1 Implications of a new chronology for the interpretation of the Middle and

2 Later Stone Age of the upper Zambezi ValleyA new chronology for the Middle

3 and Later Stone Age of the Upper Zambezi Valley.

4 Burrough SL, Thomas, DSG; Barham LS

5 Abstract

6 Single grain OSL dating has been used to produce new chronologies for three previously investigated

7 sites in the northern Kalahari basin in western Zambia containing both Middle and Later Stone Age

8 material (Phillipson 1975 a&b). We find that Mode 3 (Middle Stone Age, MSA) assemblages in the

9 Upper Zambezi Valley pre-date the Last Glacial Maximum. Ages The chronology

10 producedchronology produced here isare consistent with age estimates from a handful of dated

11 sites within the wider Kalahari basin. The A Mode 3 to Mode 5 (Later Stone Age, LSA) transition

12 relationship at one site, of Chavuma, is unlikely to be a continuous transition as previously thought.

13 Instead we find a significant chronological hiatus between MSA material deposited at 66.5 ± 9.9 ka

14 and LSA material deposited at 16.7 ± 2.6 ka. We consider these dated archaeological finds within

15 the context of current archaeological and palaeoenvironmental records for the region. The results

16 highlight demonstrate the highly variable climate history of the region and the limitations of the

17 existing archaeological record for modelling human responses to habitat change.

18

19 1. Introduction

20 1.1 Palaeolithic Archaeology in the Kalahari basin

21 The southern African interior possesses a long record of human occupation (Barham, 2000;

22 Burrough, 2016; Barham, 2000) that, for the most part, remains poorly investigated. This is despite

23 the richness of available sites reported since the early studiein the middle of the twentieth century

24 by s of Van Riet Lowe (1935), Clark (1950) Bond and Summers (1954) and others. Archaeological

25 research has favoured sites that offer good organic preservation, with a strong focus on cave-sites

26 along the South African coast (Backwell et al., 2014; Stewart et al., 2012; Backwell et al., 2014)

27 (Figure 1). The interior Kalahari basin however possesses an abundance of Stone Age archaeological

28 sites (see Burrough 2016 for an overview), albeit that many are in open air contexts. While these

29 may often lack associated organic deposits, many are situated in landscape contexts that attest to

30 extreme and repeated water deficits and surpluses (Burrough et al., 2009; Burrough and Thomas,

31 2013; Thomas et al., 2003; Thomas and Burrough, 2012) that have potentially vital implications for

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

33

34 Figure 1: Published MSA and LSA archaeological site locations within southern Africa. The upper

35 Zambezi region is marked with a red box. 1) Congo basin; 2) eastern Namib/western Kalahari rainfall

36 record; 3) Megalake Makgadikgadi; 4) Tswaing Crater; 5) Zambezi Fan; 6) Lake Chilwa; 7) Lake

37 Malawi; 8) Lake Tanganyika; Mf = Mufo; Cal3 = Calunda III; Chv = Chavuma; Si = Sioma M; Knd =

38 Kandanda; Kal = Kalambo Falls; Mz = Manzi River; MC = Mumbwa Caves; GS=Gwisho Springs; TR =

39 Twin Rivers; LH = Leopards Hill Cave; Kmb = Kalemba Rock Shelter; Tso = Tsodilo; Gi = #Gi; Tg =

40 Toteng.

41

42 Zambia, which borders includes the northeastern part of the Kalahari basin, provides key evidence

43 from the Zambezi Valley (Clark, 1950) and high plateau (Clark, 2001; Barham, 2000) that

44 demonstrate marked changes in the content and periodicity of occupation, with gaps in the record

45 tentatively related to records of palaeoenvironmental change (Barham, 2001). Important themes to

46 have emerged from this work include the potential significance of fluvial systems as refugia during

47 regionally dry conditions in the Pleistocene (Avery, 2003; Barham, 2001; Avery, 2003). There are

48 however, still too very few chronologically constrained sites (particularly in association with river

49 systems) to test whether this is a real pattern or an artefact of research to date. Nevertheless, the

50 north-south fluvial corridors of the southern African interior (Okavango, Kwando and Zambezi),

51 bringing flood pulses from the tropics, are likely to have been critical for access to food and water

52 resources. They may also have been important as human migratory corridors during times when

53 wider environmental conditions were dry.

54 In western Zambia at the northeastern margin of the Kalahari basin, an abundance of Stone Age sites

55 have been reported in the Upper Zambezi Valley (UZV) (Inskeep, 1959; Phillipson, 1975a (Phillipson,

56 1977; Phillipson, 1975b; Phillipson, 1975a;Phillipson,1977 Inskeep, 1959). However, little

57 archaeological investigation has taken place since the surveys and excavations of Laurel Phillipson

58 (Phillipson, 1975a&b, 1977) who worked at open sites along the Zambezi between the Angolan

59 border and Victoria Falls (Phillipson, 1975a). Middle (MSA) and Later (LSA) Stone Age assemblages

60 were excavated, but remain largely under-cited, perhaps known because of the difficulty of proving

61 site chronologies. Radiocarbon was the only absolute dating technique available at the time and not

62 all the sites contained charcoal, with and none containinged bone. Subsequent dating

63 developments have shown the MSA to be well beyond the range of radiocarbon (Barham and

64 Mitchell, 2008; Wadley, 2015), with the onset of the LSA in southern Africa at its upper limits (Villa et

65 al., 2012). A recent road construction project has destroyed many of the sites that Phillipson

66 investigated, but during palaeoenvironmental fieldwork in 2011 an opportunity arose to revisit three

67 remaining, but immianently threatened, Phillipson sites at Chavuma, Sioma M and Kandanda (Donke

68 gravel pit) to undertake sampling for Optically Stimulated Luminescence (OSL) dating. Here we

69 report the findings of this investigation with the aim of placing the original archaeological data

70 within the chronological context of regional records of palaeolithic and palaeoenvironmental

71 change. This paper presentsWe present the sampling and dating for each site, a re-consideration of

72 the archaeological material and a discussion of both the archaeology and their ages in relation to our

73 knowledge of the wider regional archaeological and environmental record.

