New ages from Boomplaas Cave, South Africa, provide increased resolution on late/terminal Pleistocene human behavioural variability

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ABSTRACT Boomplaas Cave, South Africa, contains a rich archaeological record, with evidence of human occupation from approximately 66,000 years ago until the protohistoric period. Notwithstanding a long history of research at the site, its existing chronology can benefit from revision. Many of the site's members are currently delimited by only a single conventional radiocarbon date and some of the existing dates were measured on materials now known to be unsuitable for radiocarbon dating. Here we present the results of an ongoing effort to redate key late/terminal Pleistocene sequences in southern Africa. This paper presents a Bayesian-modelled radiocarbon chronology for the late/terminal Pleistocene horizons at Boomplaas. Our model incorporates previously published radiocarbon dates as well as new accelerator mass spectrometry ages. We also present archaeological evidence to examine in greater detail than was previously possible the nature of occupation patterning across the late/terminal Pleistocene and to assess technological change across two of the site's Last Glacial Maximum (LGM) members. The new dates and archaeological data confirm that the site was occupied in a series of low intensity events in the early LGM and immediately thereafter. The site was occupied intensively in the terminal Pleistocene in line with major changes in palaeoenvironments and sea-level fluctuations. The lithic data show the use of variable technological strategies in contexts of shifting mobility and site occupation patterns. Our discussion informs upon hunter-gatherer behavioural variability that did not, and should not be expected to, reflect the strategies adopted and adapted by a handful of well-known arid-zone hunter-gatherers in the twentieth-century Kalahari.

RESUMÉ La caverne de Boomplaas (Afrique du Sud) contient un riche bilan archéologique, avec des preuves de l'occupation humaine depuis environ 66,000 ans jusqu'à la période protohistorique. Malgré une longue histoire de recherche sur le site, sa chronologie peut profiter de révision. Beaucoup de membres du site sont actuellement délimités par une seule date de radiocarbone conventionnelle et certaines des dates existantes ont été mesurées sur des matériaux actuellement connus pour être inadéquats pour la datation par radiocarbone. Nous présentons ici les résultats d'un effort continuant pour redéfinir les principales séquences tardives/terminales du Pléistocène en Afrique australe. Cet article présente une chronologie du radiocarbone modélisée bayésienne pour les horizons du Pléistocène tardif/terminal à Boomplaas. Notre modèle intègre les dates de radiocarbone précédemment publiées et aussi les nouveaux âges de spectrométrie de masse d'accélérateur. Nous présentons également des preuves archéologiques pour examiner en plus grand détail la nature des modèles d'occupation à travers le Pléistocène tardif/terminal et pour évaluer les changements technologiques dans deux des membres du Dernier Glaciaire Supérieur (LGM) du site. Les nouvelles dates et les données archéologiques confirment que le site a été occupé dans une série d'événements de faible intensité au début du LGM et immédiatement après. Le site a été occupé intensivement dans le terminal du Pléistocène en ligne avec les changements majeurs dans les paléoenvironnements et les fluctuations du niveau de la mer. Les données lithiques montrent l'utilisation stratégique des stratégies technologiques dans des contextes de déplacement de la mobilité et des modèles d'occupation du site. Notre discussion informe aussi de la variabilité du comportement des chasseurs-cueilleurs qui ne conforme pas (et qu'on ne pas attend de conformer) avec les stratégies adoptées et adaptées par une poignée de chasseurs-cueilleurs bien connus au Kalahari du vingtième siècle.

Introduction

Many archaeologists have used the southern African ethnographic record to develop behavioural models with which to augment our understandings of the deeper past. Yet it is increasingly apparent that not all archaeological instances of hunter-gatherers fit neatly within the parameters described by successive generations of anthropological fieldwork in the Kalahari (Mitchell 2017; Pargeter *et al.* 2016). Clear instances exist (e.g. Sealy 2006) of behavioural variability that exceeds the range reported by Marshall (1976), Lee (1979), Tanaka (1980), Silberbauer (1981) and others for the two groups most commonly cited by archaeologists working there, namely the !Kung (Ju/'hoãnsi) and the G/wi. Such variation almost certainly also transcends that noted for the many other groups, some only poorly described ethnographically, who survived into the twentieth century in Namibia, Botswana and the extreme northwest of South Africa (Barnard 1992), but remain virtually unexplored by the southern African archaeological community.

Patterning in climate and environment that influences the availability of key resources (plants, animals, water) is self-evidently among the key factors that influence human behavioural variability (Binford 2001; Kelly 2013). Such variation is likely to have been all the greater when we recall that ethnographically and historically sampled conditions by no means encompass all the environmental variability to which past

hunter-gatherer populations were exposed. In southern Africa, for instance, depressions of mean annual temperature by at least 6˚C on multiple occasions during the late/terminal Pleistocene (cf. Holmgren *et al.* 2008) are likely to have driven the Effective Temperature, i.e. the difference between the average temperatures of the coldest and warmest months of the year, of the Lesotho highlands below the threshold at which Binford (2001) predicts hunter-gatherers would need to intensify exploitation of aquatic resources such as fish to compensate for a scarcity of plant foods. That they appear to have done so, and did so again during the late Holocene Neoglacial, constitutes a behavioural expression difficult, if not impossible, to match in Kalahari ethnography (Stewart and Mitchell in press).

These limitations of recent history necessitate the development of high-precision archaeological records capable of capturing the diversity of human behavioural and adaptive responses in deeper time. In southern Africa, this is particularly pressing for Marine Isotope Stages (MIS) 3 and 2 (*c.* 59–12 kya; referred to here as the late/terminal Pleistocene), a period of climatic volatility, landscape reorganisation and episodically intense cooling as the subcontinent responded to abrupt Northern Hemisphere forcing (Chevalier and Chase 2015, 2016) and post-glacial sea-level changes (Fisher *et al.* 2010). Such conditions necessarily presented strong selective pressures for cultural adjustments. Arguably the clearest archaeological expression of such readjustments is the switch from Middle Stone Age (MSA) flaking systems to miniaturised toolkits typical of many Later Stone Age (LSA) industries, a gross technological shift almost certainly underpinned by finer-scale demographic and socioeconomic changes. Confoundingly, this period is often among the most poorly represented of all occupational phases within this region over the last 120,000 years, with small samples of archaeological material recovered from a relatively limited number of sites (Mitchell 2008; Mackay *et al.* 2014).

