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New radiometric ages for the Fauresmith industry from Kathu Pan, southern Africa: Implications for the Earlier to Middle Stone Age transition

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ABSTRACT

The Fauresmith lithic industry of South Africa has been described as transitional between the Earlier and Middle Stone Age. However, radiometric ages for this industry are inadequate. Here we present a minimum OSL age of 464 ± 47 kyr and a combined U-series–ESR age of 542^{+140}_{-107} kyr for an *in situ* Fauresmith assemblage, and three OSL ages for overlying Middle and Later Stone Age strata, from the site of Kathu Pan 1 (Northern Cape Province, South Africa). These ages are discussed in relation to the available lithostratigraphy, faunal and lithic assemblages from this site. The results indicate that the Kathu Pan 1 Fauresmith assemblage predates transitional industries from other parts of Africa e.g. Sangoan, as well as the end of the Acheulean in southern Africa. The presence of blades, in the dated Fauresmith assemblages from Kathu Pan 1 generally considered a feature of modern human behaviour (McBrearty and Brooks, 2000, The revolution that wasn't: a new interpretation of the origin of modern human behavior, J. Human Evolution 39, 453–563),-provides evidence supporting the position that blade production in southern Africa predated the Middle Stone Age and the advent of modern *Homo sapiens*.

1. Introduction

Recent discoveries demonstrating the antiquity of modern human behaviors from as early as 160–170 kyr in the Middle Stone Age (MSA) of southern Africa (Marean et al., 2007), have highlighted the importance of clarifying both the nature and timing of the Earlier Stone Age (ESA) to MSA transition in this region. A key industry in this debate is the Fauresmith of southern Africa (Fig. 1).

The Fauresmith lithic industry was first described by Goodwin and Van Riet Lowe as containing bifacially worked small handaxes made on flakes, flake scrapers and hardly any cleavers (Goodwin, 1926; Van Riet Lowe, 1927; Goodwin and Van Riet Lowe, 1929; Söhnge et al., 1937). Subsequent definitions of its artifact composition and chronological affinity have varied, with researchers emphasizing the association of different lithic components including small and broad handaxes, cleavers, large and elongated flake-blades, polyhedrons, burins/gravers, convergent (Levallois) flakes, large retouched points made on flakes and prepared (Levallois) cores as well as rare and poorly-made cleavers (Söhnge et al., 1937; Clark, 1970; Sampson, 1974; Deacon and Deacon, 1999; Klein, 2000; Beaumont and Vogel, 2006). Recent excavations at the site of Rooidam II even intimate that handaxes may not occur in all Fauresmith contexts (Richardt, 2006). Most definitions of the Fauresmith do however stress the co-occurrence of three characteristics: small handaxes, long blades and convergent points (Mitchell, 2002).

The stratigraphic position of the Fauresmith in the Vaal River gravel sequence, overlying ESA Acheulean deposits (Van Riet Lowe, 1935, 1937; Söhnge et al., 1937; Beaumont and Vogel, 2006), and the fact that its lithic technology combines handaxes characteristic of ESA Acheulean industries together with MSA characteristics – prepared core flake method and systematic blade production – has meant that the Fauresmith has variably been characterized as a Late Acheulean industry (Mason, 1962; Sampson, 1974; Klein, 2000), a transitional Acheulean-MSA contemporary with other similar industries such as the Sangoan, thought to date ca. 300 kyr (Clark,

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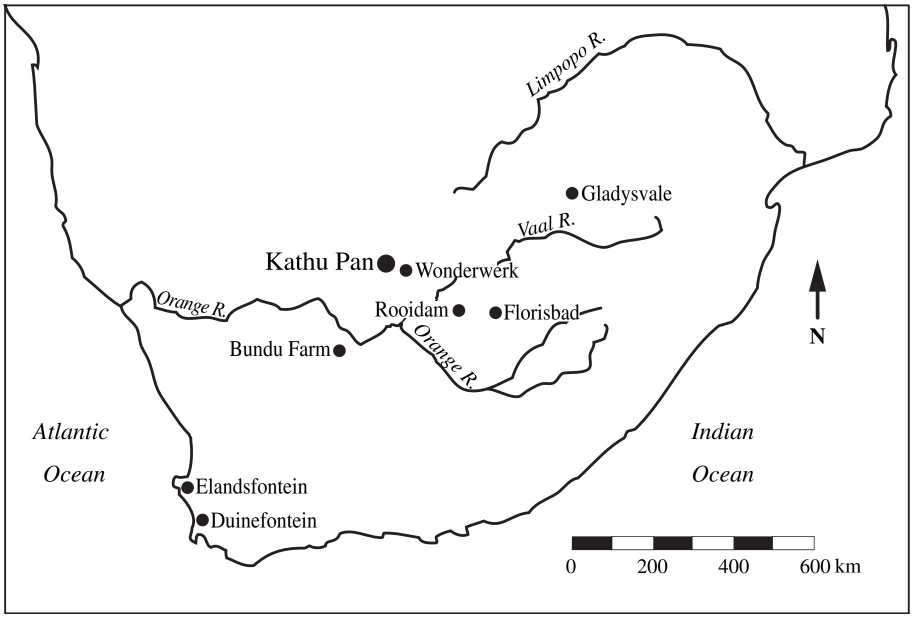

Fig. 1. Map showing the location of Kathu Pan 1 and other late ESA and early MSA sites mentioned in the text.

1970; McBrearty and Brooks, 2000), or as an early MSA industry (Bordes, 1968). Alternately, Humphreys (1970) suggested that the distinction between the Late Acheulean and the Fauresmith was the result of regional differences in raw materials.

Fig. 2 illustrates that available radiometric ages for the Fauresmith do not temporally constrain this industry. At the site of Rooidam I the Fauresmith assemblage containing broad bifaces, flakes with facetted platforms but few cleavers or choppers (Fock, 1968; Butzer, 1974), was dated by U-series to >174 kyr (Szabo and Butzer, 1979). At Bundu Farm a series of seven sedimentary horizons were identified from twenty-six excavation trenches (Kiberd, 2006). ESR dating of teeth from this site, tentatively assigned to Group 4–5 horizons, and identified as final or transitional Acheulean, produced ages of 360–150 kyr, with a mean age of 245 kyr. The lithic assemblage from these horizons consists of a flake assemblage produced on mostly radial and irregular cores. One biface was recovered from the Group 6–7 boundary (below the dated context). A more precise date is available from Wonderwerk Cave (Excavation 2, strata 3–4, Major Unit 3). Here, U-series ages on small stalagmites that are contemporaneous with the sediments, for an industry identified as Fauresmith and containing blades together with large bifaces, prepared cores and unifacial Levallois points, cluster around 286–276 kyr (Beaumont and Vogel, 2006). However, two older U-series ages >349 kyr and >350 kyr from the same site (Excavation 1, stratum 6, Major Unit 4), that were apparently associated with a Fauresmith assemblage (Beaumont and Vogel, 2006), are now thought to be associated with an Acheulean assemblage that lacks a Fauresmith component (Chazan et al., 2008; Chazan et al., in press). It is evident that radiometric ages for well-defined Fauresmith assemblages, based on multiple dating methods from controlled *in situ* contexts, are needed.

The Fauresmith deposit (Stratum 4a) from the site of Kathu Pan 1 (KP-1; Fig. 1), situated 4.5 km north west of the town Kathu [Gamagara Local Municipality, John Taolo Gaetsewe District Municipality (formerly Kgalagadi), Northern Cape Province, South Africa], offers an excellent opportunity to study the lithic composition of this industry, its associated fauna and most critically, to date it. KP-1 has yielded a rich Fauresmith assemblage comprising prepared cores, few handaxes, Levallois points, convergent or laterally retouched side-scrapers and blades in association with a rich faunal assemblage. (Klein, 1988; Beaumont, 1990, 2004).

2. The site

Kathu Pan 1 lies within a marshland (vlei) which, until modern pumping commenced, had a water table some 2–3 m below the present land surface. The site represents one of a series of 11 dolines that are developed within the Tertiary sequence of the Kalahari Group (40 m thick calcretes that are underlain by ca. 30 m thick sands, clays and basal gravels), and underwent infilling over time (Beaumont et al., 1984). The lowest 7–8 m of doline infills represent Pleistocene deposits while the upper 3.5–4 m contain Holocene peats and silty sands (Figs. 3a and 4). Eight adjacent dolines at Kathu were investigated by Beaumont and colleagues (Butzer et al., 1978; Beaumont et al., 1984; Butzer, 1984a,b; Beaumont, 1990, 2004), and have provided an excellent archaeological, sedimentary and palaeoclimatic sequence for the region, constrained by a series of radiocarbon dates for the upper levels.

Aside from pumping, artesian seepage controls the water levels in the pans today, and undoubtedly did so in the past. At different times, groundwater rising under pressure resulted in spring-eyes penetrating the Pleistocene infillings from below via vents (Butzer, 1984a). The perennial presence of water in the pans contrasts to the surrounding region where such water sources are scarce today and would have been so in the past, such that the pans would have served as nuclei attracting animals and hominins.

Excavations at KP-1 were initiated by Beaumont in 1978 and continued through the 1980s (Beaumont, 1990). Together with Butzer (1984a), an archaeological and sedimentary sequence ca. 11.7 m depth was recorded and divided into five archaeological and geomorphological units (Strata 1 through 5; see Fig. 4), spanning from the Holocene to Middle Pleistocene (Butzer et al., 1978; Beaumont et al., 1984; Butzer, 1984a,b; Beaumont, 1990). The geoarchaeological section of KP-1 (Figs. 3 and 4) is described here (from top to bottom), based on descriptions in Butzer et al. (1978), Butzer (1984a,b), Beaumont et al. (1984), Beaumont (1990), and our field observations (see below). All descriptions of the lithic industries of Strata 1–3 are based on Beaumont (1990).

