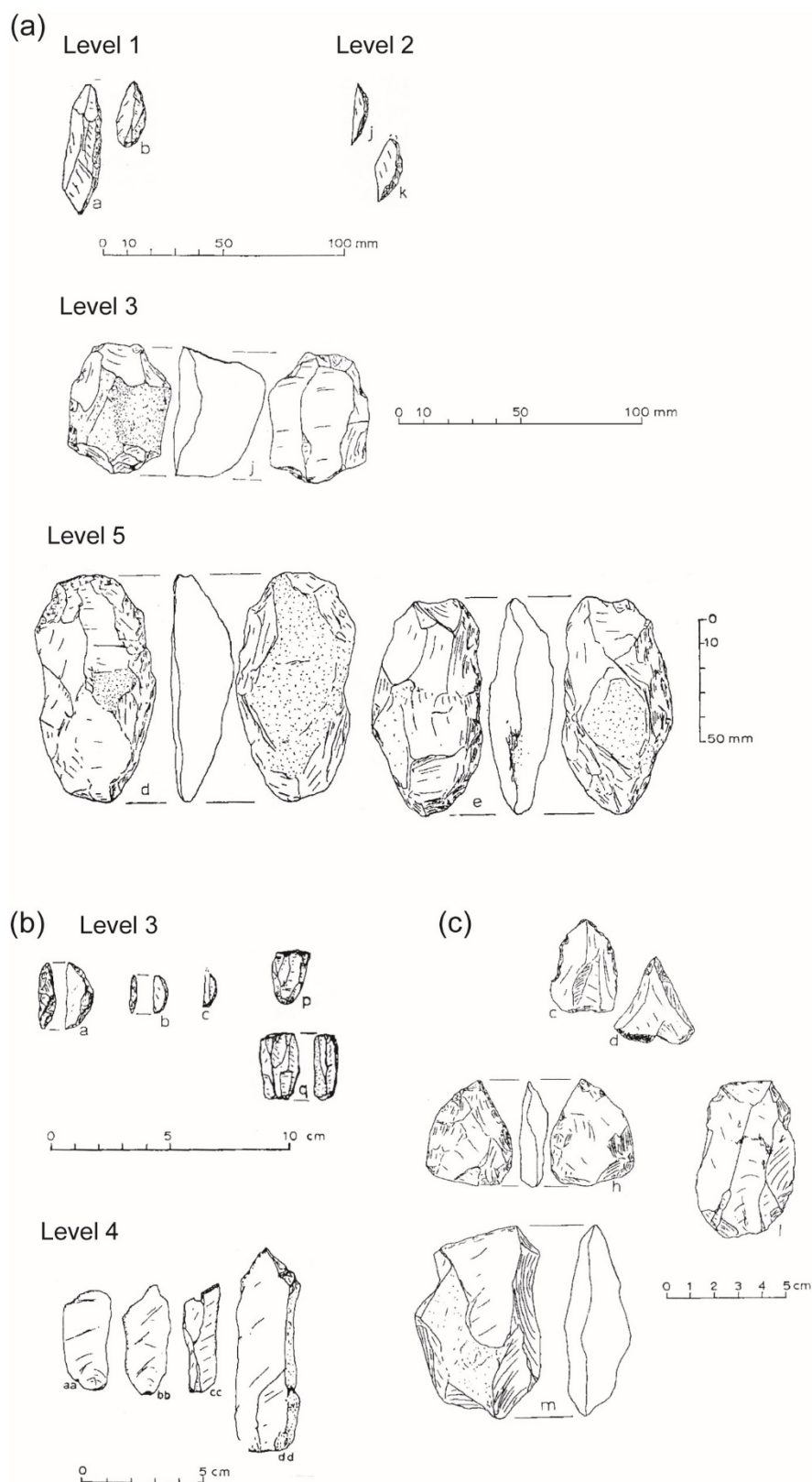


Figure 5: a) Plan view of site location at Chavuma Falls; b) sections within the Chavuma dune from 1) Phillipson's 1968 Excavation showing archaeological levels 1-5 and 2) augered section in 2011 showing location of OSL samples (open circles, ages (FMM model) and artefacts retrieved during augering (marked as 'A') [we have tied the sections using the position of the basal gravel unit and both sections are drawn on the same scale] ; c) Location of excavation in relation to dune and present day water levels; d) Photograph of the site with Falls in the distance.

248 Artefact assemblages and their downward sequence (Table 3, Figure 6A) are very similar to those
 249 described by Phillipson (1975a) at Cholwezi, a large site several kilometres north of Chavuma but not
 250 investigated further here. The smaller number of retouched artefacts and cores from Chavuma was
 251 insufficient to extract meaningful statistical generalisations. Attributions to Industries or Modes
 252 were partly based on the presence of distinctive retouched tools and core production strategies, and
 253 in part on comparisons with the more numerous Cholwezi sequence. The 'Mode' attribution is based
 254 on Clark's (1969) universal scheme of stone tool technologies. In this context, Mode 3 Levallois
 255 technology is equated with the Middle Stone Age, based on evidence of core preparation (Levallois
 256 technique) and prepared flakes with faceted butts. Mode 5 microlithic technology is equated with
 257 Later Stone Age based on the presence of microlithic cores, bladelets and the range of retouched
 258 tools made on microliths.

259 **Table 3:** Summary assemblage characteristics for each level excavated at Chavuma and the
 260 associated classification. Adapted from Phillipson (1975).

Level	Spit No.	Assemblage characteristics	Condition	Phillipson techno-typological classification
1	1-4 (0 -0.6 m)	Fine scrapers, crescents, backed blades; radial flakes comprise 18-20% of all flakes; greatest use of chalcedony and quartz.	Fresh	Mode 5
2	5-7 (0.6 -1.05 m)	Finely worked backed implements and scrapers; radial flakes comprise 36-40% of all flakes; quartz artefacts are common but chalcedony is little used.	Fresh	Mode 5
3	8-12 (1.05 -1.8 m)	Backed implements are much cruder; radial flakes comprise 24-31% of all flakes. Quartz and chalcedony rarely used.	Moderately fresh	Mode 5
4	13-15 (1.8 -2.25 m)	Scrapers; very little chalcedony and quartz; increase in the mean flake length; radial flakes comprise 24-48% but spits fourteen and fifteen yielded only 12 and 19 whole flakes respectively	Moderately fresh/slightly weathered	Mode 3
5	16-17 (2.25 -2.7 m)	Core implements including two 'fine' bifacial knives and a bifacial chopper. No flake tools other than scrapers from the top half of the level. None of the artefacts was quartz or chalcedony.	Slightly weathered.	Mode 3



261

262 **Figure 6: A)** Selected Chavuma Falls artefacts as illustrated by L Phillipson and used with permission
 263 of the British Institute in Eastern Africa and *Azania*. Artefact lettering is as appears in *Azania* Volume
 264 X, Figures. 16-18. Level 1: backed blades, sandstone (a,b); Level 2: crescents
 265 (j=mudstone,k=sandstone) Level 3: high backed ovate radial core (j=mudstone); Level 5: parallel-side
 266 bifaces (d,e=mudstone). **B)** Selected Kadanda artefacts as illustrated by L Phillipson and used with

permission of the British Institute in Eastern Africa and *Azania*. Artefact lettering is as appears in *Azania* Volume XI, Figures. 5-6. Level 3: crescents (a,b=sandstone; c=chalcedony); single-platform core (p, chalcedony); opposed platform core (q, chalcedony); Level 4: utilized blades (aa-dd, chalcedony). **C**) Selected Sioma 'M' artefacts, all chalcedony, as illustrated by L Phillipson and used with permission of the British Institute in Eastern Africa and *Azania*. Artefact lettering is as appears in *Azania* Volume XII, Figure 2; unifacial flake points (c,d); bifacial flake point (h); flake cleavers (l, m)

The basal Cholwezi sequence is attributed to Mode 3/MSA based on the presence of prepared cores. There are no prepared cores in the Chavuma sequence, and Phillipson interpreted this record as representing a continuum of the transition from Mode 3 to Mode 5/LSA with its characteristic microlithic forms. Levels 1-3 are clearly Mode 5, but the typological status of Levels 4 and 5 is less certain. They lack microliths and the artefacts are larger; there is a difference in raw material use and Level 4 has unifacial points and some platform preparation on radial cores. We tentatively attribute Level 4 to the MSA/Mode 3. Level 5 lacks points, artefacts are more abraded, and among the small number of retouched tools are large core tools including two parallel-sided 'knives' made on silicified mudstone. The assemblage is too small to assign it to a particular Mode or industry.