Most of the key rock shelters with sequences documenting occupation in the late/terminal Pleistocene were excavated between 20 and 50 years ago. The radiocarbon dates available for them were thus, without exception, obtained using conventional methods, not Accelerator Mass Spectrometry (AMS). Now-outdated pretreatment protocols were employed that required large samples with large associated errors and probably did not remove all the contaminants present, particularly for samples older than 25–30,000 cal. BP (Wood *et al.* 2012). Additionally, some of the materials dated would no longer be considered suitable (e.g. the 'stalagmite' used for two of the dates originally obtained at Boomplaas; J. Deacon 1984), while in many cases key strata were not dated at all. As a result, the chronologies produced are no longer up to the tasks that modern research demands of them, i.e. revealing finely resolved patterns of cultural change and articulating them with comparably resolved climatic and environmental variation. Furthermore, the restricted number of late/terminal Pleistocene archives renders our understanding of patterns in their dating acutely sensitive to the effects of imprecision. Together with the unsuitability of ethnographic parallels, this severely impedes a clear understanding of the causes, tempo and magnitude of late/terminal Pleistocene human behavioural variability.

We have therefore begun a large-scale project to redate many of the key archaeological sequences from MIS 3 and 2 in southern Africa using state-of-the-art AMS radiocarbon techniques. In addition to clarifying the chronologies of individual sequences, our objectives are to: 1) re-evaluate the chronology of the MSA/LSA transition in southern

Africa; 2) pin down the subsequent emergence and eventual replacement of miniaturised technologies in MIS 2; 3) explore the spatial patterning of leads, lags and areas of non-uptake in these patterns of cultural/technological change; and 4) simultaneously shed new light on the distribution of human populations during periods of intensive climatic and environmental change. Our aim is to allow southern Africa to contribute more fully to global understandings of technological change (especially stone tool miniaturisation) and palaeodemography by establishing a sound chronological basis for comparisons elsewhere in the southern hemisphere (Sahul), the Americas and beyond (Eurasia).

To do this, we have already redated the MIS 2 sequences from Nelson Bay Cave in the Forest Biome of the southern Cape and Byneskranskop 1 in the Fynbos Biome of the southwestern Cape of South Africa (Loftus *et al.* 2016), as well as that from Sehonghong in highland Lesotho (Pargeter *et al.* 2017). We are also engaged in re-excavating other relevant deposits from the Fynbos and Grassland Biomes (Stewart *et al.* 2012; Mackay 2016), in reanalysing the MIS 2 assemblages from these sites and Boomplaas, the subject of this paper (Pargeter 2017) and in undertaking excavations at newly discovered sites in previously under-explored regions of the sub-continent (Mackay *et al.* 2015; Dewar and Stewart 2016, 2017). Additionally, we are currently using AMS ^{14}C to redate the MIS 2 and MIS 3 sequences at four further sites — Rose Cottage Cave, Cave James, Jubilee Shelter and Melkhoutboom, all in South Africa. Similar work has recently been reported for three other rock shelters: Elands Bay Cave (Porraz *et al.* 2016) and Bushman Rock Shelter (Porraz *et al.* 2015) in South Africa and Apollo 11 Cave in Namibia (Vogelsang *et al.* 2010). Along with results from Sibudu Cave (Wadley 2013) and elsewhere, we feel confident that the chronology of cultural and palaeoenvironmental change in the latter half of MIS 3 and throughout MIS 2 will soon be placed on a more robust footing.

Boomplaas is a key site to include in such work. Excavated by the late Hilary Deacon between 1974 and 1979, it preserves a long occupational sequence extending from the Howiesons Poort at its base to the residues left just below the modern surface by sheep-keeping herders in the mid-first millennium AD (H. Deacon and Brooker 1976; H. Deacon *et al.* 1978; H. Deacon 1979, 1995). Although the MSA assemblages and those reported as coming from the "Early Later Stone Age" have previously only received limited publication (Volman 1981; Mitchell 1988), the overlying assemblages that date to ≤20 kya formed a core part of Janette Deacon's (1984) detailed analysis of LSA technological patterning over time that has become a cornerstone of LSA research. Rare examples of painted stones and mastic-hafted stone tools were also found (H. Deacon *et al.* 1976; H. Deacon and Deacon 1980) and the site was the focus of the first ever microwear analysis of stone tools conducted in southern Africa (Binneman 1982, 1984). In addition, Hilary Deacon's research pioneered the multi-disciplinary study within the sub-continent of palaeoenvironmental archives from rock shelter contexts: analyses of archaeological charcoals, pollen samples, micromammals, and sediments all had some of their first southern African outings here (Webley 1978; Avery 1982; H. Deacon *et al.* 1983, 1984; Scholtz 1986), complemented by Richard Klein's (1978) study of the associated macrofaunal assemblages and integrated with off-site stable isotope records from speleothems in the nearby Cango Caves (Talma and Vogel 1992).

The original dating of the MIS 2 and 3 levels from Boomplaas employed three techniques (radiocarbon, uranium series and amino acid racemisation) and a total of 31

determinations (two of which produced infinite results) that nevertheless left several stratigraphic members and units identified between 12 and ≥40 kya undated except by interpolation. Our redating of the site's late/terminal Pleistocene sequence significantly improves upon this situation. We focus on two key aspects of the Boomplaas sequence for which our newly derived AMS ^{14}C ages provide increased clarity: evidence for short-term technological change and patterns of site occupation intensity. These potentially inter-related behavioural variables depend upon high-resolution chronological data and our project therefore provides unique and updated insights into their structure within the Boomplaas sequence.

Background to Boomplaas

Boomplaas is a limestone cave with a floor area of 225 m^2 in South Africa's Western Cape Province about 80 km inland from the Indian Ocean coastline (H. Deacon 1979) (Figures 1 and 2). The site overlooks the Cango Valley and the Swartberg Mountain Range between the modern Fynbos/Karoo Biomes at 700 m above sea level (Figure 1). The Swartberg is the innermost range of the Cape Fold Mountain Belt bordered on the northern side by the Great Karoo and the south by the Little Karoo, both of which are arid to semi-arid regions. Drought is a perennial factor in the Karoo region. Despite the general aridity in surrounding areas, the Grobbelaars River drains the Cango Valley and provides a range of permanent freshwater sources. That the Cango Valley is better watered than the plains of the Little Karoo and the Great Karoo to the south and north, respectively, likely attracted humans to this area.