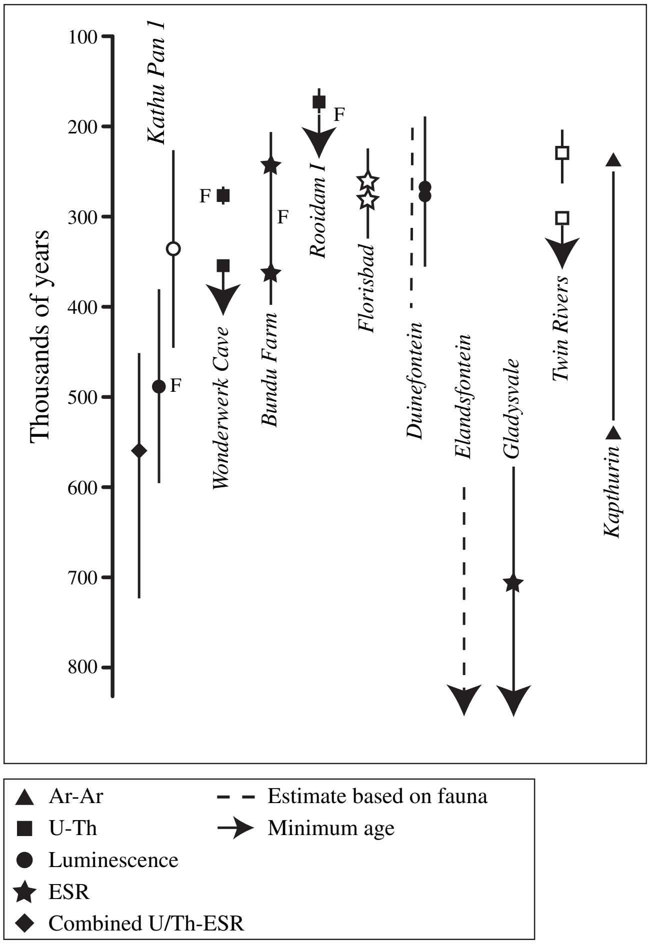

Fig. 2. Comparison of radiometric ages for Middle Pleistocene sites in South Africa (see Fig. 1 for locations) and relevant sites in East Africa. Errors or uncertainties on ages are shown in solid lines extending above and below the symbols. Arrows indicate that the dated unit provides only a minimum age for the industry, and the true age could be older. Open symbols – MSA; F – Fauresmith industry. From left to right: *Kathu Pan*, this work. *Wonderwerk Cave* (Beaumont and Vogel, 2006), the upper age and lower ages are for the Late Fauresmith (Excavation 2) and Middle Fauresmith (Excavation 1) respectively. Re-examination of the Excavation 1 assemblage has failed to corroborate the presence of a Middle Fauresmith in this part of the cave (Chazan et al., 2008). *Bundu Farm* (Kiberd, 2006), range of ages tentatively assigned to Groups 4 and 5. *Rooidam I* (Szabo and Butzer, 1979), an isochron U-series age for a unit covering Fauresmith-late Acheulean industry. *Florisbad*, ESR ages on a human tooth and animal teeth from Units N-P that are associated with early MSA artifacts (Grün et al., 1996; Kuman et al., 1999). *Duinefontein*, on the left Klein et al. (1999), estimates based on large mammals and a single large classical handaxe. On the right Feathers (2002), range of luminescence ages calculated from alkali feldspar-quartz subtraction. *Elandsfontein* (also called Saldanha, Klein et al., 2007), an archaic hominin skull, later Acheulean artifacts. *Gladysvale* (Hall et al., 2006), a single hand axe and a preliminary ESR age. *Twin Rivers* (Barham and Smart, 1996), travertine capping MSA industries in Blocks A and F. *Kapthurin* (Deino and McBrearty, 2002), minimum and maximum ages for a mixed Acheulean and MSA industry with blades in site LHA/GnJh-03. Flake and core industry from sites GnJh-41, GnJh-42 and GnJh-57 were dated at 550–520 kyr (errors on ages smaller than symbols).

Stratum 1 lies below the modern top-soil. It is ca. 2 m thick, pale grey unit of calcified sands that inter-finger with at least three dark-grey layers identified as ‘peat’, which formed in a marshland with standing water. It is mostly sterile, but the base contains Later Stone Age (LSA) artifacts (Wilton industry overlying an Albany industry).

Stratum 2 is a thick (ca. 1.5–1.8 m), sandy grey unit of aeolian origin towards the base and with increasing calcification towards the top, that formed during a relatively arid phase. It contains ostrich eggshell fragments, beads and artifacts tentatively attributed to the LSA (Robberg industry).

Butzer (1984a: 257) noted the presence of a sedimentary unconformity separating Strata 2 and 3, comprising a non-organic sediment “conformable with the upper but not the lower unit”. The upper unit deposits “begin with moderately calcareous fine sandy loam and terminate with 20 cm of highly calcareous loam. The dominant, fine sands are well sorted and aeolian, either primary or derivative. They suggest a much lower but gradually rising water table, culminating in seasonal, alkaline mud flats with little vegetation” (Butzer, 1984a).

Stratum 3 is a ca. 0.8 m thick, dark brown gravely unit in a grayish white sand matrix, containing reworked MSA artifacts and faunal remains (Table 1). These were possibly deposited by a paleostream, the Vlermuisleegte, whose path can be traced outside the pan, or, as suggested by Butzer (1984b), deposited by intermittent flash floods that swept across the Kathu area. The fact that many of the MSA artifacts are edge-worn together with the presence of a gravely sand matrix, all point to this representing a secondary deposit. A step in the exposed section occurs at the base of this unit (Fig. 3b).

Stratum 4 lies below this step and is exposed in the lower, narrow part of the doline, down to the base of the cleaned section. This unit is more than 1 m thick and is a complex deposit of fine, uncalcified yellowish-white sands that formed in seasonal ponds with higher water levels than at any later time.

This sand complex is crossed by vertically to sub-vertically oriented old spring eye vents which were created in episodes of rapid groundwater up-welling that ‘squeezed’ coarse, gravelly sands up through the existing sediments (Butzer, 1984b). These spring vents contain coarser debris including dense deposits of lithic artifacts (in fresh condition), and faunal remains dominated by teeth, mainly with only their enamel preserved (Fig. 3c). Two sub-units were identified within Stratum 4, based on their lithic and faunal components.

The *Stratum 4a* stone tool assemblage was characterized by Beaumont (1990) as Fauresmith, a finding that will be discussed in detail below, while the fauna from Stratum 4a, examined by Klein (1988), is dominated by grazers (Table 1).

Stratum 4b contained an Early Acheulean lithic assemblage (Beaumont, 1990), a finding that has been confirmed by ongoing analysis by one of the authors (MC). The fauna from Stratum 4b (Table 1) is characterized by the presence of *Elephas recki* (Fig. 5).

Stratum 5 comprises up to 3.5 m of sterile, lightly calcified pale orange aeolian sands overlying bedrock (at 11–12 m), deposited shortly after the sinkhole was formed when the overlying sediments collapsed due to a lowered water table.

2.1. New fieldwork

In 2004 further fieldwork was undertaken by our team at Kathu Pan I. The recently accumulated modern fill was removed and a 4.5 m deep section of Beaumont’s geo-archaeological section was cleaned (up to 10 cm back from the face) and documented. We exposed Strata 1 through 5 and were able to correlate the strata with the original published section (Fig. 4). As illustrated in Fig. 3, Strata 1 through 3 are stepped back from the lower Strata 4 and 5, creating a wide step near the base of Stratum 3.

Of particular interest was the Fauresmith bearing Stratum 4a. In the course of cleaning this stratum, two well-defined vertical spring vents were exposed. The lowermost vent was located to the west of the upper vent and was only sampled in a limited manner due to its inaccessibility (Lower Vent). The uppermost vent proved to be densely packed with both lithics and fauna (Upper Vent, Fig. 3c), and was sampled for both OSL and combined U-series–ESR dating.

It is important to note that the vertical spring vents occur only in Strata 4a and b and stop at the boundary with the overlying Stratum 3,

