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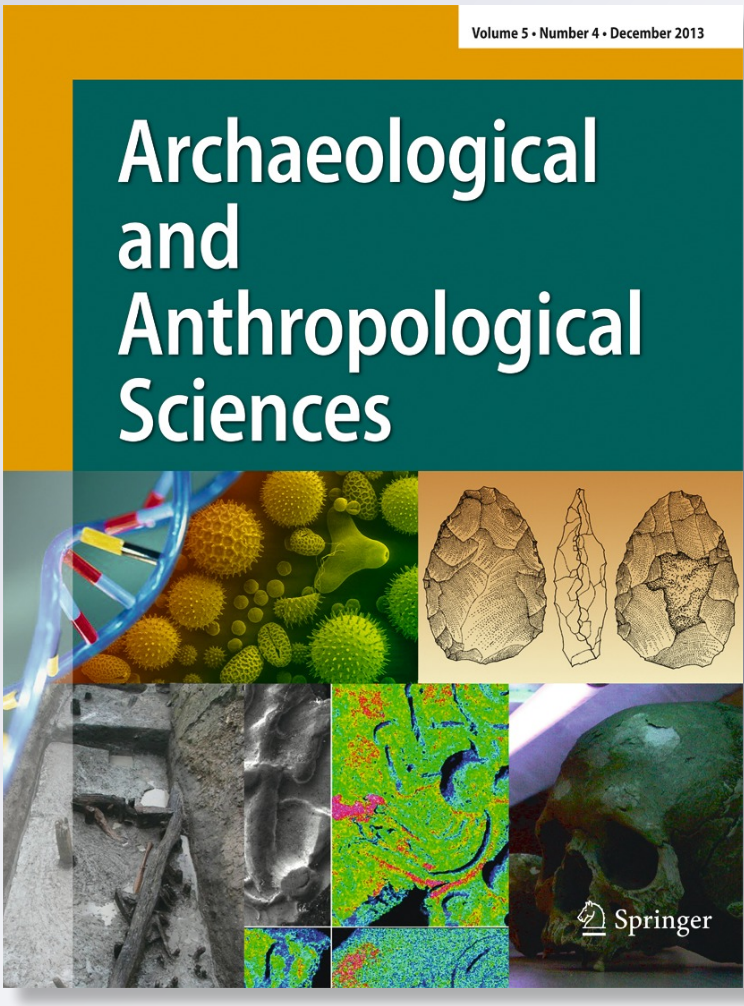
Archaeological and Anthropological Sciences

ISSN 1866-9557
Volume 5
Number 4

Archaeol Anthropol Sci (2013) 5:351-363
DOI 10.1007/s12520-013-0118-7



Springer

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ORIGINAL PAPER

The use of OSL dating in unstructured sands: the archaeology and chronology of the Hutton Sands at Canteen Kopje (Northern Cape Province, South Africa)

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Received: 17 July 2012 / Accepted: 11 January 2013 / Published online: 7 February 2013

Abstract Archaeological research at the site of Canteen Kopje, Northern Cape Province, South Africa, has focused on the rich Earlier Stone Age assemblages recovered from the Younger Vaal Gravels. This paper presents the results of excavation and optically stimulated luminescence (OSL) dating of the overlying Hutton Sands. We discuss the evidence for colonial period interaction between diamond miners and indigenous groups at the site, as well as the presence of an earlier phase of terminal Middle Stone Age/early Later Stone Age occupation. The OSL analyses demonstrate the potential distortion of OSL ages due to substantial bioturbation and its effect on the dating of archaeological sites situated in unconsolidated sands.

Electronic supplementary material The online version of this article (doi:10.1007/s12520-013-0118-7) contains supplementary material, which is available to authorized users.

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Keywords Optically stimulated luminescence (OSL) · Bioturbation · Canteen Kopje · Middle Stone Age · Early Later Stone Age · Colonial archaeology

Introduction

Optically stimulated luminescence (OSL) dating of quartz and feldspar in sediments is emerging as an essential archaeological tool as it facilitates dating sites where organic remains are not preserved (e.g., Bluszcz 2004; Wintle 2008a, b). In recent years, OSL age determinations on sediments have had a broad impact on fundamental issues in prehistory, including the origin of modern humans (e.g., Armitage et al. 2011; Barton et al. 2009; Feathers 2002, Jacobs et al. 2008a, b; Marean et al. 2007; Porat et al. 2002) and the timing of human arrival in Australia and the Americas (cf., Olley et al. 2006; Waters et al. 2011). However, because the method is based on sediments, it requires taking into consideration the depositional processes involved in site formation, factors which determine the association between the ages on the one hand and the archaeological context on the other. Several researchers (e.g., Bateman et al. 2007; Feathers et al. 2010; Tribolo et al. 2010; Gliganic et al. 2012; Rink et al. 2012) have pointed to the potential of bioturbation to affect the accuracy and precision of OSL ages in unstructured sands or archaeological sediments, an issue relevant to all buried open-air sites.

Here, we present a study of OSL dating from an archaeological context in unstructured sands at the site of Canteen Kopje, Northern Cape Province, South Africa. There is some inherent interest in this excavation with regard to the distinction between the lithics of the Middle Stone Age and early Later Stone Age and evidence of colonial period interaction between diamond miners and indigenous groups.

However, the broader significance of this project is the evidence it provides for the potential distortion of OSL ages due to bioturbation and its effect on the dating of archaeological sites occurring in unconsolidated sands.

Canteen Kopje

Canteen Kopje (28°32′35″ S, 24°31′51″ E) is a small, low hill 1.3 km southeast of the town of Barkly West (Northern Cape Province), situated on the north bank of the Vaal River, some 16 m above and 500 m distant from the river, and opposite the Mission Station at Pniel (Fig. 1). This location plays an important role in the modern history of southern Africa. Beginning in 1869, Canteen Kopje, also known as Klipdrift, was the location of the first alluvial diamond mining in interior Africa. Before miners caught wind of the potential of the deposits in Kimberley, the rush for diamonds focused on Canteen Kopje, and a mining town rapidly sprang up. The lure of diamonds was a powerful draw, bringing people up from the Cape Colony to the interior of southern Africa, and the political tension over the control of these resources set the stage for the rivalries that culminated in the Boer War (Williams 1902; Roberts 1976).