Like Phillipson (1975a), we find no statistically significant difference in the grainsize distribution or nature of sediments that would indicate a discontinuity between the lower and upper levels. The OSL data however, indicate a chronostratigraphic break between the lowest parts of the section and the upper sediments. Chronostratigraphic breaks are widely reported from other dating studies of otherwise stratigraphically-featureless Kalahari sands (e.g. Thomas and Burrough 2013). Using the best fit component of the finite mixture model, our results suggest the upper two levels are dated to between 2.9 ± 0.3 ka and 8.4 ± 1.3 ka (Figure 5b). The base of Level 3 is dated to 16.7 ± 2.6 ka. Below this, sediments relating to Phillipson's Levels 4 and 5 were dated to 66.5 ± 9.9 ka and 75.7 ± 16.6 ka respectively. These overlie a distinct, fluvial terrace demarcated by water-worn pebbles (Figure 5b-c). Importantly, however, the Chavuma dates demonstrate that the archaeological record is not preserved as a continuum as previously thought, and that the transition from a Mode 3 to a Mode 5 technology occurs between 66.5 ± 9.9 and 16.7 ± 2.6 ka.

3.2.2 Sioma M

The record at this site is characterised by large core and flake tools as well as smaller retouched flakes and scrapers (Figure 6B). Phillipson (1975a, b) considered these as two components of a single Mode 3 industry that lacked a chronology.

299 The gravel pit was relocated using published descriptions and with help from village elders at Sioma
300 who remembered the 1960s excavation and its location. Phillipson found material at the interface
301 between an overlying sand deposit and the underlying ferricrete: lithics can be found on the
302 ferricrete surface today. Some pieces were embedded in this duricrust and those not *in situ* could
303 be linked to the deposit by the adherence of ferricrete and calcrete to their surfaces. All artefacts,
304 both fresh and slightly abraded, were made from 'chalcedony' (fine-grained silcrete) or highly
305 silicified sandstone. Phillipson's assemblage comprised large irregular core and flake tools and
306 smaller retouched flake tools including unifacial and bifacial points, plus scrapers. There is evidence
307 for the deliberate production of radial and triangular flakes, the majority with multifaceted
308 platforms from core preparation. Phillipson (1975a, b) attributed the assemblage to an early Mode 3
309 phase, based in part on the production of flake cleavers from prepared cores and the presence of
310 large core tools.

311 In 2011 the pit was degraded, with slumped and eroded margins, but the site context was readily
312 identifiable. The overlying sand described by Phillipson was sampled several meters away from the
313 edge of the pit down to the underlying ferricrete in order to provide a minimum assemblage age
314 (Figure 7).

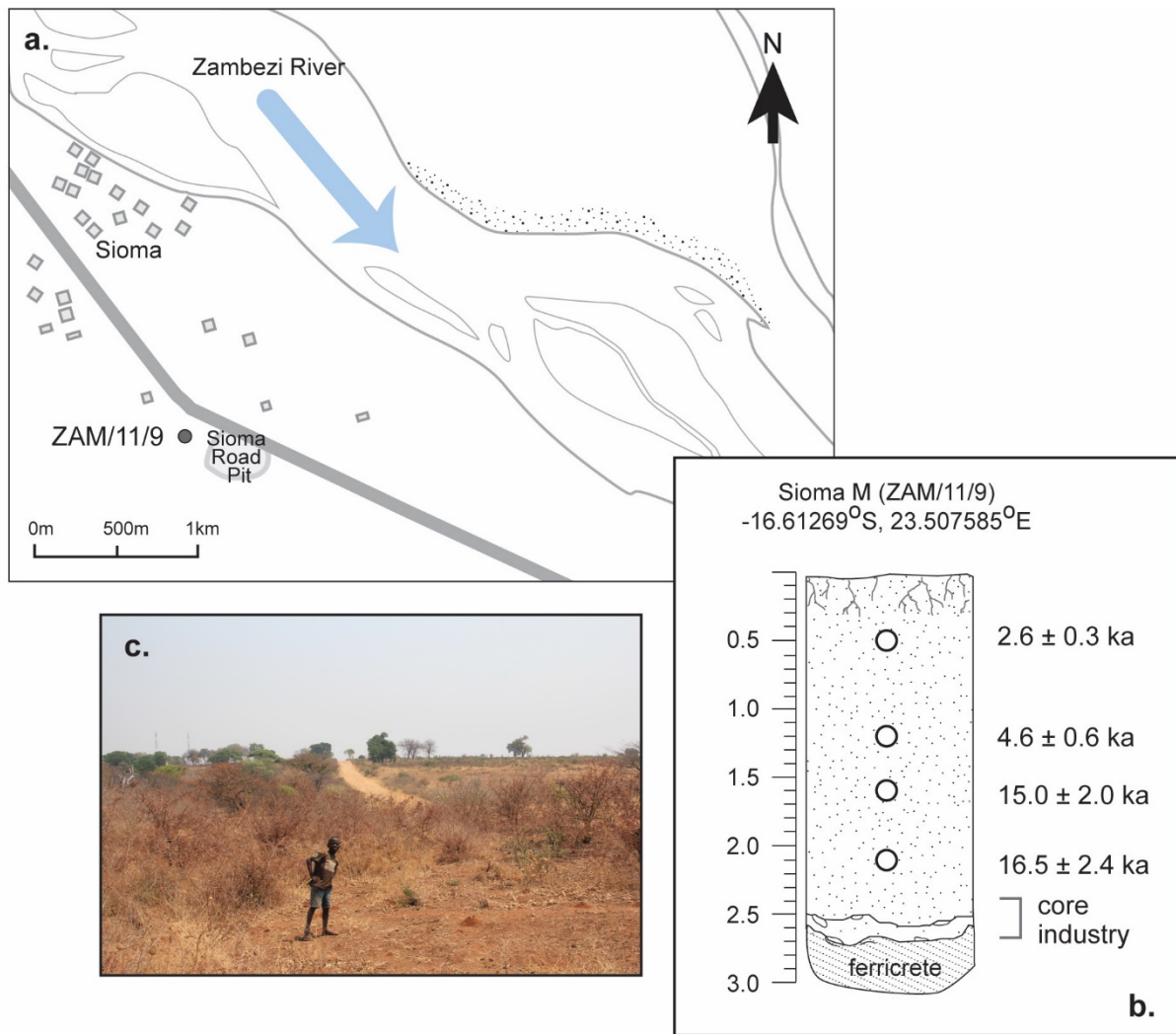


Figure 7: a) Location of Sioma M site with b) OSL dated (open circles) section within Kalahari sand overlying artefact horizon and ferricrete and c) photograph of site location.

