Environmental influences on human innovation and behavioural diversity in southern Africa 92-80 000 years ago

Supplementary Information

VR003 excavation history

VR003 has been excavated over five seasons between 2009 and 2016. The initial two seasons had the primary objective of assessing the potential of the deposit, and only selected finds were plotted. The final three seasons 2014-2016 involved plotting of all cultural items using different size cut-offs for different classes of material (≥20 mm for lithics, ≥25 mm for bone). Some classes of material, notably OES, were only plotted if modified. All plotted artefacts were assigned unique provenience ID's and individually bagged. Sedimentary aggregates were plotted with a single indicative point location, and volume was quantified as proportional bucket volume (FULL, ¾, ½, ¼). All aggregates were sieved on site through nested 3 mm and 1.5 mm mesh, and the residues from each bagged separately. All plotting was undertaken using a local grid, managed by control points emplaced around the site.

We currently recognise nine archaeological horizons and eight geological horizons in the Main Area sequence (1); for the sake of simplicity in this paper we refer to the lower two archaeological horizons (I-08 and I-09) in aggregate as the Lower Deposits. All horizons in the Main Area are associated with the MSA. Inside the small extant shelter (known as Sector III) we identify 23 geological horizons (III-01 through III-23), with Late Holocene LSA comprising the upper 14 strata (0.6-0.9 m depth). In the Main Area, I-04 was assigned to the Howiesons Poort and Still Bay (1), though initially dated by OSL in the Main Area to 45.7 ±2.8 ka. Inside the shelter in Sector III, Howiesons Poort artefacts occur in strata III-18 through III-23, with initial OSL ages of 42.3 ±2.7 ka and 41.7 ±2.9 (1) (Still Bay has yet to be encountered in this part of the site). In both areas these ages are unusually young for the Howiesons Poort. We provide a redating here (SI Geochronology below) using OSL on quartz grains from III-18 to III-20 that places the Howiesons Poort between 71.6±6.2 and 60.8±5.2, consistent with ages elsewhere, with ages for the immediately overlying post-Howiesons Poort stratum III-17 of 55.7 ±4.4 and 66.1 ±5.3 ka (Figure S1).

The *fossiles directeur* for the Howiesons Poort and Still Bay (backed artefacts and bifacial points respectively) occur as a discrete band across the entire site and include a single piece of engraved OES in the Link Trench (Figure S1). In the Main Area there is no recurrence of such artefacts in the underlying deposits, which we assign to the pre-Still Bay MSA.

