Radiometric dating of the Earlier Stone Age sequence in Excavation I at Wonderwerk Cave, South Africa: preliminary results

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Abstract

We present here the results of 44 paleomagnetic measurements, and single cosmogenic burial and optically stimulated luminescence ages for the Earlier Stone Age deposits from Wonderwerk Cave, Northern Cape, South Africa. The resulting paleomagnetic sequence: N > R > N > R > N constrains the Earlier Stone Age strata in this part of the site to between ~0.78–1.96 Ma. A single cosmogenic date of ~2.0 Ma from the base of the section offers some corroboration for the paleomagnetic sequence. Preliminary results indicate that the small lithic assemblage from the basal stratum may contain an Oldowan facies. This is overlain by several strata containing Acheulean industries. The preliminary radiometric dates reported here place the onset of the Acheulean at this site to ~1.6 Ma, which is roughly contemporaneous with that of East Africa.

Keywords: Wonderwerk Cave; Southern Africa; Acheulian; Earlier Stone Age; magnetostratigraphy; cosmogenic burial age

Introduction

Wonderwerk Cave (27°50’ 45”S; 23°33’ 19”E) is a phreatic tube, ranging from 10–20 meters in height, extending over 140 meters deep into the eastern flank of the Kuruman Hills in the Northern Cape Province, South Africa (Fig. 1). The cave formed in dolomites of the Late Archaean–Early Proterozoic of the Ghaap Group overlain by banded ironstone formations of the Griqualand West Sequence (Eriksson et al., 1993). Guano digging in the early 1940s disturbed the cave deposit and was followed by several brief archaeological excavations undertaken near the cave entrance by B.D. Malan and colleagues from the University of California’s African expedition (Malan and Cooke, 1941; Malan and Wells, 1943; Camp, 1948; Beaumont and Vogel, 2006). Between 1974 and 1977, K.W. Butzer undertook fieldwork at the site, studying material recovered from Malan’s excavations as well as the existing sections (Butzer et al., 1978; Butzer, 1984a, b). Beginning in 1978, P.B. Beaumont of the McGregor Museum initiated a series of excavations that continued through to 1993 (Beaumont, 1982, 1990, 2004; Beaumont and Vogel, 2006). Beaumont cleared material that had been disturbed when the cave deposits were exploited for fertilizer and excavated six different excavation areas (Excavations 1–6) distributed throughout the entire extent of the cave (Fig. 2; for a complete plan of the excavation areas, see Beaumont and Vogel, 2006: their Fig. 2). In 1979 Beaumont was joined by Anne and Francis Thackeray, who focused on excavation of the Later Stone Age (LSA) occupations near the front of
the cave and studied the LSA lithic and faunal assemblages, respectively (Thackeray et al., 1981; Humphreys and Thackeray, 1983; Thackeray, 1984).

These various archaeological investigations demonstrated that Wonderwerk Cave contains in situ Earlier Stone Age (ESA), Fauresmith (a final Acheulean or early Middle Stone Age facies), and Middle Stone Age through Later Stone Age deposits (Binneman and Beaumont, 1992; Beaumont, 1982, 1990, 2004). Wonderwerk is unique since few sites have yielded such a long sequence of in situ ESA horizons that also cover the ESA/MSA transition (Fauresmith), while none of the other ESA sites in southern Africa have yielded such abundant and well-preserved in situ micro- and macrofaunal and botanical remains (Klein, 1988; Thackeray and Brink, 2004; Avery, 2006; Beaumont and Vogel, 2006).

Beginning in July 2004, an interdisciplinary project was initiated aimed at dating the ESA deposits at Wonderwerk Cave, South Africa, using a range of radiometric techniques, concurrent with analysis of the lithic, faunal, and botanical remains derived from the associated archaeological strata, and

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**Fig. 1.** Map of southern Africa showing the location of Wonderwerk Cave and other sites mentioned in the text.

**Fig. 2.** A: Profile of Wonderwerk Cave creating by 3D laser scan from cave entrance to the back. B: Cross-section of Wonderwerk Cave created by 3D laser scan running through Excavation 1, 13 meters from the cave entrance (created by H. Ruther and colleagues, Department of Geomatics, University of Cape Town).
micromorphological investigation of their stratigraphic contexts.