The uppermost sand, dated to 2.6 ± 0.3 ka and 4.6 ± 0.6 ka, is paler, finer and more organic-rich than underlying redder sediments. These contain nodules of calcrete and ferricrete in lower levels and are dated to 15.1 ± 2 ka and 16.5 ± 2.5 ka (FMM, Table 2) placing a minimum age on the underlying archaeological assemblage located at the interface between the overlying sand and the underlying ferricrete.

3.2.3 Donke

Donke was excavated by Phillipson on the upper-most river terrace which formed the main centre of occupation (Figure 8). The archaeological sequence was “similar to, but more compressed than that of Kandanda” (Phillipson, 1970: page 5). As there is no other information on the Donke trenches we provide a summary of the material from excavations in the neighbouring Kandanda pit (Table 4, Figure 6C). Tools were described as manufactured from homogenous green grey sandstone,

silicified sandstone with chalcedonic inclusions, sourced from fluvial pebbles and outcropping 'pipe sandstone'. Excavations took place following natural stratigraphic divisions of the deposit but with spit thicknesses never greater than 305 mm. The uppermost fine, grey carbon-rich sands were archaeologically sterile, grading to redder coarser sand below ~20cm. A distinct charcoal concentration was visible at 45 cm depth at Kandanda, but was not present at Donke. The Donke trench was 1 m deep, compared to ~2 m at Kandanda, with a basal unit composed of irregular, friable sandstone overlain by sandstone rocks and artefacts. At Kandanda, the presence of refitted artefacts in level 2 and 3 suggested the deposit was relatively undisturbed.

Table 4: Assemblage characteristics and radiocarbon dates from levels 1-4 of the Kandanda excavation (adapted from Phillipson, 1975).

Level	Assemblage characteristics	Condition	Mode	Radiocarbon ID	Material	Age (^{14}C yrs BP)	Cal Age (cal yrs BP)	Tr
1	Fragmented potsherds with organic temper. Few tools, includes backed blades and river pebbles used as hammer-stones. Pit with Mongongo nuts.	Fresh	Mode 5	SR-200 GX-1579	Charcoal from pit infill Charred post	465 \pm 85 490 \pm 90	443 \pm 83 466 \pm 84	IV/ I/
2	Utilized small flake tools, cores, flakes (including refits to core)	Fresh	Mode 5	SR-199 SR-198	Scattered charcoal fragments Charcoal from charcoal-rich horizon	1835 \pm 50 2130 \pm 55	1701 \pm 73 2053 \pm 85	I// I/
3	Similar to level 2 but with unifacial points. Also contains broken bifaces and a bifacial pick.	Moderately fresh	Mode 5	SR-201	Very small charcoal fragments from adjacent squares	3450 \pm 80	3649 \pm 108	I// ar
4	Much greater range of tool types. Flake and core scrapers, backed microlithic blades, choppers and bifacial core tools. Increased proportion of radial to other core types.	Moderately fresh/slightly weathered	Mode 5	GX-1581 SR-202 GX-1580 SR-203	Charcoal from lowest humic horizon Scattered charcoal fragments Charcoal from lowest humic horizon Scattered charcoal fragments	3320 \pm 110 3360 \pm 95 3485 \pm 115 3690 \pm 85	3508 \pm 132 3550 \pm 114 3699 \pm 147 3960 \pm 126	I// I// I// I/

**see figure 8*

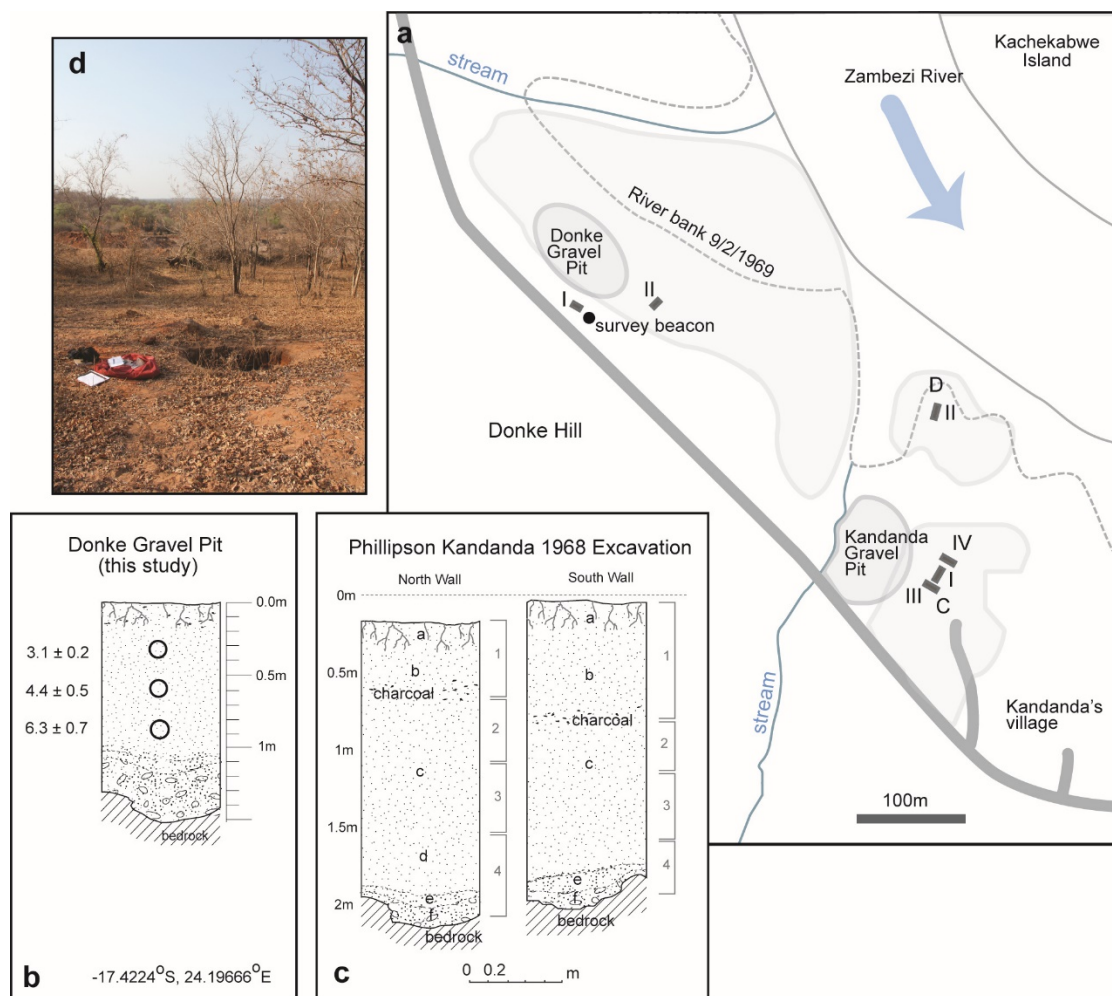


Figure 8: a) Location of Donke Gravel Pit Trench I in relation to the 1968 excavation at Kandanda (now destroyed by a road quarry); b) Pit section and dated OSL sample locations from Donke gravel pit; c) Radiocarbon dated section from Kandanda Trench I with archaeological levels labelled 1-4 (from Phillipson, 1976); d) Photograph of site location looking SE in 2011 with Kandanda road quarry pit in background.