Between 1869 and 1948, Canteen Kopje was intensively mined for diamonds, and it is estimated that at least 200,000 tons sediment was removed (De Wit 2008). Both

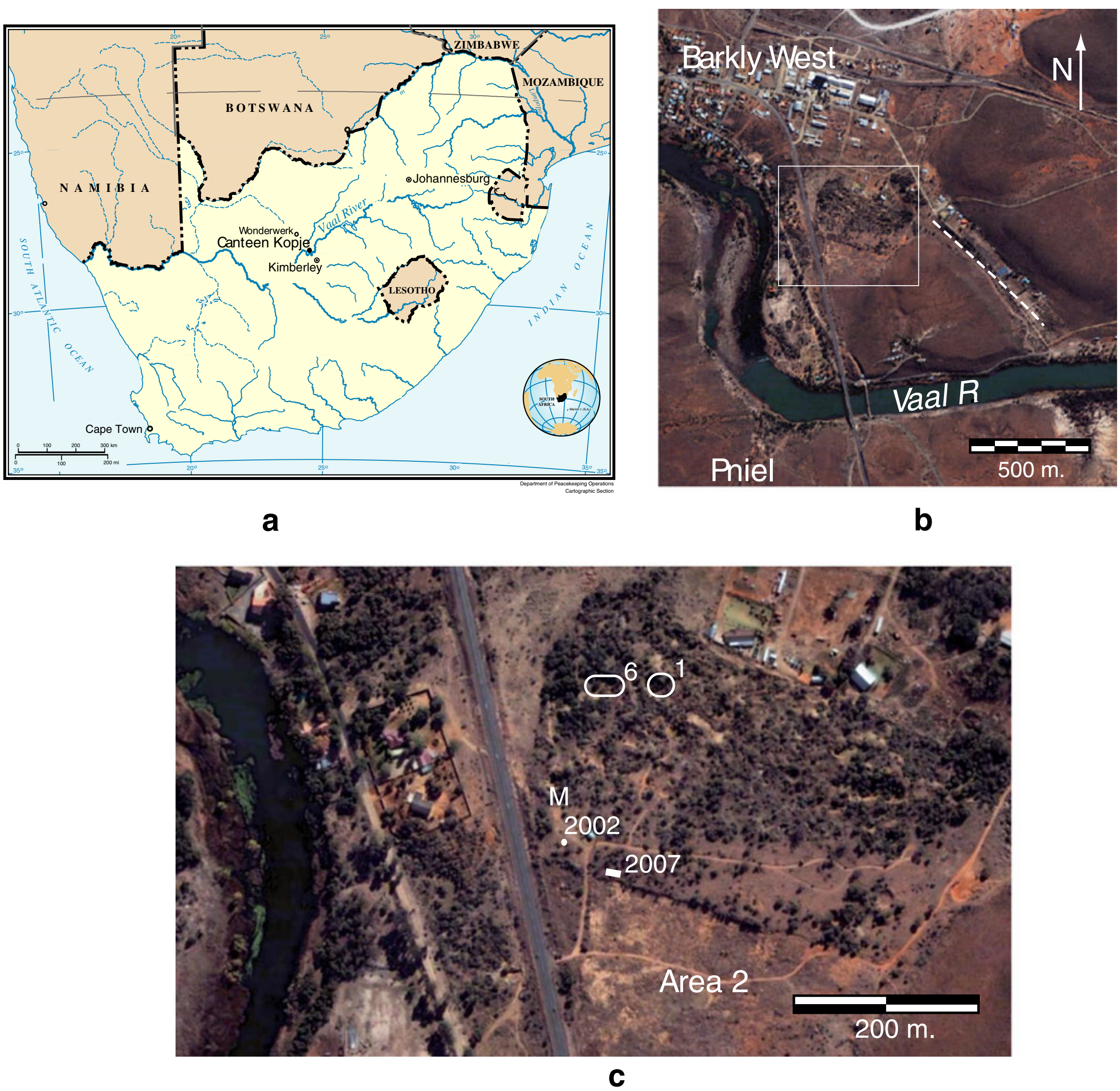

Fig. 1 Location of Canteen Kopje. **a** Map showing location of the site. **b** Satellite image of Barkley West, the Vaal River, and Canteen Kopje (*white square*). **c** Satellite image of the site with the locations of areas described in the text. *1* mining pit 1, location of Beaumont and McNabb excavations 1997–2000. *6* mining pit 6, location of excavations reported by Forssman et al., *M* location of the historic marker, *2007* our 2007 excavation, *2002* 2002 OSL sampling (Pit CK-21), *area* 2 mined area outside the declared National Monument trenched by Beaumont

the mining pits and the filled tunnels are visible across the site today, along with massive dumps and piles of concentrates.

The Vaal River, the narrow gallery forests which flank it, and the availability of raw materials for knapping of stone artifacts offered an attractive locale for past hominin populations as demonstrated by the long record of archaeological occupation along the river banks (Peringuey 1911; Goodwin 1928; Goodwin and Van Riet Lowe 1929; Helgren 1978, 1979; Söhnge et al. 1937; Power 1955; Beaumont 1990, 2004). The Hutton Sands that lie upslope of the river support a savanna–parkland with typical elements of the Kimberly Thorn Bushveld such as several species of acacia trees, buffalo thorn shepherd's tree, velvet raison shrubs, and a variety of grasses. Both early travelers and archaeozoological records document the rich and varied game supported by this mosaic environment (e.g., Skead 1980, 1987; Plug and Sampson 1996).

The presence at Canteen Kopje of archaeological remains going back to the Acheulian was first noted by Peringuey (1911) followed by Goodwin (1928). The enormous number of Acheulian artifacts at the site, along with the ease of access to the site via the Cape Town–Kimberley railroad, brought many of the luminaries of early nineteenth century archaeology to the site. In 1948, a nature reserve was created (subsequently declared a National Monument) on an area of approximately 9.2 ha encompassing the main mining pits at Canteen Kopje. In 1996, a permit was issued for small-scale mining of the area to the south of the declared area resulting in the removal of most of the intact deposits outside the limits of the National Monument. In 2000, the site was the subject of development as a heritage site and open-air displays inaugurated with the support of the Dutch government (Turkington 2000).

Despite the prominence of Canteen Kopje in the archaeological literature (cf. Peringuey 1911; Goodwin 1928; Goodwin and Van Riet Lowe 1929), there have been few controlled archaeological excavations at the site (see locations in Fig. 1c). In 1997–1998, Beaumont carried out a limited excavation in two trenches that he labeled area 1 (also called pit 1, Beaumont 2004) and area 2, the latter located outside the declared National Monument area (Fig. 1c). These excavations focused on the Vaal Gravels (stratum 2 in Beaumont 1998, see Supplement S1). The overlying Hutton Sands (stratum 1 in Beaumont 1998) had either been stripped or disturbed prior to excavation in both areas 1 and 2. In 1999, Beaumont extended the excavation to another trench in area 2, and this was excavated to bedrock. In 2000, Beaumont and McNabb renewed excavations in the Younger Vaal Gravels in area 1 (Beaumont and McNabb 2000; McNabb 2001; McNabb and Beaumont 2011). All these excavations resulted in the recovery of extensive collections of Acheulian artifacts (McNabb 2001; Sharon and Beaumont 2006; McNabb and Beaumont 2011, see Supplement S1). Recently, a team from the University of Witwatersrand has undertaken excavation of the Hutton Sands and underlying Vaal Gravels in the mining pit designated pit 6 (Forssman et al. 2010; Gibbon 2009).