The Cango Valley's flora comprises primarily fynbos and renosterveld vegetation types (Moffett and Deacon 1977). Fynbos is found in nutrient-poor soils while renosterveld occurs in more nutrient-rich soils (Carr *et al.* 2016). Plant species with edible underground storage organs, such as bulbs, corms, rhizomes and tubers, are abundant in both vegetation types. Historically, the Cango Valley's principal larger mammals were rock hyrax (*Procavia capensis*), baboon (*Papio ursinus*), grysbok (*Raphicerus melanotis*), steenbok (*Raphicerus campestris*), klipspringer (*Oreotragus oreotragus*), grey rhebuck (*Pelea capreolus*), mountain reedbuck (*Redunca fulvorufula*) and common duiker (*Sylvicapra grimmia*) (Klein 1983). Larger grazing mammals, including eland (*Taurotragus oryx*), Cape buffalo (*Syncerus caffer*), Cape mountain zebra (*Equus zebra zebra*) and red hartebeest (*Alcelaphus buselaphus*), occurred less frequently in historical times (Klein 1983). Larger mammals are notably absent today because of the limited availability of grasslands.

The region around Boomplaas currently receives an annual average of 400 mm of rainfall across both the summer and winter months. Mean summer temperatures range between a maximum of 23˚C and a minimum of 12˚C, while corresponding winter values are 19˚C and 6˚C respectively (weather data from the Oudtshoorn weather station 1992–2014, located approximately 40 km from Boomplaas) (Figure 1). The site's Effective Temperature is 14.4 (calculated using Bailey (1960) and weather data from the Oudtshoorn weather station). High evapotranspiration rates, close proximity to the semi-arid Karoo and ~80% C$_4$ grassland coverage make the Cango Valley especially sensitive to climate change.

As we have noted, the Boomplaas sequence contains evidence of human occupation from >66 ka until the protohistoric period (H. Deacon 1979). The site was excavated as

part of a project to test the effect of palaeoenvironmental change on human behavioural evolution in the southern Cape (H. Deacon *et al.* 1984). These excavations initially uncovered an area of 20 m^2, but were narrowed down to one of 6 m^2 at a depth of 2 m below the surface (Figure 2). The Boomplaas sequence was divided into a hierarchical stratigraphy of members, units, and subunits (H. Deacon 1979). Human occupation deposits are predominantly made up of thin discrete hearths, humic and ash features combined into members that are approximately 0.05 to 0.2 m thick.

Boomplaas' late/terminal Pleistocene chronology, stratigraphy and occupation patterns

Prior to our project, the late/terminal Pleistocene levels (members CL to OCH inclusive) at Boomplaas were dated by 18 conventional ^{14}C ages, five AMS ^{14}C determinations, six uranium series dates on dripstone and two samples of ostrich eggshell dated by amino acid racemisation (AAR) (Table 1). Below, we outline the available information relevant to the excavation members of interest to this project (Figure 2). We proceed in reverse chronological order, beginning with the stratigraphically uppermost member.

Member CL

This is a thick (0.25 m) carbonised loam made up of hearths and burnt organic material, which H. Deacon (1979: 251) referred to as 'a relatively thick occupation deposit without observable discontinuities.' Member CL is further divided into sub-units 1–4 with its base corresponding to sub-unit CL 4 (J. Deacon 1982: 100). J. Deacon (1984) considered member CL's sub-unit BRL 7 as the boundary between CL and member BRL above it. CL's faunal assemblage shows nearly exclusive anthropogenic inputs, marking this as the most intensive series of late/terminal Pleistocene occupations at the site (Faith 2013a). Six radiocarbon dates (five conventional, one AMS) and one uranium series age determination place the occupations represented by CL after the Last Glacial Maximum (LGM) *c.* 17,800–11,900 cal. BP (Table 1). Member CL's lithic assemblage, which has been defined as belonging to the Robberg technocomplex (J. Deacon 1984), includes small freehand and bipolar bladelet cores (J. Deacon 1982; Pargeter 2017). The raw materials used are predominantly vein and crystal quartz, with locally available chert replacing silcrete as the principal silicate rock type. Micromammalian remains, a reduction in local stalagmite formation and several major mammalian extinctions indicate significant palaeoenvironmental change and aridity across this period (Avery 1982; H. Deacon 1983; Talma and Vogel 1992; Faith 2011, 2013a). Thackeray and Fitchett's (2016) seasonality index, calculated using the relative abundance of rodent taxa in the Boomplaas members, shows a trend towards greater seasonality and summer rainfall after *c.* 18,000 cal. BP, a conclusion supported by stable isotope analyses of grazing herbivore enamel, which indicate the presence of summer-rainfall adapted C$_4$ grasses in the vicinity (Sealy *et al.* 2016).

Member GWA/HCA

This member comprises a series of highly leached ashy lenses. One conventional ^{14}C date and a second AMS date on ostrich eggshell place its occupation at the height of the LGM between 22,000 and 20,000 cal. BP (Table 1). J. Deacon (1984) classified the lithic assemblage as 'Robberg' because of its high frequency of freehand bladelet

production. The member shows a marked raw material shift towards non-local silcrete, which accounts for 34% of all the artefacts present (J. Deacon 1984). Sealy and colleagues (2016) record C_3 grassland signals in bovine enamel from this member, which suggests increased winter rainfall at the time that it accumulated. Scholtz's (1986) charcoal data suggest cold and moderately humid conditions in member GWA/HCA. The LGM members may have experienced the highest levels of effective moisture and some of the most productive environments across the Boomplaas sequence based on Faith's (2013a) assessment of its ungulate community richness. However, temperature estimates from microfaunal species abundance and diversity suggest a reduction of 6˚C below current average values (Thackeray 1990).