The dates presented in this paper are based on samples taken after extensive cleaning of existing sections in Excavation 1, located approximately 20 meters from the entrance of the cave. In this area, over two meters of ESA deposits overlain by Later Stone Age strata have been identified (Thackeray et al., 1981; Humphreys and Thackeray, 1983; Thackeray, 1984; Beaumont and Vogel, 2006). Beaumont chose to maintain the excavation grid established by Malan, resulting in the use of square yards for the areas excavated subsequently. Depth measurements were taken in centimeters and excavation took place in five centimeter spits. All excavated sediments were sieved using a 1-mm mesh (with a 0.5-mm mesh often placed on top), and all retrieved material was placed in bags with square, level, and spit recorded. These collections are now curated at the McGregor Museum in Kimberley.

Geostratigraphy of Excavation 1

The sediments from the sections closest to the cave mouth, including Excavation 1, were first described by Butzer (1984a, b) based on a suite of samples collected by the University of California’s African expedition in 1948 and another suite collected by Beaumont during his 1978 excavation season. Based on his analyses, Butzer concluded that the sediments were composed of silty sand—partly calcified with roof spall, ash lenses, and debitage in certain horizons. The sediments ranged in color from reddish brown (Munsell colors 5—7.5 YR) to pale to light brown or yellowish red (Munsell colors 5—10 YR). He concluded that the composition of the primary component of the Wonderwerk Cave sediments was a “sand and grit fraction consisting of quartz, with ancillary banded ironstone debris, dolomite, quartzite, jasper, and chert in the coarser fractions” (Butzer, 1984b: 55).

During the 2005 field season, we identified nine lithostratigraphic units (units 1—9 from top to bottom) in the main north ESA stratigraphic section in Excavation 1 (Fig. 3). These units show a limited correspondence to the archaeological strata identified by Beaumont during his excavations (Table 1; Fig. 3). Samples for micromorphological analysis were collected from all units following the procedures outlined in Goldberg and Macphail (2003). Analysis of these samples is ongoing but preliminary observations on the samples from the Excavation 1 sediments show some concordance with Butzer’s account. The sediments consist of soft, powdery, reddish bedded silt and sand with localized accumulations of roof
spall. However, in our opinion, the sediments are ultimately the result of eolian sedimentation (rather than water transport as suggested by Butzer, 1984b), decomposition of the roof, and small-scale inputs and local reworking by water; the latter is particularly visible in the bottom of the profile shown in Fig. 3. That some input is derived from introduced organic residues, as suggested by Butzer (1984a), is likely in light of the presence of secondary phosphate nodules (Shahack-Gross et al., 2004), but this constitutes only a relatively minor fraction. Most of the sediments can be ascribed to low-energy deposition. Contacts between lithostratigraphic units range from diffuse to sharp, with the latter generally a result of erosion (e.g., between lithostratigraphic units 3 and 4). Lithostratigraphic units vary in thickness vertically and laterally. For example, unit 3, is \( \approx 8 \text{ cm} \) thick in the main eastern section but up to \( 25 \text{ cm} \) thick to its south, while lithostratigraphic unit 9 is \( \approx 50 \text{ cm} \) thick. Throughout the sequence, with the exception of lithostratigraphic unit 9 at the base, diagenesis is evident as calcite cementation in lithostratigraphic units 3 and 7; calcite or phosphate nodules in lithostratigraphic units 2, 4, 5, and 8; and rock fall alteration in units 1, 4, and 6. These nodules range from highly altered to dissolved.

Field observations indicate that water played an active role in the formation and modification of at least part of the ESA depositional sequence in Excavation 1. This is evident in the erosional contacts, particularly at the base of lithostratigraphic unit 3, the presence of fine laminated silts in lithostratigraphic unit 9, which indicate sheet flow, and by flowstones and large speleothems. In addition, diagenetic transformations are visible in the form of cementation by calcite and precipitation of nodules of phosphate and amorphous silica. Field observations made in March 2006 indicate that, during a period of heavy rainfall in the region, water dripped consistently in one location near the front of the cave (David Morris, pers. comm., 2006), while Beaumont and Vogel (2006: 219) note that in April 1994, water yield from 14 active drips was only 0.4 liters over a week. They concluded that during periods of glacial aridity the contribution of roof-derived water inside the cave would have been negligible. There is no evidence for high-energy water transport that would have been strong enough to carry stone artifacts or large bones into the cave.

