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Multiproxy record of late Quaternary climate change and Middle Stone Age human occupation at Wonderkrater, South Africa

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ABSTRACT

Here we provide a multiproxy record of climate change and human occupation at Wonderkrater, a spring and peat mound site situated in the interior of southern Africa. Recently extracted sediment cores yielded a number of Middle Stone Age (MSA) artefacts, prompting exploratory excavation of the sediments to understand better the geomorphology of the site, age of the sediments, cultural lithic sequence, vegetation and faunal remains, and to try to establish whether human use of the site was to some extent climatically driven. Excavations yielded late Pleistocene mammal fauna and flora, and three small MSA lithic assemblages with age estimates of 30 ka, >45 ka and 138.01 ± 7.7 ka. The upper layers comprise peat that preserves macrobotanical and faunal remains, implying local fen conditions in *Acacia* savanna woodland at 12 ka. Below the upper peat layers, a 1 m-thick layer of white sand yielded two MSA lithic assemblages in association with faunal remains dated to between 30.8 ± 0.7 ka and >45 ka. Clay underlying the sand has an OSL age of 63.1 ± 5.8 ka, and sandy peat below it has an Infrared Stimulated Luminescence (IRSL) age of 70 ± 10 ka. Faunal remains in the lower sand levels, and dental stable carbon isotope analysis of herbivores, indicate a substantial grassland component in the landscape during late MIS 3 (>45 ka). Charcoal, phytolith and pollen data show a change from moderately warm and dry grassy savanna woodland in the lower sand levels, to cooler and wetter grassland with woody shrubs in the uppermost levels by 30 ka. The conditions that resulted in the deposition of the sand also attracted people to the site, but whether it served as an oasis in an arid landscape, or was occupied during wet phases, is unclear. The composition of the lithic assemblages, which include many tools suitable for cutting, suggest that the peat mound may have been used as a place to harvest reeds, process plant materials and butcher animals that were either deliberately or accidentally trapped in mud or peat.

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1. Introduction

1.1. Climate and hominin evolution

Climate change is hypothesized to have played a major role in early human history, from short-term (Potts, 1998), extreme (Maslin and Christensen, 2007) and rapid change (Ziegler et al., 2013), to climatic variability (Trauth et al., 2009; Thomas et al., 2012), rapid increases in aridity (Vrba et al., 1995) and sea-level fluctuations (Compton, 2011). Change in climate is also considered to have affected the development of complex modern human behaviour, population expansion and dispersal (e.g. Lahr and Foley, 1998; Mellars, 2006; Campisano and Feibel, 2007; Field et al., 2007; Hughes et al., 2007; Maslin and Christensen, 2007; Scholz et al., 2007). Major pulses in innovation have been linked with abrupt climate change towards humid conditions in southern Africa (Ziegler et al., 2013), but Chase (2010), Jacobs and Roberts (2009) and Mitchell (2008) propose that factors independent of climate were responsible. Some of the earliest traces of complex behaviour are recorded at coastal MSA sites in South Africa, including engraved artefacts (Henshilwood et al., 2002, 2009; Texier et al., 2010), ornamental shell beads (d'Errico et al., 2005), heat treatment of rocks as part of the knapping process (Brown et al., 2009; Mourre et al., 2010; Schmidt et al., 2013; Wadley, 2013) and evidence of complex hafting and hunting activities (Lombard, 2005, 2007; Backwell et al., 2008; Wadley et al., 2009; Lombard and Phillipson, 2010; Wadley, 2010; d'Errico et al., 2012a). Symbolic and abstract thought, planning, and technological innovation certainly developed in Africa in MSA contexts, but the exact timing and geographic distribution of the emergence of complex human cognition, the mode and tempo of its evolution, and whether it is specific to anatomically modern humans, is the subject of ongoing debate (Mellars, 1991; Klein, 1995, 2000, 2001; McBrearty and Brooks, 2000; Wadley, 2001, 2013; Stringer, 2002; Backwell et al., 2008; d'Errico et al., 2009; d'Errico and Stringer, 2011). This is partly because knowledge of African middle and late Pleistocene fossil hominins is limited by a small sample size, rendering the extent of their diversity, distribution, first and last appearances, and associations with lithic industries and each other, unknown (Mitchell, 2008). It is thus difficult to assess the impact of climate change on modern human evolution and dispersal when it is unclear whether there was an accretional emergence of the modern human morphotype from an archaic ancestor with a pan-African distribution (Bräuer, 2008; Pearson, 2008), or whether there was a more punctuated appearance, possibly a speciation event from a geographically-restricted subpopulation of archaic humans (Stringer, 2002). It is generally accepted that by 60 ka all people in southern Africa were anatomically modern (McBrearty and Brooks, 2000; Grün and Beaumont, 2001; Deacon and Wurz, 2005; Marean and Assefa, 2005).

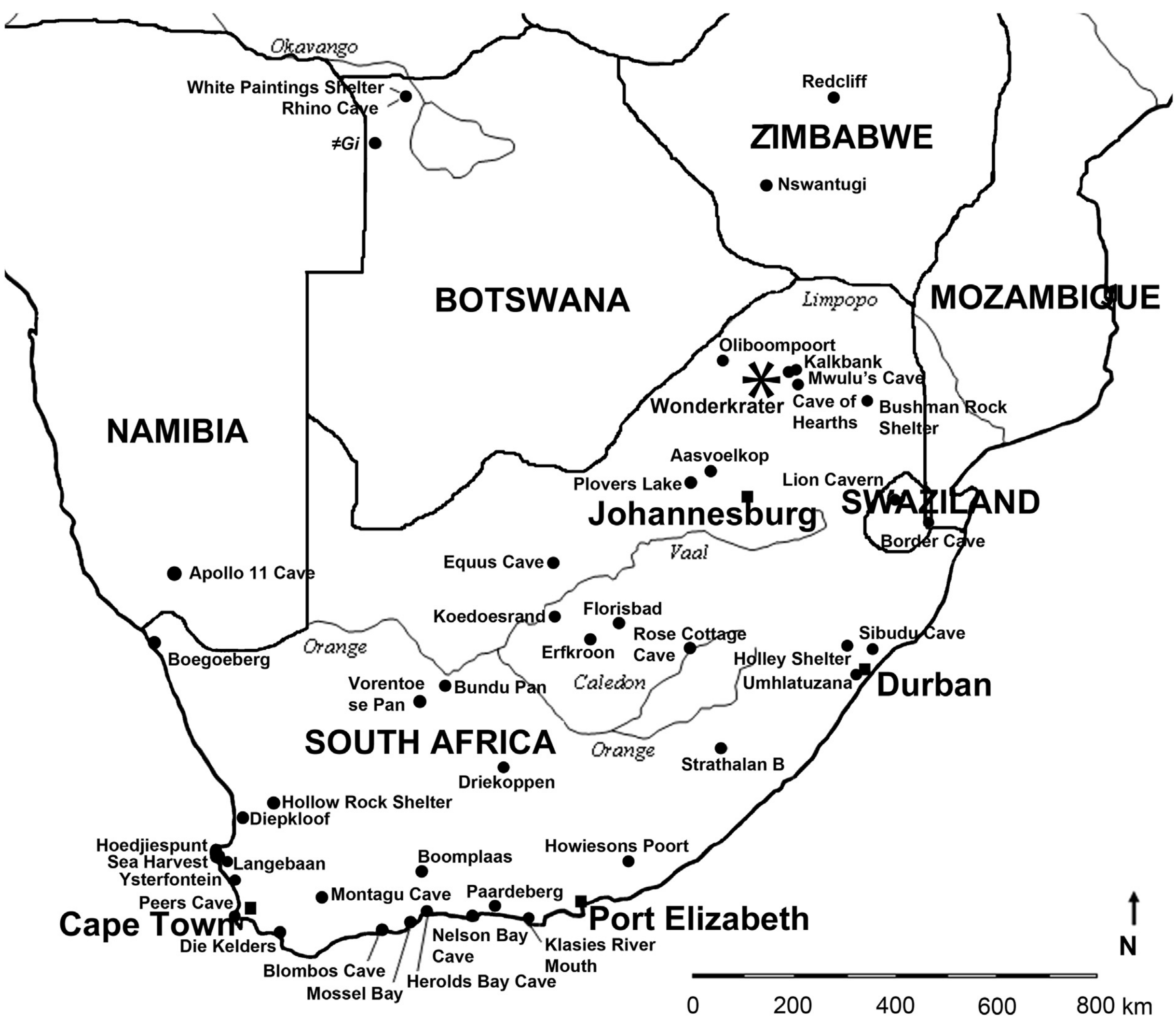

Fig. 1. Map of southern Africa showing the location of Wonderkrater in relation to other known Middle Stone Age sites.

Palaeoclimate records for sub-Saharan Africa are scarce, seldom well dated, and often contradictory. There are problems with correlating terrestrial and marine records, and southern hemisphere climate data with those from northern latitudes, which experience different temperature regimes and monsoon patterns (Chase and Meadows, 2007; Maslin and Christensen, 2007; Gasse et al., 2008; Chase, 2010; Chase et al., 2010; Blome et al., 2012). In addition to the scant climate record, relatively few well-preserved MSA sites are reported for the interior of southern Africa. This is believed to be due to sampling bias (Mitchell, 2008), unfavourable preservation conditions (Schiegl and Conard, 2006), and a lack of human habitation due to adverse climatic conditions. It has been proposed that periods of more arid climates may have pressed subcontinental African people to the coast, where evidence at a number of cave sites shows that they exploited a wide range of resources (e.g. Deacon and Deacon, 1999; Marean et al., 2007; Clark and Plug, 2008; Marean, 2010a,b). In recent years nine MSA sites in the subcontinent have been newly dated (Jacobs et al., 2008; Jacobs and Roberts, 2009), but unfortunately they are all coastal or near-coastal localities. The small number of post-200 ka sites that have been excavated in southern Africa, or dated using recent standards, together with a lack of coherence in hominin taxonomic attribution and regional palaeoenvironmental records, make it difficult to establish whether sampling bias, erosion and destructive taphonomic processes, discontinuity in cultural transmission as a consequence of population decrease and isolation linked to climate change, or the behaviour of different hominins, account for what appears at first glance to be a paucity of inland sites with evidence of cultural innovation. One of the problems highlighted by the above review is the fact that there are very few terrestrial sequences covering the Upper Pleistocene, and when available, they are difficult to correlate with early human settlement patterns. In this respect the site of Wonderkrater represents an exception, featuring layers rich in modern and ancient organic material that alternates with sand layers recording human use of the site. Scott's detailed palynological study of the pollen-rich peat deposits at Wonderkrater has provided a record of the vegetation change, and by inference regional climate, in this area for the past ~34 ka and older undated intervals (e.g. Scott and Vogel, 1983; Scott and Thackeray, 1987; Scott, 1999; Scott et al., 2003). The aim of this study is to understand better the geomorphology of the site, the processes that led to its formation, the chronology of the deposits, document environmental changes recorded in the sequence, characterize the human use of the area through an analysis of the cultural remains, and combine the results to produce a multiproxy record. Here we present the results of test excavations in different areas of the site over three field seasons from 2005 to 2007.