Member LP

This is primarily a 0.25 m-thick natural accumulation composed of dark brown loam with abundant weathered angular roof clasts associated with cold LGM conditions (Webley 1978; H. Deacon *et al.* 1984). Member LP is, from top to bottom, divided into the following sub-units: LP YOA, LP GGU, LP GGC and LP M (J. Deacon 1982: 100). Its lithic assemblage, which is attributed to an early phase of the LSA, is small and derives from a brief, approximately 20 mm-thick occupation horizon associated with a substantial increase in raw material diversity and ostrich eggshell fragments (H. Deacon 1983). Single platform irregular cores are common as are bipolar cores and small, narrow, thin unretouched flakes made predominantly on vein and crystal quartz (J. Deacon 1982; Pargeter 2017). Two AMS dates on ostrich eggshell place the occupation of LP within the LGM *c.* 25,900–25,100 cal. BP (Table 1). Stalagmite formation at the nearby Cango Cave and within the Boomplaas sequence peaks around this time (H. Deacon 1983). Talma and Vogel (1992) argue that stalagmite formation depends on moisture availability and that the Cango Valley was thus moister in the LGM than the terminal Pleistocene and Holocene. Faith (2013a) shows relatively high ungulate diversity values for member LP, which he also argues indicate increased LGM humidity.

Member LPC

This is a brown organic loam with dark carbonised inclusions associated with charcoal and ash from multiple occupations associated with LGM conditions. Member LPC is divided in descending stratigraphic order into sub-units LPC 1-2, LPC YS, and LPC 3 (J. Deacon 1982: 100). Ascribed to the earliest LSA at the site, member LPC shows signs of miniaturisation in the form of small blade and flake production on vein quartz with only rare examples of retouched artefacts (J. Deacon 1982; Pargeter 2017). Three conventional radiocarbon determinations, one on stalagmite and two on unidentified charcoal, suggest a date for its occupation of between *c.* 26,100 and 24,300 cal. BP (Table 1). The frequencies of Saunder's vlei rat (*Otomys saundersii*), a cool open-grassland adapted species, are highest in member LPC, indicating a relatively cool and open vegetation regime (Avery 1982). Grazer diversity indices are also high, as are C_3 isotope values in the Cango Cave speleothem, both of which suggest open and humid grassland environments (Talma and Vogel 1992; Faith 2013a).

Member YOL

This deposit accumulated in a depression banked up against a stalagmite, which H. Deacon (1983) describes as a non-occupation deposit occurring with the onset of the Last Glacial Maximum (LGM). H. Deacon and colleagues (1984) assigned the predominantly vein quartz assemblage from member YOL to the MSA/LSA 'transition', attributing this changeover to a break in the site's occupation. Toolmakers predominantly used vein quartz to produce a small flake-based assemblage with an emphasis on bipolar reduction (Pargeter 2017). No dates were previously available for this member. Temperature estimates derived from the presence and abundance of mammalian microfaunal species suggest a maximum reduction of mean annual temperatures in member YOL and member BP below it (Thackeray 1990). Taphonomic data suggest that this was when the anthropogenic contribution to the formation of the site's large mammal assemblage was at its lowest (Faith 2013a).

Member BP

This is a complex of occupation units including ash features and carbonised inclusions interspersed by non-occupation sediments with abundant small mammal remains. H. Deacon (1979) refers to member BP as a late MSA occupation. Its assemblage is characterised by larger flakes and blades than those in members LPC and LP, rarer bladelet and bipolar reduction, extensive retouch and centripetal core reduction on vein quartz and quartzite (Pargeter 2017). Six radiocarbon dates (five conventional, one AMS) provide an age range of *c.* 40–30,000 cal. BP and link the member's occupation to an interglacial phase. Two of these ages are problematic because of the materials on which they were run, dripstone (Pta-2268; 26,670 ± 680 BP) and charcoal dust from a soil sample (UW-304; 32,400 ± 700 BP) (Table 1). Blue wildebeest (*Connochaetes* cf. *taurinus*), a species preferring nutrient-rich and moist C_4 grasses, is found only in member BP. This species' presence corroborates the simultaneous increase in C_4 grasses recorded in the Cango Cave speleothem and in grazing herbivores' enamel samples from this member (Talma and Vogel 1992; Sealy *et al.* 2016).

Member OLP

This represents a thin discrete occupation event in a context otherwise dominated by high microfaunal densities (H. Deacon 1995). Vogel (2001) refers to a finite charcoal date of 37,400 ± 1370 BP (Pta-1811) for OLP1 near the top of the member, a dripstone radiocarbon date of 31,600 ± 550 BP (Pta-2302) and a uranium series date of 35,200 ± 2600 BP (UW-366) within the same horizon. A further conventional radiocarbon date (UW-305) run on a sample of 'charcoal dust and soil' returned an infinite age of >40,000 BP (Fairhall *et al.* (1976) (Table 1). H. Deacon (1983) describes the assemblage from member OLP as 'MSA', with large flake and blade production on quartz and quartzite and a virtual absence of chalcedony and silcrete. High frequencies of forest shrew remains (*Myosorex varius*, an indicator of moist habitats) and *Olea*/*Dodonea* woodland charcoals suggest a relatively dense and humid environment at this time (Avery 1982; H. Deacon *et al.* 1983).

Member BOL

H. Deacon (1995: 125) refers to the presence of only 'a few artefacts' perhaps linked to the 'interstadial at the top of BOL' and Fairhall *et al.* (1976) give a date of >40 kya (UW-308) from charcoal 'dust' in the member's soil matrix. Deacon and Brooker

(1976) identify six successive units within member BOL, with the >40 kya date coming from the topmost one of these. They refer to the lithic assemblage from BOL as an undefined 'Middle Stone Age' blade-based industry. Stalagmite fragments and ungulate diversity values are low in member BOL, suggesting decreased humidity (H. Deacon 1983; Faith 2013a). Relatively high frequencies of Namaqua rock rat (*Aethomys namaquensis,* an indicator of sparse, semi-arid shrubland) corroborate this pattern (Avery 1982).