The geological analysis supports the suitability of the Wonderwerk Excavation 1 sediments for paleomagnetic and cosmogenic isotope analysis. The laminated deposits are well-preserved in all lithostratigraphic units above unit 9. These results are consistent with the clear and sequential magnetostratigraphic signal obtained from samples throughout the sequence, along with those samples lacking a clear signal due to localized bioturbation (see below). There is unambiguous evidence for erosional episodes and temporal breaks such that the rate of sediment accumulation, although probably slow, cannot be considered as continuous.

**Dating**

The paleomagnetic analysis aimed at determining the magnetic polarity of the ESA sedimentary sequence in Excavation 1 at Wonderwerk Cave in order to constrain the age of the lithic assemblages and place them within the geomagnetic polarity time scale (GPTS; Baksi et al., 1992; McDougall et al., 1992; Baksi and Hoffman, 2000). For this purpose, a total of 35 paired oriented samples were taken from the freshly cleaned north and east stratigraphic sections in Excavation 1, at 10–15 cm intervals following our lithostratigraphic sequence (Fig. 3). This section begins ca. 10 cm below the contact between the ESA and overlying sediments. The increased thickness of lithostratigraphic unit 3 led to the decision to take an additional series of 11 paleomagnetic samples from the east section that abuts the main south section. Altogether 44 samples were collected and fully analyzed.

The fine-grained silt sediments were sampled by carving a cubic pedestal with a stainless steel knife, and then placing a nonmagnetic plastic capsule over the pedestal. The orientation was carefully measured before the sample was removed. Remanent magnetization of all samples was measured at the Paleomagnetic Laboratory of the Institute of Earth Sciences, The Hebrew University of Jerusalem, using a shielded three-axis superconducting 2 G 750 SRM™ magnetometer with integrated alternating field (AF) coils. The natural remanent magnetization (NRM) was measured after which samples were subjected to stepwise demagnetization with increasing intensity starting with 5 millitesla (mT) increments, going up to 70 mT and continuing to 160 mT in a few cases. This procedure removed more than 50% to 90% of the NRM intensity. The NRM intensity of all samples was measured and is in the order of \( 10^{-1} \text{ A/m} \); that is, six orders of magnitude stronger than the sample holder. The median destructive field (MDF) of the single component samples is in the range of 30 to 70 mT indicating medium coercivity NRM.

<table>
<thead>
<tr>
<th>Lithostratigraphic units&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Archaeological strata&lt;sup&gt;b&lt;/sup&gt;</th>
<th>OSL age</th>
<th>Paleomagnetic interpretation</th>
<th>Cosmogenic age</th>
<th>Lithic industry</th>
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<tr>
<td>1–3</td>
<td>9a–f</td>
<td>&gt;0.25</td>
<td>N – Brunhes (0–0.78)</td>
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<td>Acheulean</td>
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<td></td>
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<td>R – Matuyama (0.78–0.99)</td>
<td></td>
<td>Acheulean</td>
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<tr>
<td>4</td>
<td>10a–b</td>
<td></td>
<td>N – Jaramillo (0.99–1.07)</td>
<td></td>
<td>Acheulean</td>
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<tr>
<td>5–7</td>
<td>11</td>
<td></td>
<td>R – Jaramillo (1.1)</td>
<td></td>
<td>Acheulean</td>
</tr>
<tr>
<td>8–9</td>
<td>12a–c</td>
<td></td>
<td>N – Olduvai (1.78–1.96)</td>
<td>2.0 ± 0.15 or 2.26 ± 0.17</td>
<td>Oldowan</td>
</tr>
</tbody>
</table>

<sup>a</sup> Lithostratigraphic units as identified in this study.

<sup>b</sup> Archaeological strata defined by Beaumont (Beaumont and Vogel, 2006).
Characteristic remanent magnetization (ChRM) component directions were calculated for all samples using principal components analysis (Kirschvink, 1980) aided by orthogonal vector plots (Zijderveld, 1967; Fig. 4).

AF demagnetization behavior was used to set rejection criteria in order to select the appropriate samples for further paleomagnetic analysis. The samples were divided into three groups: (A) 32 samples that show a clear stable vector, (B) seven samples for which the secondary overprint could not be removed, and (C) five samples that showed erratic, unstable behavior.