Based on the continuity of artefact morphology and technology, particularly in core types, Phillipson argued that the Kandanda archaeological sequence represented a single, continually developing, stone working tradition. The excavated spits were grouped into four levels on the basis of artefact content and stratigraphy. A unity to all four levels was described in that they contain Mode 5 microlithic artefacts, in particular small backed blades. Bladelets and small flakes were found in all levels along with radial cores and flakes. Level 4 differed in having a greater number and variety of core tools and a higher proportion of radial cores. Artefacts were larger in Levels 3 and 4 with a trend towards greater use of sandstone in the lower levels. The co-occurrence of microliths with large cores was a distinctive feature of Level 4. The presence of blades, technically a feature of Mode 4 assemblages, highlights the diverse technologies produced. A noteworthy feature of Level 1

was the presence of organic tempered pottery which has wider regional significance, discussed below.

Radiocarbon ages from charcoal at Kandanda placed the sequence well within the Mid- and Late Holocene (Table 4). There are, however, issues with the reliability of the sequence arising from the sampling strategy and bioturbation. The single date from Level 3 (lab no. SR-201) is considered as out of place as it disrupts an otherwise coherent sequence. Phillipson notes that the sample consisted of small charcoal fragments combined from four adjacent squares, and that ants and roots had disturbed the sediments in this level (Phillipson 1978:79-80). Composite samples are also reported from Level 2 (SR-199) and Level 4 (SR-202; SR-203).

OSL measurements from the Donke trench place the upper levels of this section at 3.1 ± 0.3 ka and 4.5 ± 0.5 ka. The lower part of the 1 m section dates to 6.4 ± 0.7 ka. The more compressed nature of the section makes it hard to precisely relate these dates to the Kandanda archaeological sequence, but they do support the Holocene age proposed by Philipson (1975a).

4. Implications of the OSL chronology for Upper Zambezi sites

The new OSL ages we present suggest that, at least for Chavuma, the ages of the lowest archaeological units were significantly underestimated by Phillipson with the transition from Mode 3 to Mode 5 technology occurring before 16.6 ka. At Sioma M, we place a minimum age of 16.5 ± 2.5 ka on the Mode 3 archaeology. Taking these two sites together, we infer a discontinuous sedimentary record between the MSA (Mode 3) and LSA (Mode 5). The inability to firmly relate the (now destroyed) archaeological sequence from Kandanda to the new OSL ages from the remaining Donke Trench is problematic, though the sedimentary deposits do appear to affirm a Mid-Late Holocene age for the upper terrace sediments.

The nearest comparable Late Pleistocene archaeological record comes from Mumbwa Caves, 380 km east of the Zambezi (Figure 1) where there are clear gaps in the sequence that may be correlated with climate change. This site was occupied 130-105 ka, abandoned between 105- 40 ka, re-occupied briefly then abandoned again between 40 ka – 15/12 ka, after which the technology is Mode 5 (Barham, 2000). There is also evidence of a Mid-Holocene occupation hiatus between 6 and 2 ka. Barham (2000) speculated that shifts in the availability of surface water were linked to regional changes in hydrology, and ultimately climate change governed the human use of the site. At Chavuma, the MSA/Mode 3 assemblage is dated to $66 \pm 9.9/75 \pm 16.7$ ka (i.e. within errors) spanning both wetter and drier periods within the Kalahari basin; relevant given the importance of the Zambezi as a water source in the region. The LSA assemblages dated here also span a broad range of

climatic/environmental conditions, although the resolution of regional palaeoclimate records is currently too spatially and temporally coarse to allow relationships between human presence and environmental change to be tested. The proposition that fluvial corridors act as refugia in dry times also remains to be tested. The recurrent occupation of Chavuma, despite its open air context, probably reflects its position close to a persistent barrier-induced pool on the Zambezi, subject to less channel migration and drying than meander belt zones further south on the floodplain.

All archaeological sites in Zambia that post-date the Last Glacial Maximum (LGM) are Mode 5 in character with local variations in the proportions of microlithic tools relative to larger forms. There is a relative uniformity in the Late Glacial Mode 5 of Zambia (Nachikufan I) with local differences emerging in the early Holocene (Barham and Mitchell, 2008). Separate Mode 5 industries have been recognised in eastern, northern and central Zambia (Makwe, Phillipson, 1976; Nachikufan II,III, Miller, 1970; Group 1, Musonda, 1984; Zambian Wilton, Clark, 1950;) but they can be subsumed within a spatially and chronologically variable Nachikufan Industrial Complex (Barham and Mitchell, 2008). With the exception of Phillipson's work, there are no dated sites in western Zambia. The LSA complex at Gwisho, on the central Zambian Kafue Flats (~400 km east of the UZV) is dated between 3600 \pm 70 BP to 4700 \pm 100 BP (3935 cal BP [mean, 106 sigma] – 5361 cal BP [mean, 152 sigma]) (Gabel, 1965; Fagan and Van Noten, 1971) making it comparable in age to the Kandanda Level 4 deposit and overlapping chronologically with the Donke pit OSL ages. The occupants of Gwisho made microlithic tools (backed flakes) *and* large scraping, cutting, chopping and pounding tools comparable to some of the macrolithic components seen at Kandanda. At Kamusongolwa Rockshelter in northwestern Zambia (~300 km east of Chavuma) there are two composite radiocarbon dates that bracket the LSA between 13,300 \pm 250 (BP) (15,925 cal BP [mean, 375 sigma]) at the base to 4,000 \pm 105 BP (4417 cal BP [mean, 171 sigma]) at the top, with a gap of ~3000 years between the overlying Iron Age occupation (Savage, 1983). The Mode 5 technology is characterised by backed flakes and blades, comparable to the wider Zambian microlithic tradition including the material from the UZV. The calibrated age of the lower LSA overlaps with that of Sioma M and Chavuma and provides further evidence of a Late Glacial Mode 5 in northwestern Zambia. The calibrated Mid-Holocene assemblage from Kamusongolwa also overlaps with Kandanda and Donke Pit.

A combination of microlithic and macrolithic technology characterises the LSA on the margins of the Congo basin to the north. For the Chavuma/Cholwezi transitional Mode 3- Mode 5 sequence, Phillipson (1975a) proposed typological links with the Tshitolian Industry which appears to span the Late Glacial to Mid-Holocene (Cornelissen 2013, but see Taylor, 2016). The Tshitolian, however, is

not well constrained chronologically and comparisons with Zambian Mode 3 or Mode 5 assemblages are currently difficult to sustain.

There has been very little systematic archaeological research within the wider Kalahari basin, with the few reliable MSA ages come from Toteng near Lake Ngami at 52 ± 7 ka (Brook et al., 2008); # Gi pan, western Botswana, at 77 ± 11 ka (Brooks et al., 1990); and at Tsodilo between 54 ± 10 ka (Ivester et al., 2010) and 94 ± 9 ka (Feathers, 1997; see also Staurset and Coulson (2014) and Robbins et al. (2016) for considerations of chronology), all in northern Botswana. The earliest microlithic LSA technology ages are from the Tsodilo Hills (~300 km to the SW of the UZV) with an increase in small retouched tools between c.36-30 ka (Ivester et al., 2010; Feathers, 1997; Robbins et al., 2000) following a 'large blade' transitional MSA/LSA phase from 55 ± 4.7 ka to 37 ± 1.3 ka (Brooks et al., 1990; Feathers, 1997) (Figure 9a). Thereafter the pattern of technological change in this northern belt of southern Africa differs slightly to that south of the Kalahari. In the study region, bladelet based microlithic Mode 5 industries continue well into the Pleistocene/Holocene transition (Mitchell, 2002). To the south of the Kalahari basin, the Later Stone Age presents a more regionally variable technological record from c.20-12 ka of microlithic (Robberg Industry) then an early Holocene c. 12-8 ka macrolithic (Oakhurst Complex) and microlithic (Wilton Industry) between c.8 -4 ka with macrolithic technologies post-4 ka (Vogelsang et al., 2010, Sealy, 2016).