Member OCH

Member OCH captures an approximately 1.2 m-thick deposit composed of six successive sub-units (H. Deacon 1983). H. Deacon (1995) describes the lithic assemblage as belonging to the Howiesons Poort industry based on its small blade production, high silcrete frequencies and the presence of a single large backed tool. Five dates (four uranium series and one AAR) provide an age range of *c.* 49–79,000 cal. BP. Collectively these dates indicate a substantial hiatus between member OCH and the MSA members above it. The OCH ages are problematic because of their large standard deviations and the fact that four of them were run on dripstone (U-365, U-414, U-417, Pta-2464) (Table 1). Faith (2013a) identifies carnivores and raptors as member OCH faunal assemblage's primary accumulators. This, together with a low overall artefact density suggests that human occupation was short and ephemeral. Relatively high rodent and insect species diversity values indicate a warmer and more productive environment, becoming gradually less productive towards member BOL (Avery 1982). Depleted $\delta^{13}C$ values in the OCH bovine enamel indicate a C_3 grassland environment (Sealy *et al*. 2016). Below OCH, the lowest member of the Boomplaas sequence — LOH — described as a sandy loam with occupation units is of Last Interglacial age (H. Deacon 1995).

To sum up, the dates available for the late/terminal Pleistocene sequence at Boomplaas before our project show a series of punctuated occupation events between >40,000 and 11,900 cal. BP. Four significant breaks in the sequence occur between *c.* 49,000 and 44,000, between *c.* 30,000 and 26,000 cal. BP, between 26,000 and 22,000 cal. BP and between 22,000 and 18,000 cal. BP. Member YOL remained undated, though along with members LPC and LP (*c.* >23,000 cal. BP) it captures the MSA to LSA transition and the earliest LSA. Thereafter, members GWA/HCA and CL contain what J. Deacon (1982) has argued represents the Robberg bladelet-based techno-complex (*c.* 22,000 cal. BP). Palaeoenvironmental indicators suggest that intensive occupations in member CL occurred in contexts of post-glacial warming and increased aridity. Cooler and generally more humid conditions prevailed across much of the sequence below member CL.

Methods

Radiocarbon dating

We have acquired twelve new AMS radiocarbon dates on charcoal fragments from the late and terminal Pleistocene levels at Boomplaas. The charcoal samples used were selected from the archaeological materials stored at the Iziko South African Museum in Cape Town. Intact, twig-like fragments were preferentially selected to limit any possible "old wood" effect, although this is not expected to be a concern for this region

over these timescales. No consolidants or chemicals had been used on the charcoal for purposes of conservation.

Three charcoal pretreatment methods were used: the acid-base-acid (ABA) method (Brock *et al.* 2010), the acid-base-wet oxidation-stepped combustion (ABOx-SC) method (Brock *et al.* 2010) and the new AOx-SC method (see the pre-treatment code for each sample in Table 2). The latter two methods are used for samples anticipated to be older than *c.* 25 ka. The ABOx-SC protocol is more effective at removing contaminating carbon, particularly humic acids from charcoals, and generally produces older dates than other pretreatment methods (Bird *et al.* 1999; Wood *et al.* 2012). This is particularly important for older samples where even small amounts of younger contaminating carbon will greatly affect the apparent age of the sample. AOx-SC is a modified ABOx-SC protocol that omits the NaOH wash step. The new protocol has been developed and tested at Oxford's Radiocarbon Accelerator Unit (ORAU) for dating old and fragile charcoal samples (Douka *et al.* in prep.) Graphitised samples were then dated on the Unit's HVEE AMS system (Bronk Ramsey *et al.* 2004). The greater sensitivity of AMS systems permits the measurement of samples considerably smaller in size than what is required for conventional beta-counting measurements and typically produces more accurate and precise dates.

The new AMS and previously published ^{14}C measurements were calibrated with the OxCal v 4.2 software (Bronk Ramsey 2009a), using the latest SHCal13 calibration curve for the Southern Hemisphere (Hogg *et al.* 2013). The dates were modelled according to Bayesian statistical principles in OxCal, using stratigraphic information from Hilary Deacon's excavations. Outliers were identified according to the indices method (Bronk Ramsey 2009a) and discarded from the models. The chronology was modelled using the OxCal software, in a *Sequence* model, with stratigraphic levels represented as *Phases*, separated by a single or double *Boundary*, and with the age of each level modelled using the *Date* function, which provides a mean age for each phase (Figure 3). Possible hiatuses in the sequence were tested by inserting *Intervals* between the double *Boundaries* in each model. *Intervals* greater than zero confirm a hiatus in the chronology (Bronk Ramsey 2009b).

Occupation intensity

We calculated site occupation intensity at Boomplaas using the ratio of total lithic artefacts recovered to the age range for each excavation member. We derived age ranges from each member's newly updated ^{14}C model outputs (Table 3). Artefact discard rates are a proxy for the intensity of site occupation, albeit one with known limitations (Hiscock 1981). One drawback is that it assumes that discard rates were uniform within a member's upper and lower boundaries. By necessity, our analysis is confined to comparisons between broad members, not their sub-units. We are thus dealing with time-averaged occupations representing the accumulation span for each member. A more fine-grained analysis would compare occupation intensity across sub-units (e.g. LP GG vs. LP GGU). We do not yet have the data to do this. We thus consider other proxy indicators (i.e. taphonomic signals on the fauna, depositional contexts and the density/nature of excavated features) from each member to verify our occupation intensity values. Barton and Riel-Salvatore (2014) also point out the value of time-averaged sequences for tests of long-term trends in land-use and site occupation structure. Single-occupation episodes or pristine archaeological horizons are unlikely

to provide the data necessary to untangle the complexities of human occupation and site use over the *longue durée*.

Lithic analysis

Here we focus on comparisons between members LP and GWA/HCA as our redating shows that these two members can now be considered to have been contemporaneous. This is important because both Hilary Deacon (1983) and Janette Deacon (1984) refer them to different phases of the LSA with different technological characteristics. Comparison of their lithic material should therefore shed light on short-term behavioural variability within the Boomplaas sequence. To do this we have drawn lithic data from Pargeter's (2017) reanalysis of the site's late/terminal Pleistocene lithic assemblage. Pargeter applied an attributed-based approach to a sample of lithic materials from two of the site's 1-m^2 excavation areas (Squares P14/15). The attributes studied tracked aspects of core reduction, flake morphology and raw material selection. A stratified random sample of approximately 400 lithic artefacts (cores and flakes) regardless of size was analysed from each excavation member.