A close examination of the Group C samples indicates that the primary texture of the sediments had been disturbed, possibly by bioactivity (i.e., bioturbation by insects, rodents) and/or erosion, as noted in the geostratigraphic description above. It is possible that this is the source of the magnetic instability. The samples from Groups B and C were then excluded from further paleomagnetic analysis (samples denoted in Fig. 3 either with an X or ?).

The 32 samples from Group A all showed a stable single vector or dual vector where the first vector removed is the secondary chemical remanent overprint and the second is the stable primary characteristic remanent magnetization that probably resides in a higher coercivity magnetic cubic phase (Figs. 4–5). In this group, samples W32 and W33, which showed dual component vectors, also produced the same results as the single component vector. The AF demagnetization path of samples W32 and W33 shows a clear drift of the NRM.

Fig. 4. Vector projection diagrams of three representative samples from Excavation 1 sediments at Wonderwerk Cave during alternating field (AF) demagnetization of normal (W38), reverse (W20), and reverse with normal overprint (W33) specimens that had not fully demagnetized. Open symbols denote projection onto vertical plane; solid symbols denote projection on horizontal plane.
vector from northerly oriented and negative inclination vector to southerly oriented with positive inclination vector. Furthermore, principal component analysis of remanent magnetization of sample W33 shows two component vectors: one is northerly oriented with negative inclination (normal polarity) and the stable one is southerly oriented with positive inclination (reverse polarity). In the Southern Hemisphere, these findings are sufficient to identify the magnetization as a reverse polarity.

The fact that ~90% of the magnetization has been removed by AF of up to about ~100 mT in all the samples (as can be seen in the orthogonal vector plots, Fig. 4) implies that, most probably, the remanent magnetism is carried by a cubic mineral phase, namely detritus Ti-magnetite or maghemite (if sulfides are excluded), and not hematite or goethite. Although thermal demagnetization would support this conclusion, and even facilitate distinguishing between magnetite and maghemite (since they have Tc of 580 °C and ~350 °C, respectively), the Wonderwerk sediment is too fragile and could not be sampled for thermal demagnetization. As such, we preformed a series of thermomagnetic experiments to elucidate which iron oxides are present in the sediments.

A fully computer controlled ‘variable field translation balance’ (VFTB) was used to obtain thermomagnetic curves between room temperature and 700 °C. The VFTB combines the principles of a classical horizontal Curie balance and an alternating gradient force magnetometer. Six samples that represented the full range of sediment colors and covered the entire sequence, were measured and analyzed. All samples show parallel heating curves with intensity decaying to zero at about 600 °C indicating that the magnetic carrier is magnetite.

The paleomagnetic results yielded the following polarity sequence: N > R > N > R > N. As illustrated in Fig. 8, this sequence could be interpreted in two ways. The first interpretation is based on the premise that, for reasons such as localized
bioturbation, the uppermost Reverse signal is an aberrant result. The resulting sequence would then be: the uppermost Normal represents the Brunhes Normal Chron (0–0.78 Ma) (Baksi et al., 1992), the Reverse below is the Matuyama Reverse Chron (0.78–0.99 Ma), and the lowest Normal represents the Jaramillo subchron (0.99–1.07 Ma) (McDougall et al., 1992; Baksi and Hoffman, 2000). In this case, lithostratigraphic unit 9 at the base of the section in Excavation 1 would date to 0.99–1.07 Ma.

The second, and in our opinion, more parsimonious interpretation of this sequence, as shown in Fig. 8 and Table 1, is that the top N is the Brunhes Chron (0–0.78 Ma) with the Reverse immediately below it representing the Matuyama Chron (0.78–0.99 Ma). This Reverse-to-Normal transition is the transition from the Matuyama to the Brunhes, but not necessarily the Brunhes–Matuyama boundary of 0.78 Ma (Baksi et al., 1992). The N immediately underneath represents the Jaramillo subchron (0.99–1.07 Ma), with the Reverse at the base of the Jaramillo subchron dating to ~1.1 Ma. The lowest Normal in the sequence then represents the top of the Olduvai subchron (~1.78–1.96 Ma; McDougall et al., 1992; Baksi and Hoffman, 2000). This means that the sampled ESA section in Excavation 1 at Wonderwerk Cave is constrained between ~0.78 to 1.96 Ma.