74 1.2. Western Zambia

75 Western Zambia (Figure 1) occupies the eastern margin of the 2.5 million km2 Kalahari sedimentary

76 basin (Thomas and Shaw, 1991), and is covered by sand up to 200 m thick (Haddon, 2005;Thomas

77 1988; Haddon, 1999, 2005). Mean annual rainfall in interior southern Africa decreases from

78 northeast to southwest, controlled principally by the seasonal migration of the tropical rainbelt,

79 decreasing in the UZV from 1,375 mma-1 at Mwinilunga (near the source of the river on the Central

80 African Plateau) to 700 mma-1 at Sesheke (Fanshawe, 1971). The wet season extends from

81 November to May in the north of the valley, though is several weeks shorter in its southern reaches,

82 near Katima and Livingstone. The Zambezi moves water through the broad Barotse floodplain,

83 which floods up to 30 km in width between December and May, steepening and narrowing below

84 Senanga as it incises into Karoo-age basalts of the sub-Kalahari bedrock, creating a series of rapids.

85 The UZV spans an ecological transition zone from dense miombo woodland through woodland-

86 savanna and edaphic grassland to a much more xeric-savanna system in its the southern reaches

87 (Burrough and Willis, 2015). Like the Okavango and Kwando rivers, the UZVis part of the Zambezi

88 carries water from the wetter sub-tropics into drier sub-humid areas. Permanent fluvial channels

89 within the Zambezi floodplain and dambos (shallow wetlands) away from the river provide critical

90 dry season water sources for modern occupants of the UZV (Burrough et al., 2015). That this was

91 also the case in the past may be reflected in the distribution of archaeological sites along channel

92 margins.

93 The deep Kalahari sands which blanketof westernof western Zambia are also a challenge for locating

94 archaeological deposits, with the majority of sites described by Phillipson (1975a) exposed in road

95 quarries dug in the 1960s and 70s. The sand cover also limited the exposure of rock outcrops for

96 Stone Age people, potentially making procurement resources for lithic tool manufacture

97 challengingscarce. It is notable that many of the UZV in-situ sites are adjacent to major rapids where

98 bedrock is revealed, with a significant proportion of documented lithics tools manufactured from

99 poor- quality sandstone and quartzites exposed in these locations, including derived quartzite

100 pebbles (Money, 1972). Fluvial erosion may also affect archaeological visibility in this otherwise

101 sandy landscape, which could contribute bias to site distributions.

102 1.3 Site locations

103 The three investigated sites, Chavuma, Sioma M and Kandanda are shown in Figure 2. Locations

104 and conditions of preservation are outlined briefly here with the archaeological content summarised

105 following the presentation of the dating methods and results.

106 Chavuma (-13.0946oS, 22.68899oE)

107 Chavuma Falls archaeological site is on the east bank of the Zambezi at a point where the river is

108 ponded behind a rock barrier as it passes through the Chavuma Hills. It is adjacent to a deep pool at

109 the base of Chavuma Falls and located within a 5 m section of a thick sandy bank. The base of the

110 section grades into fluvially-deposited pebbles and gravels that rest on the underlying bedrock. The

111 absence of material suitable for 14C dating meant Phillipson (1975a & b) was unable to provide a

112 chronology.

113 Sioma M (-16.61269 oS, 23.507585oE)

114 Exposed in a quarry pit during road construction in 1965, Sioma M is 1.3 km southwest of the

115 present Zambezi channel and comprises 0.3 m of hard ferricrete on and in which archaeological

116 material is located. This is overlain by 1.2 – 2.5 m of red- yellow sand (Munsell colour 10YR 6/8).

117 Donke Gravel Pit near Kandanda (-17.4224 oS, 24.19666 oE)

118 Kandanda is adjacent to rapids where the Zambezi has cut through bedrock obstructions, forming

119 three valley-side terraces. Phillipson (1975a, 1977) described the archaeological site as exposed by a

120 large quarry, on the northeast side of the Senanga road between Kandanda village and the

121 Kachekabwe tributary stream. Forty years later, when sampling occurred for this study, the site was

122 again being used as a quarry for road construction, where enlargement had destroyed the majority

123 of Phillipson’s 1969 excavation trenches. A few sections remained, including Donke, on the

124 uppermost terrace, adjacent to survey beacon BM6R. Charcoal fragments within the Kandanda

125 section provided several 14C ages in the original analysis (see section 3.2.3)

126

127 Figure 2: Regional Digital elevation model of the Upper Zambezi Valley (UZV) showing archaeological

128 site locations (filled black circles) investigated in this study. Major settlements discussed in text are

129 also given as grey squares.

130

131 2. OSL Dating

132 Sediments for dating were sampled collected at Chavuma (7 samples; ZAM/11/5) and Sioma M (4

133 samples; ZAM/11/9) using an auger with a light-tight sampling head. At Donke (Kandanda),

134 Phillipson’s 1968 test pit remained open; this was dug out and sampled from a cleaned face (3

135 samples; ZAM/11/14). Samples for OSL dating were prepared under subdued red light (600 nm)

136 conditions at the Oxford Luminescence Dating Laboratory (OLDLab). The outer material

137 (approximately 60% of an 8 x 15 cm tube) from each sample was separated and later used for

138 dosimetry and sedimentological measurements. The centre of the sample (uncontaminated by light)

139 was processed using standard quartz isolation methods e.g. Burrough et al., (2009). A total of 14

140 samples were dated for this study.

141 2.1 Equivalent dose (De) Determination

142 All samples were dated using 800-1000 individual quartz grain De measurements per sample. The

143 distribution of De measurements from single-grain analysis is advantageous for age determinations

144 from Kalahari sediments. First, multiple grain analysis averages De signals in a manner that can mask

145 erroneous data from ‘rogue’ grains (c.f. Russell and Armitage, 2012) that would otherwise be

146 rejected in a single grain analysis. These averaging errors will most likely produce overestimated

147 ages. Second, single grain analysis provides a De distribution that allows a much clearer assessment

148 of depositional and/or post depositional processes, which is critical for informing the choice of age

149 model used to produce the final age. For details on measurement conditions and rejection criteria

150 see supplementary info S1.

151

152 2.2 Dose rate (D’) determination

153 Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was used to measure the isotope

154 concentrations (232Th, 238U and 40K) that determine each sample’s dose rates. For two samples

155 (ZAM/11/5/4 and ZAM/11/5/5), up to 10 small (~1g) subsamples of bulk sediment were separated

156 for additional ICP measurements to attempt to capture any variability within the sediment. In

157 addition, one sample (ZAM/11/5/4) was density-separated to obtain both heavy mineral and

158 feldspar fractions. The latter was too small by mass to undertake analyses but U, Th and K

159 concentrations in quartz and heavy mineral fractions were measured independently to assess

160 within-sample micro-dosimetry variability. Field gamma spectrometry measurements were also

161 made taken for samples ZAM/11/9/2; 9/3; 9/4 and ZAM/11/14/3 to check that direct radiation

162 measurements returned within-error estimates of the sedimentary gamma dose. Conversion to

163 external beta and gamma components (to account for grain-size, HF etching and moisture content)

164 used the dose-rate conversion and beta attenuation factors of Guerin et al., (2011)(Adamiec and

165 Aitken, 1998) and (Mejdahl (, 1979), assuming radioactive equilibrium in the 238U and 232Th series.

166 Sample moisture contents during burial were estimated at 10-18 % (Table 1) based on ‘as found’

167 values. An absolute internal alpha dose uncertainty of 0.012 Gy/ky (Vandenberghe et al., 2008) was

Commented [1]: Would it be worth adding, ‘a critical issue that is

often ignored in dose rate calculations’

168 added in quadrature to the total dose rate error. Cumulative cosmic dose during the burial period

169 was iteratively modelled based on the overlying depositional history (Burrough et al., 2007). Total

170 dose rate uncertainties were calculated using Monte Carlo methods.