The sedimentary and associated archaeological sequence at Canteen Kopje has been described by several researchers (Partridge and Brink 1967; Butzer et al. 1973; Helgren 1978, 1979; Beaumont 1990, 2004; McNabb and Beaumont 2011) and, most recently and comprehensively, by De Wit et al. (1997) and De Wit (2008) (see Supplement S1).

Stratum 1, the Hutton Sands, is the uppermost unit at the site. It comprises red silty sand of aeolian origin that occurs as a thin cover in the distal part of the gravel units and increases in thickness in the lee of the gravel splay. Helgren (1978, 1979) suggested that the sands represent two intervals of valley colluviation (Riverton III, early Riverton IV), while Beaumont (1998, 2004) noted four horizontal sublevels separated by paleosols or grit lenses in a new section of the Hutton Sands excavated in 1998, which he interpreted as separate episodes of glacial accretion.

In his earlier 1990 description, Beaumont (1990, p. 14) reported the presence of sporadic Later Stone Age (LSA) artifacts within the Hutton Sands and "a few MSA [Middle Stone Age] lithics of unknown affinities within it." In a later paper (Beaumont 2004, p. 26), this description was revised, and LSA artifacts are noted as being on the surface of the Hutton Sands, and MSA artifacts within the Hutton sands, while a small number of Fauresmith artifacts were recovered in the lowest level of the Hutton Sands at the interface with stratum 2a (depth of 0.3 m within this stratum). In neither paper are descriptions or illustrations of the LSA or MSA artifacts given. In a recent publication, Forssman et al. (2010) report on a LSA assemblage in the Hutton Sands in pit 6 at Canteen Kopje (Fig. 1c) which resembles the late Holocene Smithfield industry. This archaeological occurrence lay 70–140 cm below datum and was dated by radiocarbon to 1436 AD to present. Below this, ca. 140–150 cm below datum, MSA lithic pieces occurred.

The 2007 excavation

In 2007, a 2-week field season was undertaken by the authors at Canteen Kopje, aimed at sampling the archaeological horizons and dating the Hutton Sands. Our excavation was placed in close proximity to an exposed section of the Hutton Sands located at the eastern edge of the declared historic area (Fig. 1c). This location was chosen because there was no evidence of disturbance by diamond mining (the remains of the tunnels were visible to the east of the excavation area), and lithic artifacts were visible in the exposed section. Initially, four 2×2-m squares (designated V20–V26) were laid out, and excavation began in arbitrary 10-cm spits (Supplement S2). All sediments were dry sieved through a 0.025-in. (1-mm) mesh. No faunal or other organic remains were found, probably due to the poor preservation of organic material at the site which is also the case of the Vaal Gravels at Canteen Kopje. Although it was suggested (Broom 1929; Beaumont 1990) that a human skull found during diamond digging in 1929 may derive from either stratum 1 or 2, a recent reanalysis of this skull concluded that it probably represents an LSA intrusion into the Vaal gravels or the base of the Hutton Sands (Smith et al. 2012).

The stratigraphic section compiled from the excavation and the OSL results are presented in Figs. 2 and 3. Archaeological material was discovered immediately below the surface during the 2007 excavation, while the base of the main artifact distribution is 45 cm below the current surface (Fig. 3). During excavation, it was not possible to identify sediment changes in the deposits associated with archaeological material. However, two archaeological components (termed here "Upper Component" and "Lower Component") were identified in the excavated material. Their distinction was based on typo-technological criteria

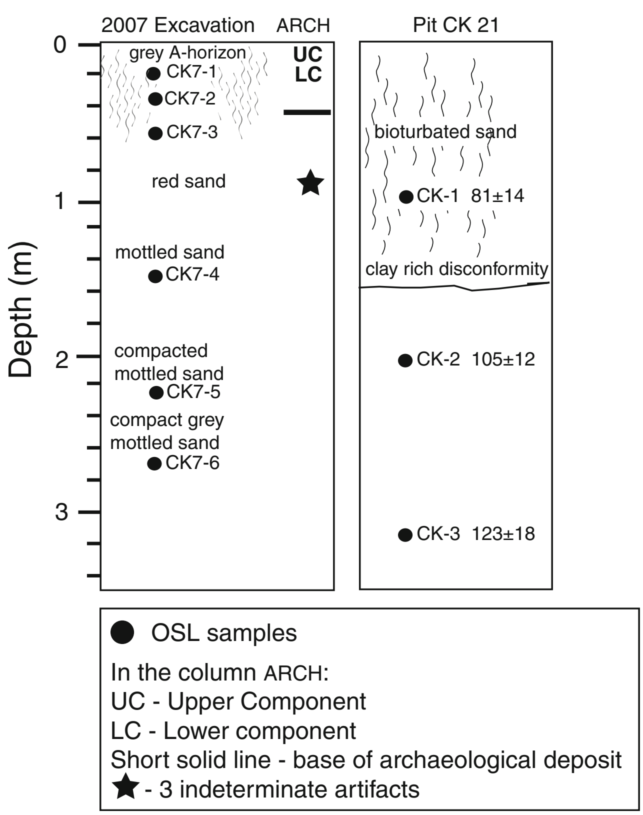

Fig. 2 *Left* columnar stratigraphic section of the Hutton Sands (stratum 1) in square V22 (the deepest sounding). *Right* a comparison to pit CK 21 that was sampled in 2002 (De Wit 2008). Samples collected for OSL dating from both sections are shown, together with the ages (in thousand years) for pit CK 21 (De Wit 2008), which are multi-grain, large aliquot measurements. The tops of pit CK 21 and the 2007 excavation are, respectively, 2.8 and 1.00 m below the base of the historical marker (shown in Fig. 1c)

(Fig. 4) and, to some degree, depth below surface, although there is clearly some degree of vertical mixing of artifacts as attested to by the overlap in depth below datum (set at current surface height) of material from the two components (Supplement Table S1). A small sample of lithic material was recovered at a significant depth below the Lower Component (Fig. 3).