1.2. The site

Located on the farm Driefontein in Limpopo Province, South Africa (Fig. 1), at an altitude of ~1100 m above sea level, the site of Wonderkrater (24° 25′80.60 S, 28°44′62.60 E) is situated in a mixed bushveld environment (Low and Rebelo, 1996) that forms part of the current tropical savanna biome (Rutherford, 1997), receiving a mean annual rainfall of approximately 630 mm. Wonderkrater is a

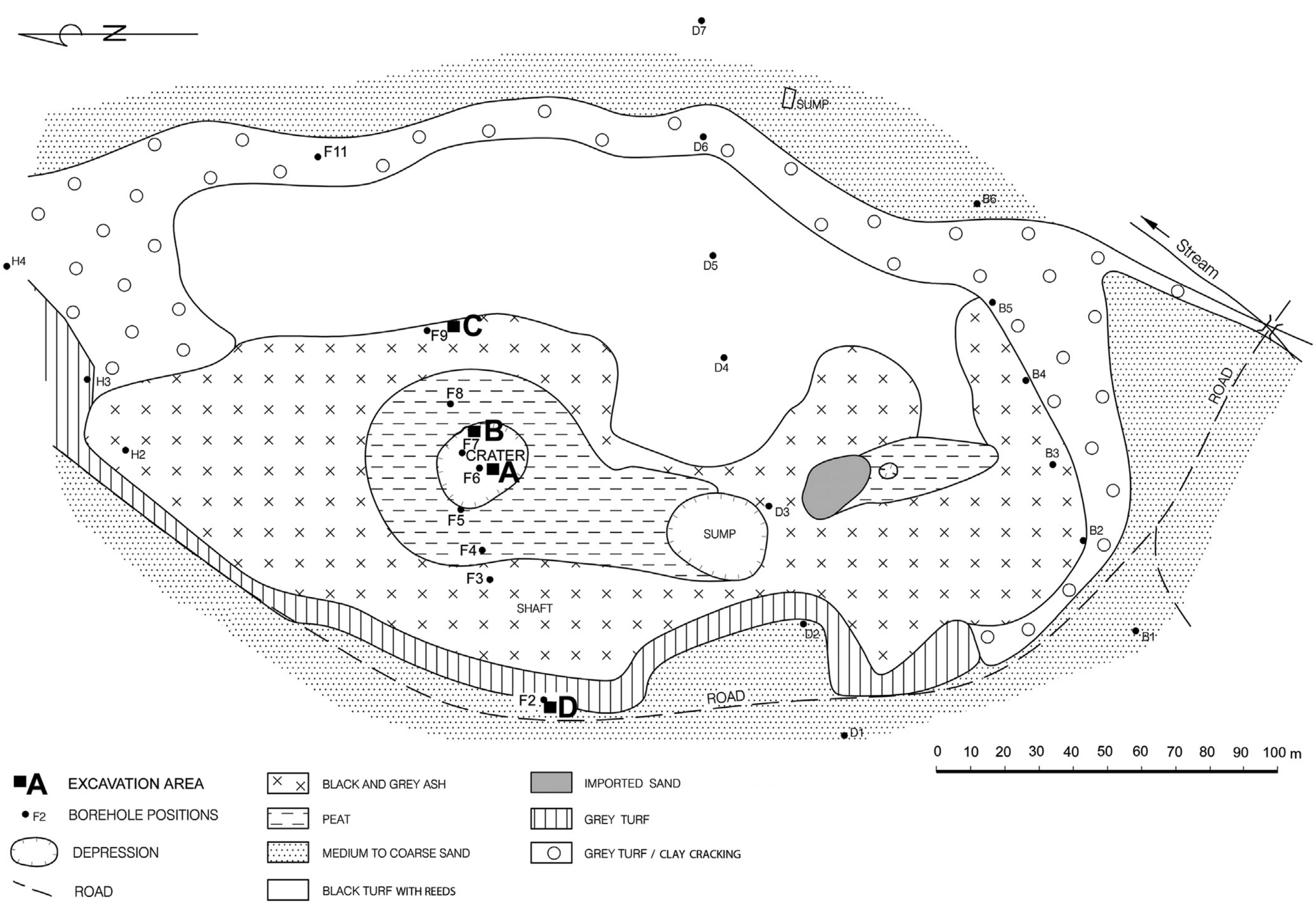

Fig. 2. Subsurface soil map of the site showing the position of excavation areas along the F-line transect. Areas A and B sample black peat in the wet centre of the mound; C the dry clearly stratified margin, and D the medium-coarse sand surrounding the site (modified after McCarthy et al., 2010). Cross reference to Fig. 3 for cross-section.

large peat mound that covers an area of approximately 25,000 m^2 and currently rises 2.50 m above the surrounding terrain. The mound consists of ash-rich peat, and is covered with *Phragmites australis* reeds, *Carex acutiformis* sedges, and some *Acacia karoo* trees, while the alluvial plains around the spring are dominated by *Acacia* woodland (see Appendix Fig. A.1). The mound is fed by an artesian spring that rises along a fault intersecting rocks of the Karoo Supergroup, Bushveld Complex and Waterberg Group. Wonderkrater is situated on a gently sloping alluvial plain which fringes the Nylsvlei floodplain, and is fed from the Waterberg mountain range to the west. This is an area of active sedimentation, and all sediment delivered by the tributaries is retained on the alluvial plain. Earlier investigations suggest that both the mound and the surrounding terrain have aggraded at a more or less constant rate during the Holocene (between 26 cm/1000 yrs [Scott et al., 2003] and ~17 cm/1000 yrs, this paper). The plain receives sediment, mainly coarse- to medium-grained sand, by stream flow from small rivers that lose discharge downslope, which results in sediment deposition. The sediment is further distributed by sheet flooding during heavy storms (McCarthy and Hancox, 2000; McCarthy et al., 2002; Burri, 2013). Wonderkrater is fed by rainfall and deeply circulating ground water, so it is technically a fen, with a distinctive chemical composition rich in fluoride, calcium carbonate, sodium and chloride. The mound aggrades as a result of the accumulation of peat, a brownish-black soil composed mainly of partially decomposed, loosely compacted organic matter that lived and died on the mound, and exists in a relatively fresh state of preservation because of the anaerobic waterlogged conditions. Because the spring is artesian, the accumulation of peat has created a topographically elevated feature that has excluded clastic sediment which forms the surrounding terrain (McCarthy et al., 2010).

2. Materials and methods

2.1. Excavations

Based on a subsurface sediment map of Wonderkrater (McCarthy et al., 2010), four sites were selected for excavation (Areas A–D) (Fig. 2). Area C was selected because stone tools were discovered in stratified deposits recovered from an auger hole (F9) (Fig. 3), which was bored in this area using an 8 cm diameter hand auger. Area A sampled wet peat (also referred to as moist black turf) in a 2.0 m × 0.5 m × 1.0 m deep excavation in the centre of the mound where the water table is shallow. Area B is 3.0 m × 3.0 m × 4.5 m deep, and is located a few metres away from the centre of the mound, where the sediment sequence consists of moist peat, ash and sand deposits (Figs. 2 and 3, Appendix Fig. A.2). Ash refers here to burnt peat and possibly vegetation, including grass and trees. Area C is 4.0 m × 4.0 m × 2.70 m deep, and is located on the dry margin of the mound in black turf and ash (Figs. 2 and 3, Appendix Fig. A.3). Area D is 2.0 m × 2.0 m × 0.15 m deep, and is located in sediment consisting of medium to coarse white sand around the edge of the mound (Figs. 2 and 3). Data recording procedures are presented in Appendix B.1.

2.2. Sediment sampling

Sediment samples were taken at 10 cm depth intervals from Areas B and C for analysis and Munsell chart colour clarification. Samples were taken from five layers in Area C (Fig. 4), and 10 layers between 1 m and 4 m below the surface in Area B for phytolith analysis. Sediment samples from the west wall of Area B, from the bottom of the peat to the bottom of the white sand unit (2.90 m and

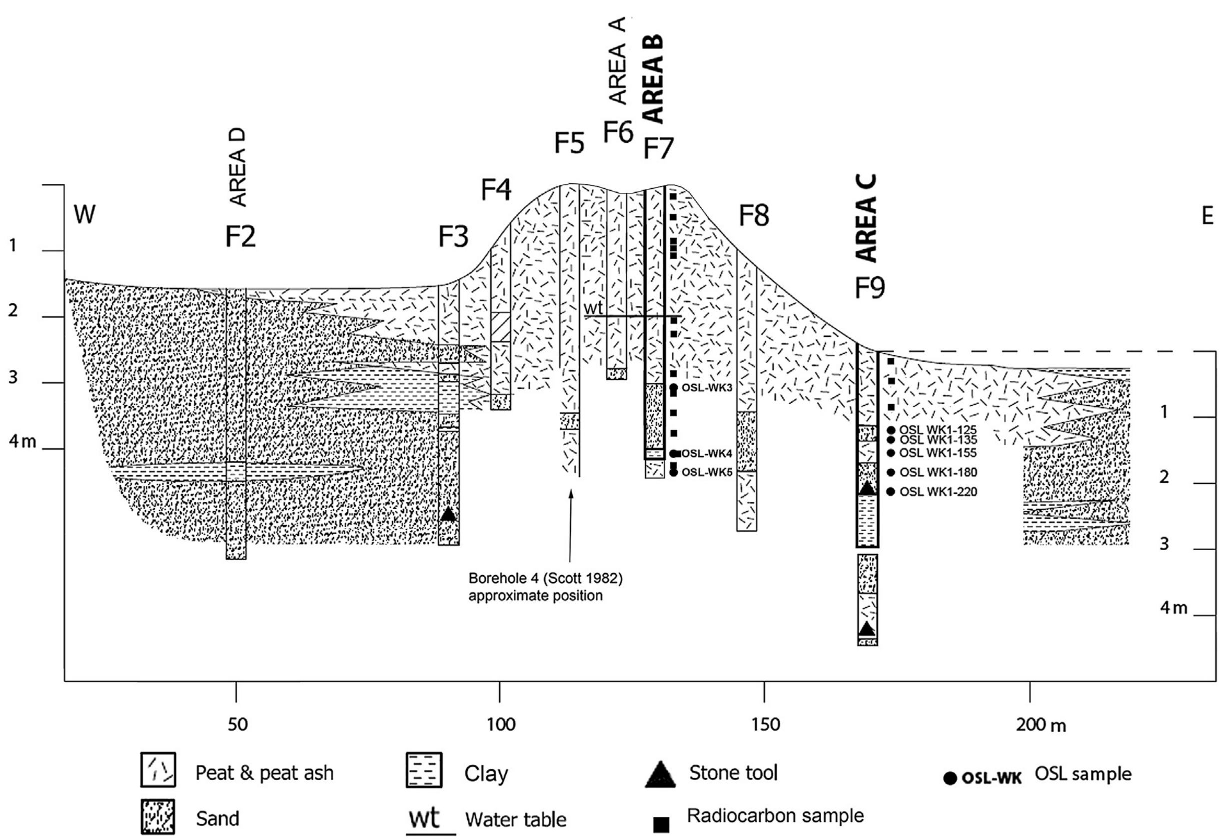

Fig. 3. Cross-sectional reconstruction of subsurface stratigraphy of the mound obtained through sediment cores bored along the F-line (modified after McCarthy et al., 2010). Note the locations of the excavations, particularly Area B in the wet centre of the mound and Area C on the dry margin. Radiocarbon and OSL samples were taken *in situ* during excavations.