As a generalisation, the LSA in the region of the UZV is still too poorly described and dated to make firm attributions to better known industries to the south and north. Systematic research is needed along the Upper Zambezi Valley to resolve lingering typological and chronological issues.

4.1 Palaeoenvironmental change and the regional Mode 3-Mode 5 Transition

Previous archaeological studies, particularly from inland cave sites have revealed marked changes in the content and periodicity of occupation during the late Pleistocene, with gaps in the record tentatively related to records of palaeoenvironmental change (Barham, 2001). One theory is that fluvial systems such as the Zambezi may have offered refugia during regionally dry conditions in the Pleistocene (Barham, 2001; Avery, 2003). The emergence, in the last decade, of more robust records of hydrological and palaeo-environmental change (Figure 9a) potentially provides a basis for testing this theory. However, this is somewhat countered by overwhelming evidence that wetting and drying was not spatially homogenous within southern Africa through the late Quaternary (e.g. Figure 9b). These new records cannot therefore be spatially extrapolated without care. The idea of homogenous 'dry periods' that extended across the continent (e.g. during the LGM) are increasingly rejected (Thomas et al., 2012) in favour of more nuanced models of tropical climate response

(Singarayer and Burroughs, 2015). For example, it seems likely that the LGM in both eastern and central southern Africa were, on the whole, wetter in comparison to regions to the southeast and northeast (Figures 9a and b). This spatial pattern of climate/environmental conditions however, changes over time. In the context of the UZV and the broader Kalahari basin the temporal and spatial resolution of palaeoclimatic and archaeological evidence is low but both Mode 3 and Mode 5 assemblages appear to span regionally wetter and drier conditions, suggesting the upper Zambezi valley was suitable for occupation during a range of environmental conditions.

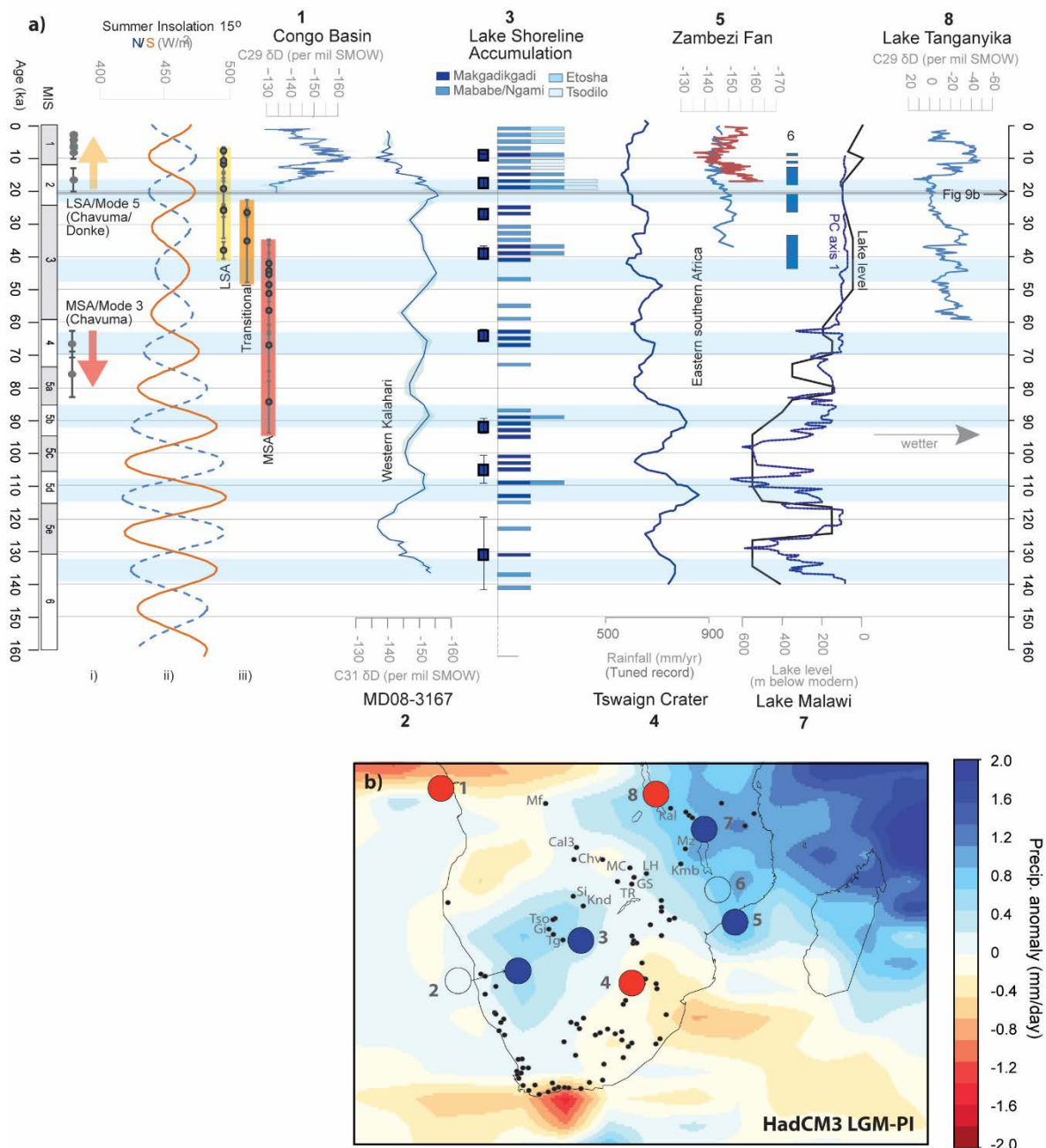


Figure 9: a) Temporal variability of climate/environment as shown by palaeorecords showing i) dated archaeological records at Chavuma in relation to ii) insolation variation at 15°N and S (Berger and Loutre, 1991) and iii) dated regional MSA, LSA and Transitional archaeological records in the Kalahari basin. 1) δD_{wax} rainfall record from the Congo basin (Schefuß et al., 2005); 2) δD_{wax} eastern Namib/western Kalahari rainfall record (Collins et al., 2014); 3) Shoreline records from the megalake Makgadikgadi system (Burrough et al., 2007; Burrough and Thomas, 2008; Burrough et al., 2009); 4) Rainfall record inferred from grainsize characteristics in the Tswaig Crater, South Africa (Partridge et al., 1997); 5) Rainfall intensity over the Zambezi Fan δD_{wax} (‰) (Schefuß et al., 2011; Wang et al., 2013); 6) Shoreline records inferring high stands at Lake Chilwa (Thomas et al., 2009); 7) Lake level record from Malawi (Scholz et al., 2007; Cohen et al., 2007); 8) Tanganyika δD_{wax} (‰) (Tierney et al., 2008). Numbers refer to site locations on Figure 9b. Blue bars highlight potentially wetter conditions in the Kalahari basin. **b):** An example of spatial variability in past climate patterns across the southern African interior. In this case we show model data from the HadCM3 model (modified from Singarayer and Burrough (2015)) with annual precipitation anomalies for LGM-PI in mm/day. Overlaid are LGM conditions from regional palaeorecords shown in figure 9a and the MSA and LSA sites plotted in figure 1.