Since there was difficulty in distinguishing between industries based on stratigraphic criteria or depth below surface on the basis of 10-cm spits, six 1×1-m squares were opened at the eastern end of the excavation area and were excavated in 5-cm spits. Piece plotting was not undertaken given the exploratory nature of this excavation. Future excavation in this context should employ piece plotting to further clarify the relationship between the components. Excavation in most of these units was terminated at 70 cm below datum as sediment without archaeological remains was reached. A deep sounding in square V22 was dug to a depth of 3.5 m (Fig. 2). At about 1.9-m depth, the sands become grayer in color and are more compact in the very deepest part of the excavation (Fig. 3). The total area excavated was 22 m^2 (Supplement Fig. S2.1).

The upper component

The Upper Component is largely confined to 0–45 cm below datum, with most finds from a depth of 5–15 cm below datum. In the top 5 cm of the deposit, a small hearth was identified in square V22 (Fig. S2.2b). The hearth was characterized by black staining of the red sand approximately 20 cm in width. No evident structures were associated with the hearth, and the charcoal remains were too fragmentary for dating. The artifact assemblage from the upper component includes a significant amount of glass, a lithic assemblage with bipolar bladelet production, metal items, and ceramics (Supplement Fig. S3, Supplement Table S3).

In the uppermost layer, only ten small pieces of pottery were recovered during the excavation. None are diagnostic or larger than 2 cm. All are dark colored, coarse earthenware with thickness between 6 and 7 mm. The pottery is grit tempered and shows no evidence of surface decoration other than a single incised line on one sherd. The six metal objects are nondescript bits of iron with the exception of a fragment of a nail, a bullet shell, and a crushed can with heavy soldiering at the top and base (the lid is folded in). The diameter of this object is 7.9 cm, and the height is 7.7 cm.

The glass assemblage includes 18 objects, most of which show evidence of knapping (Fig. 4, a–b, Supplement Fig. S3.1). The colors of glass are clear (n=7), frosted (n=7), and dark green (n=4). Identifiable fragments include the bottom of a bottle, the neck of a jar, a base fragment, a base fragment with two parallel grooves above the base, and the

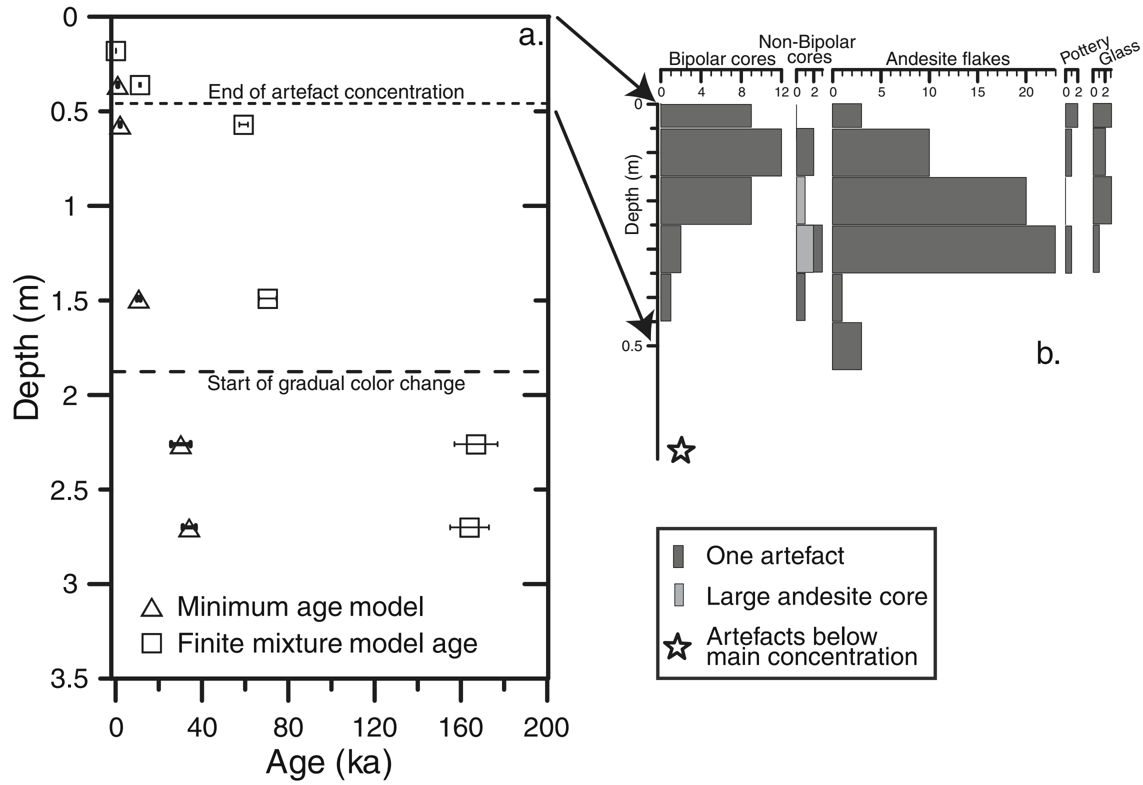

Fig. 3 *a* OSL single grain model ages versus their depth in the section (see details and Tables 2 and 3). *b* The frequency of key artifact types from main excavation squares (V20–26) as a function of depth. The *horizontal dashed line* on panel *a*. Separates an older phase, isolated from bioturbation at 30–40 ka, from a younger phase that is still effected by surface mixing

corner of a square-sided vessel. There is one triangle with no signs of retouch (all edges broken off), one distal bladelet fragment, and three flakes. Six pieces are flakes along an edge, and one piece has a flake detached from the interior surface. Five pieces do not show clear signs of modification.

Bipolar cores (*n*=36 for squares V20–26) on small chalcedony pebbles, and flakes and bladelets produced from these cores are the dominant element of the Upper Component lithic assemblage (Fig. 4, d; Supplement Fig. S3.2). The evidence for bipolar reduction includes opposing bulbs of percussion,