One sediment sample was taken from lithostratigraphic unit 1, near the top of the ESA sequence in Excavation 1, for optically stimulated luminescence (OSL) dating (Fig. 3; Table 1). Sample preparation entailed purifying fine-sand quartz (88–125 μm) from the sample. After sieving for the selected grain size, carbonates were dissolved with 10% HCl, organic matter oxidized with concentrated H2O2, and heavy minerals and most feldspars removed by magnetic separation (Porat, 2002). Etching with HF was subsequently used to dissolve any remaining feldspars and to etch the outer layer of the quartz grains. Equivalent doses (De) were determined with a modified single aliquot regenerative (SAR) dose protocol (Murray and Wintle, 2003) on 12 aliquots. Preheat was 10 s at 260 °C, after preliminary experiments showed that De values do not vary between 220–260 °C. Dose rates were evaluated from the concentration of U, Th, and K in the sediment, and from burial depth. Water content was estimated to be 5 ± 2%.

The De values average 363 ± 28 Gy, well beyond saturation values for quartz. Therefore, the age of this sample is considered to be a minimum age estimate. With a dose rate of 1.42 Gy per 1,000 years, the calculated age is 256 ± 21 ka, indicating that the top of the ESA at Wonderwerk Excavation 1 is older than this age. The OSL dating correlates well with two U-series dates on stalagmites from archaeological stratum 6 published by Beaumont and Vogel (2006). These dates are both minimum ages, the first >349 ka and the second >350 ka.

A single sample for cosmogenic burial dating was collected and analyzed from lithostratigraphic unit 9 from the bottom of the Excavation 1 sequence (Fig. 3; Table 1). Cosmogenic burial dating is based on the radioactive decay of 26Al and 10Be that were produced in quartz that was initially exposed to cosmic radiation and subsequently buried and shielded from such radiation (Granger et al., 1997; Granger and Muzi-kar, 2001; Partridge et al., 2003; Stock et al., 2005; Granger, 2006). These two nuclides are produced at a known ratio, and the concentration of each one depends on the residence time of the quartz near or at the surface. If the dosed quartz grains are buried instantaneously (for example, in a cave) then production is slowed or ceases. Because 26Al decays faster than 10Be, the 26Al/10Be ratio changes as a function of time and provides a means to estimate the burial age of the sediment containing the quartz grains. The burial dating method of sediments in caves has been successfully applied in the past and shown to be reliable when compared to other dating methods (Stock et al., 2005; Granger, 2006).
The Wonderwerk sample comprised very fine-grained sand and was processed following Bierman and Caffee (2001). $^{26}$Al and $^{10}$Be concentrations were analyzed at the Center for Accelerator Mass Spectrometry at the Lawrence Livermore National Laboratories. Stable Al was measured at the US Geological Survey. The sample yielded a $^{26}$Al/$^{10}$Be ratio equivalent to an age of $2.0 \pm 0.15$ Ma (using a half-life of 1.5 Ma). Using an alternative shorter half-life of 1.36 Ma (Nishiizumi et al., 2007), a burial age of $2.26 \pm 0.17$ Ma was obtained. Thus, while the use of a longer half-life (1.5 Ma) for the burial calculation yields an age that corresponds within 1 s with the Olduvai subchron, the use of the shorter half-life (1.36 Ma) yields an age slightly older than the Olduvai. An apparent older burial age could be caused by shielding of quartz grains and a slight depression in their $^{26}$Al/$^{10}$Be ratios prior to their deposition in the cave. It should be noted that the debate as to the correct value for the $^{10}$Be half-life (1.36 Ma versus 1.5 Ma) has as yet yielded no definitive resolution and remains ongoing (Fink et al., 2006, and references therein).

Nevertheless, irrespective of which half-life is considered here, when the standard deviations of the Wonderwerk cosmogenic dates are taken into account, both yield a burial age of c. 2 Ma for the basal lithostratigraphic unit 9 of Excavation 1. Although this result was obtained from a single sample, and as such cannot be considered a well-established age, it supports the paleomagnetic interpretation of lithostratigraphic unit 9 as dating to the Olduvai subchron and excludes the interpretation of this unit as dating to the Jaramillo subchron. Further samples for cosmogenic dating covering the entire sequence have now been collected and are under preparation for analysis.