171

172 3. Results and Discussion

173 3.1 Equivalent Dose distribution

174 Dose rate data, De estimates and ages are given in Table 1 and 2. De distributions were consistently

175 broad. Overdispersion (statistical distribution) values, ranging from 43% to 120% (Figure S1), lie

176 within the upper end of the range of overdispersion values typical for single grain measurements. In

177 all samples 2-4% of measured grains had natural signals which far exceeded the growth curve. All

178 accepted De’s were below 86% of saturation (2\* D0) (Wintle and Murray, 2006). Multiple subsample

179 aliquots for ZAM/11/5/4 and ZAM/11/5/5 suggested bulk dose rate variability of ~20%

180 (subsequently factored into the uncertainty of all sample radioisotope concentrations). Sediments

181 were typically quartz-dominated with a small heavy mineral proportion (0.3-1% by mass). Heavy

182 minerals create very different dose rates at the inter-grain scale (Ffigure 3b), with implications for

183 age model selection. These data suggest a proportion of the observed sample overdispersion can be

184 attributed to dose rate variability at the single grain scale (see supplementary info S2 for details).

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

Radioisotope Concentrationsa Sediment dose rates (Gy/ka)

Site

Name Sample ID K (%) Th (ppm) U (ppm)

Moisture

content (%) b Beta Gamma Cosmicd Total dose rate

(Gy/ka)

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

Chavuma

ZAM/11/5/7 0.05 1.40 0.40 0.18 0.09 0.10 0.16 0.35 ± 0.06

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 0.11c 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

Sioma M

ZAM/11/9/4 0.07 1.63 1.60 0.10 0.25 0.23 c 0.20 0.69 ± 0.10

ZAM/11/14/1 0.35 1.36 0.36 0.10 0.29 0.17 0.23 0.69 ± 0.06

Don

ZAM/11/14/2 0.36 1.60 0.37 0.10 0.31 0.18 0.23 0.72 ± 0.07

ke

ZAM/11/14/3 0.43 1.62 0.47 0.12 0.36 0.20 c 0.22 0.79 ± 0.08

186 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

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

188 c Measurements made using in situ gamma spectrometry.

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

190

191

192

193

194 Figure 3: a) Grain size distribution for each site and b) Separated heavy mineral and quartz fraction

195 radioisotope concentrations from sample ZAM/11/5/5 (question marks indicate measurements

196 below detection limits (<0.1 ppm).

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

Sample ID Depth

(m) na Equivalent

Doseb (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

198 a Number of accepted OSL signals / total number of grains measured. 199 b Weighted mean De ± 1σ

200

201

202 3.2 Age model selection

203 It is unknown whether the highly overdispersed Des are a common or anomalous feature of the

204 region: despite a long history of Kalahari OSL applications (c.f. Thomas and Burrough, 20134) very

205 few studies have utilised the single grain methodology. It is vital therefore to consider this further.

206 There are three possible reasons for a large De distributional spread: i) partial bleaching, whereby

207 grains were insufficiently exposed to sunlight prior to deposition, leaving some with a residual dose

208 from a previous depositional cycle; ii) bioturbation, with grains of different depositional ages moved

209 or mixed by biological processes after deposition; and iii) beta dose rate heterogeneity, whereby

210 grains of the same age were exposed to different dose rates within the sediment. In each case, a

211 different statistical age model can be used to derive an accurate estimate of the specific targeted

212 depositional event associated with the archaeological material. In this case the wide De distributions

213 likely result from a combination of both beta heterogeneity (see supplementary info S2) and a

214 degree of post-depositional mixing. We assume the latter because of the biologically productive

215 nature of the UZV savanna region (Burrough and Willis, 2015). Zero dose De values on modern

216 Zambezi fluvial deposits indicate that residual doses from any incomplete bleaching are minimal and

217 unlikely to impact the equivalent dose distributions (Figure S2).

218 The central age model (CAM: (Galbraith et al., 1999) and fFinite mixture model (FMM: (Roberts et

219 al., 2000) were fitted using the Luminescence R package (Kreutzer et al., 2012, 2017). Representative

220 De estimates were derived assuming overdispersion was caused by dose rate heterogeneity and

221 biological mixing (see S3 for model specification). In addition to CAM and FMM we also calculated

222 weighted mean Des for each sample. This age model is appropriate where overdispersion can be

223 entirely attributed to between-grain dose rate variability and where radioisotope concentrations,

224 estimated from homogenised bulk sediment sub-samples, will provide average sediment dose rates.

225 Comparative age/depth relationships for each model are shown in Ffigures 4 a-c for each

226 archaeological site. Based on the radio-isotope characteristics of the sediment and observations of

227 sediment mixing within this region, we use a Finite Mixture Model (prescribed with overdispersion,

228 (σb-values, of between 0.3-0.8 as expected from natural/dose-driven grain-to-grain

229 variability) in the final calculation of depositional ages.

230

231

232

233 Figure 4: Comparative age depth relationships for each site using three age models – The Central

234 Age Model (CAM), the Finite Mixture Model (FMM) and the Weighted Mean (Wgt Mean).

235

236 3.3 Site archaeology and age

237 4.3.1 Chavuma

238 Phillipson’s (1975a,b) excavation at Chavuma Falls was undertaken in a 3.7 m high sand body

239 (interpreted as an aeolian dune) above the ‘land surface’ or ‘rubble horizon’, which slopes down 1.5

240 m to the modern Zambezi flood season Zambezi water level. The 1968 excavation occurred in the

241 exposed lower ~1.2 m of the sand unit, and was carried out in 15 cm spits down to the ‘rubble

242 horizon’. Spits were integrated into separate’ levels’ based on similarities in selected artefact

243 categories and to a lesser extent in raw material use.

244 Artefacts were described as comprising sandstones and mudstones with rare quartz and chalcedony,

245 probably sourced from water-polished cobbles on the edge of the Chavuma pool (Figure 5). None of

246 the upper level artefacts were heavily weathered and some pieces showed signs of utilisation. A few

247 artefacts resting on the land surface were heavily abraded but most were moderately fresh in

248 condition. Some older, very abraded pieces were reworked for the production of more recent

249 artefacts (cortex flakes). Phillipson found no consistent statistically-significant differences between

250 assemblages from adjacent spits. One pot sherd was found in Level 1 and one in Level 2; they were

251 regarded as intrusive given their small size and rarity.