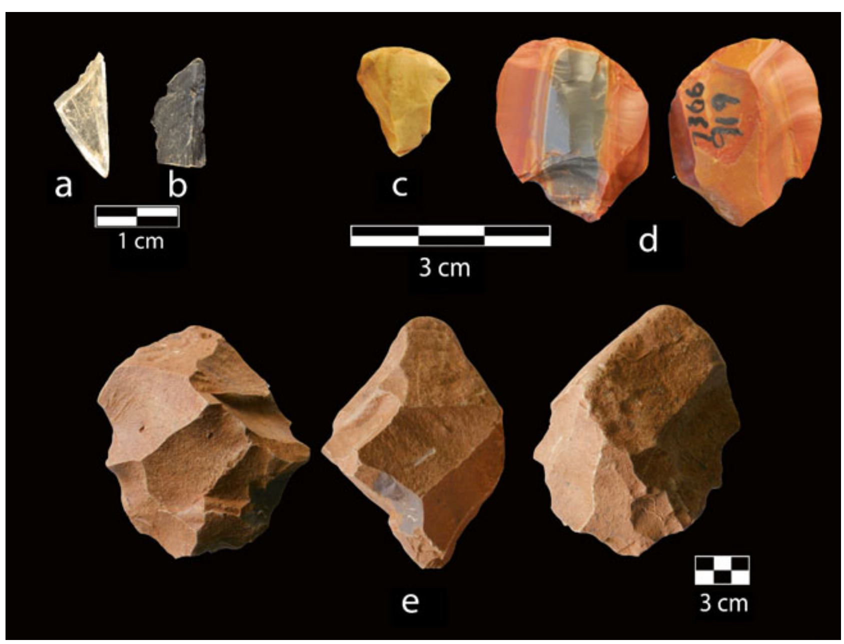

Fig. 4 Glass and lithic artifacts from Canteen Kopje, Hutton Sands. *a–b* Glass artifacts from the Upper Component. *a* Triangle with flake scars. *b* Bladelet. *c–d* Artifacts from the Upper Component made on chalcedony pebbles. *c* Micro-endscraper. *d* Split pebble/bipolar core. *e* Andesite discoidal core from the Lower Component

crushed platforms, and highly irregular cores. Formal microliths are rare, and backed bladelets are absent. There are two micro-endscrapers, with lengths of 15 and 14 mm (Fig. 4, c). The other retouched tools consist of a square flake with marginal retouch at the distal end and a bladelet with fine marginal retouch (Supplement Fig. S3.2b).

Significance of the upper component

Given the paucity of diagnostic material, it is difficult to attribute this assemblage with any certainty to a specific industry, but it probably falls within the range of variation of the late Holocene Smithfield complex, characterized by large end scrapers, few microliths, and the presence of pottery and European artifacts (Sampson 1974; Deacon 1984; Close and Sampson 1998).

A number of authors have noted the significance of glass in late LSA sites located in the arid interior of South Africa. Mason (1949) documents a glass scraper recovered from the Riverview Estates at Windsorton, also on the Vaal River, as well as similar tools recovered near Phillipolis on the Colesberg road, while Saitowitz and Sampson (1992) note the increasing use in the Seacow Valley of European building materials, including glass, after 1880. There seems little question that the presence of glass as a raw material in an assemblage indicates contact between hunter–gatherer/pastoralists and colonial settlers. It is important to emphasize that the diamond diggings at Canteen Kopje were the first significant colonial occupation in this area and was continuous after 1869, so that it is unlikely that the use of glass on the site predates mining. The diversity of glass used is striking, including a range of bottle shapes, thickness, and colors. Thus, it appears that the tools were made from the scavenged remains of many broken bottles rather than from a complete vessel.

Both Beaumont (1961) and Allen and Jones (1980) have commented on the difficulty of distinguishing between flaked glass and glass that is fractured accidentally by trampling (see the discussion in Cooper and Bowdler 1998). At Canteen Kopje, a number of lines of evidence support the identification of intentional knapping of glass: (1) bifacial and alternate retouch, often indicative of trampling (McBrearty et al. 1998), is rare; (2) bladelets and flakes are present along with bottle fragments with modified edges; and (3) there is little evidence on the chert artifacts for large-scale trampling in this location.

The production of tools on small chalcedony pebbles might also serve as evidence of interaction between local people and the early miners. The geological source for the chalcedony is small pebbles that formed as amygdales in vesicular rocks, that like the diamonds, were trapped in the Younger Vaal Gravels (De Wit 2008, p. 57). Both translucent and highly lustrous pieces were used in bipolar core production. There is some question as to how the occupants of Canteen Kopje came to have access to such a large number of these pebbles that would normally be deeply buried in the Vaal Gravels. One intriguing possibility is that the bipolar industry at the site is evidence of the exploitation of concentrate heaps left behind by miners as they searched through the Vaal Gravels. If this scenario is correct, then the glass and the bipolar industry both reflect an opportunistic use of resources generated by the early miners at Canteen Kopje by hunter gatherers or pastoralists.

In conclusion, it appears that the Upper Component can be identified as dating to the colonial occupation of the site beginning in 1869, based on the presence of bottle glass and metal objects. The very young OSL ages (see below) are consistent with such a recent occupation. Alternative scenarios may explain the presence of European manufactured materials as the result of earlier trade relations, but this is unlikely to explain the prevalence of artifacts made on chalcedony pebbles. Once diamond mining was underway at Canteen Kopje, European presence was continuous.

The lower component

At 15–25 cm below datum, a series of flat slabs of andesite and a small assemblage of large andesite artifacts were found that we identify on techno-typological grounds as an early LSA/terminal MSA occupation (Fig. 4, e; Supplement Fig. S3.3). The most characteristic component of this assemblage is the production of large andesite flakes on radial cores (Fig. 4, e; Supplement Fig. S3.3g). The cores show some evidence of platform preparation and the production is well organized. This industry is best defined as discoidal, with organized flaking of two faces at an acute angle to the plain of intersection between the two surfaces. A number of large andesite slabs (length and width ranging from 10 to 16 cm) were found in association with the Lower Component assemblage (Supplement Fig. S2.2c). One slab is incised with three parallel lines, and one has an incised x (Supplement Fig. S2.2d).

A non-bipolar small flake industry comprises an ambiguous element of the assemblage (Supplement Fig. S3.3, Supplement Table 3.1c, cores, n=4). This industry is found in contexts dominated by large andesite flakes and cores rather than glass and bipolar core reduction that characterize the Upper Component. However, it is unclear whether they belong to the Lower Component or whether these tools represent a distinct occupation. The non-bipolar small flake production includes a range of raw materials including quartz, chert, and other fine-grained materials. Retouched tools (n=8) include a circular scraper and endscraper on fine-grained volcanic rock (both cortical flakes) (Supplement Fig. S3.3c and e); marginally retouched flakes on quartz, quartzite, and an unidentified fine-grain raw material (Supplement Fig. S3.3a); a convex sidescraper on quartzite (Supplement Fig. S3.3b); a truncation on an unidentified fine-grained raw material; a notched quartzite flake; and a steep scraper on fine-grained volcanic rock. The cores are mostly discoidal and range from 4.5 to 3.2 cm in their maximum dimension (Fig. 4, e; Supplement Fig. S3.3d).