**Archaeology**

Of the eight ESA archaeological strata 5–12 identified by Beaumont in the north and east section in Excavation 1, only dates for archaeological strata 9–12 are presented in this study. The correlation of the archaeological strata 9–12 with the lithostratigraphic units as well as the magnetostratigraphy and cosmogenic date is shown in Fig. 3 and Table 1. In Beaumont’s (1990) publication, sixteen strata are defined for Excavation 1. These archaeological strata were based on a small probe of four squares. Subsequent excavations led to a clarified stratigraphy consisting of twelve archaeological strata, which were then grouped into major units (Beaumont and Vogel, 2006). Lithic, faunal, and botanical remains occur throughout the ESA sequence, and there is currently no compelling geological evidence to suggest that the material is not in situ.

In general terms, in the upper archaeological strata (5–11) of Excavation 1, the character of the lithic assemblages correlates well with an Acheulean industry (Mode 2), with bifaces being the dominant tool type but with few cores or flakes (Figs. 9–10; for a more detailed report, see Chazan et al., in press). Features (such as Victoria West technology and cleavers) characteristic of Acheulean lithic industries in South Africa, including the nearby Vaal River sites, are absent in the Wonderwerk Cave assemblage (Klein, 2000; McNabb, 2001; Mitchell, 2002; Sharon and Beaumont, 2006). This may reflect constraints imposed by banded ironstone, the raw material most commonly used at this site.

Contrary to earlier reports (Beaumont and Vogel, 2006), there is no evidence in the Excavation 1 ESA sequence at Wonderwerk a Fauresmith industry, characterized by the
co-occurrence of small bifaces, convergent (Levallois) points and prepared cores, as well as long and narrow flake-blades (see Söhnge et al., 1937; Deacon and Deacon, 1999; Klein, 2000; Beaumont and Vogel, 2006).

Following the early dating scenario favored here, archaeological stratum 11 (second from the bottom), that admittedly contained only two crudely asymmetrical bifaces, is roughly coeval with the onset of the Acheulean in East Africa that is dated to \( \sim 1.6 \) (Asfaw et al., 1992), as well as with the flake-based Early Acheulean industry of Sterkfontein with an estimated, but not an absolute, date of \( \sim 1.4-1.7 \) Ma (Kuman and Clark, 2000).

Although the lithic assemblage from bottommost archaeological stratum 12, at Wonderwerk is small, and limited to two cores and 28 very small flakes (<2.5 cm in maximum dimension; Figs. 10—11), the dominance of very small flakes and absence of bifaces recalls the Oldowan of southern Africa reported from Swartkrans and Sterkfontein (Clark, 1993; Kuman and Clark, 2000). It is important to note that small flake-dominated assemblages have been documented in many Lower Paleolithic contexts, including the Oldowan contexts of Omo 57 and Omo 123 (de la Torre, 2004) and a number of sites in Europe and the Middle East (Burdukiewicz and Ronen, 2003). Further excavations are planned to provide detailed contextual information on artifacts and faunal remains in the Excavation 1 sequence.

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Fig. 10. Lithic artifacts from Wonderwerk Cave, Excavation 1. A: Biface from archaeological stratum 10. B: Biface from archaeological stratum 11. C–D: Small flakes from archaeological stratum 12. Dorsal face on left, ventral face on right. E: Core from archaeological stratum 12.

Fig. 11. Scatterplot of length versus width for flakes from Excavation 1, stratum 12.
Throughout the ESA sequence in Excavation 1, both micro- and macrofaunal remains were found in close association with the lithic artifacts (Malan and Cooke, 1941; Malan and Wells, 1943; Klein, 1988; Avery, 1995, 2006). Many of the bones are burnt. At this stage of the research the role played by hominins in bone accumulation and/or modification is unclear since the remains are extremely fragmented and many exhibit carnivore and/or porcupine gnawing.

Conclusions

The lithostratigraphy, magnetostratigraphy, OSL, and cosmogenic dates for the ESA levels in Excavation 1 at Wonderwerk Cave correlate well with the lithic typology. They provide excellent corroborative evidence for the lengthy chronology of the Wonderwerk sequence and for the antiquity of the early Acheulean in this site as roughly coeval with that in East Africa. Furthermore, they suggest that the occupation of this cave during the ESA may have begun as far back as the Oldowan. Further excavation of archaeological stratum 12 is planned to elucidate the nature of this horizon, which, given the dates presented here, may represent the earliest evidence for intentional cave exploitation worldwide. The archaeological sequence at Wonderwerk Cave thus offers a unique opportunity for the construction of a rigorous radiometric, typological, and biochronological framework for the ESA of southern Africa, as well as offering insights into the antiquity of hominin cave use.

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