252

253 Figure 5: a) Plan view of site location at Chavuma Falls; b) sections within the Chavuma dune from 1)

254 Phillipson’s 1968 Excavation showing archaeological levels 1-5 and 2) augered section in 2011

255 showing location of OSL samples (open circles, ages (FMM model) and artefacts retrieved during

256 augering (marked as ‘A’) [we have tied the sections using the position of the basal gravel unit and

257 both sections are drawn on the same scale] ; c) Location of excavation in relation to dune and

258 present day water levels; d) Photograph of the site with Falls in the distance.

259 Artefact assemblages and their downward sequence (Table 3, Figure 6A) are very similar to those

260 described by Phillipson (1975a) at Cholwezi, a large site several kilometres north of Chavuma but not

261 investigated further here. The smaller number of retouched artefacts and cores from Chavuma was

262 insufficient to extract meaningful statistical generalisations. Attributions to Industries or Modes

263 were partly based on the presence of distinctive retouched tools and core production strategies, and

264 in part on comparisons with the more numerous Cholwezi sequence. The ‘Mode’ attribution is based

265 on Clark’s (1969) universal scheme of stone tool technologies. In this context, Mode 3 Levallois

266 technology is equated with the Middle Stone Age, based on evidence of core preparation (Levallois

267 technique) and prepared flakes with facetted butts. Mode 5 microlithic technology is equated with

268 Later Stone Age based on the presence of microlithic cores, bladelets and the range of retouched

269 tools made on microliths.

270 Table 3: Summary assemblage characteristics for each level excavated at Chavuma and the

271 associated classification. Adapted from Phillipson (1975).

Level Spit No. Assemblage characteristics Condition

Phillipson

technotypological

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

272

273 Figure 6: A) Selected Chavuma Falls artefacts as illustrated by L Phillipson and used with permission

274 of the British Institute in Eastern Africa and Azania. Artefact lettering is as appears in Azania Volume

275 X, Figures. 16-18. Level 1: backed blades, sandstone (a,b); Level 2: crescents

276 (j=mudstone,k=sandstone) Level 3: high backed ovate radial core (j=mudstone); Level 5: parallel-side

277 bifaces (d,e=mudstone). B) Selected Kadanda artefacts as illustrated by L Phillipson and used with

278 permission of the British Institute in Eastern Africa and Azania. Artefact lettering is as appears in

279 Azania Volume XI, Figures. 5-6. Level 3: crescents (a,b=sandstone; c=chalcedony); single-platform

280 core (p, chalcedony); opposed platform core (q, chalcedony); Level 4: utilized blades (aa-dd,

281 chalcedony). C) Selected Sioma ‘M’ artefacts, all chalcedony, as illustrated by L Phillipson and used

282 with permission of the British Institute in Eastern Africa and Azania. Artefact lettering is as appears

283 in Azania Volume XII, Figure 2; unifacial flake points (c,d); bifacial flake point (h); flake cleavers (l, m)

284

285

286 The basal Cholwezi sequence is attributed to Mode 3/MSA based on the presence of prepared cores.

287 There are no prepared cores in the Chavuma sequence, and Phillipson interpreted this record as

288 representing a continuum of the transition from Mode 3 to Mode 5/LSA with its characteristic

289 microlithic forms. Levels 1-3 are clearly Mode 5, but the typological status of Levels 4 and 5 is less

290 certain. They lack microliths and the artefacts are larger; there is a difference in raw material use

291 and Level 4 has unifacial points and some platform preparation on radial cores. We tentatively

292 attribute Level 4 to the MSA/Mode 3. Level 5 lacks points, artefacts are more abraded, and among

293 the small number of retouched tools are large core tools including two parallel-sided ‘knives’ made

294 on silicified mudstone. The assemblage is too small to assign it to a particular Mode or industry.

295 Like Phillipson (1975a), we find no statistically significant difference in the grainsize distribution or

296 nature of sediments that would indicate a discontinuity between the lower and upper levels. The

297 OSL data however, indicate a chronostratigraphic break between the lowest parts of the section and

298 the upper sediments. Chronstratigraphic breaks are widely reported form other dating studies of

299 otherwise stratigraphically-featureless Kalahari sands (e.g. Thomas and Burrough 2013). Using the

300 best fit component of the finite mixture model, our results suggest the upper two levels are dated to

301 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.

302 Below this, sediments relating to Phillipson’s Levels 4 and 5 were dated to 66.5 ± 9.9 ka and 75.7 ±

303 16.6 ka respectively. The smaller proportional distribution between components of the single grain

304 Des in the FMM of the two lowest levels (Table 2) could be due to some reworking of the lower

305 sediments prior to the onset of another phase of deposition at c. 17 ka. The two older unitsThese

306 overlie a distinct, fluvial terrace demarcated by water-worn pebbles (Ffigure 5b-c). Importantly,

307 however, the Chavuma dates demonstrate that the archaeological record is not preserved as a

308 continuum as previously thought, and that the transition from a Mode 3 to a Mode 5 technology

309 occurs between 66.5 ± 9.9 and 16.7 ± 2.6 ka.

310 3.2.2 Sioma M

311 The record at this site is characterised by large core and flake tools as well as smaller retouched

312 flakes and scrapers (Figure 6B). Phillipson (1975a, b) considered these as two components of a

313 single Mode 3 industry that lacked a chronology.

314 The gravel pit was relocated using published descriptions and with help from village elders at Sioma

315 who remembered the 1960s excavation and its location. Phillipson found material at the interface

316 between an overlying sand deposit and the underlying ferricrete: lithics can be found on the

317 ferricrete surface today. Some pieces were embedded in this duricrust and those not in situ could

318 be linked to the deposit by the adherence of ferricrete and calcrete to their surfaces. All artefacts,

319 both fresh and slightly abraded, were made from ‘chalcedony’ (fine-grained silcrete) or highly

320 silicified sandstone. Phillipson’s assemblage comprised large irregular core and flake tools and

321 smaller retouched flake tools including unifacial and bifacial points, plus scrapers. There is evidence

322 for the deliberate production of radial and triangular flakes, the majority with multifaceted

323 platforms from core preparation. Phillipson (1975a, b) attributed the assemblage to an early Mode 3

324 phase, based in part on the production of flake cleavers from prepared cores and the presence of

325 large core tools.

326 In 2011 the pit was degraded, with slumped and eroded margins, but the site context was readily

327 identifiable. The overlying sand described by Phillipson was sampled several meters away from the

328 edge of the pit down to the underlying ferricrete in order to provide a minimum assemblage age

329 (Figure 7).

330

331 Figure 7: a) Location of Sioma M site with b) OSL dated (open circles) section within Kalahari sand

332 overlying artefact horizon and ferricrete and c) photograph of site location.