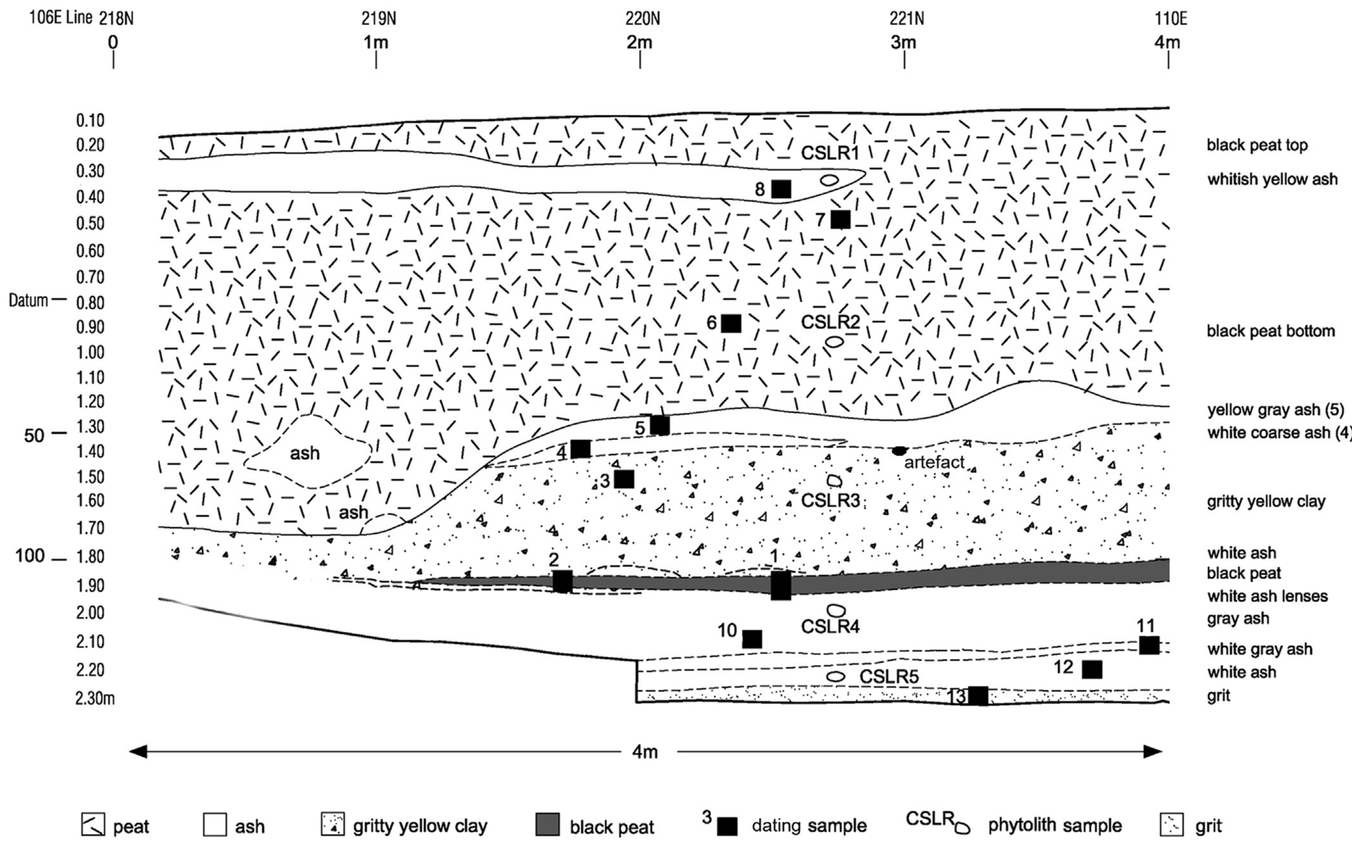

Fig. 4. West wall of Area C showing the position of sediment samples taken for radiocarbon dating and phytolith analysis. Note the artefact *in situ* in the gritty yellow clay at 1.40 m below the surface.

3.90 m below the surface) were collected for pollen analysis. Sand samples were subjected to granulometric analysis using a combination of standard sieves for the coarser material and a laser granulometer for finer material (Malvern Mastersizer, 2000 granulometer, Version 5.40). Data were analysed using the Gradistat software. Mineralogical compositions of the sediment were determined using grain mounts under a petrographic microscope. The grain mounts were also used to estimate roundness (following Powers, 1953).

2.3. Lithic collection

The Wonderkrater lithic collection was classified by rock type and the stage of knapping reached at the point of discard. Tool classes are simplified because the lithic assemblages are small. Lengths and breadths of all whole pieces were measured with digital callipers. The *t*-test was used to investigate statistical significance in the stone tool assemblages in the centre and on the margin of the mound, and a Mann–Whitney *U* test was run on the length and the width of complete blanks (blades and flakes) from Area C and B lower. Refitting was attempted with pieces >20 mm in length, and the orientation of lithics in Area C on the dry margin of the mound was recorded in detail during excavations conducted in 2006.

2.4. Isotope analysis

Dental samples were taken for stable carbon isotope analysis from 11 herbivore specimens (equid, hippopotamid, bovid) from the lower sand layers (levels 35–42). Enamel samples (3–4 mg) were taken from adult molars and analysed using a Finnigan MAT 252 mass spectrometer at the Stable Light Isotope Laboratory, University of Cape Town. Preparation and cleaning protocols followed Lee-Thorp et al. (1997). See Appendix B.2 for the reporting of $\delta^{13}C$ values.

2.5. Radiocarbon dating

Peat samples from Areas A, B and C (Figs. 3–5) were submitted for radiocarbon dating to the CSIR in South Africa, Beta Analytic (USA) and the Leibniz laboratory, Christian-Albrechts University, Germany. The dates were calibrated using the SHCal13 dataset (Reimer et al., 2013). Unless otherwise noted, radiocarbon ages are expressed as calibrated years before present (cal yr BP). The age-depth model and individual sample ages were calculated using the Bacon v2.2 software of Blaauw and Christen (2011). This is a Bayesian age/depth modelling tool that presumes prior knowledge on the distribution of tenable sedimentation rates in the site as well as the inter-layer variability in sedimentation rates. Separate runs of the model were performed for Area A and Area B using 5 cm depth resolution and an initial estimated accumulation rate of 20 cm/ka with a default shape factor (accumulation rate variability factor) of 1.5. Age and error estimates of the calibrated radiocarbon dates constrain the age and error estimates for any layer interpolated by the Bacon model, and while the model is able to reject patent dating errors in the form of age inversions, it includes a "memory factor" that accommodates variability in the sedimentation rate. The memory factor was set to a low value of 0.01 indicative of rapid sedimentation rate in order to accommodate the radiocarbon dates. The results of the Bacon age/depth model are presented in Appendix C.

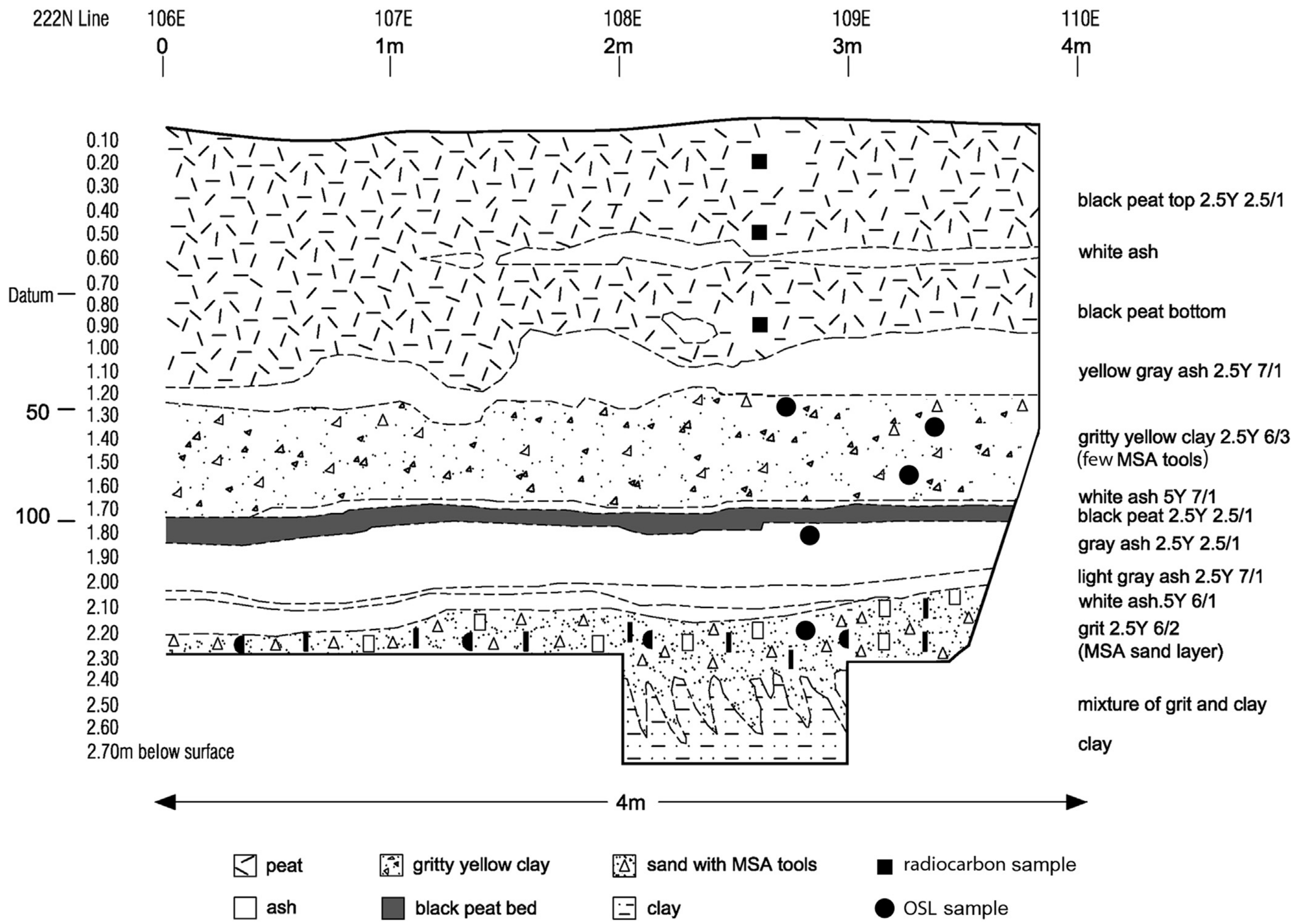

Fig. 5. Section of the north wall of Area C on the dry margin of the mound showing the position of radiocarbon and OSL samples. The MSA lithics were found in the grit layer 2.20–3.30 m below the surface (OSL dated to 138.01 ± 7.7 ka). The numbers and letters next to the descriptions of the layers refer to their Munsell chart colour.