Significance of the lower component

The Lower Component is either a terminal MSA or early LSA industry and is dominated by andesite flakes and cores. The only typologically significant element of the Lower Component is the circular scrapers on flat cortical flakes. These tools have parallels in early LSA sites along the Orange River (Sampson 1968). Overall, the Lower Component has technological similarity to the Kuruman Industry identified by Thackeray at Wonderwerk Cave Excavation 1, Level 4d, spanning the period 10,200±90 BP to 7,430±60 BP (Humphreys and Thackeray 1983; for compilation of radiocarbon ages, see Thackeray 1981, p. 105). According to Humphreys and Thackeray (1983, p. 282–283), the Kuruman Industry is found along the western and eastern fringes of the Ghaap Plateau. It is characterized by large scrapers manufactured on coarse-grained materials and rare-backed artifacts, while the common tool types are large scrapers made on dolomite or banded ironstone.

The Kuruman Industry is considered equivalent, but not identical, to other early Holocene regional variants spanning the period ca. 12,000–8,000 BP, such as the Lockshoek Industry in the eastern Karoo and the Albany of the southern and eastern Cape. These industries are characterized by large scrapers on coarse-grained materials and absence of microliths, while blades and backed artifacts are absent or rare (Bousman 2005; Deacon 1984; Humphreys and Thackeray 1983; Sampson 1974). The early LSA of the Northern Cape Province thus appears to be characterized by large flake industries that in undated assemblages will be difficult to distinguish from a late MSA lithic assemblage (see also Henderson et al. 2006). It is possible that this is the MSA material referred to by Beaumont (1990, 2004) and Forssman et al. (2010) as present in the Hutton Sands in other parts of Canteen Kopje

Below the lower component

Excavation below the Lower Component was restricted to a deep sounding in a 0.5-m square, square V22. Excavation of this unit was terminated at 3.5 m below datum (Fig. 2). By the base, the sands were highly compacted and gray in color; however, the top of the Younger Vaal Gravels was not reached. Artifacts and non-artifacts were extremely rare. Below 0.95 m, only 6 fragments of andesite and 40 small pebbles were recovered, but none were modified. At a depth between 0.85 and 0.95 m, a fine-grained andesite flake, a split chalcedony pebble with a single flake removal, and a large fragment of igneous rock (8.5 cm maximum dimension) were recovered.

Field and laboratory analyses

Sediment analyses

Bulk sediment samples were taken for grain size analyses from the deep sounding within the excavation at depths of 0.18–2.7 m (Fig. 2; Table 1). Analyses were carried out on five samples by laser diffraction (Malvern Mastersizer MS-2000). The results (Table 1) show that the sediment from Canteen Kopje has a bimodal grain size distribution, with a substantial silt fraction, and grain size mode ranges from 200 to 120 μm. The location of Canteen Kopje, well south of the current Kalahari Desert boundary, raises questions about the source of these sands. The modal grain size of the Kalahari dunes is ~200 μm; it gradually decreases with distance south of the Kalahari and reaches ~100 m at Wonderwerk Cave, a distance of 150 km (Matmon et al. 2012). Since the site of Canteen Kopje is at an even greater distance from the Kalahari dune field, and the grain size coarser than in Wonderwerk Cave, the source of the sand fraction is likely to be from the adjacent Vaal drainage system.

OSL dating

Sediment samples for OSL dating (Aitken 1998) were collected in 2002 from the section of an open pit located near the current excavation (marked as "2002" in Fig. 1c, De Wit 2008) and then in 2007 from the deep sounding within the excavation (marked as "2007" in Fig. 1c). Sampling procedure entailed cleaning the section under cover and then hammering dark PVC pipes into the section while ensuring no exposure to sunlight. Down-section, the sediments became very compacted, making it impossible for the pipe to penetrate very far. For these samples (CK7-5 and CK7-6), blocks of sediment were removed from the sections, immediately wrapped in thick aluminum foil, and later cleaned in the laboratory under dim orange lighting from any material that might have been exposed to light. Dose rates were calculated on additional bulk sediment samples collected from the same sampling locations. The concentrations of U, Th, and K in the sediment were measured by ICP-MS (U and Th) or ICP-AES (K). Cosmic dose rates were evaluated from burial depths, and moisture contents were estimated as 5±2 % for the sandy samples and 10±3 % for the lower, compact samples, based on moisture content in sandy sediments in

Table 1 List of sediment samples, their depth and brief description, and grain size analyses results. Grain size measurement details are as in Crouvi et al. (2008)

Sample	Depth (m)	Description	Clay (%)	Silt (%)	Sand (%)	Modal grain size (μm)	Munsel color
CK7-1	0.18	Below contact between gray soil horizon and red sand. Root penetration	4.1	38.5	57.4	152	
CK7-2	0.36	Red sand with few roots	4.0	34.3	61.7	166	
CK7-3	0.57	Red sand with very few rootlets					
CK7-4	1.49	Mottled red soil	5.0	32.9	62.1	200	7.5 YR 5/4
CK7-5	2.26	Hard, compact mottled sand	5.7	45.5	48.8	122	7.5 YR 5/8
CK7-6	2.70	Very hard, gray with orange mottling	5.4	50.1	44.5	122	7.5 YR 5/8

semi-arid regions. The concentrations of the radioactive elements and the dose rates per sample are given in Table 2.

Quartz with grain size 88–125 m was purified using routine laboratory procedures (Porat 2007). Briefly, carbonates were dissolved with 10 % HCl and organic material removed using H_2O_2. The rinsed and dried samples were passed through a Frantz magnetic separator to remove heavy minerals and most feldspars. A 40-min rinse in HF (42 %) was used to dissolve any remaining feldspars and etch the quartz grains, followed by rinsing in 16 % HCl to remove any fluorides which may have precipitated. After rinsing and drying, the samples were measured.

The equivalent dose (De) was determined using the single aliquot regenerative dose protocol (Murray and Wintle 2000) using a refurbished DA-12 Risø reader or a single-grain DA-20 Risø reader, with calibrated beta sources. Dose recovery experiments over a range of preheats determined that the optimal preheat temperature is 10 s at 260 °C, combined with a test dose preheat of 5 s at 220 °C (Supplement Fig. S4.2). In addition, De was measured with preheats ranging from 220 to 260 °C, using 5-mm aliquots ("large aliquots"; ~1,000 grains) to average out any grain-to-grain differences. When it became apparent that the samples are highly nonhomogenous, 2-mm aliquots ("small aliquots"; ~200 grains), followed by single-grain measurements, were carried out on the samples, and measurement procedures and data screening closely followed those outlined by Jacobs et al. (2003). The available quartz grain size from the Canteen Kopje, 125–88 μm, is smaller than the grain holes in the sample holder, 300 μm. Therefore, three to four grains filled each hole, and essentially, these are micro-aliquot measurements; this is the term used throughout the paper.