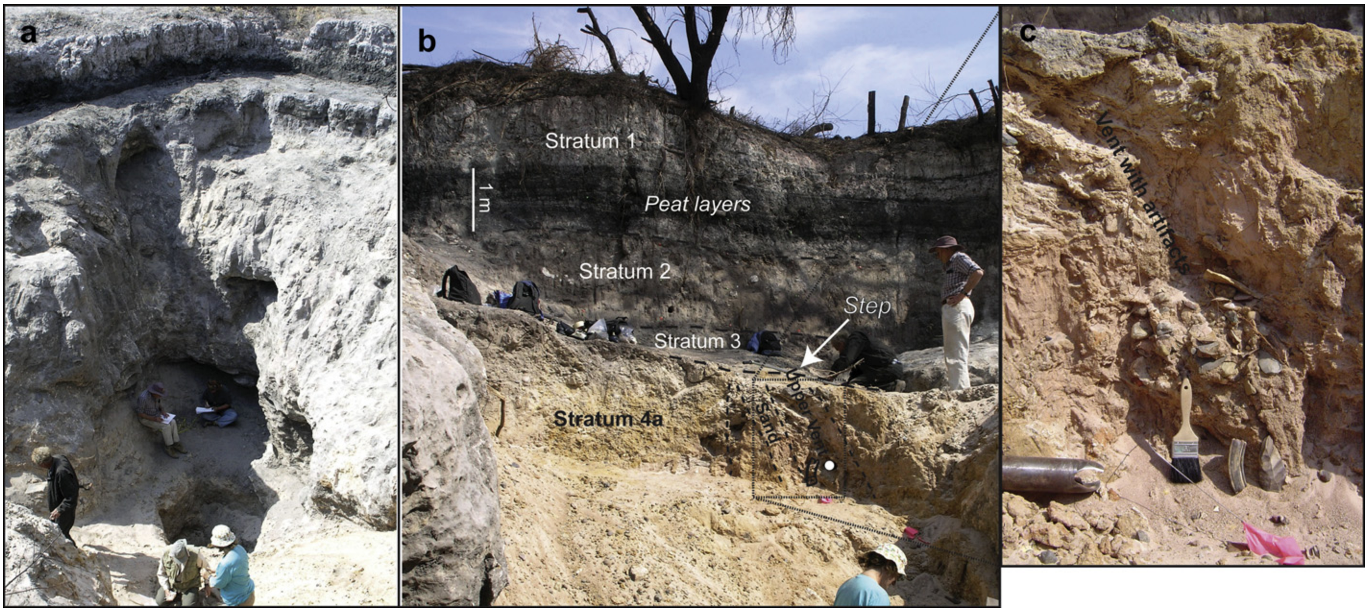

Fig. 3. Views of KP-1. a. View towards the south showing the calcrete edge of the doline. b. View towards the north showing most of the infill. The contacts between the strata are shown as dashed lines, as well as the location of OSL sample #4 (white circle) and the *Equus capensis* tooth sample dated by U-series–ESR dating (tooth cartoon) in the Upper Vent. c. Close up of the Upper Vent after partial cleaning (hand brush is 20 cm long). Note density of artifacts. To the right of the brush are the *E. capensis* tooth and one of the lithic finds.

negating any possible sedimentary contamination between these strata. Furthermore, the Stratum 3 gravel deposit differs significantly in its composition from the underlying Stratum 4a, so there is a clear sedimentological boundary between the two units. Likewise, there is no evidence for mixing of material between Strata 4a and 4b, despite similarities in the depositional matrix, with each unit containing markedly different but homogeneous faunal and lithic assemblages. The precise mechanisms that led to the concentration of lithic material and fauna within the vents remains unclear and neither Beaumont (1990, 2004) nor Butzer (1984a,b) offered any explicit explanation. Similar concentrations are known from Florisbad and Amanzi Spring (Butzer, 1984b; Deacon, 1970; Grobler and Loock, 1988) but KP-1 differs from these in the absence of a spring mound and in the overall sedimentological formation processes. The most likely scenario is that lithics and fauna were incorporated into the spring vent along with sediments during annual cycles of rising and falling groundwater levels, with winnowing of the fine fraction. This process could not have involved high-energy transport as many of the lithics are fresh and completely unabraded.

3. Lithic assemblage

A small assemblage of flaked stone artifacts ($n = 34$) was collected by us from the cleaned section in the Upper Vent of Stratum 4a (Fig. 6). The samples for OSL and U-series–ESR dating were taken in direct association with these artifacts (Fig. 3c). The artifacts resemble material excavated from the immediately adjoining Stratum 4a Square F21 by Beaumont (1990) and attributed by him to the Fauresmith. Using the ANOVA test it was determined that there is no significant effect of context (the individual excavation spits in Square F21 compared to the sample from the dated Upper Vent) on flake elongation (Table 2), implying that the differences in elongation between our collected sample and the material excavated by Beaumont are statistically insignificant. This uniformity allowed us to combine the lithics from the cleaned section with those of the excavation and enlarge the lithic sample to a total of 217 flakes, of which 152 are complete.

The majority of artifacts in both samples are fresh with sharp edges (Table 3). Raw material is varied and artifacts were made on fine-grained rocks with little exploitation of the locally available banded ironstone. Plain platforms are dominant (47%) but faceted platforms are also frequent (27.2%; Table 3). Cores are dominated by typologically Levallois cores ($n = 11$), followed by polyhedron shaped cores ($n = 8$), and discoid cores ($n = 6$; Fig. 7). Blade cores such as those found in the early blade industries of the Kapthurin Formation, Kenya, are absent (Tyron and McBrearty, 2006). KP-1 production appears to fit the technological criteria for the Levallois method as defined by Geneste et al. (1990). The overpassing flake in Fig. 8e clearly shows the bidirectional exploitation that predominates in this assemblage, as does the blade in Fig. 8a and the cores in Fig. 7b and c. Radial preparation of cores is shown in the core in Fig. 7a. Blades were produced by the creation of an extremely laterally convex flaking surface. Fig. 6b and d and Fig. 8b and c show flakes and blade produced in this fashion and gives a sense of the range of flake elongation. The blades in Figs. 6c and 8d show the production of blades at the edge of a core. The overpassing blade in Fig. 8a can be regarded as an unintentional accident of knapping that demonstrates the extent of lateral core convexity used to produce blades. This extreme lateral convexity distinguishes the KP-1 assemblage from the norm for the Levallois method [see Van Peer (1992) for a similar technology from the Nubian MSA].

The blades are often triangular in shape and tend to have one oblique edge. Retouch is found on 24.5% of the flakes and blades ($n = 53$), with notches and side-scrapers the dominant type of retouch. The ratio of flakes to blades at KP-1 is 8:1. Following Bordes (1961), we define blades as detached pieces that are twice as long as they are wide, with length and width measured along the axis of percussion. As shown in Fig. 9, the blades were produced as part of a reduction strategy that produced flakes with a range of morphologies, producing a near normal distribution.

Bifaces are absent from both our dated sample and from Square F21. However, they do occur in other parts of Stratum 4a excavated by Beaumont, where they are in association with flakes and blades like those found in our Upper Vent sample and Square F21. Bifaces were found in the Lower Vent uncovered during our cleaning. The

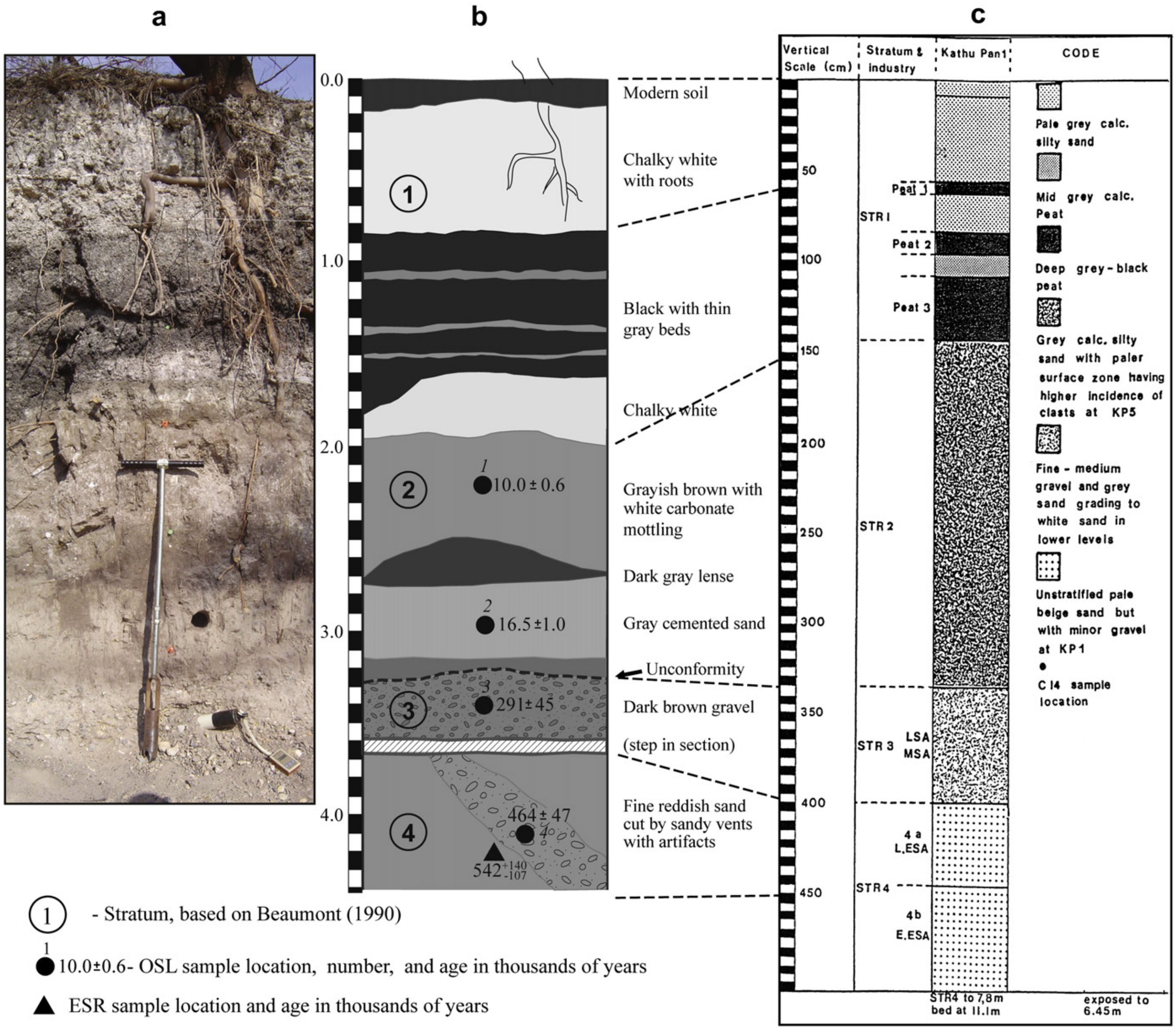

Fig. 4. Columnar section of KP-1 showing the stratigraphy of the old and newly exposed sections. a: compiled photograph of the section cleaned during the 2004 season, auger is 1.6 m; b. Stratigraphic interpretation of the 2004 section with OSL and ESR ages;. The actual location of the ESR sample (triangle) is within the vent, almost overlapping the circle marking the OSL sample c. Stratigraphic section of the old excavation by Beaumont (1990). Correlations between the old and new sections are marked with dashed lines.

bifaces from both this Lower Vent collection and from Beaumont's excavation conform to the Fauresmith; they are small in size and irregular in form (Fig. 10). These pieces are clearly distinguished from the bifaces found in the underlying Early Acheulean of Stratum 4b in their shape, size, and raw material (Fig. 11). The Stratum 4a bifaces are made on a wide diversity of raw materials in marked contrast to the exclusive exploitation of banded ironstone in the underlying Stratum 4b. In addition, the Stratum 4b bifaces are symmetrical and refined while those from the Fauresmith Stratum 4a are crude and irregular. The absence of bifaces from our dated sample appears to reflect spatial variability within Stratum 4a, and is probably an artifact of the small area that was cleaned.