2.6. Optically stimulated luminescence dating

The first batch of samples (WK3, WK4, WK5) for optical dating was collected by a team of researchers from the University of Quebec, Montreal. They were taken from Area B from the top of the MSA artefact-bearing sand layer at 3.10 m below the surface (sample WK3), from an underlying green clay layer 4.10 m below the surface (sample WK4), and sandy peat (WK5) at 4.40 m below the surface in the same quadrant (Fig. 3). The two minerals used for optical dating of Area B were quartz and K-feldspar. The use of feldspar provides a stronger absolute chronology as one can compare quartz and feldspar, and not have to depend upon results coming from only one of these minerals. Details of the luminescence dating protocol are published in Barré et al. (2012). A second batch of five samples was taken from the north wall of the excavation in Area C on the margin of the mound (Figs. 3 and 5) for dating at the University of the Witwatersrand, Johannesburg. In order to sample a pump had to be used to drain the pit first, meaning that the sediment samples were saturated. The first three samples (WK1-125, WK1-135 and WK1-155) were taken from a yellow gritty clay layer that yielded MSA lithic material between 1.25 and 1.55 m below the surface. Sample WK1-180 was taken at 1.80 m within a grey ash layer, and WK1-220 was taken at the top of a gritty deposit containing MSA lithic material at 2.20 m below the surface (Figs. 3 and 5). All samples were duplicated within 20 cm horizontally for sedimentology and mass spectrometry, to derive the external dose for OSL dating. See Appendix B. Materials and methods, Text B.3 and Appendix Table B.1 for an explanation of the OSL dating methods used.

3. Results

3.1. Geomorphology and age of deposits

3.1.1. Site stratigraphy

The Wonderkrater site sediments are stratigraphically extremely heterogeneous due to the interfingering nature of the peat, which forms the core of the mound (Area B) and the surrounding sandy sediment (Areas C and D, Fig. 3). Further heterogeneity is provided by layers of fine grey powdery ash, formed by periodic burning of peat. Excavation at the apex of the mound (Area B) revealed a sequence from bottom to top that consists of a green, clay-rich layer, overlain by a metre of sand (Figs. 3 and 6). The sand comprises a lower 70 cm thick layer of white sand with minor greenish clay matrix, and an upper 30 cm thick white sand layer with a few green clay nodules, possibly intraclasts. This sequence was overlain by 3.00 m of peat that contains sparse and patchy quartz, feldspar and rhyolite grains (<1.5 mm in diameter) throughout. The full thickness of the deposit underlying the mound is unknown. Excavations on the margin of the mound (Area C) revealed interlayered peat, peat ash and clayey sand (Figs. 3 and 5). The excavation in this area was supplemented by coring that penetrated to a depth of 4.50 m, and again the base of the succession was not intersected. Excavations and coring away from the mound revealed a monotonous succession of

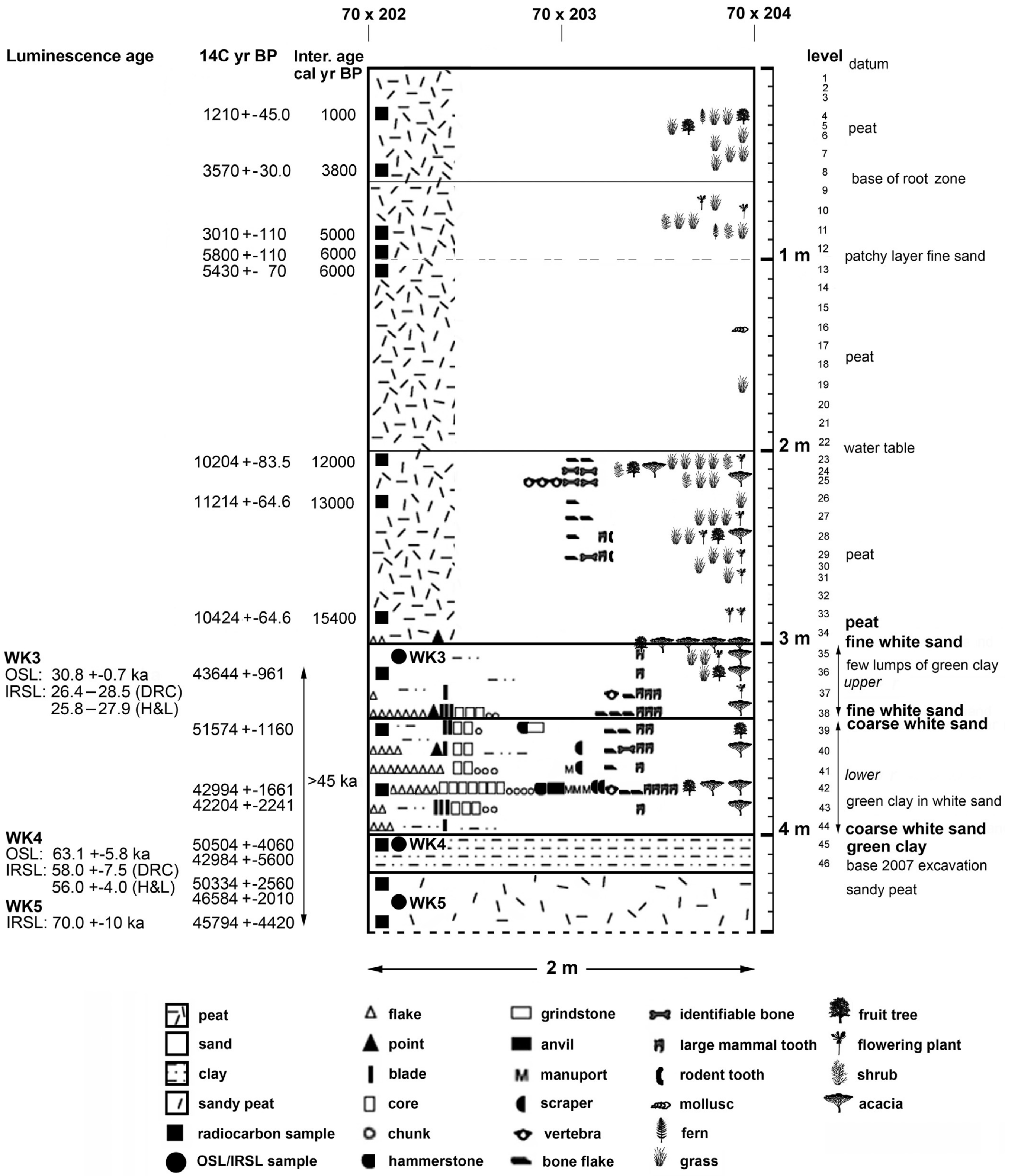

Fig. 6. Schematic representation of the west wall of Area B showing the type and number of finds. Note the increase in organic preservation below the water table, and the lithics in the lower sand unit. Plant remains above 1 m represent those preserved in nearby excavation Area A. DRC: Dose Rate Correction (Lamothe et al., 2003); H&L: Huntley and Lamothe (2001) correcting method. Inter. age: Interpolated age in cal yr BP (ka), calculated using the Bacon v2.2 software of Blaauw and Christen (2011).

clayey sand. The sand layers encountered in the excavations are described in Appendix C.1.

3.1.2. Radiocarbon age estimates

Radiocarbon ages for peat from Areas A and B in the wet centre of the mound suggest that during the last 16 ka it aggraded approximately 0.17 m every 1000 years. While the deepest peat sampled for dating, at 2.87 m below the surface in Area B (Fig. 6), dates to 12,295 ka (Table 1), stratigraphic inconsistencies in the data raise the possibility that a more realistic age, based on average accumulation rates, is ~15,441 ka. A table and plot of the age models for Areas A and B showing interpolated ages for sample depths are presented in Table C.1. While there is a slight depth offset in the age/depth relationship for these two areas they can nominally be considered the same in terms of the analyses of the remains from these excavations. Radiocarbon ages for the sand centre on ~45 ka, with a weighted mean of 44,553 ± 910 ^{14}C yr BP for a sequence of six samples (Table 1, Fig. 6). Considering the effective range of radiocarbon dating is ~50 ka, this is considered a minimum estimate, and the age of the lower layers is undoubtedly older than this. Attempts at radiocarbon dating the peat horizons in Area C were unsuccessful due to modern root contamination.

3.1.3. Luminescence age estimates

In Area B in the wet centre of the mound, at 3 m below the surface, the peat is replaced by a 1 m-thick white sand layer containing a MSA lithic assemblage (Fig. 6). An OSL age estimate places the top of the sand (sample WK3, level 35, 3.10 m below surface) at 30.8 ± 0.7 ka. IRSL age estimates are 26.4–28.5 ka (using the dose rate correction (DRC) of Lamothe et al., 2003) and 25.8–27.9 ka (using the correction method of Huntley and Lamothe, 2001). There is thus a hiatus of approximately 11,000–14,000 years between the peat and sand deposit. OSL age estimates for the green clay underlying the sand (sample WK4, levels 45–46, 4.10 m below surface) are 63.1 ± 5.8 ka, while IRSL ages are 58.0 ± 4.1 ka (DRC Lamothe et al., 2003) and 56 ± 4 ka (following Huntley and Lamothe, 2001). IRSL age estimates for the sandy peat below the clay (sample WK5, 4.40 m below surface) are 70 ± 10 ka. The large uncertainty reflects the apparent age variability between aliquots, which can be due to both anomalous fading and partial bleaching (Table 2).