OSL results and discussion

The OSL signal of the measured samples is very bright and is dominated by the fast component (Supplement Fig. S4.3). Dose recovery tests over a range of preheats (Supplement Fig. S4.2) show that laboratory doses can be recovered reliably. Recycling ratios are mostly within 3 % of unity, and IR depletion ratios are negligible.

The De values for the multi-grain measurements have a large scatter, illustrated by the high over-dispersion values (Table 2). Nonetheless, overall, the ages calculated from the averaged De are in stratigraphic order (Table 3). The ages range from 1,200±1,200 years (before 2010, when measurements were carried out) at the top, to 143,000±24,000 years at a depth of 2.7 m (Table 3). This age range agrees with previous multi-grain large aliquot OSL ages of samples from similar depths collected from the open pit at Canteen Kopje in 2002 (Fig. 2; De Wit 2008).

To better constrain the age of the sand and to elucidate the scatter in the De, micro-aliquots were measured. A total of 200 micro-aliquot holes were measured for each sample; of these, between 46 and 160 micro-aliquots were suitable for further data processing, after passing the criteria of Jacobs et al. (2003). It appears that the scatter of the De values of the micro-aliquot measurements is even greater, with over-dispersion values as high as 110 % (Table 2). Two statistical models (Galbraith and Roberts 2012) were used to isolate significant grain populations from the micro-aliquot measurements: the minimum age model (MAM) was used to isolate the youngest grain population and the finite mixture model (FMM) to identify the most prevalent age component. The youngest grain population isolated by the first model was, used as an indication of the time up to which the sample was close to the surface and was exposed to bioturbation. The second model assumes that the sediment comprises several components of grains with discrete ages and attempts to isolate them. The most prevalent grain population will, in our opinion, most likely represent the major deposition event of the sediment, prior to any diagenetic mixing. All samples contain a mixture of young and old grain components, indicating substantial mixing (Supplements S4.1 and S5), but the deeper the sample, the older is the youngest grain population (Fig. 3). Bioturbation is probably also reflected in

Table 2 OSL field and laboratory data, chemical analyses, dose rates, and number of measurements carried out by each technique

Sample	Depth (m)	Water (%)	K (%)	U (ppm)	Th (ppm)	Ext. α (μGy/a)	Ext. β (μGy/a)	Ext. γ (μGy/a)	Cosmic (μGy/a)	Total dose (μGy/a)	Measurement technique	No. of disks/grains	Over-dispersion (%)
CK7-1	0.18	5	0.83	1.9	6.7	10	943	696	247	1,896±38	LA	37	100
											MA	160/200[a]	110
CK7-2	0.36	5	0.91	1.4	6.1	8	921	634	223	1,785±37	LA	18	47
											SA	24	51
											MA	99/200[b]	110
CK7-3	0.57	5	0.91	1.2	4.9	6	848	546	205	1,606±35	LA	18	33
											SA	24	52
											MA	160/200	110
CK7-4	1.49	10	1.00	1.2	5.0	6	878	554	174	1,612±44	LA	13	14
											MA	147/200	81
CK7-5	2.26	10	1.08	1.0	3.7	5	877	495	159	1,535±46	LA	13	39
											MA	46/200	71
CK7-6	2.70	10	1.08	1.1	4.5	6	906	539	150	1,602±49	LA	13	16
											MA	131/200	62

Grain size for all samples is 88–125 m. Errors on chemical analyses are: K ±3 %, U ±5 %, and Th ±10 %. Water contents were estimated from similar sand deposits in semi-arid regions, with an associated error of ±30 %. No. of disks/grains is the number of aliquots or grain measurements. For the micro-aliquots, the number of accepted grains is shown as a proportion of those measured

LA large aliquots (5 mm, ~1,000 grains), *SA* small aliquots (2 mm, ~200 grains), *MA* micro-aliquots ("single grain", 3–4 grains)

[a] Only 72 grains (of 160) were, within errors, >0

[b] 94 grains (of 99) were, within errors, >0

Table 3 OSL ages using various measurement techniques and models

Sample	Depth (m)	LA	SA	MA MAM	MA FMM
CK7-1	0.20	1.2±1.2			0.13±0.01
CK7-2	0.35	36±20	24±11	1.0±0.2	11.3±0.4
CK7-3	0.60	61±20	52±23	2.1±0.2	59±2
CK7-4	1.50	78±14		10.7±0.8	71±4
CK7-5	2.25	146±62		30.3±4.4	167±10
CK7-6	2.70	143±24		34.0±3.0	164±9

The MA ages were calculated using both the MAM and the FMM. The De values obtained from the different models and used for the age calculations are in Supplementary Table S4.1

LA large aliquots (~1,000 grains per measurement), *SA* small aliquots (~200 grains per measurement), *MA* micro-aliquots ("single grains", 3–4 grains per measurement).

the distribution of the archaeological artifacts, which do not appear in a single horizon but are dispersed over some depth range (Fig. 3).

The MAM could not be used on the uppermost sample due to its very young nature and the presence of grains with "negative" ages. The MAM for the remaining samples range from 1.0±0.2 ka at a depth of 0.36 m, 2.1±0.2 ka at a depth of 0.57 m, and 11±1 ka at 1.5 m (Table 3; Fig. 3, a). The youngest grain population for the two lowermost samples gives an age of 30–34 ka. The FMM found three to seven components in the samples, and the most frequent grain population was used for age calculations (Supplement S4). The ages range from 130±10 years (before 2010) for the uppermost sample to 164±9 ka for the lowermost sample, at a depth of 2.7 m (Table 3; Fig. 3, a). These micro-aliquot model ages (Table 3, Fig. 3) can be used to better constrain the time of sand deposition and the degree of mixing by bioturbation, even though some blurring of grain populations might have occurred due to the measurements of three to four grains in the same measurement hole. Starting from the two lowermost samples (CK7-5 at 2.3 m and CK7-6 at 2.7 m), the FMM ages of the most frequent grain population (Table 3 and Supplement Table S4.1) of these samples are 167±10 ka (39 % of all grains) and 164±9 ka (36 % of all grains), respectively. These similar ages could be interpreted as the time of the major sand deposition. However, both samples also contain a substantial fraction of grains (20–23 %) with ages of 300–315 ka, which could indicate even greater antiquity for the sand at the base of the studied section. The MAM for those two samples are 30±4 and 34±3 ka, respectively; these are somewhat older than the youngest FMM age component of 26 ka (7 % of grains) and 23 ka (3 % of grains), respectively. The ages obtained using the MAM represent in our opinion the time when the beds were buried deep enough to no longer be affected by bioturbation.