4. Faunal assemblage

Fauna from KP-1 were studied and published by Klein (Klein, 1988; Klein in Beaumont, 1990) (Table 1). Due to groundwater chemistry, mainly enamel caps of the teeth were preserved, a feature that has probably biased the range and abundance of species represented. Stratum 3 contains a narrow range of taxa, predominantly grazers (Table 1). The majority of taxa in both Strata 4a and 4b are grazers, with few browsers or mixed feeders indicating a very grassy, savanna environment. Stratum 4a is characterized by an abundance of bovines followed by equids (Klein, 1988), while the high water table at the time of Stratum 4a is attested to by the only remains of *Hippopotamus* at the site. Remains of *E. recki* are restricted to the Early Acheulean of Stratum 4b. The high crowns and very thin, tightly folded enamel of the Kathu specimens (Fig. 5) resemble Todd's Group III (Todd, 2005), spanning the broad time range of 2.85–0.4 Ma.

A well preserved upper cheek tooth of *Equus capensis* was recovered in 2004 during section cleaning from the Upper Vent in Stratum 4a (Fig. 12), and after morphological and biometric analyses was used for ESR dating. The tooth is extremely large (Fig. 12), larger than any premolars of Cornelian age (1.0–0.6 Ma; Codron et al., 2008). If it is a molar, which is probable, its size is even more

Table 1
Faunal representation at Kathu Pan 1, Strata 3–4 (after Klein, 1988 and Klein in Beaumont, 1990).

Stratum/Period species	3 MSA	4a Fauresmith	4b Acheulean/ Oldowan
Elephas recki			x
Equus burchelli	x	x	
Equus capensis	x	x[a]	x
Equus spp. (Burchell's, great Cape, hipparion)	x	x	x
Ceratotherium simum	x	x	x
Hipopotamus amphibius		x	
Phacochoerus aethiopicus		?	x
Giraffa cf. *camelopardalis*		?	x
Large tragelaphine (kudu or eland)		?	x
Hippotragus sp. (roan or sable)	x		
Redunca arundinum		x	
Small-sized alcelaphine (bontebok or blesbok)		x	
Medium-sized alcelaphine (black wildebeest or Cape hartebeest)	x	?	x
Megalotragus cf. *priscus*		x	
Antidorcas marsupialis		?	x
cf. *Antidorcas bondi*		?	
Undet. Antilopine/s (Reck's, Bond's or common springbok)		?	x
Syncerus caffer	x	?	x
Pelorovis antiquus	x	x	
Undet. large bovine (Cape or giant buffalo)	x	x	
Pedetes capensis		x	x
Hystrix africaeaustralis			x

[a] The presence of *E. capensis* was tentatively proposed by Klein (in Beaumont (1990)), and this species was positively identified by V. Eisenmann (this paper).

striking. The tooth is relatively unworn, and its estimated occlusal dimension was calculated as the mean of its occlusal dimensions: $[(OL = 40.2 + OW = 34.9)/2] = 37.6$ mm. On the vestibular view of the crown, the occlusal length is 38.3 mm, the protocone length is 14.3 mm, and the height is 128 mm. Incidentally, this tooth may well be the second largest *Equus* cheek tooth known in the world, the largest (Sellards, 1940) belonging to the North American *Equus giganteus* collected in San Diego Creek, probably from Pleistocene deposits (length of the section: 40 mm; width of the section: 39 mm). As shown in Fig. 12, the closest tooth to that from Kathu Pan 1 is from the Cornelian assemblage recovered from the site of Florisbad.

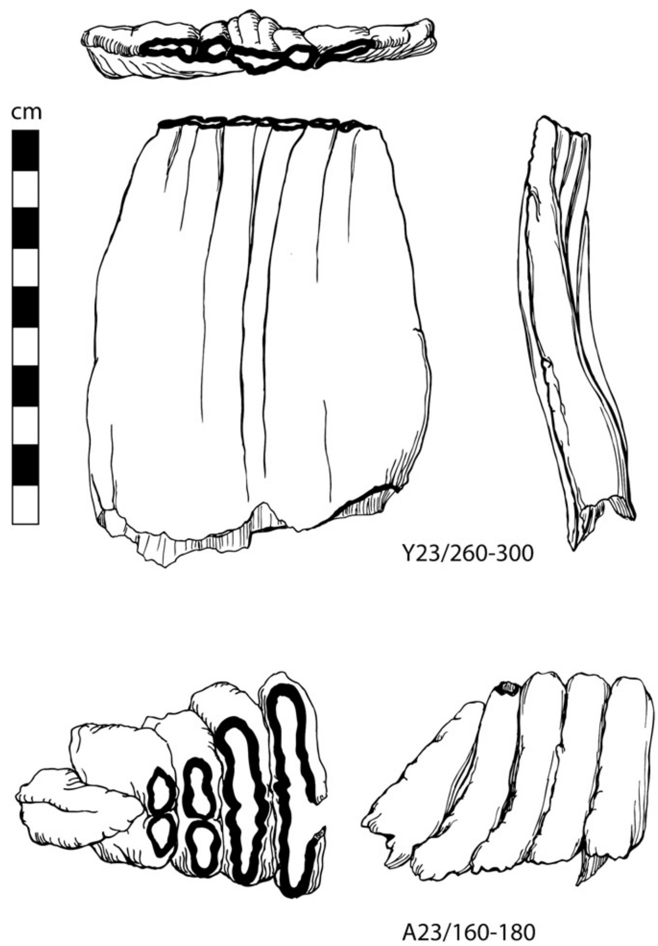

Fig. 5. *Elephas reckii* teeth from KP-1 Stratum 4b, Beaumont excavation (Courtesy R.G. Klein).

5. Optically stimulated luminescence dating

The luminescence methods date the last event of exposure of a mineral grain to sunlight (Aitken, 1998) and as such are highly suitable for the quartz-rich sand found in the different strata in KP-1. Four sediment samples were taken in 2004 from the cleaned section for optically stimulated luminescence dating (OSL) by horizontally drilling 30–40 cm deep holes into the section with a hand-held auger. Under an opaque sheet, the sediment samples were scooped out from the holes and placed in light-proof black bags. For determination of the dose rate, a second sediment sample was collected from each hole and from around a well preserved *E. capensis* tooth found *in situ* in the Upper Vent in Stratum 4a, selected for U-series–ESR dating. Gamma and cosmic dose rates were measured in the field at the same location as the sediment samples using a calibrated gamma scintillator. Alpha and beta dose rates were calculated from the concentrations of U, Th and K measured in the samples using ICP-AES (Table 4).

Fine sand quartz was extracted from the samples using routine laboratory procedures at the Geological Survey of Israel (Porat, 2007). After selecting grain size by sieving, carbonates were dissolved by 8% HCl, heavy minerals removed by magnetic separation and subsequently the quartz was etched by concentrated HF. Equivalent doses (D_e) were measured using the OSL signal and the single aliquot regenerative dose (SAR) protocol (Murray and Wintle, 2003). The OSL signal is strong (Fig. 13a) and the sensitivity-corrected dose response curves were fitted with a linear + exponential fit (Fig. 13b). Repeated dose ("recycling") points fell mostly within 4% of unity. Between 12 and 18 aliquots were measured for each sample, and the samples show a narrow range of single aliquot D_e values (Fig. 13d). Preheat temperatures ranged from 200 °C to 260 °C and overall no change in D_e values as a function of preheat temperatures was observed (Fig. 13c). The presence of feldspar traces in the samples was checked by measuring the infrared stimulated luminescence (IRSL) using the depletion method (Duller, 2003). The IRSL signal forms no more than 5% of the total signal, which is overwhelmingly dominated by the OSL signal.