Area C records dry and well-stratified deposits that preserve fine ash lenses, representing burning events. Table 2 presents OSL age estimates for samples from Area C, namely gritty clay at 1.25 m below the surface (WK1-125) dated 32.18 ± 3.6 ka. A second gritty clay layer at 1.35 m (WK1-135) is 46.30 ± 4.7 ka, and another at 1.55 m (WK1-155) yields an age estimate of 100.62 ± 7.8 ka. These dates are treated with caution because of the impact of water dynamics and burning on both the dose rate and D_e values (Appendix B.3. OSL dating). An ash layer 1.80 m below the surface (WK1-180) yielded an age of 102.36 ± 6.5 ka, and the gritty sand layer containing MSA lithics at 2.20–2.30 m (WK1-220) is 138.01 ± 7.7 ka (Fig. 5). These dates are less affected by burning and may be tested with further dating programmes in the future. No dates were

Table 1
Radiocarbon ages by depth for excavation Areas A, B and C.

Sample	Area	Level	Depth (m)	^{14}C age yr BP	1 Sigma error	95.4% (2s) calibrated age ranges	Relative area under distribution	Median probability (cal yr BP)
Pta 9675	C		0.20	2380	90	cal BP 2303–2492	0.732	2396
–	–	–	–	–	–	cal BP 2183–2239	0.149	–
–	–	–	–	–	–	cal BP 2640–2679	0.098	–
–	–	–	–	–	–	cal BP 2600–2608	0.021	–
Pta 9673	C		0.50	2440	90	cal BP 2342–2508	0.675	2482
–	–	–	–	–	–	cal BP 2633–2697	0.217	–
–	–	–	–	–	–	cal BP 2590–2616	0.085	–
–	–	–	–	–	–	cal BP 2529–2536	0.023	–
Pta 9582	A	3	0.25	1210	45	cal BP 1049–1108	0.457	1071
–	–	–	–	–	–	cal BP 984–1025	0.317	–
–	–	–	–	–	–	cal BP 1139–1172	0.226	–
Pta 9580	A	7	0.55	3570	30	cal BP 3724–3795	0.604	3794
–	–	–	–	–	–	cal BP 3818–3864	0.396	–
Pta 9574	C	11	0.90	3010	110	cal BP 2972–3525	0.932	3130
–	–	–	–	–	–	cal BP 3299–3324	0.396	–
	C	11	0.90	3380	60	cal BP 3543–33638	0.640	3573
–	–	–	–	–	–	cal BP 3480–3538	0.360	–
Pta 9576	B	12	1.00	5800	110	cal BP 6435–6670	0.985	6560
–	–	–	–	–	–	cal BP 6415–6420	0.015	–
Pta 9590	B	13	1.10	5430	70	cal BP 6175–6284	0.657	6176
–	–	–	–	–	–	cal BP 6115–6153	0.187	–
–	–	–	–	–	–	cal BP 6024–6048	0.100	–
–	–	–	–	–	–	cal BP 6064–6077	0.055	–
Pta 9581	B	23	2.10	10,260	83.5	cal BP 11,747–12,057	0.969	11,900
–	–	–	–	–	–	cal BP 11,718–11,737	0.031	–
Beta 248400	B	26	2.31	11,270	64.6	cal BP 13,032–13,157	1.000	13,095
Beta 248401	B	33	2.87	10,480	64.6	cal BP 12,105–12,229	0.417	12,295
–	–	–	–	–	–	cal BP 12,264–12,342	0.276	–
–	–	–	–	–	–	cal BP 12,365–12,433	0.250	–
–	–	–	–	–	–	cal BP 12,496–12,513	0.047	–
–	–	–	–	–	–	cal BP 12,533–12,537	0.010	–
KIA 43466	B	36	3.20	43,700	961	cal BP 45,888–47,904	1.000	46,955
KIA 43467	B	39	3.50	51,630	1160.248249	–	–	–
KIA 43468	B	42	3.80	43,050	1661	cal BP 44,804–47,992	1.000	46,407
KIA 43468	B	42	3.80	42,260	2241	cal BP 43,600–47,625	1.000	45,718
KIA 43469	B	45	4.10	50,560	4060.070935	–	–	–
KIA 43469	B	45	4.10	43,040	5600	cal BP 42,950–50,000	1.000	44,931
KIA 43470	B	47	4.30	50,390	2560.112498	–	–	–
KIA 43470	B	47	4.30	46,640	2010.143278	–	–	–
KIA 43471	B	49	4.50	45,850	4420	cal BP 45,548–50,000	1.000	46,892

Table 2
Age estimates for optically dated samples from excavation Areas B and C.

Depth (m)	Area	Soil type	Sample no.	Optical dating method		
				OSL	IRSL (DRC)	IRSL (H&L)
3.10	B	Sand	WK3	30.8 ± 0.7	26.4–28.5	25.8–27.9
4.10	B	Clay	WK4	63.1 ± 5.8	58 ± 4.1	56 ± 4.0
4.40	B	Sandy peat	WK5	–	70 ± 10.0	>Range
1.25	C	Gritty clay	WK1-125	32.18 ± 3.6	–	–
1.35	C	Gritty clay	WK1-135	46.30 ± 4.7	–	–
1.55	C	Gritty clay	WK1-155	100.62 ± 7.8	–	–
1.80	C	Ash	WK1-180	102.36 ± 6.5	–	–
2.20	C	Grit/sand	WK1-220	138.01 ± 7.7	–	–

OSL ages from Area C are based on a minimum age model.
DRC: Dose Rate Correction (Lamothe et al., 2003); H&L: Huntley and Lamothe (2001) correction method.
For WK5: Large uncertainty due to variability related to both fading and partial bleaching.
>Range: Natural luminescence beyond linear laboratory growth curve, thus Huntley and Lamothe (2001) not applicable.

obtained for Areas A and D. The theodolite co-ordinates enabled us to reconstruct a subsurface map of the site, which, together with radiometric age estimates, shows that the sequence recorded below the water table in the centre of the mound (Area B) is continued in dry stratified deposits 31 m away in Area C on the margin of the mound (Fig. 7), where a core (F9) extracted from this area shows the MSA horizons described here to be the youngest of the archaeological deposits at the site.

3.2. Archaeology

A total of 382 lithic artefacts >20 mm in dimension were recovered during excavations in Areas B (upper and lower sand unit) and C (Fig. 8). None of the pieces could be refitted. Area B included two sedimentary deposits in the thick white sand unit 3–4 m below the surface, distinguished by sediment size and clay content (Fig. 6). The younger assemblage (Area B upper, 3.4–4.0 m) comprises 21 lithics that came from the upper 20 cm of sand with an OSL age estimate of 30 ka. The lithics were retrieved from an area 2.00 m long × 0.50 m wide × 0.20 m deep. In Area B lower (3.40–4.00 m), 69 artefacts were retrieved from an area 2.00 m long × 0.50 m wide × 0.80 m deep, from sand dated >45 ka (Fig. 6). Area C on the margin of the mound revealed two archaeological horizons. The first horizon, with age estimates of 32.18 ± 3.6 ka and 46.30 ± 4.7 ka (Fig. 7), contained six lithics. None was encountered during careful excavation of the 1 m^3 test pit. The six stone tools in this layer were recorded in the wall of the excavation (see Fig. 4, middle) and in the dump. They are all made from rhyolite and are similar to the lithics in the lower horizon in the same area, and are not discussed further. The second horizon yielded 292 artefacts from an area 4.00 m × 2.00 m × 0.10 m deep in a gritty sand layer 2.20–2.30 m below the surface (see Figs. 5 and 7), dated by OSL to 138.01 ± 7.7 ka.

Due to the small sample size of the Area B upper lithic assemblage, and because of its similarity to pieces from Area B lower, results are presented as comparisons between lithics from Area B (upper and lower combined) in the wet centre of the mound, and Area C on the dry margin (Appendix D. Results – Lithics, Tables D.1–D.8). After rhyolite, constituting nearly two-thirds of the rock type in Area B upper and lower, and 80% in Area C, basalt is the next most common rock, and in low number (Area B upper 14%, Area B lower 8%, Area C 1%). Frequencies of rock types by lithic category in the three assemblages are presented in Appendix Table D.1. Broken and whole flakes predominate in both areas, followed by broken blades and denticulates (Appendix Table D.2). The predominant core type in both assemblages is the prepared core (Appendix Table D.3). All big cores and the anvil stone are from Area B lower. Several of the prepared cores from both areas are flat and intensively exploited. See Appendix Fig. D.2 for examples of cores from Area B (upper and lower), and Appendix Fig. D.3 for examples of cores from Area C. Appendix D.1 describes the cores from both areas, and Appendix D.2 provides definitions of terms used to differentiate grindstones, hammerstones and anvils. A large granite anvil stone (230 mm × 170 mm) from Area B lower is smoothed from grinding on one face, whilst the opposite face has both grinding and pitting (Fig. 8, middle row left). A combined grindstone and hammerstone (with grinding on all four sides and hammering on one end) is made of sandstone, and a broken hammerstone is made of quartzite (Fig. 8, middle left). Several large lithic manuports (transported, unmodified rocks) were also recovered from Area B lower; these include quartzite and basalt cobbles or slabs. Most flakes and broken flakes occur in Area C on the margin of the mound (Appendix Table D.2). Plain and faceted platforms are most commonly represented (Appendix Table D.4). Flakes in Area B are significantly ($p = <0.001$) longer, broader and more elongated than their equivalents in Area C (Appendix Table D.5). Chips (all flaking debris <20 mm in dimension) are most common in Area C (*n*. 1067) and rare in Area B (*n*. 8). Blades are not as common as flakes and the near absence of blade cores is consistent with this finding. Blades and blade fragments were selectively chosen for use as retouched denticulates. See Appendix Table D.6 for summary data on whole denticulates from both areas, and Appendix Fig. D.4 for images of retouched pieces from Area B. Most of the denticulation is irregular, and six of the tools have notches on them (see Appendix Fig. D.4.a). Denticulation occurs on a range of rock types, but scrapers are mostly made of rhyolite. Scrapers include side, end and convergent forms (Fig. 8 and Appendix D.5.d, e, f). Area C scrapers are smaller than those of Area B (Appendix Table D.7). Points are rare in both areas, with three found in each. There is a distal tip of an unifacial point in Area B upper (Appendix Fig. D.4.b), and a small, partly bifacial point occurs in Area C (Appendix Fig. D.5.b). Nearly half of the lithics in Area B are in a fresh state of preservation, while Area C tools from the dry margin of the mound are more weathered (Appendix Table D.8) and show more edge damage (5.8% as opposed to 3%). Trampling damage to the edges of pieces is insignificant (3.3% in Area B and 5.6% in Area C). The orientation and dip (inclination) of artefacts in Area C is random (Appendix Table D.9, Appendix Fig. D.6). One small piece of slightly polished deep red ochre was recovered from the gritty sand layer in Area C (Fig. 8, bottom right corner). The lithic samples from Area B upper and lower are described in Appendix D.3. Morphometric analysis of modified and unmodified blanks from Area B (upper and lower) and Area C reveals the production of larger blanks and tools in Area B compared to Area C (Appendix Fig. D.7). There is a shared tendency to leave the smallest and largest blanks unretouched (Appendix Fig. D.8), and to retouch flakes with a length shorter than the width (Appendix Fig. D.9). A Mann–Whitney *U* test confirms that the size of unretouched blanks in Area B and Area C is significantly different (length $p = ,0002$; width $p = ,0012$), but fails to identify a significant size difference between the tools from the two areas because of sample size.