Results

Dates

Table 2 presents the new AMS ^{14}C measurements for Boomplaas, together with their calibrated age ranges (2σ level) and δ^{13}C values. The new dates are generally stratigraphically coherent, although a few inversions must be noted. The new age for CL1 (OxA-33812, 10,505 ± 45 BP) is younger than that for the overlying context BRL7 (OxA-33811, 11,930 ± 50 BP), the uppermost sub-unit of CL. Describing the site's stratigraphy, J. Deacon (1982: 100) notes that a portion of member CL's deposits were 'highly leached — stratigraphy unclear', which may well account for the discrepancy. The AMS date from BRL7 does, however, accord with the previous dates acquired for the surrounding units, BRL6 (*c.* 10,500 cal. BP) and CL1 (*c.* 12,000 cal. BP). Two AMS dates for the underlying sub-units CL2 (OxA-33813, 12,635 ± 50 BP) and CL3 (OxA-33814, 12,985 ± 55 BP) correspond with the previous dates for the base of CL (*c.* 14–13,000 cal. BP). The new AMS age from GWA/HCA (OxA-33815, 17,935 ± 80 BP) also aligns well with the previous ages acquired for GWA (*c.* 17,800 cal. BP). Interestingly, the results obtained from the underlying LP units, dated here for the first time (OxA-33816 from LPGG, 17,930 ± 90 BP, and OxA-33817 from sub-unit LPGGU, 17,640 ± 80 BP), indicate that they are essentially contemporaneous with the overlying GWA/HCA member.

The two new ages acquired for member YOL (OxA-35696, 13,975 ± 65 BP, and OxA-35661, 13,925 ± 50 BP) are clearly incorrect for this level. They may indicate downward movement of charcoal fragments through the sequence, although there is no indication of a stratigraphic disturbance in Hilary Deacon's unpublished excavation notes. Alternatively, given the close approximation of the two dates, we cannot rule out the possibility that some of member YOL's charcoals were mislabelled. Two new ages for the BP member (OxA-33818, 34,270 ± 360 BP, and OxA-33819, 34,860 ± 390 BP), on the other hand, are consistent with previous dates for this level. The new AMS date from BOL member returned a finite age estimate of 51,200 ± 2600 BP (OxA-33820). This date is very near the limit of the radiocarbon method (accounting for the large

associated error), but significantly improves on the previous estimate of > 40,000 BP for this level.

Figure 4 shows two comparative models for the Boomplaas dates. One model includes only the previously published ages, while the second, which is otherwise identical, incorporates the new AMS ages. The very early date for member BOL (51,200 ± 2600 BP) was modelled as a *terminus ante quem* from 48,560 cal. BP, using the *C_Date* function, as the SHCal13 calibration curve only extends to 50,000 BP. OxA-33812, OxA-33817 and OxA-35305 were identified as outliers and discarded from the model. The inclusion of the new dates confirms two significant hiatuses in the chronology (indicated by double lines in Figure 4). One hiatus, between members CL and GWA/HCA, is modelled as spanning between 1400 and 5200 years (at 2σ), with the other, between LP and LPC, spanning between 400 and 3800 years (at 2σ).

The most notable effects of the new dates are seen for the revised modelled age estimates for members LP and GWA/HCA and for members CL and BRL (Figure 4). The age range for GWA/HCA, initially modelled as spanning 4500 years (at 2σ), is now constrained to a 1400-year period *c.* 21,900–20,500 cal. BP. The age range of LP is similarly constrained, to a 2100-year period between 23,500 and 21,400 cal. BP. Thus, the modelled ages of LP and GWA/HCA now partly overlap, unlike the very dispersed modelled age range for this period before the inclusion of the new dates. The other notable effect of the new dates is to clarify the transition between member CL and the overlying post-Pleistocene accumulations in member BRL. The new date for BRL 7 shows a short and punctuated occupation event at the end of the CL member's formation.

Occupation intensity

The new AMS ages provide greater clarity for Boomplaas' occupation intensity patterns (Table 3 and Figure 5). Occupation intensity values are low in all members deposited between *c.* 61,200 and 34,900 cal. BP (before the LGM), i.e. in members BOL (0.07), OLP (0.12), BP (0.18) and YOL (0.06). Occupation intensity then increases in member LPC (4.73), which was deposited between *c.* 25,900 and 24,000 cal. BP (with the onset of the LGM). Humans also occupied the site between *c.* 22,900 and 22,000 cal. BP, during the height of the LGM, in a series of low intensity frost spall-rich members, LP (1.93) and GWA/HCA (2.04). Subsequently, occupation intensity rises dramatically in member CL (*c.* 13,000–12,000 cal. BP) to its highest value (20.43) in the Pleistocene portion of the Boomplaas sequence. This suggests a major change in the use of the site during the terminal Pleistocene.

Our new ages shed light on the relationship between breaks in human occupation at Boomplaas and gross technological (dis)continuities through the sequence. The interface between the MSA and LSA at the site occurred in member YOL, the minimally anthropogenic and spatially circumscribed deposit recovered from a depression between members BP and LPC (H. Deacon 1983). While our dating program unfortunately failed to establish the age of this member, we have clarified that of the member BP below it. It is now clear that a substantial reduction in site occupation intensity took place between it and LPC (*c.* 34,900 to 25,100 cal. BP) marking the MSA and LSA transition at the site (H. Deacon 1995). After this, we see a marked increase

in occupation intensity from *c.* 0.6 artefacts/year in YOL to *c.* 47 artefacts/year in LPC (Figure 5).

H. Deacon (1995) describes the lithic assemblages from members LPC–CL as belonging to the Robberg technocomplex (Lombard *et al.* 2012). The new ages we have obtained show that these members cover a substantial unit of time from *c.* 25,000 to 11,900 cal. BP, encompassing the LGM and the onset of post-glacial environmental conditions. Our revised ages show several hiatuses within the Robberg members, between members LPC and LP (*c.* 4000 years) and between members GWA/HCA and CL (*c.* 2000 years). Occupation intensity varied widely across these Robberg members, with values as low as 19 in LP and as high as 204 in member CL. Perhaps unsurprisingly, our data thus show that no single occupation pattern, and by extension no one human land-use strategy or settlement structure, characterised this long interval.