5.1. Dose rates

Two variables needed to be evaluated in order to asses the annual dose rates to the samples for correct age calculations; life-time moisture contents of the samples and their burial depths histories. Water attenuates gamma dose and substantially reduces the amount of radiation reaching the grains, and burial depth affects the amount of cosmic dose absorbed by the grains. For a given D_e value, a higher moisture content or deeper burial depths would result in older OSL ages. The pans at Kathu are seasonal features with fluctuating water levels that affect the average water

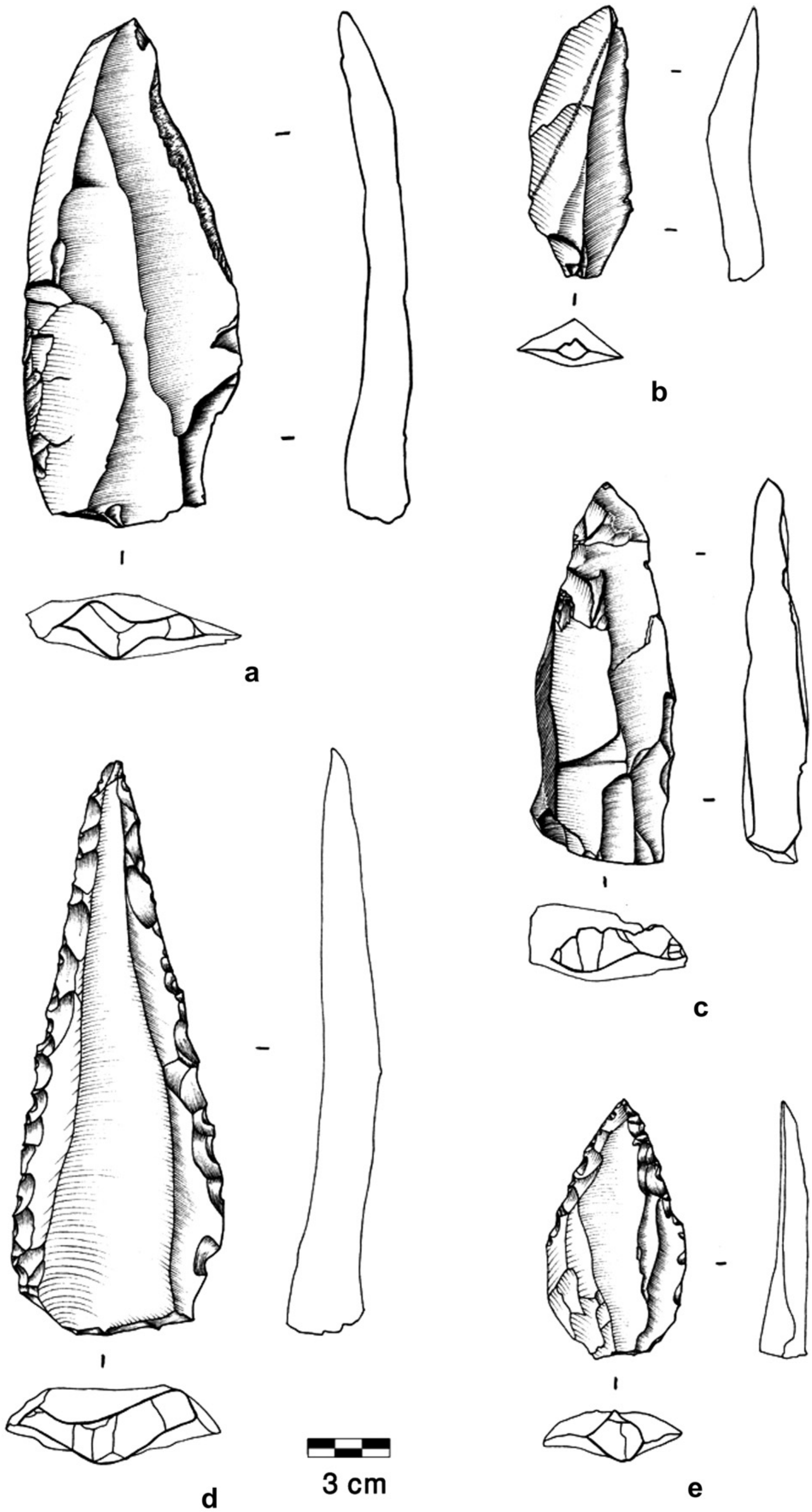

Fig. 6. Drawings of stone artifacts collected in direct association with the dated faunal and sediment samples in the Upper Vent in stratum 4a. a–c: Unretouched blades. Note that a. and c. have large facetted butts. Flake scars tend to be unidirectional. d: Retouched point on blade. e: retouched point on flake. Drawing by A. Sumner.

Table 2
ANOVA test in SPSS 16 of means for elongation (length/width ratio) between Upper Vent lithic assemblage and spits from Square F21 at the $p < 0.05$ level for three conditions [$F(5,145) = 0.285$, $p = 0.921$].

Elongation	Sum of squares	DF	Mean square	F	Significance
Between groups	0.417	5	0.083	0.285	0.921
Within groups	42.411	145	0.292		
Total	42.828	150			

content of a sample. In the recent past, water levels in the pan were on average higher (Butzer, 1984b) than that observed during our field season in the winter of 2004. Due to extensive pumping and after several years of drought, the pan was dry at this time down to the base of the exposed section, namely Stratum 4b.

The time-averaged moisture content increases with depth due to proximity to groundwater, thus, even in seasonally fluctuating water levels, the upper OSL samples spent less time submerged in groundwater than the lower OSL samples. Maximum (saturation) moisture content commonly given for sand and gravel such as those that constitute the KP-1 section range between 20 and 40% (e.g. Yim et al., 2008). The values selected here for age calculations are conservative (on the low side resulting in younger ages): for the upper samples #1 and #2 it was assumed that half of the year they were water-saturated, and a value of 15 ± 7% water was used. The lower samples were water-saturated for longer parts of the year, and a value of 30 ± 15% was used (Table 4). The large ± errors (50%) cover any uncertainty but increases the errors on the ages.

The distinct sedimentary unconformity at the contact of Strata 2 and 3 (Butzer, 1984a,b) raises the issue of burial depth histories for the lower samples #3 and #4, relevant for calculating the cosmic dose rates the samples were exposed to during their burial time. For these samples, two extreme models were used for calculating ages: one which assumed that the samples were always buried at the same depth as today – implying lower cosmic doses and thus older ages, and one which assumed that the surface of the pan was, for most of its history, at the same level as the unconformity today – implying higher cosmic doses and younger ages. In the latter scenario burial depth increased during the Holocene, however the effect of this on the much older samples is minor and well within the errors introduced by uncertainties in moisture contents. Thus, the depth for sample #3 is estimated to have been either 3.35 m, the current burial depth, or 0.2 m, the distance to the unconformity, and a time-averaged depth of 1.8 ± 1.6 m was used for the age calculations. The respective depths for sample #4 are 4.1 m or 0.9 m, and an average of 2.5 ± 1.6 m was used for age calculations (Table 4). As dose rates are generally low, the cosmic component is very significant, and the large uncertainty in burial history introduces large errors into the ages.

Table 3
Characteristics of the Stratum 4a lithic assemblage ($n = 217$ items).

	N	%
a. Condition		
Fresh	190	87.5
Partial gloss	14	6.5
Heavy gloss	2	0.9
Abraded	11	5.1
b. Platform		
Cortical	7	3.2
Plain	102	47.0
Faceted	59	27.2
Linear	5	2.3
Punctiform	3	1.4
Bifacial	5	2.3
Dihedral	29	13.4
Indeterminate	7	3.2

5.2. OSL ages

The OSL ages for the KP-1 section are in stratigraphic order and range from 10.0 ± 0.6 kyr (sample #1) for Stratum 2 to 464 ± 47 kyr (sample #4) for Stratum 4a (Table 4). Stratum 2 is bracketed by sample #1 at its upper part, with an age of 10.0 ± 0.6 kyr, and sample #2 at its lower part, dated to 16.5 ± 1.0 kyr. The unconformity between Strata 2 and 3 suggested by Butzer (1984a) is now striking, roughly spanning the time between the deposition of sample #2 at 16.5 ± 1.0 kyr and the deposition of sample #3 at 291 ± 45 kyr.

There are no direct radiocarbon ages for the upper layers at KP-1, and the minimum ages of 1.5–4.7 kyr (uncal.) BP for the Stratum 1 peats are stratigraphic extrapolations with other dated dolines at Kathu (Beaumont et al., 1984; Beaumont, 2004). Kathu Pan 5 (KP-5), a doline infill site located ~100 m south west of KP-1, offers a comparable stratigraphy (Beaumont, 1990) and was dated by radiocarbon: The upper peat layers in Stratum 1 of KP-5 were dated to 2.7–3.6 kyr BP, and Stratum 2 was dated to 5.98–32.1 kyr BP (Beaumont et al., 1984). By extrapolating sedimentation rates, Butzer (1984a) suggested that sediment accumulation at KP-1 began between roughly between 15,000 and 7,500 BP, which is in conformity with the OSL ages for samples #1 and #2 given above.

OSL sample #3, from the grayish white sand matrix of the gravel containing reworked MSA artifacts of Stratum 3, elements which were clearly co-deposited, provided an age of 291 ± 45 kyr (the large errors stemming from the uncertain burial history). This age determination is considered reliable as the D_e value is only 138 Gy, well within the acceptable range of OSL dating of quartz. OSL sample #4, collected from the Stratum 4a Upper Vent with Fauresmith artifacts, gave an age of 464 ± 47 kyr. While the stability of the OSL signal up to this time range appears to be assured (Wintle and Murray, 2006), the D_e value, of 303 Gy, is at the current limit of OSL dating, implying that this age may be a minimum estimate (Murray et al., 2008).

The ages indicate that the KP-1 doline developed in several stages: an earlier stage is represented by the deposition of Stratum 4a at around 400–500 kyr. The following stage ended with the deposition of Stratum 3 at about 290 kyr; the coarse character of the sediment and the sharp contact indicates that the underlying Stratum 4a may have been eroded. At that stage the doline was entirely filled with sediments. A later stage could have started with re-deepening of the doline prior to ~17 kyr, followed by the deposition of Stratum 2, and ended with the complete filling of the doline during the Holocene.

6. Combined U-series–ESR dating

An *in situ* upper right cheek tooth of *E. capensis* from Stratum 4a was sampled for combined U-series–ESR dating (ANU sample number 2261). The tooth was found in direct association with the lithic sample describe above and adjacent to OSL sample #4 taken from this stratum (Fig. 3c).