3.3. Fauna

Excavations in Area B showed that bone preservation occurred in peat below the present water table, from 2.10 m below the surface, and continued in the white sand layer to a depth of nearly 4 m (levels 23–43, Fig. 6). Area B yielded 54 specimens, of which 32 could be identified to taxon and/or element (Appendix Table E.1). A minimum number of 11 individuals of different taxa are represented. See Appendix Table E.2 for a list of faunal specimens by

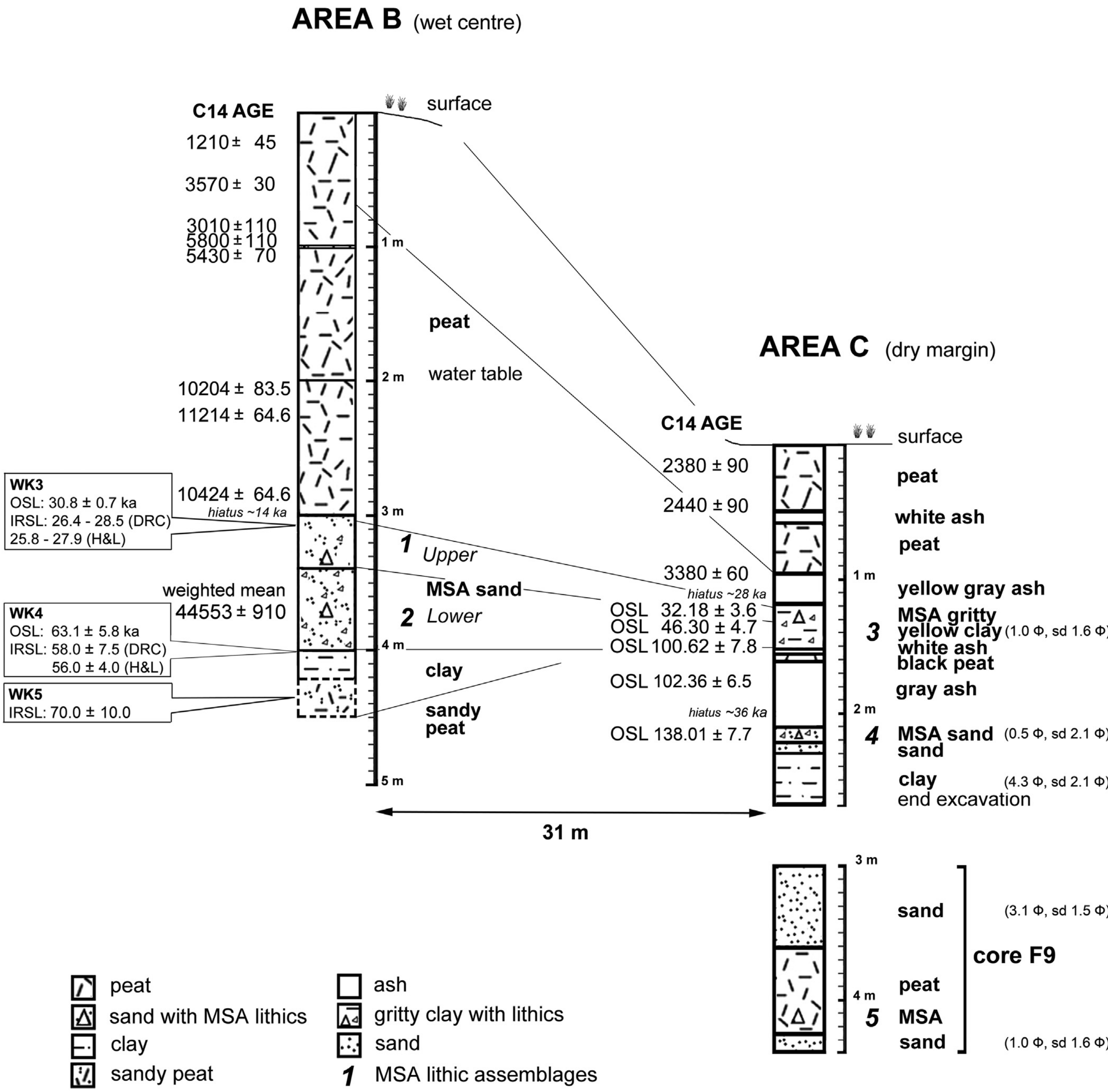

Fig. 7. Schematic diagram of stratigraphic columns of excavated Area B in the wet centre of the mound at an elevation of 2.50 m above the surrounding terrain, and Area C on the dry margin 31 m away. Note how deposits absent in Area C are represented in Area B from ~1 to 3 m below the surface. Layers with MSA stone tools are represented as 1–5 in bold italics. Numbers in parentheses are the mean grain size and standard deviation.

taxon. Complete specimens are well-preserved, but fragmented teeth and bones are water worn. Of the bone specimens in the pre-Holocene peat levels, five were identified as fresh and eight showed pre-depositional weathering stage 1 (following Behrensmeyer, 1978). Possible carnivore gnawing was observed on two pieces, and four possible coprolites were recovered. Of the bone specimens found in the MSA sand layer, one could be identified as fresh and four showed weathering stage 1. Possible carnivore gnawing was observed on four pieces and two showed traces of burning. No evidence of butchering in the form of cut or impact marks was observed on the faunal remains. The fauna is described in Appendix E.1 and shown in Appendix Figs E.1 and E.2. The $\delta^{13}C$ values are presented in Appendix Table E.3 and Appendix Fig. E.3, and indicate savanna environment in the area during late marine Oxygen Isotope Stage (MIS) 3.

3.4. Flora

Plant remains in the form of charcoal and fruiting structures, which were retrieved from Areas A and B, are presented in Appendix Table F.1. The results of charcoal analysis are discussed in Appendix F.1, and fruits and seeds are discussed in Appendix F.2. A provisional examination of pollen from the west wall of Area B, levels 33–43, between 2.90 m and 3.90 m below the surface (bottom of the peat to the bottom of the white sand unit, see Fig. 6), suggests two vegetation phases. Apart from abundant grass, sedge,

Fig. 8. Top row: Lithic assemblage from Area B upper dated ~30 ka. Middle: Collection from Area B lower dated >45 ka. Bottom: Lithics from Area C (OSL dated to 138.01 ± 7.7 ka). Scale bar = 10 cm. Knapped artefacts are oriented with their striking platform at the top. The lithics are grouped into categories, starting with complete examples followed by broken ones. In each collection flakes are followed by blades, retouched pieces, scrapers, cores, chunks and other types.

Typha and other local elements, the lower part of the white sand between 3.70 m and 3.90 m (levels 41–43), aged >45 ka, contains Asteraceae with some woodland types: *Tarchonanthus*, Capparidaceae, Combretaceae, *Peltophorum*, Mimosoideae, etc., suggesting relatively warm dry savanna vegetation. Above this, from 2.90 m to 3.60 m (levels 33–40), grass pollen, aquatics, semi aquatics and Asteraceae persist, but the latter began to include more *Stoebe* and *Artemisia* types. Together with Ericaceae, *Passerina*, yellow wood (*Podocarpus*) and wild olive (*Olea*) pollen, they indicate somewhat cooler and wetter conditions by 30 ka. Phytolith analysis, which focused mainly on sedge and grass phytoliths because they provide the most direct evidence of C_4/C_3 or xeric/mesic conditions in terms of the phytolith signal, show that large sedge-type, as well as bulliform-shaped grass phytoliths are the most abundant elements in the upper peat-rich sections. Trapeziform short cell phytoliths, associated with relatively cool winter rainfall conditions occur more frequently in the sand unit between 3.00 m and 4.00 m below the surface in levels 33–44, aged ~30 to >45 ka (Fig. 6). C_4 grasses adapted to warm summer rainfall climates in southern Africa, represented by saddle, cross and associated bilobate short cell phytoliths (Rossouw, 2009) are absent from the sand levels, supporting cooler conditions between 30 and >45 ka.

4. Discussion

4.1. Geomorphology and age

Considering the potential for younger carbon contamination in the peat sequence from rootlet penetration into underlying layers during peat formation, we feel that the timing of the events and trends described for this site should be treated as best estimates only. Radiocarbon ages obtained through this study indicate a significantly slower accumulation rate compared to those previously reported from cores by Scott et al. (2003). This is likely the result of varying accumulation rates across the spring mound. The depth of the sand level with MSA artefacts in the excavation in the centre of the mound was found to be 1.35 m lower than in sediment cores extracted from a nearby part of the mound two years later. This is most likely due to expansion and contraction of the spring and peat mound during wet and dry phases, as reported by Almendinger et al. (1986), as the water table in this study plotted half a metre lower than the level reported by McCarthy et al. (2010). Excavations were always conducted during dry winter months, while coring took place amid the heavy rains of summer when the peat was swollen. Whether wet or dry, the site stratigraphy remains the same.

Excavations revealed a geological event or process in the stratigraphic sequence in the form of a 1 m-thick sand layer, comprising two depositional events. The top of the sand has an age of 30 ka. Radiocarbon ages for the rest of the sand are centred on 45 ka, which is interpreted as a minimum age estimation. The age of the white sand is bracketed by the luminescence dates from the top of the layer, and the dates for the underlying clay layer, placing the period of sand deposition in the age range *c.* 60 ka–30 ka. The actual time span of sand deposition is unknown and further age control will be required to determine this. The poorly sorted nature of the sediment, its angularity and fresh state would appear to reflect deposition during flash flooding, but with the data available it cannot be determined if these sediments reflect a durable long-term change in mean environmental conditions or single events. The conditions that resulted in the deposition of the sand also attracted people to the site, but whether it served as an oasis in an arid landscape, or was visited during wet phases, remains unclear.