333 The uppermost sand, dated to 2.6 ± 0.3 ka and 4.6 ± 0.6 ka, is paler, finer and more organic-rich than

334 underlying redder sediments. These contain nodules of calcrete and ferricrete in lower levels and

335 are dated to 15.1 ± 2 ka and 16.5 ± 2.5 ka (FMM, Table 23) placing a minimum age on the underlying

336 archaeological assemblage located at the interface between the overlying sand and the underlying

337 ferricrete.

338 3.2.3 Donke

339 Donke was excavated by Phillipson on the upper-most river terrace which formed the main centre of

340 occupation (Figure 8). The archaeological sequence was “similar to, but more compressed than that

341 of Kandanda” (Phillipson, 1970: page 5). As there is no other information on the Donke trenches we

342 provide a summary of the material from excavations in the neighbouring Kandanda pit (Table 4,

343 Figure 6C). Tools were described as manufactured from homogenous green grey sandstone,

344 silicified sandstone with chalcedonic inclusions, sourced from fluvial pebbles and outcropping ‘pipe

345 sandstone’. Excavations took place following natural stratigraphic divisions of the deposit but with

346 spit thicknesses never greater than 305 mm. The uppermost fine, grey carbon-rich sands were

347 archaeologically sterile, grading to redder coarser sand below ~20cm. A distinct charcoal

348 concentration was visible at 45 cm depth at Kandanda, but was not present at Donke. The Donke

349 trench was 1 m deep, compared to ~2 m at Kandanda, with a basal unit composed of irregular,

350 friable sandstone overlain by sandstone rocks and artefacts. At Kandanda, the presence of refitted

351 artefacts in level 2 and 3 suggested the deposit was relatively undisturbed.

352 Table 4: Assemblage characteristics and radiocarbon dates from levels 1-4 of the Kandanda

353 excavation (adapted from Phillipson, 1975).

Level Assemblage

characteristics Condition Mode Radiocar

bon ID Material Age

(14C yrs BP)

Cal Age

(cal yrs BP) Trench\*

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 ± 85

490 ± 90

443 ± 83

466 ± 84

IV/I/D/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 ± 50

2130 ± 55

1701 ± 73

2053 ± 85

I/B/I/A/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 ± 80 3649 ± 108 I/A, and 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 ± 110

3360 ± 95

3485 ± 115

3690 ± 85

3508 ± 132

3550 ± 114

3699 ± 147

3960 ± 126

I/D/I/C I/C/I/C/354

355 \*see figure 8

356

357

358 Figure 8: a) Location of Donke Gravel Pit Trench I in relation to the 1968 excavation at Kandanda

359 (now destroyed by a road quarry); b) Pit section and dated OSL sample locations from Donke gravel

360 pit; c) Radiocarbon dated section from Kandanda Trench I with archaeological levels labelled 1-4

361 (from Phillipson, 1976); c) Photograph of site location looking SE in 2011 with Kandanda road quarry

362 pit in background.

363 Based on the continuity of artefact morphology and technology, particularly in core types, Phillipson

364 argued that the Kandanda archaeological sequence represented a single, continually developing,

365 stone working tradition. The excavated spits were grouped into four levels on the basis of artefact

366 content and stratigraphy. A unity to all four levels was described in that they contain Mode 5

367 microlithic artefacts, in particular small backed blades. Bladelets and small flakes were found in all

368 levels along with radial cores and flakes. Level 4 differed in having a greater number and variety of

369 core tools and a higher proportion of radial cores. Artefacts were larger in Levels 3 and 4 with a

370 trend towards greater use of sandstone in the lower levels. The co-occurrence of microliths with

371 large cores was a distinctive feature of Level 4. The presence of blades, technically a feature of

372 Mode 4 assemblages, highlights the diverse technologies produced. A noteworthy feature of Level 1

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

374 below.

375 Radiocarbon ages from charcoal at Kandanda placed the sequence well within the Mid- and Late

376 Holocene (Table 4). There are, however, issues with the reliability of the sequence arising from the

377 sampling strategy and bioturbation. The single date from Level 3 (lab no. SR-201) is considered as

378 out of place as it disrupts an otherwise coherent sequence. Phillipson notes that the sample

379 consisted of small charcoal fragments combined from four adjacent squares, and that ants and roots

380 had disturbed the sediments in this level (Phillipson 1978:79-80). Composite samples are also

381 reported from Level 2 (SR-199) and Level 4 (SR-202; SR-203).

382 OSL measurements from the Donke trench place the upper levels of this section at 3.1 ± 0.3 ka and

383 4.5 ± 0.5 ka. The lower part of the 1 m section dates to 6.4 ± 0.7 ka. The more compressed nature

384 of the section makes it hard to precisely relate these dates to the Kandanda archaeological

385 sequence, but they do support the Holocene age proposed by Philipson (1975a).

386 4. Implications of the OSL chronology for Upper Zambezi sites

387 The new OSL ages we present suggest that, at least for Chavuma, the ages of the lowest

388 archaeological units were was were significantly underestimated by Phillipson and thatwith the

389 transition from Mode 3 to Mode 5 technology occurringed before 16.6 ka. At Sioma M, we place a

390 minimum age of 16.5 ± 2.5 ka on the Mode 3 archaeology. Taking these two sites together, we infer

391 a discontinuous sedimentary record between the MSA (Mode 3) and LSA (Mode 5). The inability to

392 firmly relate the (now destroyed) archaeological sequence from Kandanda to the new OSL ages from

393 the remaining Donke Trench is problematic, though the sedimentary deposits do appear to affirm a

394 Mid-Late Holocene age for the upper terrace sediments.

395 The nearest comparable Late Pleistocene archaeological record comes from Mumbwa Caves, 380 km

396 east of the Zambezi (Figure 1) where there are clear gaps in the sequence that may be correlated

397 with climate change. This site was occupied 130-105 ka, abandoned between 105- 40 ka, re-

398 occupied briefly then abandoned again between 40 ka – 15/12 ka, after which the technology is

399 Mode 5 (Barham, 2000). There is also evidence of a Mid-Holocene occupation hiatus between 6 and

400 2 ka. Barham (2000) speculated that shifts in the availability of surface water were linked to regional

401 changes in hydrology, and ultimately climate change governed the human use of the site. At

402 Chavuma, the MSA/Mode 3 assemblage is dated to 66 ± 9.9/75 ± 16.7 ka (i.e. within errors) spanning

403 both wetter and drier periods within the Kalahari basin; relevant given the importance of the

404 Zambezi as a water source in the region. The LSA assemblages dated here also span a broad range of

405 climatic/environmental conditions, although the resolution of regional palaeoclimate records is

406 currently too spatially and temporally coarse to allow relationships between human presence and

407 environmental change to be tested. The proposition that fluvial corridors act as refugia in dry times

408 also remains to be tested. The recurrent occupation of Chavuma, despite its open air context,

409 probably reflects its position close to a persistent barrier-induced pool on the Zambezi, subject to

410 less channel migration and drying than meander belt zones further south on the floodplain.