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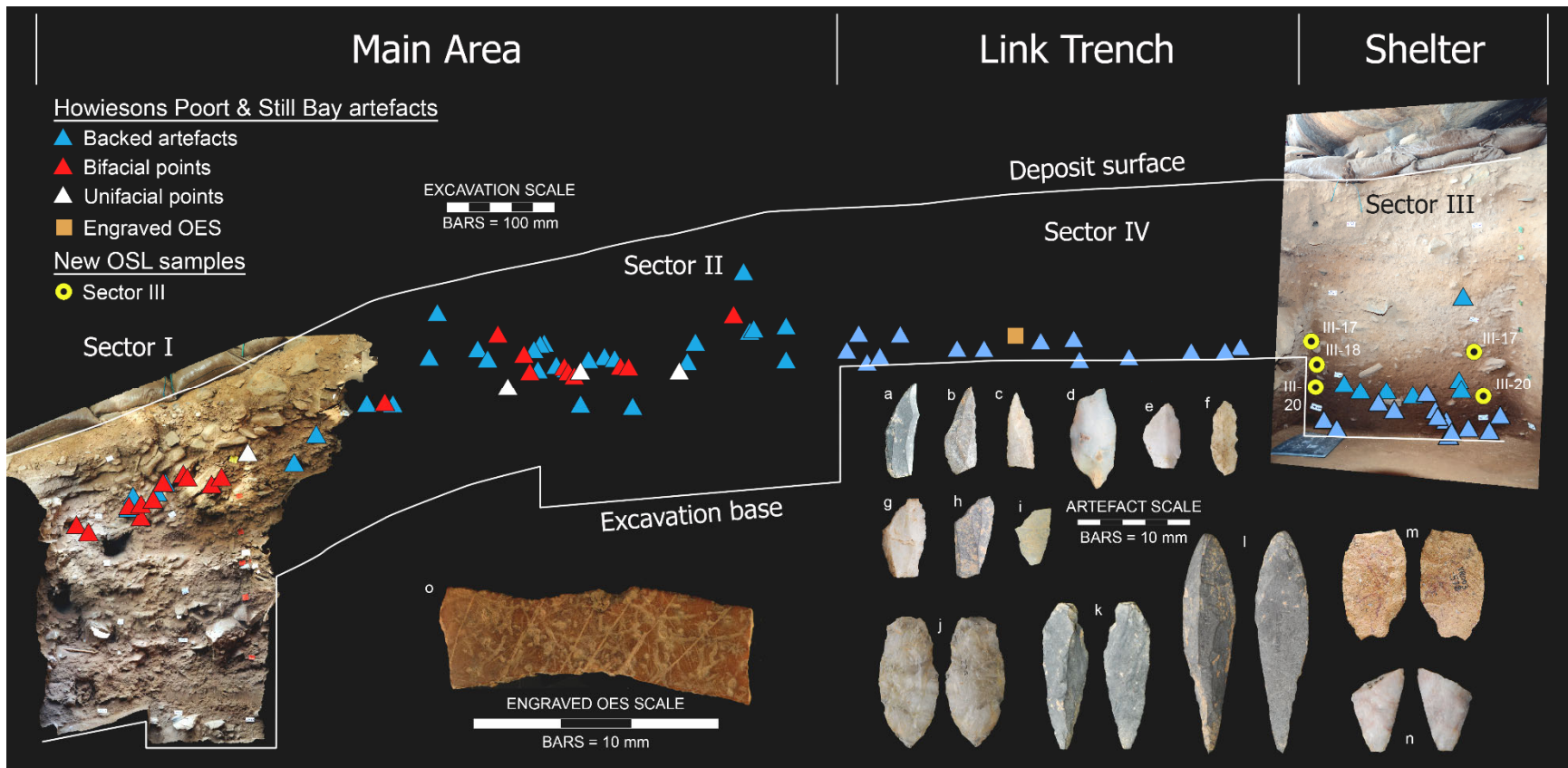
Figure S1. East section view of VR003 deposits showing distribution of Howiesons Poort (backed artefacts, blue triangles) and Still Bay (bifacial points, red triangles) type markers across the excavation area, and the sampling locations for the five new Sector III quartz OSL ages reported on here (yellow circles). Unifacial points (white triangles) may occur in either the post-Howiesons Poort or Still Bay; in this case they appear limited to the Still Bay. a-c, truncated pointed backed pieces; d-f, segments; g-i, truncated oblique pieces; j-n, bifacial and partly-bifacial points and fragments; o, engraved OES.