The use of intercalated sand layers in the peat as climatic indicators is clearly problematic. The mound and the surrounding piedmont have aggraded more or less in concert (McCarthy et al., 2010) and for much of the time, the peat mound formed a topographically positive feature, thus confining sand deposition to the periphery. Apart from the tiny quartz, feldspar and rhyolite grains up to 1.5 mm in diameter dispersed throughout the peat – which were probably incorporated through transportation by animals rather than wind, considering that the mean grain size of windblown Kalahari sand is 0.2 mm – the incursion of sand layers into the mound could be caused by a number of factors. For example, prolonged drought may have greatly reduced artesian flow into the mound, resulting in subsidence and possibly burning of the peat, thus allowing the surrounding sediment to encroach partially or completely over the mound. Another possibility is a shift in the position of the spring due, for example, to an earthquake or to clogging of the sub-surface flow path by precipitation of minerals. The original mound may have been thus isolated from its water supply, resulting in shrinkage and sediment invasion, with the mound position moving elsewhere in the area.

4.2. Stone tools

Although small, the Wonderkrater lithic collection includes a wide range of products frequently found in a knapping sequence: unmodified blocks, chunks, chips (knapping products <20 mm), cores, whole flakes and blades, broken flakes and blades, and several classes of retouched tools. There is a high percentage of prepared cores, flakes with convergent flake scars and faceted platforms, so knapping that took place at the site was not expedient. If it had been so, we should expect to find many more casual cores than is the case. Denticulates and scrapers are the most commonly represented retouched tools. Denticulates and blades seem suitable knives for cutting hide, flesh and sinews during the dismembering of animals. However, blade-shaped denticulates may also have been used at the site to cut reeds and grasses that may have served a number of purposes, such as creating screens for shelter, bedding or shafts for composite weapons. Scrapers are traditionally thought to imply hide-working, which would be expected at a site where carcasses are processed. The Wonderkrater scrapers are so varied in form, however, that a variety of tasks could be implied. Large manuports, the hammerstone and the anvil occur in Area B lower in the wet centre of the mound. The anvil may have been part of the tool knapping process and this could explain the pitted surface on one side of the block. Smoothing and grinding is present on the opposite face and this could be accounted for by a range of activities, some of which might be associated with butchery, such as bone breakage and pounding on an anvil, and the processing of plant foods. Notwithstanding the presence of cores and large knapping products, there are hardly any chips in Area B. Most chips (82%) are in the older Area C where there are also smaller knapping products and cores. This suggests that little winnowing occurred here, and that most knapping, and activities that required the use of denticulates and scrapers, took place on the margin of the mound. Most lithics in Area C on the margin are weathered, indicating that they were exposed on the surface for some time. Only half the lithics in Area B are weathered, most likely because the artefacts were covered by sand soon after they were abandoned. Trampling damage to the edges of pieces is insignificant (3.3% in Area B and 5.6% in Area C). The composition of the assemblage and randomly aligned positions of lithics greater than 20 mm in Area C, also seem to indicate relatively little disturbance. Refitted artefacts are a good indicator that sediments are *in situ*, but refitting was unsuccessful, possibly due to the small sample size. The rarity of retouched points, which are generally considered to be the tips of hunting spears, implies that the spring mound was not a hunting venue. The composition of the lithic assemblages, rich in cutting tools, suggests that the site was a place primarily used for processing animals that were deliberately or accidentally trapped in mud or peat (Weigelt, 1989). People may also have visited the site to exploit other resources, such as birds, amphibians, reptiles, edible and medicinal plants, and plants used for shelters, tools and bedding. Such resources are utilised by modern San communities at similar sites (Cowley, 1968; Seiner and Esche, 1977; van Wyk and Gericke, 2000). Of the numerous resources available at Wonderkrater, *Citrullus lanatus* (tsamma melons) and *Phragmites* reeds, now shown to have grown on the mound in deposits dated >45 ka, were no doubt of particular interest to hunter–gatherers. Reeds are a common organic component of traditional San material culture (Lee and DeVore, 1976; Marshall, 1976; Silberbauer, 1981; Wanless, 2007), recently shown to be in place by 44 ka at Border Cave, on the KwaZulu-Natal north coast of South Africa (d'Errico et al., 2012b). Most cores are of the prepared core type, and the morphologies of the scrapers, denticulates and retouched pieces confirm a MSA industry throughout the sequence, with no significant technological difference between the lithic assemblages in Area B upper (30 ka), Area B lower (>45 ka) and Area C (138.01 ± 7.7 ka). The differences recorded in the lithics from Area B in the wet centre of the mound, and those from Area C on the dry margin, may reflect diverse activities and thus functions in different parts of the site, cultural differences, or both. An argument in favour of function is supported by the fact that, in spite of using the same strategy in the choice of the blanks, artisans from Area B in the wet centre of the mound wished to produce tools that are much bigger than those from Area C.

Area C on the margin of Wonderkrater has a basal age of 138 ka ago, placing it in late MIS 6. Assemblages dating to MIS 6 have been found in other South African sites such as Florisbad (top of Peat II with an age of 133.0 ± 31.0 ka) (Grün et al., 1996), Border Cave (Grün et al., 2003), Bundu Farm (Kiberd, 2006), Pinnacle Point 13 B (Jacobs, 2010), Wonderwerk (Beaumont and Vogel, 2006), and Ysterfontein 1 (Halkett et al., 2003; Avery et al., 2008). Wurz (2013) suggests that no spatial or chronological patterns can be recognized in the MSA prior to MIS 5, 130 ka ago. It is therefore not surprising that the Wonderkrater 138 ka assemblage cannot be matched with contemporary assemblages. The ‘Pietersburg’ techno-complex is well-represented in the northern part of South Africa, for example at Cave of Hearths (Sinclair, 2009), but there are no clear links between Pietersburg technology and that from Wonderkrater. In Volman's (1984) numerical classification system for South Africa the earliest phase is MSA 1, in which denticulates are prominent. Denticulates are a typological feature in Ysterfontein 1, in the earliest Klasies River assemblage (Wurz, 2002) and also at Wonderkrater.

Southern African sites with ages more recent than about 58 ka have been informally assigned to the post-Howiesons Poort (post-HP). At Apollo 11, Namibia, the immediate post-HP layer (called MSA Complex 4) contains blades, triangular flakes and only rare retouched tools, including some unifacial points and scrapers (Wendt, 1976; Vogelsang, 1996; Jacobs et al., 2008). Several Western Cape sites have post-HP assemblages. The Klasies sequence contains large blades and “knives” that comprise flat retouch on blades (Wurz, 2002), at Klein Kliphuis unifacial points are common (Jacobs et al., 2008), while at Diepkloof Rock Shelter there are unifacial points together with scrapers and denticulates (Parkington, 2006; Porraz et al., 2013). Farther east, the coastal site of Die Kelders contains blades, but little retouch (Thackeray, 2000). The post-HP lithic assemblages from Rose Cottage Cave, eastern Free State, contain unifacial points and Levallois and bipolar reduction strategies (Villa and Lenoir, 2006; Soriano et al., 2007). At Ntloana Tsoana, Lesotho, formal tools, which account for only 0.6% of the entire assemblage, are dominated by unifacial points, knives and scrapers, and the assemblage shows clear parallels with Rose Cottage. At Sehonghong, also in Lesotho, scrapers are the most common tool type (Jacobs et al., 2008). At Border Cave, the post-HP assemblages from layer 2WA contain blades (Beaumont et al., 1978; Villa et al., 2012), while the prolific Sibudu assemblage has unifacial points (Villa et al., 2005; Wadley, 2005). Mwulu's Cave (Tobias, 1949), is another MSA site close to Wonderkrater. Wonderkrater lacks the bifacial points of Mwulu's Cave, but contains similar scrapers. Unfortunately Mwulu's is also undated.

MSA assemblages continue late in the South African sites of Sibudu (Wadley, 2005), Rose Cottage Cave (Wadley and Vogel, 1991; Wadley, 1993, 1997; Clark, 1997a,b; Valladas et al., 2005), Florisbad (Kuman et al., 1999), Strathalan Cave B (Opperman and Heydenrych, 1990), Driekoppen Shelter (Wallsmith, 1990), Highlands Rock Shelter (Deacon, 1976), Boomplaas (Deacon, 1995), Umhlatuzana (Kaplan, 1990; Lombard and Phillipson, 2010) and Grassridge (Opperman, 1987). MSA tools also seem to continue late at Sehonghong in Lesotho (Carter et al., 1988; Mitchell, 1994), at Sibebe, Swaziland (Price-Williams, 1981), and Apollo 11, Namibia (Wendt, 1976). At Sehonghong and at Rose Cottage a variety of scrapers has been found together with several unifacial points, but there are low frequencies of formal tools, as at Strathalan Cave B (Opperman and Heydenrych, 1990). The youngest MSA layer at Boomplaas, dated by radiocarbon on charcoal to *c*. 36,600 ka (Deacon, 1979, 1995), has many long blades like the ones at Highlands (Volman, 1981, 1984). South-western Namibian final MSA sites also have few formal tools and an apparent lack of standardization among other lithics (Vogelsang, 1996). The presence at Sibudu, Shongweni and Umhlatuzana of some backed tools in the final MSA is noteworthy and may represent a local tradition (Wadley, 2005). The Wonderkrater Area B upper (~30 ka) and lower (>45 ka) lithic assemblage also cannot easily be matched to other late or final MSA assemblages described from a variety of sites in southern Africa, but this is not surprising since late MSA assemblage are highly variable (Wadley, 2005). Florisbad is an open-air spring site like Wonderkrater and its MSA horizon is a Last Interglacial human occupation in primary context, on a palaeo-surface that records directly associated lithic and subsistence remains (Brink and Henderson, 2001). The uppermost MSA levels may be contemporary with the Wonderkrater Area B occupation. The Wonderkrater Area B MSA assemblages correspond temporally most closely to Unit E at Florisbad (Kuman et al., 1999: 1418), but does not readily match it. This is the final MSA unit at Florisbad, which predates the c. 22–13.5 ka hiatus in the cultural sequence. It contained 116 decayed artefacts, three or four triangular flakes and ten faceted striking platforms. The two spring sites, although geographically far apart, seem to have encouraged the same type of existence, even though their technologies are not really comparable. Research on societal responses to prolonged drought, identifies water availability as the key environmental determinant for life in semi-arid regions (DeMenocal, 2001). The importance of water to the survival of people inhabiting a semi-arid environment is documented by Lee (1968) in his ethnographic account of Bushmen hunter-gatherer subsistence. This work also highlights the importance of plant foods, which constitute 60–80% of the diet, with nutritious and calorie-rich mongongo nuts providing half of the vegetable diet. While the mongongo nut is drought resistant, prolonged millennial scale drought would destroy mongongo forests, with devastating effects to those dependent upon them as a predictable, abundant and sedentary food source. In this regard, environmental stress, a decline in the number and diversity of inland fauna, and the growth of carbohydrate-rich corms elsewhere, likely led late Pleistocene hunter-gatherers in southern Africa to migrate to other areas. This is particularly likely for people living in the Wonderkrater area, considering that fruiting trees, including frost-tender marulas provide most of the wild plant food available to people in a savanna environment (Wadley, 1993). While the effect of climate change on MSA human demographics and behaviour is unclear, the lack of Later Stone Age artefacts in the overlying warm and wet Holocene peat deposits at Wonderkrater, at a time when there was a dramatic increase in LSA sites in the rest of southern Africa (Deacon and Thackeray, 1984), suggests a distinct choice by LSA people to adapt socially and culturally to other biomes.