Wetter/drier conditions would, no doubt, have impacted the landscape, habitat use and perhaps the geographical range of early humans, resulting in resource shortages in some areas and abundance in others. This emerging picture of spatial heterogeneity of palaeoclimate change (Fig 9b) may go some way to explaining regional patterns of human resource use and changes in lithic technology but more detailed records (both archaeological and palaeoenvironmental) are required before these links can be robustly examined.

5. Conclusion

Single grain OSL dates from Chavuma on the Upper Zambezi Valley suggest the MSA/Mode 3 archaeological record is much older than initially hypothesised (Phillipson, 1978) and likely dates to $66.5 \pm 9.9 - 75.7 \pm 16.6$ ka. The Mode 3 to Mode 5 transition at this site occurred within the period between 66.5 ± 9.9 ka and 16.7 ± 2.6 ka. Further south at Sioma M, sterile Kalahari sands deposited on ferricrete overlying Mode 3 tools date to 16.5 ± 2.5 ka, placing a minimum age on the underlying archaeological record. Donke pit was the only remaining section at Kandanda not destroyed by road quarrying though there is little existing information with regard to the archaeological units except that it is a 'compressed' version of the Kandanda site.

Barham (2000) suggested that human use of the archaeological sites at Mumbwa Caves was linked to the availability of surface water in the vicinity. In the UZV there is similar chronological discontinuity between occupation phases although, at least at Chavuma, part of the record may be missing due to periods of fluvial erosion. What does seem clear from these re-dated sites is that the

'Mode 3' (MSA) assemblages described by Phillipson (1975a, b) in the Upper Zambezi Valley significantly pre-date the LGM and are chronologically consistent with the handful of sites dated within the Kalahari in Botswana (Figure 9).

At all of these sites, when the available records of palaeohydrological change are examined, the archaeological assemblages appear to span a broad range of climate/environmental conditions. However, there are still too few high-resolution palaeoenvironmental and archaeological records from the interior of southern Africa to draw robust relationships between long-term regional climate change and observations in the archaeological record. What is increasingly clear however, is that there is strong spatial variability in patterns of climate change across southern Africa. Rather than extrapolation to distant palaeoclimate records, theoretical models linking changes in regional resource distribution and predictability with hunter-gatherer strategies of mobility, settlement patterning, foraging range size and tool design (Ambrose and Lorenz, 1990, McCall, 2007) offer a potentially more useful perspective for understanding the regional diversity in the archaeological record as the resolution of these records improves.

Acknowledgements

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Figure and Table Captions

Figure 1: Published MSA and LSA archaeological site locations within southern Africa. The upper Zambezi region is marked with a red box. 1) Congo basin; 2) eastern Namib/western Kalahari rainfall record; 3) Megalake Makgadikgadi; 4) Tswaing Crater; 5) Zambezi Fan; 6) Lake Chilwa; 7) Lake Malawi; 8) Lake Tanganyika; Mf = Mufo; Cal3 = Calunda III; Chv = Chavuma; Si = Sioma M; Knd = Kandanda; Kal = Kalambo Falls; Mz = Manzi River; MC = Mumbwa Caves; GS=Gwisho Springs; TR = Twin Rivers; LH = Leopards Hill Cave; Kmb = Kalembo Rock Shelter; Tso = Tsodilo; Gi = #Gi; Tg = Toteng.

Figure 2: Regional Digital elevation model of the Upper Zambezi Valley (UZV) showing archaeological site locations (filled black circles) investigated in this study. Major settlements discussed in text are also given as grey squares.

Figure 3: a) Grain size distribution for each site and b) Separated heavy mineral and quartz fraction radioisotope concentrations from sample ZAM/11/5/5 (question marks indicate measurements below detection limits (<0.1 ppm).

Figure 4: Comparative age depth relationships for each site using three age models – The Central Age Model (CAM), the Finite Mixture Model (FMM) and the Weighted Mean (Wgt Mean).

Figure 5: a) Plan view of site location at Chavuma Falls; b) sections within the Chavuma dune from 1) Phillipson's 1968 Excavation showing archaeological levels 1-5 and 2) augered section in 2011 showing location of OSL samples (open circles, ages (FMM model) and artefacts retrieved during augering (marked as 'A') [we have tied the sections using the position of the basal gravel unit and both sections are drawn on the same scale] ; c) Location of excavation in relation to dune and present day water levels; d) Photograph of the site with Falls in the distance.

Figure 6: A) Selected Chavuma Falls Dune artefacts as illustrated by L Phillipson and used with permission of the British Institute in Eastern Africa and *Azania*. Artefact lettering is as appears in *Azania* Volume X, Figures. 16-18. Level 1: backed blades, sandstone (a,b); Level 2: crescents (j=mudstone,k=sandstone) Level 3: high backed ovate radial core (j=mudstone); Level 5: parallel-side bifaces (d,e=mudstone). **B)** Selected Kadanda artefacts as illustrated by L Phillipson and used with permission of the British Institute in Eastern Africa and *Azania*. Artefact lettering is as appears in *Azania* Volume XI, Figures. 5-6. Level 3: crescents (a,b=sandstone; c=chalcedony); single-platform core (p, chalcedony); opposed platform core (q, chalcedony); Level 4: utilized blades (aa-dd, chalcedony). **C)** Selected Sioma 'M' artefacts, all chalcedony, as illustrated by L Phillipson and used with permission of the British Institute in Eastern Africa and *Azania*. Artefact lettering is as appears in *Azania* Volume XII, Figure 2; unifacial flake points (c,d); bifacial flake point (h); flake cleavers (l, m)

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b): An example of spatial variability in past climate patterns across the southern African interior. In this case we show model data from the HadCM3 model (modified from Singarayer and Burrough

(2015)) with annual precipitation anomalies for LGM-PI in mm/day. Overlaid are LGM conditions from regional palaeorecords shown in figure 9a and the MSA and LSA sites plotted in figure 1.

Table 1: Radioisotope concentrations and estimated sediment dose rates for each sample

Table 2: Equivalent dose distribution characteristics and OSL age estimates.

Table 3: Summary assemblage characteristics for each level excavated at Chavuma and the associated classification. Adapted from Phillipson (1975).

Table 4: Assemblage characteristics and radiocarbon dates from levels 1-4 of the Kandanda excavation (adapted from Phillipson, 1975). *see Figure 8

References

Adamiec G and Aitken MJ (1998) Dose-rate conversion factors: Update. *Ancient TL* 16: 37-50.

Ambrose SH and Lorenz KG (1990) Social and ecological models for the Middle Stone Age in Southern Africa. In: Mellars P (ed) *The Emergence of Modern Humans: An Archaeological Perspective*. Edinburgh: Edinburgh University Press, 3-33.

Avery DM (2003) Early and middle Pleistocene environments and hominid biogeography; micromammalian evidence from Kabwe, Twin Rivers and Mumbwa Caves in central Zambia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 189: 55-69.

Backwell LR, McCarthy TS, Wadley L, et al. (2014) Multiproxy record of late Quaternary climate change and Middle Stone Age human occupation at Wonderkrater, South Africa. *Quaternary Science Reviews* 99: 42-59.

Barham L (2001) Central Africa and the emergence of regional identity in the Middle Pleistocene. In: Barham L and Robson Brown K (eds) *Human Roots: Africa and Asia in the Middle Pleistocene*. Bristol: Western Academic and Specialist Press, 65 - 80.

Barham L and Mitchell P (2008) *The First Africans: African Archaeology from the Earliest Toolmakers to Most Recent Foragers*, Cambridge: Cambridge University Press.