The dating procedures followed those routinely applied in the ANU laboratory. An enamel fragment with attached dentine was removed from the tooth and analysed for U and Th using laser ablation ICP-MS (Eggins et al., 2003, 2005). Two laser ablation tracks across the enamel and dentine yielded concentration values of 15.1 ± 1.6 and 41.6 ± 2.9 ppm U, $^{234}U/^{238}U$ activity ratios of 1.690 ± 0.021 and 1.661 ± 0.007 and $^{230}Th/^{234}U$ activity ratios 0.549 ± 0.022 and 0.603 ± 0.007 for enamel and dentine, respectively. The U-series ratios correspond to respective apparent U-series ages of $80.7^{+4.7}_{-4.5}$

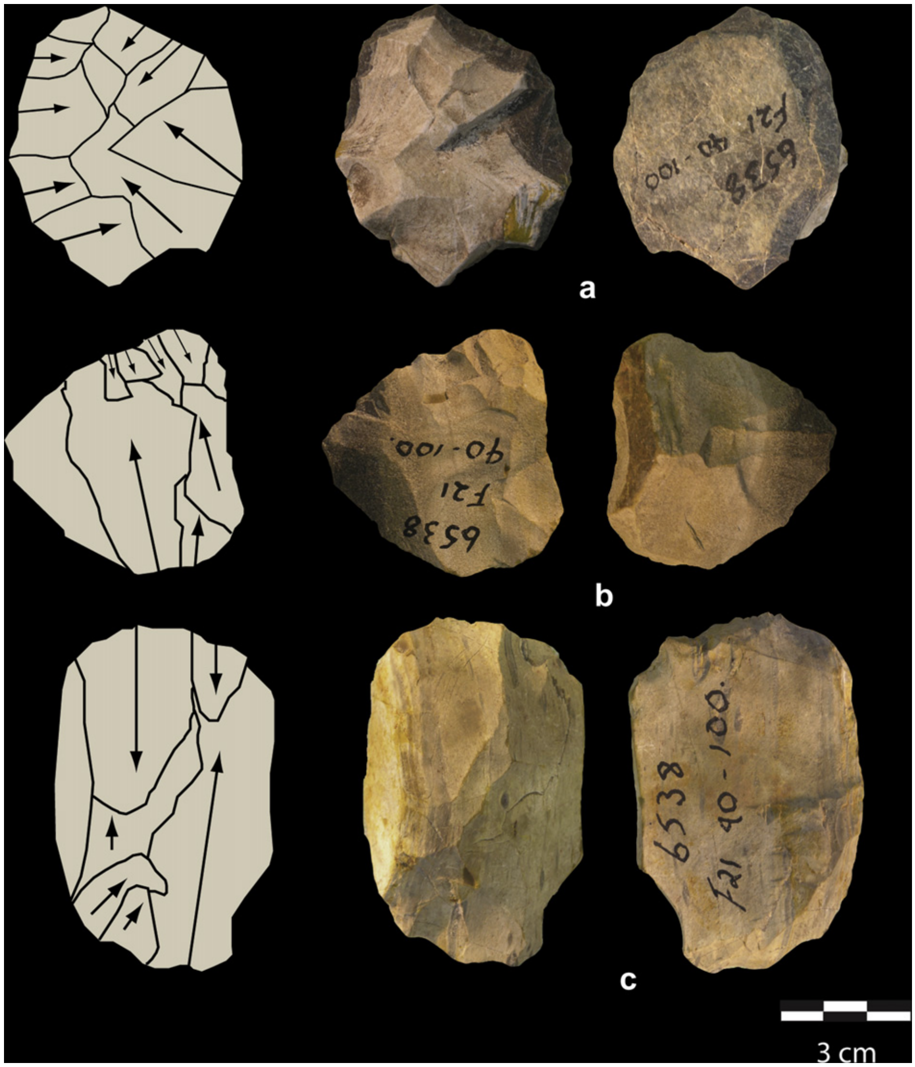

Fig. 7. Cores from KP-1 Stratum 4a, Square F21. Diagrams show the direction of flake removal. An intact negative bulb of percussion is present if the arrow begins from the outline of the core.

and $92.9^{+1.6}_{-1.5}$ kyr (Table 5). This rather young age implies late U-uptake, which may be related to the unconformity between Stratum 2 and 3.

For ESR D_e analysis, the enamel was powdered and 2 aliquots (2261A and B) were successively irradiated in 12 steps up to 6627 Gy. Radiation doses were monitored with alanine dosimeters and evaluated against a calibrated dosimeter set (A. Wieser, Messtechnik, München). D_e values of 1064 ± 39 and 1146 ± 38 Gy were obtained by fitting the natural spectrum back into the irradiated ones (Grün, 2002).

For the assessment of the environmental dose rate, the sediment sample collected in the immediate vicinity of the tooth was analysed by neutron activation analysis for U, Th and K (Table 5). An *in situ* measurement with a gamma scintillator yielded an environmental gamma dose rate of 390 ± 50 μGy/a, which included the cosmic dose rate for a sample deposited at a depth of 4.1 m below the surface. Water concentrations in dentine was assumed to be $10 \pm 5\%$ (Grün et al., 1988) and in the sediment $30 \pm 15\%$, as for the adjacent OSL sample #4. For the calculation of the internal dose rate values, beta attenuation values of Marsh (Grün and Katzenberger-Apel, 1994) and an alpha efficiency of 0.13 ± 0.02 (Grün et al., 1988) were used.

Combining the ESR and U-series data for the modelling of the U-uptake (Marsh, 1999), U-series–ESR ages of 497^{+182}_{-138} kyr (2261A) and 608^{+216}_{-169} kyr (2261B) were obtained. This results in a weighted mean age of 542^{+140}_{-107} kyr for the tooth (Table 5).

For OSL sample #4 adjacent to the tooth, the combined cosmic and gamma dose rates contribute ~70% of the annual dose rate to the quartz (Table 4). Due to the high U contents in the enamel and dentine (Table 5), the cosmic and gamma dose rates are only 20% of the modelled dose rates for the tooth. In addition, the uncertainties in the *p*-values are large and are reflected in large errors (20–26%) on the combined ESR-U-series age (Table 5). Therefore the uncertainties associated with water content and burial histories have a smaller affect on the ESR-U-series age than on the OSL age.

7. Discussion and conclusions

The timing and character of the ESA–MSA transition in Africa is as yet unclear. The sequence from KP-1 offers an important chronological and archaeological sequence with which to elucidate this issue.

The OSL age obtained for the MSA bearing Stratum 3 at KP-1 (291 ± 45 kyr) is similar to the ESR age of 279 ± 47 obtained for the

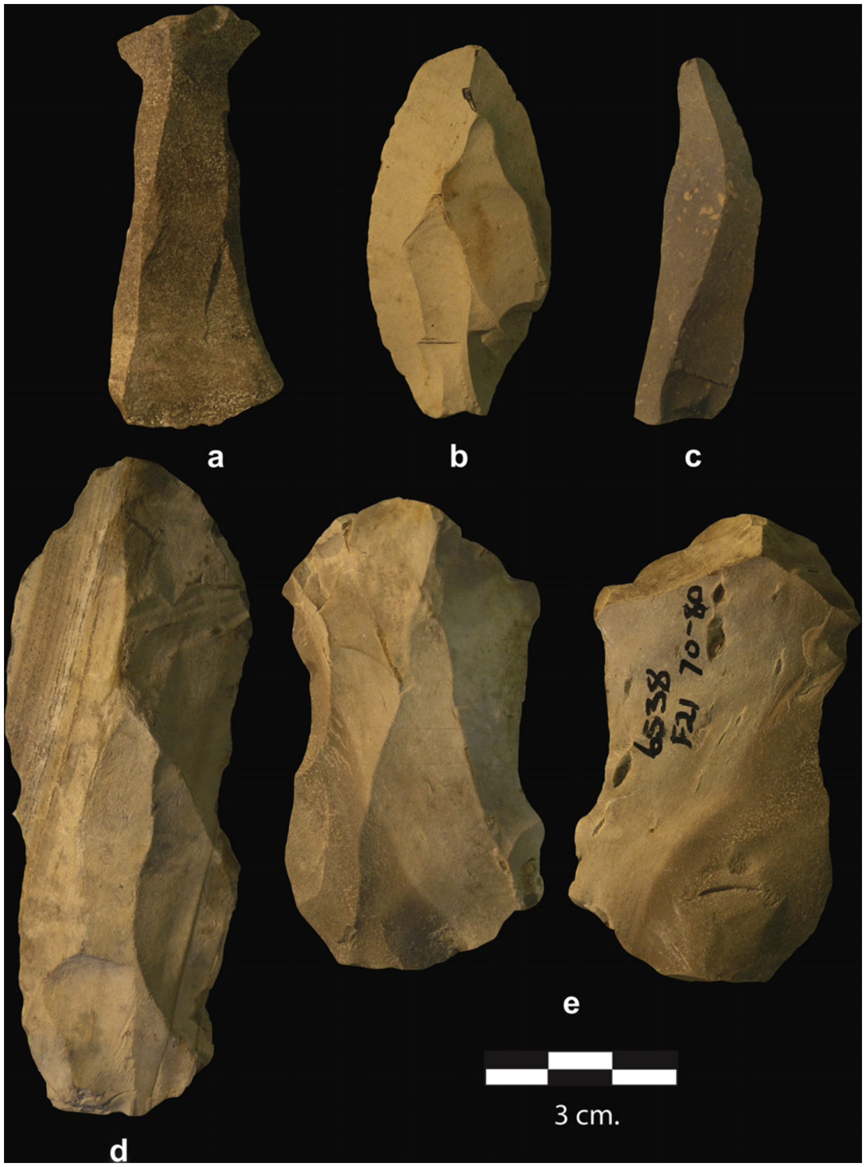

Fig. 8. Flakes from KP-1 Stratum 4a, Square F21.

early MSA at Florisbad, Units N-P, a site also located in the interior of South Africa (Kuman et al., 1999). These ages concur with U-series ages on travertines of 230^{+35}_{-28} kyr that seal the lower Lupemban (MSA) industry at the site of Twin Rivers (Zambia; Barham and Smart, 1996), and at Malewa Gorge (Kenya), there dated to earlier than ca. 240 ka by K-Ar (Evernden and Curtis, 1965). New K-Ar ages for the MSA in the Gademotta and Kulkuletti Formations (Ethiopia) of $>276 \pm 4$ kyr extend the MSA further back in time (Morgan and Renne, 2008), corroborating $^{40}Ar/^{39}Ar$ dates for MSA interstratified with Acheulean in the Kapthurin Formation (Kenya) of $>284 \pm 24$ ka (Deino and McBrearty, 2002).