Lithic technological comparisons between members LP and GWA/HCA

Our new radiocarbon dates and occupation intensity values show that members LP and GWA/HCA overlap in time. Hilary Deacon excavated them as separate members and classified them as such, which provides us with an opportunity to examine short-term shifts in the organisation of technology during the LGM in the southern Cape.

Table 4 provides data on eight lithic variables compared between members LP and GWA/HCA. Included in it are the Fisher's α values for grazer species diversity at the site (accounting for differences in sample sizes) and the frequency of two microfaunal species, *Otomys saundersii* and *Myosorex varius* (Faith 2013b). Faith (2013b) infers variations in the relative availability of moisture from ungulate diversity data, with greater diversity signalling greater humidity and reduced diversity indicating reduced humidity (cf. Thackeray 1980). The two microfaunal indicators provide a relative measure of local vegetation changes across the two members.

The data in Table 4 show a series of marked differences in the organisation of lithic technology between members LP and GWA/HCA. First, the two members show contrasting patterns of raw material procurement. Member GWA/HCA shows a 65% increase in silcrete compared with member LP, which instead shows a 27% increase in vein and crystal quartz. These values correlate with different core reduction patterns in the two members; member LP shows a 31% increase in bipolar core reduction over member GWA/HCA (Table 4 and Figure 6). Core initiation flakes (flakes with 100% dorsal surface cortex or signs of cresting (cf. Soriano *et al.* 2007)) decrease by 36% in member GWA/HCA. This suggests that toolmakers initiated fewer reduction sequences at the point in which silcrete becomes more common at the site. Minimally worked nodules (as a proxy for stockpiled raw material) decrease by 21% in member GWA/HCA, suggesting a reduced emphasis on provisioning the site with raw materials compared to member LP. Data on flake morphology suggest that toolmakers increasingly organised core reduction around bladelet, as opposed to small flake, production in member GWA/HCA (which shows a 47% increase in bladelets over member LP). Retouched tool frequencies show a 50% decrease in member GWA/HCA, signalling a different approach to tool use, modification and curation. Median core mass and variance values change little between the two members (a 12% increase in member GWA/HCA), which suggests similar core discard thresholds.

The Fisher's α values decrease by 22% in member GWA/HCA. This signals a possible shift towards reduced humidity in the site's broader geographical context. Stalagmite fragments are also more common in member LP, suggesting possible increases in humidity when compared to the formation of member GWA/HCA (H. Deacon 1983). The observed faunal pattern could also signal short-term shifts in carnivore scavenging/hunting preferences given the similarity in dates between the two members and the significant contribution of non-anthropogenic agents into the fauna at this time (Faith 2013a). Equids and alcelaphines (black wildebeest/hartebeest) increase in member GWA/HCA, while giant long-horned buffalo (*Syncerus antiquus*) and klipspringer are more common in member LP (Faith 2013a). The two members show the same faunal alteration signatures, suggesting that these patterns are independent of changes in the agents of accumulation (Faith 2013a). *Otomys saundersii* and *Myosorex varius* frequencies shift marginally between the two members (9.5% and 3.2% respectively). Collectively, these patterns suggest similarly cool, humid, and open local vegetation regimes during the accumulation of both members.

Discussion and conclusions

Boomplaas Cave possesses a rich suite of cultural and palaeoenvironmental data important for our interpretations of variability in southern Africa's late/terminal Pleistocene prehistory. Despite its excellent history of excavation and exceptional preservation conditions, detailed palaeoenvironmental and behavioural reconstructions for the site's late/terminal Pleistocene sequence have been hampered by gaps and uncertainties in the site's existing chronological and stratigraphic sequence. Our dating project is designed to address this problem at Boomplaas and at other sites with sequences ascribed to the late/terminal Pleistocene Later Stone Age across southern Africa (cf. Loftus *et al.* 2016; Pargeter *et al.* 2017). For the most part, the new ages that we have obtained using state-of-the-art techniques match well with the site's previous dates, confirming the integrity of these prior estimates. The good degree of fit between old and new dates also refutes the notion (Ambrose 1998: 384) that curated charcoal stored in museums for several years, or even decades, is necessarily unsuitable for dating (cf. Barham & Mitchell 2008: 284). Moreover, the application of Bayesian modelling approaches, and the inclusion of more precise age estimates to these models, alongside the previously acquired conventional and AMS dates, permits greater confidence in the Boomplaas chronology.

Beyond this, our redating of the Boomplaas sequence provides renewed insights into several features of late/terminal Pleistocene human behavioural variability. The occupation intensity data, which we have calculated based on our new radiocarbon dates, indicate two main trends in Boomplaas' late/terminal Pleistocene occupation sequence: variable occupation intensity and short-term technological turnover. Human occupation at Boomplaas was highly variable through time and was by no means continuous. Late/terminal Pleistocene occupation intensity peaks in members LPC and CL, but Boomplaas otherwise remained an ephemerally visited location with low artefact discard intensities and high non-anthropogenic inputs into its faunal assemblage. Our new ages confirm that a substantial reduction, or possibly a hiatus, in site occupation occurred between members BP and LPC (*c.* 30,300–26,150 cal. BP), i.e. the section of the Boomplaas sequence traditionally seen to capture the MSA and LSA technological transition (H. Deacon 1995). The dating of member YOL in order to fill the gap between members BP and LPC is a priority for future work. Our dating

program provides the chronological framework against which future work drawing on newly derived technological data (Pargeter 2017) will be able to unpack the complexities of this process. Boomplaas' discontinuous occupation pattern matches that seen at other large rock shelters across southern Africa and suggests that such sites were part of wider land use systems (J. Deacon 1982; cf. Mackay 2016; Stewart *et al.* 2016). The choice to occupy large rock shelters was assuredly influenced by a range of social and environmental factors.