4.3. Fauna

Excavations at Wonderkrater yielded a relatively diverse Florisian fauna (Klein, 1984a). The bone surfaces appear fresh or slightly weathered, indicating that they were buried quite rapidly. Several key faunal indicators aid in the interpretation of environmental conditions at the site at the time of MSA human occupation (~30 to >45 ka). The *Syncerus antiquus* (African long-horned buffalo) and *Megalotragus priscus* (resembling wildebeest) indicate highly productive grasslands (Brink and Lee-Thorp, 1992; Brink, 2005; Codron et al., 2008), while the $\delta^{13}C$ values indicate grassland and at least some C_3 woody vegetation in the area during late OIS 3. There are three extinct taxa in the faunal assemblage, *S. antiquus* in the upper white sand layer dated ~30 ka, and *Equus capensis* (Cape zebra) and *M. priscus* in the lower sand unit, dated >45 ka. These taxa form part of a range of large mammals that went extinct between 12 ka and ~0.8 ka (Klein, 1980, 1984b; Brink, 2005; Barnosky, 2008), and they are absent at Wonderkrater after 30 ka, as are signs of human occupation. The presence of *Diceros bicornis* (black rhino) in younger peat deposits (12–15 ka) indicates some bush or low tree cover at this time. Even though the fauna and lithics were found in association in the saturated sand layer 2.00–3.00 m below the surface in Area B, the fossils record no evidence of butchering. On the one hand, this may be because the animals are represented mostly by teeth and distal limbs, elements that often do not preserve evidence of butchering activities (Enloe, 1993; Fisher, 1995; Thompson and Henshilwood, 2011). On the other hand, the rhino might not have been processed by humans, who performed other tasks at the site.

4.4. Flora

4.4.1. Fruits and seeds

The cf. *Vahlia capensis* fruits and cf. *Xyris capensis* flowers confirm the presence of moist conditions (Pooley, 1998), in this case probably a fen, between ~1500 ka and 5500 ka. The *Acacia* seeds, cf. *Searsia* fruit and *C. lanatus* (watermelon) seed suggest sandy grassland interspersed with woody plants (Meeuse, 1962; Smit, 1999) at ~12 ka. The oldest seed, recovered from 16 ka peat deposits, is *Acacia* cf. *nilotica*. *A. nilotica* has a wide habitat tolerance, but is generally absent from watercourses (Smit, 1999; 57) and thus is likely to have been growing beyond the fen, possibly in *Acacia* woodland similar to the present day environment (Appendix Fig. A.1).

4.4.2. Pollen and microscopic charcoal

Provisionally, the pollen sequence observed in Area B through excavations between 2.90 m and 3.90 m below the surface (above and including the 1 m-thick sand unit) appears to follow the transition in Scott's Borehole 4 in Zones W2 to W4 (Scott, 1982, 1999), but this correlation should be confirmed by more pollen counts from this excavation. Based on the different dating results, including the Bayesian age modelling (Appendix Fig. C.1), the transition suggests that the MSA experienced a marked change in climate from moderately warm and dry conditions with savanna woodland vegetation (>40 ka, 3.70–3.90 m or levels 41–43) to cool and wet conditions with grassland that included woody shrubs ~30 ka (3.00–3.40 m or levels 35–38). The charcoal pieces are likely to represent more local elements, whereas the pollen represents a mixture of local and long-distance wind transported elements. Microscopic charcoal in the pollen preparations of Scott's Borehole 4, which is an indication of burning, seems to suggest moderately increased fire frequency as conditions cooled during this transition (Borehole 4, Zones W2–3), reaching higher values during the coolest phase (Borehole 3 and 4, Zone W4) (Scott, 2002), but this should be confirmed by charcoal counts from Area B. The new dates for the fossil and bone rich levels in Area B seem to support the suggestion (Scott, 1982, 1999; Scott et al., 2003) that the oldest of the radiocarbon dates in Borehole 4 (c. 34,400 yr BP, un-calibrated) is a minimum age estimate.

4.4.3. Grass phytoliths

Relatively cool growing conditions for grasses occurred in the region ~30 ka, as evidenced by the predominance of trapeziform short cell phytoliths in the sand layers, normally found in relatively cool, winter rainfall areas and environments with relatively moist, edaphic conditions (Rossouw, 2009). Their occurrence in the record could be attributed solely to the local edaphic surroundings at the spring, but the marked paucity of characteristic C_4 phytolith types, such as saddle and long-necked bilobates, adapted to warm summer rainfall climates, supports a cool and moist late MSA climatic interpretation. A shift towards predominantly bulliform phytoliths in the peat deposits above 3 m indicates a marked change in climatic conditions. The formation of silicified bulliform cells is attributed to grasses growing under conditions of increased transpiration or stress caused by a lack of water, leading to silica saturation and deposition (Bremond et al., 2005). An overall predominance of bulliform phytoliths in the peat deposits thus indicates relatively warmer conditions and increased drought stress over the last ~14,000 years relative to the period >30 ka.

4.4.4. Charcoal

In the first 85 cm below the surface in the wet centre of the mound, *Phragmites* sp. charcoal is abundant; grass occurs as well, but there is no dicotyledonous wood. The abundance and dominance of *Phragmites* in the upper peat levels (<6 ka) indicates a permanent wetland. Appendix Table F.1 details the plant remains preserved by depth in the centre of the mound. From 2.10 to 2.40 m (~12–13 ka), woody *Diospyros austro-africana* charcoal is found sporadically amongst the *Phragmites* and grass charcoal dominated assemblage, perhaps indicating fluctuating wetter and drier periods that correspond to rapid climate shifts in the interior during the terminal Pleistocene (Holmgren et al., 2003; Truc et al., 2013). *Schotia brachypetala*, found in the upper white sand levels at 3.00 m below the surface in levels 34–36, dated ~30 ka, generally inhabit quite wet areas, including the region around Wonderkrater today. Unlike in the Holocene levels, the woodland component during this time is much greater than the rare *Phragmites* and grass. This implies, in accordance with the pollen and phytolith data, moist conditions at *c*. 30 ka. Charcoal from the basal white sand levels (>45 ka) does not include any grass, and is represented by *Acacia* and *Combretum* trees, common in woodland, wooded grassland and bushland, supporting pollen evidence of warm savanna vegetation.

5. Conclusion

A suite of absolute and relative ages for sediments containing late Pleistocene fauna and flora, and evidence of human activity during MIS 3–1, and MIS 6, has been obtained for Wonderkrater. The lower peat layers, dated 12–16 ka, preserve a rich Florisian fauna and flora indicative of local fen conditions in moderately warm grassy woodland immediately prior to the megafaunal extinction in southern Africa. Below the peat a unit of coarse white sand was encountered, the top of which dates to 30 ka, evidencing a hiatus of ~11–14 ka between the peat and sand deposits, a period that includes the Last Glacial Maximum. The sand unit comprises two sedimentary events or processes; the upper sand layer has an OSL age estimate of 30 ka, and the lower a weighted mean age of 45 ka. Both layers contain late MSA lithics and a large mammal fauna. The *Damaliscus*, *Megalotragus* and *Equus* in the lower sand layer point to a substantial grassland component in the landscape >45 ka, while charcoal, phytolith and pollen data show a change from moderately warm and dry grassy savanna woodland in the lower sand levels to cooler and wetter grassland with woody shrubs in the younger levels by 30 ka. Because the lower part of the white sand layer has not yielded finite dates, there is a possibility that a second hiatus of 12–18 ka occurs between the older MSA sand layer with a weighted mean age estimate of >45 ka, and the organic-rich clay deposit underlying it, aged 70 ± 10 ka. Hiatuses need explaining, and until corroborative data are available we speculate that they may correspond to cold, dry and possibly windy periods, when the mound was deflated and subject to repeated erosion. Three small MSA lithic assemblages with age estimates of 30 ka, >45 ka and 138.01 ± 7.7 ka have been retrieved. The depth of the cultural sequence is unknown, but a subsurface sedimentary core from the margin of the peat mound shows the sand layers containing the three MSA assemblages described here to be the youngest archaeological deposits at the site.

Cave sites have been preferentially studied over open air sites, which suffer the effects of erosion and a range of destructive taphonomic processes, presenting problems with dating, association and representation. Unlike open air sites that generally served a specific short-lived subsistence-related function, cave sites have the potential to preserve a range of manifestations of different aspects of daily life over a significant period of time. The data derived from open air and cave contexts are thus hardly comparable. Apart from symbolic items that may have been lost, one would not expect to find evidence of symbolic behaviour in the context of a carcass processing site, just as one would not expect the distribution of MSA sites to fall within the borders of modern geopolitical divisions. Few MSA sites in caves or rock shelters are recorded for Namibia and Botswana (Lane et al., 1998), but we know that the land surface is littered with *in situ* MSA and older artefact knapping sites. Of the few rock shelter sites studied, Apollo 11 in Namibia has yielded the oldest *art mobilier*, and White Paintings Rockshelter in Botswana has recently produced ancient bone arrow points, OSL dated from their association with sediments to between 35 and 37 ka (Robbins et al., 2012). Until now, the disparate record of ancient bone arrow points was restricted to a few near-coastal or coastal cave sites. Good examples of innovative material culture are recorded at five inland sites (Wonderwerk, Apollo 11, Sibudu, Cave of Hearths and Bushman Rock Shelter), so we know that complex human cognition was widespread. Wonderkrater can now be added to the list of MIS 6 sites recording the use of ochre. Until such time that more MSA sites in the interior are excavated and properly dated, the deficiency in data available on inland MSA populations will continue to hinder meaningful comparison between the cultural technology and cognitive abilities of contemporaneous coastal or near-coastal dwellers, and render attempts at identifying the geographic or taxonomic origin(s) of innovative technology and complex human cognition biased.

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Appendix A. Supplementary data

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