The early MSA assemblages of Southern Africa are characterized by small, broad flakes/blades, high frequencies of radial and disc cores but little evidence of core preparation, few heavily retouched artifacts or scrapers, and the absence of retouched points and bifaces (Volman, 1984). Work is currently in progress to better characterize the KP-1 MSA assemblage. Butzer (1984a: 258) and Beaumont (1990: 90) note that in the adjacent Kathu Pan 6, early MSA artifacts are overlain by a later Howieson's Poort MSA industry dated by OSL to 64 kyr (J. Feathers, cited in Beaumont (2004: 51)). Elsewhere in South Africa the Howieson's Poort industry was dated by OSL to between 65 kyr and 60 kyr (Jacobs et al., 2008). The OSL age for the Stratum 3 MSA at KP-1 of 291 ± 45 kyr provides a *terminus post quem* for the underlying Fauresmith in Stratum 4a.

The Stratum 4a ages presented here for the Fauresmith industry at KP-1 derive from two independent dating methods. They give a minimum OSL age of 464 ± 47 kyr and a combined U-series–ESR age of 542^{+140}_{-107} kyr. The presence of *E. recki* in Stratum 4b offers limited biochronological information given the broad time range of this taxon (Todd, 2005). A late appearance of this taxon in southern African at the Acheulean site of Namib IV (Shackley, 1980) is estimated at 400–700 kyr, an age inferred from similarities in lithic typology to East African sites also containing *E. recki.* This offers a rough *terminus ante quem* for the Fauresmith in Stratum 4a.

Since its inception, the Fauresmith has been a poorly defined lithic entity. However, the dated Stratum 4a sediments and fauna from KP-1, associated with a prepared core industry that included the systematic production of blades, provide a robust chronological context for this industry. These ages serve as a foundation for assessing whether the Fauresmith is a single taxonomic entity

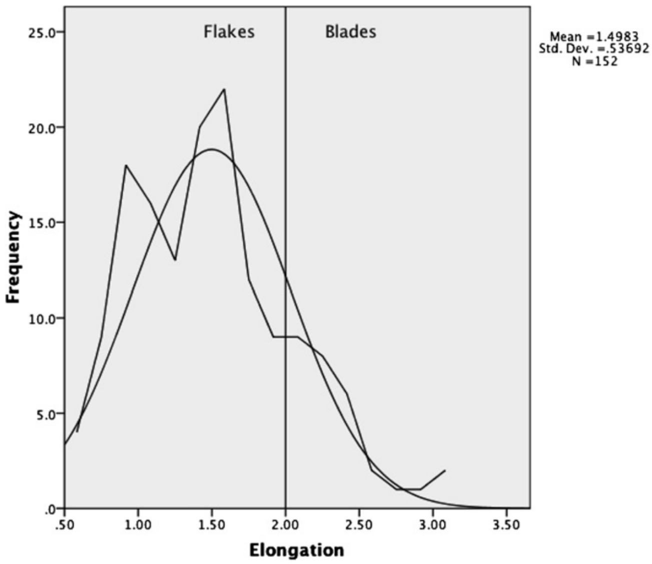

Fig. 9. Distribution of the elongation of flakes and blades from KP-1 Stratum 4a. The sample from the dated Upper Vent is combined with the assemblage from Square F21. Elongation = length/width. The jagged curve is the distribution of 152 complete flakes (out of a total of 217). The smooth line is a normal distribution curve fitted to the data.

defined by a common technology of tool manufacture and constrained within a continuous time range. The results presented here call into question the conceptualization of the Fauresmith as a transitional ESA–MSA industry contemporary with the Sangoan (Clark, 1970; McBrearty, 1988, 1991), since the earliest OSL ages for the Sangoan (Sai Island, Sudan, dated to 182 ± 20 kyr; Van Peer et al., 2003) places this industry far later in time. However, the U-series ages for the lower Lupemban (MSA) industry at Twin Rivers (Barham and Smart, 1996), imply that, at least in Zambia, the Sangoan industry is older than 265 kyr. Similarly, $^{40}Ar/^{39}Ar$ ages constrain the Kapthurin Formation (Kenya) K4 member (235–284 kyr) and the underlying tuff deposits of K3, both containing Sangoan artifacts interstratified with Acheulean and MSA artifacts (Deino and McBrearty, 2002; Tyron and McBrearty, 2002, 2006). These ages point toward the Sangoan being close in age to the KP-1 MSA.

Although dated Late Acheulean industries in southern Africa are rare (Fig. 2), the KP-1 assemblage predates the Late Achuelean industries at Duinefontein II Horizons 2 and 3, dated by IRSL to 292 ± 55 and 265 ± 83 kyr, that do not include prepared core flake production (Feathers, 2002; Klein et al., 1999). Consequently, there is reason to question whether there was a progressive trajectory of change in lithic technology during the later Acheulean, culminating in the abandonment of bifaces and reliance on prepared core technology in the MSA, since at KP-1 the use of prepared core technology predates the end of the Acheulean by at least 200 kyr. This corroborates McBrearty's (1988) contention that prepared core technology originated in the Acheulean. The observed spatial variability within the Fauresmith assemblage from KP-1 with regard to the occurrence of handaxes, has been attributed to the low number of these artifact types in Fauresmith assemblages, and may also explain their absence in recent excavations at Rooidam II (Richardt, 2006).

The presence of blade tools and prepared core technology in deposits dated to >400 kyr at KP-1 is of considerable interest. In East Africa, blade tools co-occur with Acheulean bifaces, Levallois flake production and points at the site of LHA/GnJh-03 in the Kapthurin Formation (Kenya), and are found in a stratum located stratigraphically below the base of the K4 member. This stratum is constrained by $^{40}Ar/^{39}Ar$ ages of the overlying K4 member and underlying K2 Pumice Tuff of 235 ± 2–284 ± 12 kyr and 543 ± 5 kyr, respectively (Deino and McBrearty, 2002; Tyron and McBrearty, 2002, 2006). Thus, the shift from Acheulean to MSA industries occurred prior to 284 kyr in the Kapthurin Formation and probably also in the Gademotta and Kulkuletti Formations (Morgan and Renne, 2008). Indeed, recently Johnston and McBrearty (2009) announced the presence of blades in the lower portion of the Kapthurin Formation dated to 545-509 kyr. The KP-1 ages bring the Fauresmith closer in time to the Kapthurin Formation assemblages, demonstrating that blade production and prepared core technology developed in Africa during the final phases of the Acheulean, preceding anatomical modernity in hominins.

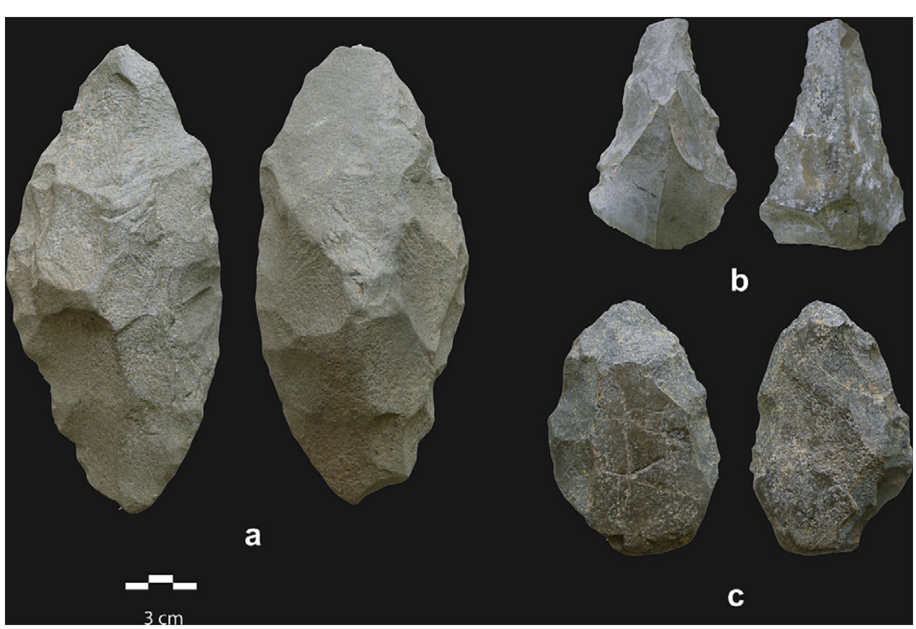

Fig. 10. Bifaces from KP-1 Lower Vent in Stratum 4a.

Fig. 11. Bifaces from KP-1 Stratum 4b.