Barham LS (2000) *The Middle Stone Age of Zambia, South Central Africa*. Bristol: Western Academic and Specialist Press.

Berger A and Loutre MF (1991) Insolation values for the climate of the last 10 million years. *Quaternary Science Reviews* 10: 297-317.

Brook GA, Srivastava P, Brook FZ, et al. (2008) OSL chronology for sediments and MSA artefacts at the Toteng quarry, Kalahari Desert, Botswana. *South African Archaeological Bulletin* 63: 151-158.

Brooks AS (1984) San land-use patterns, past and present: implications for southern African prehistory. In: Hall M, Avery G, Avery DM, et al. (eds) *Frontiers: Southern African Archaeology Today*. BAR International Series 207, 40-52.

608 Brooks AS, Hare PE, Kokis JE, et al. (1990) Dating Pleistocene archaeological sites by protein
609 diagenesis in ostrich eggshell. *Science* 248: 60-64.

610 Burrough SL (2016) Late Quaternary environmental change and human occupation of the southern
611 African interior. In: Jones S and Stewart BA (eds) *Africa from MIS 6-2: Population Dynamics and*
612 *Paleoenvironments*. Dordrecht: Springer, 161-174.

613 Burrough SL and Thomas DSG (2008) Late Quaternary lake-level fluctuations in the Mababe
614 Depression: Middle Kalahari palaeolakes and the role of Zambezi inflows. *Quaternary Research* 69:
615 388-403.

616 Burrough SL and Thomas DSG (2009) Geomorphological contributions to palaeolimnology on the
617 African continent. *Geomorphology* 103: 285-298.

618 Burrough SL and Thomas DSG (2013) Central southern Africa at the time of the African Humid
619 Period: A new analysis of Holocene palaeoenvironmental and palaeoclimate data. *Quaternary*
620 *Science Reviews* 80: 29-46.

621 Burrough SL, Thomas DSG and Bailey RM (2009) Mega-Lake in the Kalahari: A Late Pleistocene record
622 of the Palaeolake Makgadikgadi system. *Quaternary Science Reviews* 28: 1392-1411.

623 Burrough SL, Thomas DSG, Orijemie EA, et al. (2015) Landscape sensitivity and ecological change in
624 western Zambia: The long-term perspective from dambo cut-and-fill sediments. *Journal of*
625 *Quaternary Science* 30: 44-58.

626 Burrough, SL, Thomas, DSG, Orijemie, EA, Willis, KJ (2015). Landscape sensitivity and ecological
627 change in western Zambia: The long-term perspective from dambo cut-and-fill sediments, *Journal of*
628 *Quaternary Science* 30: 44-58.

629 Burrough SL, Thomas DSG, Shaw PA, et al. (2007) Multiphase Quaternary highstands at Lake Ngami,
630 Kalahari, northern Botswana. *Palaeogeography, Palaeoclimatology, Palaeoecology* 253: 280-299.

631 Burrough SL and Willis KJ (2015) Ecosystem resilience to late-Holocene climate change in the Upper
632 Zambezi Valley. *The Holocene* 25: 1811-1828.

633 Clark JD (1969). *World Prehistory: A New Synthesis*. Cambridge: Cambridge University Press.

634 Clark JD (2001). *Kalambo Falls Prehistoric Site, Volume III*. Cambridge: Cambridge University Press.

635 Clark, JD (1950). *The Stone Age Cultures of Northern Rhodesia*. Claremont: South African
636 Archaeological Society.

637 Cohen AS, Stone JR, Beuning KRM, et al. (2007) Ecological consequences of early Late Pleistocene
638 megadroughts in tropical Africa. *Proceedings of the National Academy of Sciences of the United*
639 *States of America* 104: 16422-16427.

640 Collins JA, Schefuß E, Govin A, et al. (2014) Insolation and glacial-interglacial control on
641 southwestern African hydroclimate over the past 140000 years. *Earth and Planetary Science Letters*
642 398: 1-10.

643 Cornelissen E (2013). Hunting and gathering in Africa's tropical forests at the end of the Pleistocene
644 and in the early Holocene. In: Mitchell P and Lane P (eds): The Oxford Handbook of African
645 Archaeology. Oxford: Oxford University Press, 403-417.

646 Fagan, BM and Van Noten, F (1971). The Hunter-Gatherers of Gwisho. Musée Royal de l'Afrique
647 Centrale, Tervuren. Séries in-8°, no. 74.

648 Fanshawe DB (1971) The vegetation of Zambia. Lusaka: Ministry of Rural Development. Forest
649 Research Bulletin 7.

650 Feathers JK (1997) Luminescence dating of sediment samples from White Paintings Rockshelter,
651 Botswana. Quaternary Science Reviews 16: 321-331.

652 Gabel, C (1965). Stone Age Hunters of the Kafue: The Gwisho A Site. Boston University African
653 Research Studies, no. 6.

654 Galbraith RF, Roberts RG, Laslett GM, et al. (1999) Optical dating of single and multiple grains of
655 quartz from Jinmium rock shelter, northern Australia: Part I, experimental design and statistical
656 models. Archaeometry 41: 339-364.

657 Haddon IG (2005) The sub-Kalahari geology and tectonic evolution of the Kalahari Basin, southern
658 Africa. The Sub-Kalahari Geology and Tectonic Evolution of the Kalahari Basin, Southern Africa: 343.

659 Haddon IG (1999) Isopach Map of the Kalahari Group. Council for Geoscience Pretoria, South Africa.

660 Inskeep RR (1959) A late Stone Age camping-site in the Upper Zambezi Valley. South African
661 Archaeological Bulletin 14: 91-96.

662 Ivester AH, Brook GA, Robbins LH, et al. (2010) A sedimentary record of environmental change at
663 Tsodilo Hills White Paintings Rock Shelter, Northwest Kalahari Desert, Botswana. Palaeoecology of
664 Africa 30: 53-78.

665 Kreutzer S, Dietze, M, Burow C, Fuchs MC, Schmidt C, Fischer M, Friedrich, J (2017). Luminescence:
666 Comprehensive Luminescence Dating Data Analysis. R package version 0.7.5. [https://CRAN.R-](https://CRAN.R-project.org/package=Luminescence)
667 [project.org/package=Luminescence](https://CRAN.R-project.org/package=Luminescence)

668 Kreutzer S, Schmidt C, Fuchs MC, Dietze M, Fischer M, Fuchs M (2012). "Introducing an R package for
669 luminescence dating analysis." Ancient TL, 30, pp. 1-8.

670 McCall, GS (2007) Behavioral ecological models of lithic technological change during the later Middle
671 Stone Age of South Africa. Journal of Archaeological Science 34 (10), 1738-1751.

672 Mejdahl V (1979). Thermoluminescence dating: Beta-dose attenuation in quartz grains.
673 Archaeometry 21: 61-72.

674 Mitchell PJ (2002). The Archaeology of Southern Africa, Cambridge and Cape Town: Cambridge
675 University Press.

676 Moernaut J, Verschuren D, Charlet F, et al. (2010). The seismic-stratigraphic record of lake-level
677 fluctuations in Lake Challa: Hydrological stability and change in equatorial East Africa over the last
678 140 kyr. *Earth and Planetary Science Letters* 290: 214-223.

679 Money NJ (1972). An outline of the geology of western Zambia. . Records of the Geological Survey,
680 Republic of Zambia. Republic of Zambia, 103-123.

681 Musonda, FB (1984). Late Pleistocene and Holocene microlithic industries from the Lunsemfwa
682 Basin, Zambia. *The South African Archaeological Bulletin* 39:24-36.Kreut

683 Partridge TC, deMenocal PB, Lorentz SA, et al. (1997) Orbital forcing of climate over South Africa: a
684 200,000-year rainfall record from the Pretoria Saltpan. *Quaternary Science Reviews* 16: 1125-1133.