At Boomplaas, major shifts in occupation intensity occurred alongside large-scale environmental changes at the onset of the LGM (member LPC) and during the post-glacial period (member CL). Although cold, the Cango Valley shows high ungulate diversity measures and signatures for increased precipitation, which promoted the expansion of C_3 grasses and the opportunity to target a broad range of ungulate species (Faith 2013b). Boomplaas' faunal assemblage patterns suggest that the LGM, which has previously been interpreted here as relatively harsh with low environmental productivity, need not have been as such. In fact, humans appear to have chosen the Cango Valley for short-lived, sometimes intensive and repeated habitation in the LGM. The Valley's permanent freshwater sources and abundant lithic raw materials may help explain its attractiveness in the past. Low occupation intensity values could be the result of relatively poor chronological control on the occupation events at this depth in the site's sequence. Intensity estimates for member YOL should also be approached with caution as the member's age estimates are derived from the ages of the members above and below it.

The dates for the sudden increase in occupation intensity in member CL correlate with broader landscape change and reorganisation across the southern Cape. This period saw a 40–80 m rise in sea levels along the southern Cape coast (Mitchell 2008; Fisher *et al.* 2010; Faith 2013a). Marean (2010) argues that southern Cape coastal plains once supported extensive grassland ecosystems and the migration of large mammalian species. Increased sea levels would have disrupted coastal grassland ecosystems, displaced grazing species and impacted heavily upon the hunter-gatherer groups that organised their land-use strategies around their movements (Copeland *et al.* 2016). The earliest appearance of marine shell in the Boomplaas sequence in member CL corroborates increased contact with coastal contexts at this time, either through exchange or group movement (J. Deacon 1984). Ostrich eggshell fragments, serving as possible water storage vessels and blanks for ostrich eggshell bead production, tortoiseshell bowls and bone tools also increase sharply in member CL (J. Deacon 1984). Together, these factors suggest the operation of complex processes of technological and social change in the face of larger palaeoenvironmental shifts and landscape reorganisation. As Faith (2013a: 727) argues, 'the combination of population pressure and competition for resources may have forced some LSA human populations to expand into less favourable inland CFR [Cape Floristic Region] habitats' such as the Cango Valley and semi-arid Karoo (cf. Inskeep 1978).

These patterns of larger landscape reorganisation raise interesting questions about how rapidly humans adapt to differing coastal foraging strategies (*sensu* Marean 2016). The Boomplaas data suggest that humans may have avoided rapidly shifting coastlines and instead pressed inland where resources may have been more marginal, but at least predictable. Similar processes appear to have attracted humans to southern Africa's highland regions during the later phases of the Pleistocene (Stewart *et al.* 2016). It could

also be that what we are seeing at Boomplaas is the tip of the proverbial iceberg, an outer extension of a reorganised social landscape in which sites formerly far from the ocean now became nearer-coastal bases for groups subsisting on coastal resources. The increase in the number of southwestern Cape sites nearer to the post-glacial coastline (e.g. Byneskranskop 1, Nelson Bay Cave and Elands Bay Cave) with suites of dates in the order of 16,000 cal. BP provides some support for the latter scenario (Loftus *et al.* 2016; Tribolo *et al.* 2016). Future extensions of the strontium isotope map around the southern Cape (Copeland *et al.* 2016), coupled with renewed efforts to derive strontium values for ostrich eggshell remains at Boomplaas, may shed further light on the matter.

Our redating of Boomplaas finds strong evidence for short-term technological turnover in the site's late/terminal Pleistocene sequence. Members LP and GWA/HCA, now dated to the same period, show different occupation intensity values and patterns of technological organisation. Member GWA/HCA shows that toolmakers preferred freehand reduction and bladelet production on non-local silcrete with low retouched tool frequencies. Member LP, in contrast, shows a strong pattern of local quartz bipolar reduction, small flake production, higher raw material stockpiling and increased flake retouch. These data suggest relatively short-term variability in human use of the site and the wider landscape. It is unclear whether we are witness here to seasonal occupations, different groups of people visiting the site, differences in site use or a combination of these factors. The macrofaunal and micromammalian data suggest relatively similar palaeoenvironmental contexts for both members implying that, unlike in member CL, palaeoenvironmental variability did not drive these patterns.

Our observations on short-term technological turnover within the Boomplaas sequence join a growing number of southern African studies that highlight the dynamic tempo of late/terminal Pleistocene human behavioural change in southern Africa (e.g. Conard and Wills 2015; Mackay *et al.* 2015; Stewart *et al.* 2016; Pargeter *et al.* 2017). These variable patterns should not come as a surprise. Much like humans today, our late/terminal Pleistocene ancestors were able to respond to changes in social and environmental conditions in creative and flexible ways (Shea 2011). For how would they have otherwise survived the rapid climate change and landscape reorganisation characteristic of the last 70,000 years in southern Africa? Crucially, however, they appear not to have done so with the same range of material culture and behavioural responses described in the limited ethnographic sample of hunter-gatherer populations in southern Africa. The Boomplaas sequence, despite its otherwise exceptional organic preservation, provides little to no evidence for the use of ornaments, bone points, wooden digging sticks and ground stone artefacts prior to the Holocene. The site also provides little evidence for the use of plant food resources until *c.* 14,000 cal. BP (J. Deacon 1984; H. Deacon 1993). Like other sites (e.g. Elands Bay Cave; Parkington 1986), Boomplaas likely shifted in importance and in its role as an occasional hunting station and longer-term residential/aggregation space through time. Each of these changes resulted in a different suite of material culture relative to the shifting needs of those occupying this ecotonal site in the Cape Fold Mountains. However, these specific material combinations typically did not, nor should we expect them to, line up with those adopted and adapted by a handful of well-known arid-zone hunter-gatherers in the twentieth-century Kalahari.

The value of our renewed efforts to redate key southern African late/terminal Pleistocene archaeological sequences is not so much in demonstrating our ancestors'

inherent behavioural variability, but rather in contributing to a robust chronological framework with which to interpret this variability. Our study highlights several areas of the Boomplaas sequence that could benefit from future high-resolution excavations designed to test questions about the evolution of social complexity in specific bio-geographical contexts (Marean *et al.* 2015). It also highlights the pressing need for comparable precision and intensity of dating at other sites across the region in order to refine patterns of regional coherence. Ultimately, chronological precision is critical if, in the future, we hope to test the various proximate and ultimate causes for human behavioural variability.

Acknowledgements

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