411 Following the Last Glacial Maximum (LGM), all All investigated archaeological sites in Zambia that

412 post-date the Last Glacial Maximum (LGM) are Mode 5 in character with local variations in the

413 proportions of microlithic tools relative to larger forms. There is a relative uniformity in the Late

414 Glacial Mode 5 of Zambia (Nachikufan I) with local differences emerging in the early Holocene

415 (Barham and Mitchell, 2008)). Separate Mode 5 industries have been recognised in eastern,

416 northern and central Zambia (Makwe, Phillipson, 1976; Nachikufan II,III, Miller, 1970; Group 1,

417 Musonda, 1984; Zambian Wilton, Clark, 1950; ) but they can be subsumed within a spatially and

418 chronologically variable Nachikufan Industrial Complex (Barham and Mitchell, 2008). With the

419 exception of Phillipson’s work, in western Zambia there are no dated sites in western Zambiain this

420 part of the country. The LSA complex at Gwisho, on the central Zambian Kafue Flats (~400 km east of

421 the UZV) is dated between 3600 ±70 BP to 4700 ±100 BP (3935 cal BP [mean, 106 sigma] – 5361 cal

422 BP [mean, 152 sigma]) (Gabel, 1965; Fagan and Van Noten, 1971) making it comparable in age to

423 the Kandanda Level 4 deposit and overlapping chronologically with the Donke pit OSL ages. The

424 occupants of Gwisho made microlithic tools (backed flakes) and large scraping, cutting, chopping and

425 pounding tools comparable to some of the macrolithic components seen at Kandanda. At

426 Kamusongolwa Rockshelter in northwestern Zambia (~300 km east of Chavuma) there are two

427 composite radiocarbon dates that bracket the LSA between 13, 300 ± 250 (BP) (15,925 cal BP [mean,

428 375 sigma]) at the base to 4,000 ± 105 BP (4417 cal BP [mean, 171 sigma]) at the top, with a gap of

429 ~3000 years between the overlying Iron Age occupation (Savage, 1983). The Mode 5 technology is

430 characterised by backed flakes and blades, comparable to the wider Zambian microlithic tradition

431 including the material from the UZV. The calibrated age of the lower LSA overlaps with that of

432 Sioma M and Chavuma and provides further evidence of a Late Glacial Mode 5 in northwestern

433 Zambia. The calibrated Mid-Holocene assemblage from Kamusongolwa also overlaps with Kandanda

434 and Donke Pit.

435 A combination of microlithic and macrolithic technology characterises the LSA on the margins of the

436 Congo basin to the north. , and Phillipson (1975a) sees inFor the Chavuma/Cholwezi

437 transitionalCholwezi transitional Mode 3- Mode 5 sequence, Phillipson (1975a) proposed typological

438 links with the Tshitolian Industry which appears to span the Late Glacial to Mid-Holocene

439 (Cornelissen 2013, but see Taylor, 2016). The Tshitolian, however, is not well constrained

440 chronologically and comparisons with Zambian Mode 3 or Mode 5 assemblages are currently

441 difficult to sustain at present.

442 There has been very little systematic archaeological research More broadly, within the wider

443 Kalahari basin, with the few reliable MSA ages come from Toteng near Lake Ngami at 52 ± 7 ka

444 (Brook et al., 2008); # Gi pan, western Botswana, at 77 ± 11 ka (Brooks et al., 1990); and at Tsodilo

445 between 54 ± 10 ka (Ivester et al., 20110) and 94 ± 9 ka (Feathers et al., 1997; see also Staurset and

446 Coulson (2014) and Robbins et al. (2016) for considerations of chronology), all in northern Botswana.

447 There has been very little systematic Kalahari archaeological research beyond these isolated sites

448 (Robbins et al., 2016; Burrough, 2016 and references therein). The earliest microlithic LSA

449 technology ages are from the Tsodilo Hills (~300 km to the SW of the UZV) with an increase in small

450 retouched tools between c.36-30 ka (Ivester et al., 2010; Feathers, 1997; Robbins et al., 2000)

451 following a ‘large blade’ transitional MSA/LSA phase from 55 ± 4.7 ka to 37 ± 1.3 ka (Brooks et al.,

452 1990; Feathers, 1997) (Figure 9a). Thereafter the pattern of technological change in this northern

453 belt of southern Africa differs slightly to that south of the Kalahari. In the study region, bladelet

454 based microlithic Mode 5 industries continue well into the Pleistocene/Holocene transition

455 (Mitchell, 2002 ). To the south of the Kalahari basin, the Later Stone Age presents a more regionally

456 variable technological record from c.20-12 ka of microlithic (Robberg Industry) then an early

457 Holocene c. 12-8 ka macrolithic (Oakhurst Complex) and microlithic (Wilton Industry) between c.8 -4

458 ka with macrolithic technologies post-4 ka (Vogelsang et al., 2010, Sealy, 2016).

459 As a generalisation, the LSA in the region of the UZV is still too poorly described and dated to make

460 firms attributions to better known industries to the south and north. Systematic research is needed

461 along the Upper Zambezi Valley to resolve lingering typological and chronological issues.

462 4.1 Palaeoenvironmental change and the regional Mode 3-Mode 5 Transition

463 Previous archaeological studies, particularly from inland cave sites have revealed marked changes in

464 the content and periodicity of occupation during the late Pleistocene, with gaps in the record

465 tentatively related to records of palaeoenvironmental change (Barham, 2001). One theory is that

466 fluvial systems such as the Zambezi may have offered refugia during regionally dry conditions in the

467 Pleistocene (Barham, 2001; Avery, 2003). We hoped to contribute to testing these ideas with the

468 new data from this study. However, the spatial resolution of palaeoenvironmental records required

469 to test such hypotheses is still too low to do so. The emergence, in the last decade, of increasingly

Commented [2]: NOTE- should Siggie’s more recent stuff from

Tsodilo and Robbin’s repost be cited here? It seems an omission.