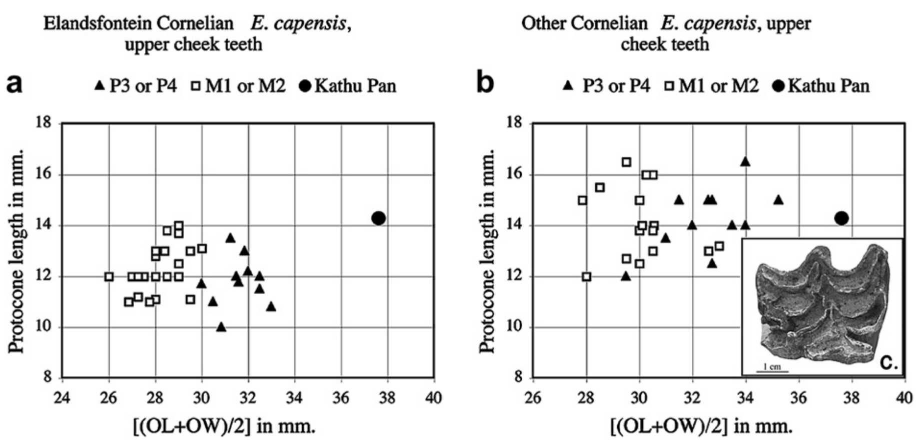

Fig. 12. Comparison of the *Equus capensis* tooth from the Upper Vent in Stratum 4a in Kathu Pan 1 with Equid teeth from other Cornelian age South African sites. a. Elandsfontein (Cape Province). b. Three sites in the Free State – Cornelia, Florisbad and Mahemspan. c. Occlusal view of the Equid tooth.

Table 4
Field and laboratory data and ages for the OSL samples.

OSL ages for KP-1															
Sample No.	Lab code	Sediment type	Depth (m)	Water [a](%)	Grain size (μm)	K (%)	U (ppm)	Th (ppm)	Ext. β[b] (μGy/a)	Ext. γ[b] (μGy/a)	Cosmic[c] (μGy/a)	Total dose (μGy/a)	Aliquots used[d]	D_e[e] (Gy)	Age (ka)
1	KP-3	Gray sand	2.2	15 ± 7	88–125	0.35	0.7	1.8	323	213	190 ± 20	730 ± 39	11/12	7.3 ± 0.2	**10.0 ± 0.6**
2	KP-1	Gray sand	2.9	15 ± 7	150–177	0.41	0.8	1.9	363	240	175 ± 18	779 ± 41	10/12	12.8 ± 0.3	**16.5 ± 1.0**
3	KP-2	Gravel	1.8 ± 1.6[f]	30 ± 15	150–177	0.17	0.4	1.1	142	103	228 ± 66	474 ± 72	11/12	138 ± 4	**291 ± 45**
4	KP-4	Sand with Fauresmith	2.4 ± 1.6[f]	30 ± 15	88–125	0.21	1.1	2.2	253	209	188 ± 36	653 ± 59	16/18	303 ± 14	**464 ± 47**

[a] Water estimated using geological considerations; see text for discussion.
[b] Beta and gamma dose rates calculated from the radioactive elements measured on dried and powdered sediments, attenuated for estimated moisture contents. Contribution of alpha particles to dose rates is 1–4 μGy/a (not in Table).
[c] Cosmic dose rates, calculated from elevation and latitude and attenuated for burial depth.
[d] The number of aliquots used for the average De out of the aliquots measured.
[e] De averaged and errors calculated using the Central Age model (Galbraith et al., 1999).
[f] An average between current depth and the distance to the unconformity; see text for discussion.

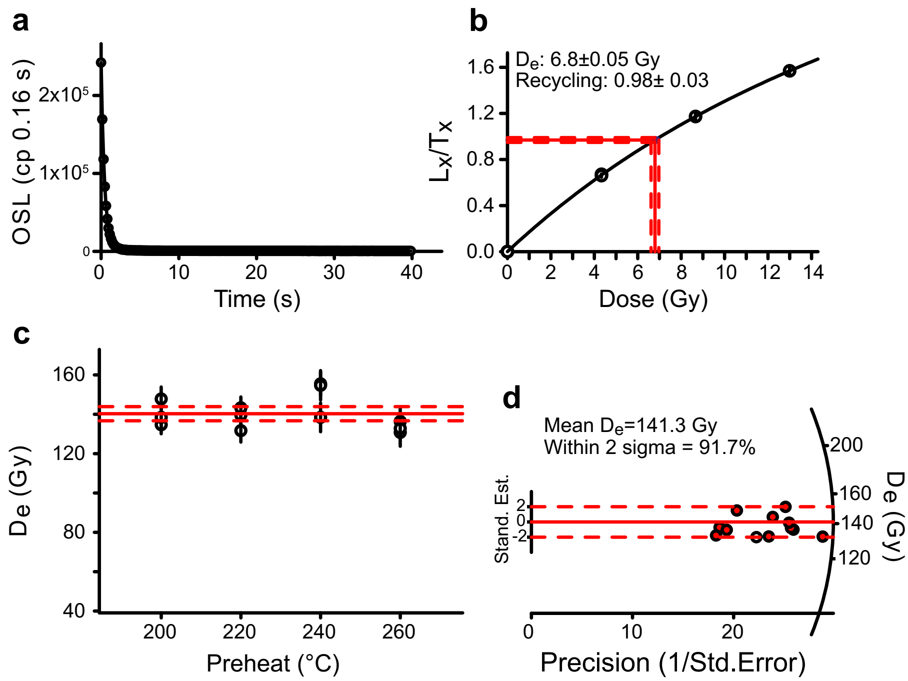

Fig. 13. Optically stimulated luminescence (OSL) dating results. a. Natural OSL signal from sample #1. Note the rapid decay of the signal with illumination time, with a dominance of the fast component. b. Dose response curve for an aliquot from sample #1. Two repeated dose points at ~4 Gy are within 2% of each other (recycling ratio of 0.98), indicating that the sensitivity corrections are adequate. c. preheat plateau for sample #3. There is no systematic change in D_e values with preheat temperatures. d. Radial plot for sample #3. Note the small errors and tight clustering of the D_e values.

Evidence of early blade manufacture has been documented from northwestern Europe during OIS 9 (303–339 kyr), further demonstrating that anatomical modernity is not a precondition for blade production (Conard, 1990; Révillion and Tuffreau, 1994). In the Middle East, blades are found in the Amudian industry of the Late Lower Paleolithic. The dating of this industry is the subject of debate based on discordant ESR ages (on teeth) which place this industry in OIS 7 (186–245 kyr), as opposed to TL ages (on burnt flint) which place the Amudian in OIS 9 (Porat et al., 2002; Barkai et al., 2005; Millard, 2008).

It has been asserted that the Fauresmith and Sangoan mark the beginning of localised specializations that occurred towards the end of the ESA, and that this development may be linked to the appearance of archaic *Homo sapiens* (Clark, 1970; Kuman et al., 2005). However, our results raise questions about the relationship between evolutionary events in the genus *Homo* and changes in lithic technology. In the absence of dated fossil hominins from southern Africa coeval with the KP-1 Fauresmith, this assemblage remains bracketed by the Saldanha (Elandsfontein) skull, attributed to *Homo heidelbergensis* or archaic *Homo sapiens* (Klein et al., 2007; Rightmire, 2001), associated with Acheulean artifacts and dated by faunal associations to ca. 320–790 kyr (Millard, 2008) [or 600-1,000 kyr (Klein et al. 2007)], and the Florisbad skull associated with MSA artifacts, usually attributed to early archaic *Homo sapiens* and directly dated by ESR to 259 ± 35 kyr (Grün et al., 1996; Rightmire, 2001). The KP-1 ages clearly demonstrate that the advent of blade production predated the appearance of modern *Homo sapiens* in Africa, as attested to by the Kibish Formation fossils with an inferred age of 195 ± 10 ka and the Herto *H. sapiens* dating to 160 ± 4–154 ± 14 ka (Millard, 2008 and references therein). This implies that the advent of prepared core technology with blade production may no longer be a suitable criterion for inclusion in the suite of modern behaviours (Marean et al., 2007; McBrearty and Brooks, 2000).

Table 5
ESR and U-series data for the *Equus capensis* tooth. a. ESR data. b. U-series age and the combined ESR-U-series model age.

ESR and U-seris data for tooth sample 2261:
a. ESR data

Sub-sample	D_e (Gy)	Thickness (μm)	U (ppm)		Early uptake model		Linear uptake model		*p*-values	
		Enamel	En.	Den.	Dose rate (μGy/a)	Age (10^3 yr)	Dose rate (μGy/a)	Age (10^3 yr)	Enamel	Dentine
A	1064 ± 39	1100	15	50.7	7352 ± 766	144 ± 15	4026 ± 418	264 ± 29	2.4 ± 1.5	1.7 ± 1.0
B	1146 ± 38	1050	16.3	52	7493 ± 787	152 ± 16	4093 ± 428	279 ± 30	3.2 ± 1.8	2.4 ± 1.2

b. U-series data

	U (ppm)	$^{234}U/^{238}U$	$^{230}Th/^{234}U$	U/Th Age (ka)	Combined Age (ka)
Enamel	15.1 ± 1.6	1.690 ± 0.021	0.549 ± 0.20	80.7 ± 4.6	497^{+182}_{-138}
Dentine	41.6 ± 2.9	1.661 ± 0.07	0.603 ± 0.07	92.9 ± 1.6	608^{+216}_{-169}
				AVERAGE	$\mathbf{542^{+140}_{-107}}$

Alpha efficiency = 0.13 ± 0.02; water in dentine = 20 ± 10%; enamel removed = 100 μm from each side; enamel density = 2.95.
Sediment composition: U = 0.45 ± 0.03 ppm; Th = 1.93 ± 0.05 ppm; K = 0.24 ± 0.01%. Water in sediment = 30 ± 15%; external gamma and cosmic dose rate = 415 ± 45 μGy/a; beta from sediment = 20 ± 5 μGy/a.

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