The overlying samples (CK7-3 at 0.6 m and CK7-4 at 1.5 m) have FMM ages of 59±2 ka (22 % of all grains) and 71±4 ka (32 % of all grains), respectively. Their MAM ages are substantially younger than for the underlying samples, 2.1±0.2 and 10.7±0.8 ka, respectively, indicating, at least for sample CK7-3, that until recently, it was within the bioturbation zone.

The uppermost samples (CK7-1 at 0.2 m and CK7-2 at 0.35 m) give FMM ages of 0.13±0.01 (92 % of all grains) and 11.3±0.4 ka (30 % of all grains), respectively. That the shallowest sample also contains a small grain population (2 %) giving an age of ~52 ka is evidence for the level of bioturbation. In this horizon, a mixture of bipolar and non-bipolar cores, as well as andesite flakes, pottery, and glass of mixed ages, were found (Fig. 3), attesting to substantial post-depositional mixing.

This high level of grain mixing is consistent with the observation by Bateman et al. (2007) that bioturbation is most significant in the top 1.5 m of stable deposits; sand grains are brought to the surface by, for example, termite activity; their OSL signal is partially or fully reset; and subsequently, they are reburied by the same processes. McBrearty (1990) stresses the capacity of termites to create buried stone lines, while Johnson (1990) argues that bioturbation of sediments by ants can lead to vertically distinct horizons of artifacts deposited on the surface at different times (see also Frolking and Lepper 2001). Recently, Rink et al. (2012) demonstrated the role of ants in bringing older grains closer to the surface.

If older grains are considered as remnants of old unbleached sediment, and the young grains represent more recent bleaching, then two scenarios are possibly applicable to Canteen Kopje. The first is that a period of rapid sand accumulation was followed by an extensive period of stability, during which sediments were reworked by bioturbation. The stratigraphic order of the ages is in fact a mixing profile between the original old grains and the surface zero-age grains; as one goes down the profile, the proportion of young grains (those with more recent bleaching) decreases, but these can be found all the way to the depth of bioturbation. The depth to which artifacts have "sunk" through bioturbation in this scenario is linked to the time since deposition on the surface. The overlapping vertical distribution of the two archaeological components which were identified based on techno-typology is consistent with such a scenario.

The second scenario could be of gradual sand deposition over time, augmented by bioturbation. As a layer is buried below the depth of bioturbation, it ceases to be mixed with younger grains, and thus the lowermost samples should have very few, if any, zero-age grains. Supporting this scenario are the lowermost two samples, which do not contain grains younger than 23–26 ka, suggesting that by that time, they were buried below ~1.5 m of sand, not far from their current depth. These samples were deposited at least ~165 ka, or even ~300 ka, as indicated by a substantial, old grain population.

As depicted in the results of the micro-aliquot measurements, mixing is substantial, and grains as old as 52 ka are found in small quantities in the uppermost sample. In both scenarios, the increased ages through the profile are a result of declining turbation efficacy with depth rather than a true measure of age of deposition and as such cannot be used as ages for the deposition of the sands or, by extension, as ages for the archaeological assemblages. Similar mixing has been reported from other sites, for example, Kobo I and 'Abri aux Vaches, Mali (Tribolo et al. 2010) and Mumba Rock Shelter, Tanzania (Gliganic et al. 2012).

Although OSL dating does not provide a direct means of assessing the age of the archaeological assemblages recovered from the Hutton Sands at Canteen Kopje, these results do have archaeological implications. The presence of a substantial grain population dated to ~300,000 ka provides a minimum age for the underlying Younger Vaal Gravels. It is likely that this age constraint also applies to the Fauresmith assemblage, deriving from the interface between the Younger Gravels and the Hutton Sands that was described by Beaumont (2004).

There is strong evidence from the lower OSL samples for a deposition event ~165 ka. However, these sediments remained open to bioturbation until 23–26 ka, suggesting that the deposition of the Hutton Sands was not the result of a single event. If this were the case, we would expect that the lowest samples would not contain significant evidence of bioturbation, since they would have been more than 1.5 m below the surface. An indication of multiple depositional events is also hinted by Beaumont's observations of paleosols in the Hutton Sands (Beaumont 1998, 2004) and our finding of a small number of artifacts at a depth of 0.85–0.95 m below the surface.

The key archaeological question was whether the lithics of the Lower Component should be attributed to the MSA or the early LSA. Although the OSL dating fails to provide an age for this assemblage, the results heavily favor an age in the Late Pleistocene or Early Holocene. The absence of grains younger than 23–26 ka in the lower samples suggests that by that time, the Late Pleistocene, the upper 2 m of sands was deposited. Since the most likely scenario is that the burial of the Lower Component is due to bioturbation rather than deposition, it is difficult to reconstruct an age of >40 ka for the Lower Component, as might be expected from an MSA assemblage. In fact, an age of <25 ka seems more parsimonious. The Lower Component for Canteen Kopje thus offers tentative support for the identification of a distinctive early Later Stone Age industry in the region as had been proposed by Thackeray (1981) based on the lithic assemblage from Wonderwerk Cave Layer 4d.

Conclusions

The project at Canteen Kopje began with the expectation that OSL age determination on sediments would provide strong constraints on the age of stratigraphically associated archaeological assemblages. The goal was to add much needed chronological control for the Late Pleistocene/Early Holocene archaeology of the Northern Cape. One important result was the identification of a colonial component at the site that appears to offer concrete evidence for interaction between indigenous people and the early miners at Klipdrift. The presence of an ambiguous industry in the Lower Component, one that might date to the late MSA or early LSA, is also of interest given the dearth of MSA sites in the region. Despite initial optimism that a series of OSL ages in stratigraphic order might provide an absolute date for these assemblages, further micro-aliquot analyses as undertaken here suggest that the large scatter in the ages obtained for the sediments associated with the archaeological assemblage is most likely the result of mixing and bleaching of sand grains due to bioturbation, and the age of the archaeological layers can only be roughly constrained. The OSL micro-aliquot ages do, however, provide insight into sedimentological processes at the site and illustrate the role of bioturbation in unstructured sands. The oldest grains measured, of ~300 ka, suggest that the onset of the accumulation of sands at Canteen Kopje was at least this early, offering a limited constraint on the age of the underlying Younger Vaal Gravels. Although the OSL analysis does not provide a secure age for the Lower Component, the data support a Late Pleistocene/Early Holocene age for this assemblage

Acknowledgments Research was carried out under SAHRA permit no. 80/04/06/016/51. Funding was provided by the Canadian Social Sciences and Humanities Research Council and the University of

Toronto International Experiential Study Program. We would like to thank the director and staff of the McGregor Museum and the students from the University of Toronto who participated in the excavation. We thank the reviewers for their comments that greatly improved the manuscript.

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