Ive added ina n appropriate way

Commented [3]: Id remove this sentence- the para works without

it and it's a bit odd esp in the conclusion about what we wanted to

do. Have modified next sentnec so that the theme remains

considered but ina more usual way

470 Bbettermore robust records of hydrological and palaeo-environmental change (Figure 9a) potentially

471 provides a basis for testing this theory. However, this is Currently we possess only a discontinuous

472 picture of southern-central African palaeoclimate change are somewhat countered by overwhelming

473 evidence that wetting and drying was not spatially homogenous within southern Africa through the

474 late Quaternary (e.g. Figure 109b). These so that these new records cannot therefore be spatially

475 extrapolated without care. The idea of homogenous ‘dry periods’ that extended across the continent

476 (e.g. during the LGM) are increasingly rejected (c.f. Thomas et al., 2012) in favour of more nuanced

477 models of tropical climate response (Singarayer and Burrough, 2015). For example, it seems likely

478 that the LGM in both eastern and central southern Africa were, on the whole, wetter in comparison

479 to regions to the southeast and northeast (Figures 9a and 10b). This spatial pattern of

480 climate/environmental conditions however, changes over time. In the context of the UZV and the

481 broader Kalahari basin the temporal and spatial resolution of palaeoclimatic and archaeological

482 evidence is low but both Mode 3 and Mode 5 assemblages appear to span regionally wetter and

483 drier conditions, suggesting the upper Zambezi valley was suitable for occupation during a range of

484 environmental conditions.

485

486 Figure 9: a) Temporal variability of climate/environment as shown by palaeorecords for the southern

487 African Kalahari/Zambezi region showing i) dated archaeological records at Chavuma in relation to ii)

488 insolation variation at 15oN and S (Berger and Loutre, 1991) and iii) dated regional MSA, LSA and

489 Transitional archaeological records in the Kalahari basin. 1) δDwax rainfall record from the Congo

490 basin (Schefuß et al., 2005); 2) δDwax eastern Namib/western Kalahari rainfall record (Collins et al.,

491 2014); 3) Shoreline records from the megalake Makgadikgadi system (Burrough et al., 2007;

492 Burrough and Thomas, 2008; Burrough et al., 2009); 4) Rainfall record inferred from grainsize

493 characteristics in the Tswaign Crater, South Africa (Partridge et al., 1997); 5) Rainfall intensity over

494 the Zambezi Fan δDwax (‰) (Schefuß et al., 2011; Wang et al., 2013); 6) Shoreline records inferring

495 high stands at Lake Chilwa (Thomas et al., 2009); 7) Lake level record from Malawi (Scholz et al.,

496 2007; Cohen et al., 2007); 8)Tanganyika δDwax (‰) (Tierney et al., 2008). Numbers refer to site

497 locations on Figure 9b. Blue bars highlight potentially wetter conditions in the Kalahari basin. b): An

498 example of spatial variability in past climate patterns across the southern African interior. In this

499 case we show model data from the HadCM3 model (modified from Singarayer and Burrough (2015))

500 with annual precipitation anomalies for LGM-PI in mm/day. Overlayed are LGM conditions from

501 regional palaeorecords shown in figure 9a and the MSA and LSA sites plotted in figure 1.

502

503

504 Wetter/drier conditions would, no doubt, have impacted the landscape, /habitat use and perhaps

505 the geographical range of early humans, resulting in resource shortages in some areas and

506 abundance in others. Thise emerging picture of spatial heterogeneity of palaeoclimate change (Fig

507 9b) may go some way to explaining regional patterns of human resource use and changes in lithic

508 technology but more detailed records (both archaeological and palaeoenvironmental) are required

509 before these links can be robustly examined. Theoretical models linking changes in resource

510 distribution and predictability with hunter-gatherer strategies of mobility, settlement patterning,

511 foraging range size and tool design (Ambrose and Lorenz, 1990, McCall, 2007) offer a potentially

512 useful perspective for understanding the regional diversity in the archaeological record of the late

513 Pleistocene and much of the Holocene.

514 In the context of the UZV and the broader Kalahari however the temporal and spatial resolution of

515 palaeoclimatic and archaeological evidence remains too low at present to make strong links

516 between the patterns of environmental variability and observations from the archaeological record.

517 It seems likely though that regional shifts to wet/dry conditions would have impacted the

518 landscape/habitat use and perhaps the geographical range of early humans, resulting in resource

519 shortages in some areas and abundance in others. We can expect to see habitat variability

520 expressed in the archaeological record in terms of site distribution, density, lithic raw material

521 sourcing and in tool design. Presently the Mode 3-Mode 5 transition in the UZV is imperfectly

522 understood but may be a reflection of adaptation to changing environments across the last glacial

523 cycle. That observed strategies of mobility and raw material exchange differ regionally in the

524 archaeological record is not surprising in the context of how different these environmental changes

525 may have been across regional scales (e.g. Figure 10).

526 5. Conclusion

527 Single grain OSL dates from Chavuma on the Upper Zambezi Valley suggest the MSA/Mode 3

528 archaeological record is much older than initially hypothesised (Phillipson, 1978) and likely dates to

529 66.5 ± 9.9 - 75.7 ± 16.6 ka. The Mode 3 to Mode 5 transition at this site occurred within the period

530 between 66.5 ± 9.9 ka and 16.7 ± 2.6 ka. Further south at Sioma M, sterile Kalahari sands deposited

531 on ferricrete overlying Mode 3 tools date to 16.5 ± 2.5 ka, placing a minimum age on the underlying

532 archaeological record. Donke pit was the only remaining section at Kandanda not destroyed by road

533 quarrying though there is little existing information with regard to the archaeological units except

534 that it is a ‘compressed’ version of the Kandanda site.

535 Barham (2000) suggested that the availability of surface water was linked to human use of the

536 archaeological sites at Mumbwa Caves was linked to the availability of surface water inwater in the

537 vacinity. In the UZV there is similar chronological discontinuity between occupation phases

538 although, at least at Chavuma, part of the record may be missing due to periods of fluvial erosion.

539 What does seem clear from these re-dated sites is that the ‘Mode 3’ (MSA) assemblages described

540 by Phillipson (1975a, b) in the Upper Zambezi Valley significantly pre-date the LGM and are

541 chronologically consistent with the handful of sites dated within the wider Kalahari basin in

542 Botswana (Figure 9).

543 At all of these sites, the archaeological assemblages appear to span a broad range of

544 climate/environmental conditions when the available records of palaeohydrological change are

545 examined, the archaeological assemblages appear to span a broad range of climate/environmental

546 conditions. We can expect to see habitat variability expressed in the archaeological record in terms

547 of site distribution, density, lithic raw material sourcing and in tool design. However, there are still

548 too few high-resolution palaeoenvironmental and archaeological records from the interior of

549 southern Africa to draw robust relationships between long-term regional climate change and

550 observations in the archaeological record. What is increasingly clear however, is that there is strong

551 spatial variability in patterns of climate change across southern Africa and that these regional

552 differences would have had an impact on human use of the landscape and resources that left

553 regional signatures in the archaeological record.. Rather than extrapolation to distant palaeoclimate

554 records, theoretical models linking changes in regional resource distribution and predictability with

555 hunter-gatherer strategies of mobility, settlement patterning, foraging range size and tool design

556 (Ambrose and Lorenz, 1990, McCall, 2007) offer a potentially more useful perspective for

557 understanding the regional diversity in the archaeological record as the resolution of these records

558 improves.