685 Phillipson, L (1970) Excavations at Kandanda and Donke, *Archaeologia Zambiana*, Vol.12

686 Phillipson L (1975a) Survey of the Pleistocene and Holocene archaeology of the Upper Zambezi
687 Valley, Zambia. University of California at Berkeley.

688 Phillipson L (1975b) Survey of the Stone Age archaeology of the Upper Zambezi Valley: III. The
689 northern part of the valley. *Azania* 10: 1-48.

690 Phillipson L (1977) Survey of the Stone Age Archaeology of the Upper Zambezi Valley: III. The
691 Southern Part of the Valley. *Azania* 12: 83-110.

692 Phillipson D (1976). *The Prehistory of Eastern Zambia*. Nairobi: British Institute in Eastern Africa.

693 Robbins LH, Murphy ML, Brook GA, et al. (2000) Archaeology, palaeoenvironment, and chronology of
694 the Tsodilo Hills White Paintings Rock Shelter, northwest Kalahari Desert, Botswana. *Journal of*
695 *Archaeological Science* 27: 1085-1113.

696 Robbins LH, Brook GA, Murphy ML, Ivester AH, Campbell AC (2016). The Kalahari During MIS 6-2
697 (190–12 ka): Archaeology, Paleoenvironment, and Population Dynamics. In: Jones S, Stewart B (eds)
698 *Africa from MIS 6-2*. Springer, Dordrecht *Vertebrate Paleobiology and Paleoanthropology*, 175-193.

699 Roberts RG, Galbraith RF, Yoshida H, et al. (2000) Distinguishing dose populations in sediment
700 mixtures: A test of single-grain optical dating procedures using mixtures of laboratory-dosed quartz.
701 *Radiation Measurements*. 459-465.

702 Russell, NJ, Armitage, SJ (2012). A comparison of single-grain and small aliquot dating of fine sand
703 from Cyrenaica, northern Libya, *Quaternary Geochronology* 10, 62-67.

704 Savage, DK (1983). Identifying industries in South Central Africa: The Zambian Wilton example.
705 Unpublished PhD thesis, University of California, Berkeley.

706 Schefuß E, Kuhlmann H, Mollenhauer G, et al. (2011) Forcing of wet phases in southeast Africa over
707 the past 17,000 years. *Nature* 480: 509-512.

708 Schefuß E, Schouten S and Schneider RR (2005) Climatic controls on central African hydrology during
709 the past 20,000 years. *Nature* 437: 1003-1006.

710 Scholz CA, Johnson TC, Cohen AS, et al. (2007) East African megadroughts between 135 and 75
711 thousand years ago and bearing on early-modern human origins. *Proceedings of the National*
712 *Academy of Sciences of the United States of America* 104: 16416-16421.

713 Sealy J (2016). Cultural Change, Demography, and the Archaeology of the Last 100 kyr in Southern
714 Africa. In: Jones S and Stewart B (eds), *Africa from MIS 6-2. Population Dynamics and*
715 *Paleoenvironments*. Springer Dordrecht: *Vertebrate Paleobiology and Paleoanthropology*, 65-75.

716 Singarayer JS and Burrough SL (2015) Interhemispheric dynamics of the African rainbelt during the
717 late Quaternary. *Quaternary Science Reviews* 124: 48-67.

718 Staurset S and Coulson S (2014) Sub-surface movement of stone artefacts at white Paintings Shelter,
719 Tsodilo Hills, Botswana: implications for the Middle stone age Chronology of central southern Africa.
720 *Journal of Human Evolution* 75: 153-165.

721 Stewart BA, Dewar GI, Morley MW, et al. (2012) Afromontane foragers of the Late Pleistocene: Site
722 formation, chronology and occupational pulsing at Melikane Rockshelter, Lesotho. *Quaternary*
723 *International* 270: 40-60.

724 Taylor N (2016). Across Rainforests and Woodlands: A Systematic Reappraisal of the Lupemban
725 Middle Stone Age in Central Africa. In: Jones S., Stewart B. (eds) *Africa from MIS 6-2*. Springer,
726 Dordrecht: *Vertebrate Paleobiology and Paleoanthropology*, 273-299.

727 Thomas DSG 1988 The nature and depositional setting of arid and semi-arid Kalahari
728 sediments, southern Africa. *Journal of Arid Environments* 14: 17-26.

729 Thomas, DSG, Shaw, PA (1991). *The Kalahari environment*, Cambridge University Press, Cambridge.

730 Thomas DSG, Bailey R, Shaw PA, et al. (2009) Late Quaternary highstands at Lake Chilwa, Malawi:
731 Frequency, timing and possible forcing mechanisms in the last 44 ka. *Quaternary Science Reviews*
732 28: 526-539.

733 Thomas DSG, Brook G, Shaw P, et al. (2003) Late Pleistocene wetting and drying in the NW Kalahari:
734 An integrated study from the Tsodilo Hills, Botswana. *Quaternary International*. 53-67.

735 Thomas DSG and Burrough SL (2012) Interpreting geoproxies of late Quaternary climate change in
736 African drylands: Implications for understanding environmental change and early human behaviour.
737 *Quaternary International* 253: 5-17.

738 Thomas, DSG, Burrough, SL, Parker AG, (2012) Extreme events as drivers of early human behaviour
739 in Africa? The case for variability, not catastrophic drought. *Journal of Quaternary Science* 27: 7-12.

740 Thomas, DSG, Burrough, SL (2013). Luminescence-based dune chronologies in southern Africa:
741 Analysis and interpretation of dune database records across the subcontinent, *Quaternary*
742 *International*.

743 Tierney JE, Russell JM, Huang Y, et al. (2008) Northern hemisphere controls on tropical southeast
744 African climate during the past 60,000 years. *Science* 322: 252-255.

745 Vandenberghe D, De Corte F, Buylaert JP, et al. (2008) On the internal radioactivity in quartz.
 746 Radiation Measurements 43: 771-775.

747 Van Riet Lowe, C (1935). Implementiferous gravels of the Vaal River at Riverview Estates, Nature
 748 136, 53-56.

749 Villa, P, Soriano, S, Tsanova, T, Degano, I, Higham, TFG, D'Errico, F, Backwell, L, Lucejko, JJ,
 750 Colombini, MP, Beaumont, PB, (2012). Border Cave and the beginning of the Later Stone Age in
 751 South Africa, Proceedings of the National Academy of Sciences of the United States of America 109,
 752 13208-13213.

753 Vogelsang, R, Richter, J, Jacobs, Z, Eichhorn, B, Linseele, V, & Roberts, R (2010). New Excavations of
 754 Middle Stone Age Deposits at Apollo 11 Rockshelter, Namibia: Stratigraphy, Archaeology,
 755 Chronology and Past Environments. Journal of African Archaeology, 8(2), 185-218.

756 Wadley, L, (2015). Those marvellous millennia: The Middle Stone Age of Southern Africa, Azania 50,
 757 155-226.

758 Wang YV, Larsen T, Leduc G, et al. (2013) What does leaf wax δD from a mixed C3/C4 vegetation
 759 region tell us? Geochimica et Cosmochimica Acta 111: 128-139.

760 Wintle AG, Murray, AS (2006) A review of optically stimulated luminescence characteristic and their
 761 relevance in single-aliquot regeneration dating protocols. Radiation Measurements 41(4):369-391.

762
 763
 764