559

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564 research and, and the Livingstone Museum for their assistance and valued support in Zambia. We

565 thank two anonymous reviewers for their helpful comments.

566

567 Figure and Table Captions

568 Figure 1: Published MSA and LSA archaeological site locations within southern Africa. The upper

569 Zambezi region is marked with a red box. 1) Congo basin; 2) eastern Namib/western Kalahari rainfall

570 record; 3) Megalake Makgadikgadi; 4) Tswaing Crater; 5) Zambezi Fan; 6) Lake Chilwa; 7) Lake

571 Malawi; 8) Lake Tanganyika; Mf = Mufo; Cal3 = Calunda III; Chv = Chavuma; Si = Sioma M; Knd =

572 Kandanda; Kal = Kalambo Falls; Mz = Manzi River; MC = Mumbwa Caves; GS=Gwisho Springs; TR =

573 Twin Rivers; LH = Leopards Hill Cave; Kmb = Kalemba Rock Shelter; Tso = Tsodilo; Gi = #Gi; Tg =

574 Toteng.

575 Figure 2: Regional Digital elevation model of the Upper Zambezi Valley (UZV) showing archaeological

576 site locations (filled black circles) investigated in this study. Major settlements discussed in text are

577 also given as grey squares.

578 Figure 3: a) Grain size distribution for each sizte and b) Separated heavy mineral and quartz fraction

579 radioisotope concentrations from sample ZAM/11/5/5 (question marks indicate measurements

580 below detection limits (<0.1 ppm).

581 Figure 4: Comparative age depth relationships for each site using three age models – The Central

582 Age Model (CAM), the Finite Mixture Model (FMM) and the Weighted Mean (Wgt Mean).

583 Figure 5: a) Plan view of site location at Chavuma Falls; b) sections within the Chavuma dune from 1)

584 Phillipson’s 1968 Excavation showing archaeological levels 1-5 and 2) augered section in 2011

585 showing location of OSL samples (open circles, ages (FMM model) and artefacts retrieved during

586 augering (marked as ‘A’) [we have tied the sections using the position of the basal gravel unit and

587 both sections are drawn on the same scale] note that sections are shown to same scale to allow

588 correlation with the archaeological record]; c) Location of excavation in relation to dune and present

589 day water levels; d) Photograph of the site with Falls in the distance..

590 Figure 6: A) Selected Chavuma Falls Dune artefacts as illustrated by L Phillipson and used with

591 permission of the British Institute in Eastern Africa and Azania. Artefact lettering is as appears in

592 Azania Volume X, Figuress. 16-18. Level 1: backed blades, sandstone (a,b); Level 2: crescents

593 (j=mudstone,k=sandstone) Level 3: high backed ovate radial core (j=mudstone); Level 5: parallel-side

594 bifaces (d,e=mudstone). B) Selected Kadanda artefacts as illustrated by L Phillipson and used with

595 permission of the British Institute in Eastern Africa and Azania. Artefact lettering is as appears in

596 Azania Volume XI, Figures. 5-6. Level 3: crescents (a,b=sandstone; c=chalcedony); single-platform

597 core (p, chalcedony); opposed platform core (q, chalcedony); Level 4: utilized blades (aa-dd,

598 chalcedony). C) Selected Sioma ‘M’ artefacts, all chalcedony, as illustrated by L Phillipson and used

599 with permission of the British Institute in Eastern Africa and Azania. Artefact lettering is as appears

600 in Azania Volume XII, Figure 2; unifacial flake points (c,d); bifacial flake point (h); flake cleavers (l, m)

601 Figure 7: a) Location of Sioma M site with b) OSL dated (open circles) section within Kalahari sand

602 overlying artefact horizon and ferricrete and c) photograph of site location..

603 Figure 8: a) Location of Donke Gravel Pit Trench I in relation to the 1968 excavation at Kandanda

604 (now destroyed by a road quarry); b) Pit section and dated OSL sample locations from Donke gravel

605 pit; c) Radiocarbon dated section from Kandanda Trench I withI with archaeological levels labelled

606 1-4 (from Phillipson, 1976); c) Photograph of site location in 2011 looking SE with Kandanda road

607 quarry pit in background.

608 Figure 9: a) ClimateTemporal variability of climate/environment as shown by palaeo records for the

609 southern African Kalahari Zambezi region showing i) dated archaeological records at Chavuma in

610 relation to ii) insolation variation at 15oN and S (Berger and Loutre, 1991) and iii) dated regional

611 MSA, LSA and Transitional archaeological records in the Kalahari basin. 1) δDwax rainfall record

612 from the Congo basin (Schefuß et al., 2005); 2) δDwax eastern Namib/western Kalahari rainfall

613 record (Collins et al., 2014); 3) Shoreline records from the megalake Makgadikgadi system (Burrough

614 et al., 2007; Burrough and Thomas, 2008; Burrough et al., 2009); 4) Rainfall record inferred from

615 grainsize characteristics in the Tswaingn Crater, South Africa (Partridge et al., 1997); 5) Rainfall

616 intensity over the Zambezi Fan δDwax (‰) (Schefuß et al., 2011; Wang et al., 2013); 6) Shoreline

617 records inferring high stands at Lake Chilwa (Thomas et al., 2009); 7) Lake level record from Malawi

618 (Scholz et al., 2007; Cohen et al., 2007); 8)Tanganyika δDwax (‰) (Tierney et al., 2008). Numbers

619 refer to site locations on Figure 19b. Blue bars highlight potentially wetter conditions in the Kalahari

620 basin.

621 b)Figure 10: An example of spatial variability in past climate patterns across the southern African

622 interior. In this case we show model data from the HadCM3 model (mModified from Singarayer and

623 Burrough (2015).) with Mean Aannual Pprecipitation anomalies for LGM-PI in mm/day for available

624 PMIP3/CMIP5 climate models. Overlayed are with overlay of LGM conditions from regional

625 palaeorecords discussed in the textshown in figure 9a and the MSA and LSA sites plotted in figure 1.

626 See Ffigure 1 & 9 for key to sites. Modified from Singarayer and Burrough (2015).

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

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

629 Table 3: Summary assemblage characteristics for each level excavated at Chavuma and the

630 associated classification. Adapted from Phillipson (1975). The ‘Mode’ attribution is based on Clarke

631 1969 where Mode 3 is equated to the Middle Stone Age based on evidence of core preparation and

632 Mode 5 to Later Stone Age based on microlithic core and retouched tool types.

633 Table 4: Assemblage characteristics and radiocarbon dates from levels 1-4 of the Kandanda

634 excavation (adapted from Phillipson, 1975). \*see Ffigure 8

635

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