Geoarchaeology

Sedimentology. Grain size analysis, loss on ignition, and magnetic susceptibility shows structured variation through the Main Area deposits (Figure S2). The upper 0.3 m (I-02 & I-03) are significantly finer grained that the rest of the Main Area deposit and show large variations in magnetic susceptibility frequency dependence suggesting that these sediments contain a significant amount of superparamagnetic ferrimagnetic grains interpreted to be formed via anthropogenic burning. Though magnetic susceptibility increases in the lower deposits, the consistency of the frequency dependence indicates a natural signal likely driven by changes in the mineralogy of the deposit. The lower 1.6 m of the Main Area shows a deceasing grain size trend through strata I-04 to I-09, with a significant increase in carbonate percentage in the bottom 100 mm of the section.
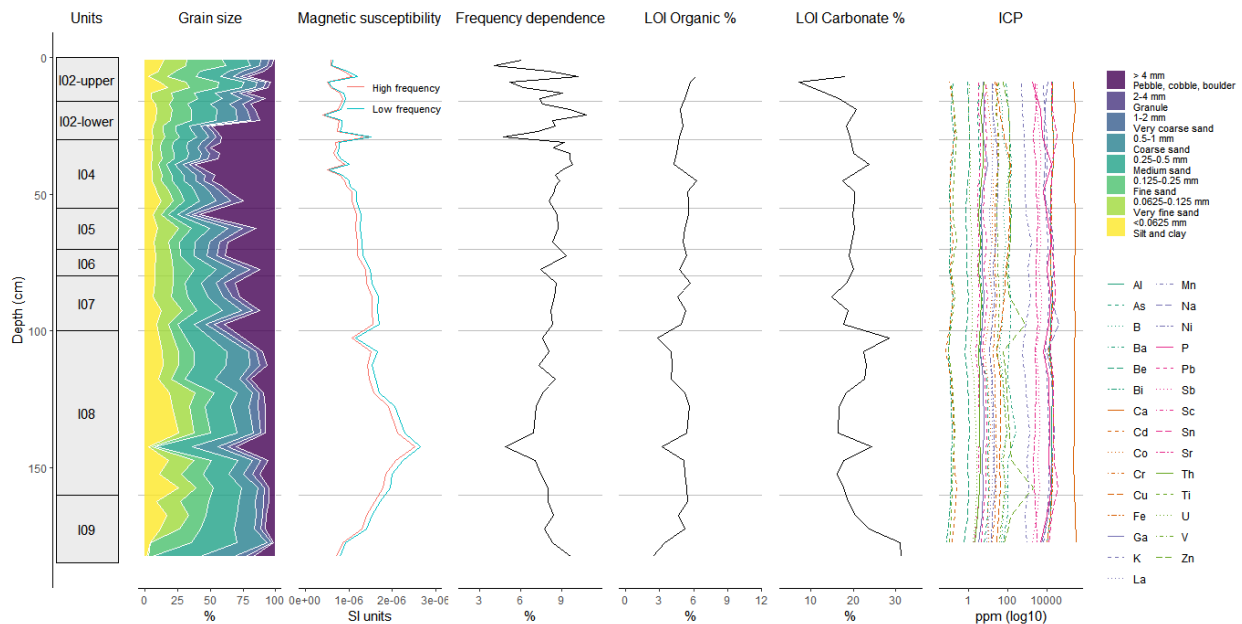
Figure S2. Grain size, LOI, and magnetic susceptibility data for the Main Area, Sector I.

Micromorphology. Micromorphological analyses were directed at investigating the sedimentary components and formation processes including post-depositional alterations. To this aim we collected three block samples from layers I-08, I-09, and their respective contact. One thin section of each was produced by P. Kritikakis (University of Tübingen, Germany), T. Beckmann (Schwülper-Lagesbüttel, Germany) and T. Culligan (University College Dublin, Ireland). The three thin sections show overall similar characteristic with each other but also with the upper

64   deposits as previously described (1). The related distribution of fine and coarse materials is

65   dominantly porphyric, but sand sized grains generally exhibit a coating with fine material (Figure

66   S3 C). Additionally, cemented areas were observed (Figures S3 A&B, Figure S3 A&C) which

67   show a dense calcitic crystallitic micritic groundmass with floating coarse grains. Otherwise, void

68   space is open and dominated by simple and complex packing voids. Star shaped vughs,

69   channels and chambers are also present. The microstructure is thus massive to spongy, but can

70   also appear as granular due to coated grains. One thin section from I-08 appears to be partially

71   disturbed and shows several deviations from this general microstructure. This includes a clear

72   and wavy contact with the intact part (Figure S4 A & F), silty crusts with vesicles (Figure S4 F),

73   increased density/cementation, a darker shade (compare Figures S4 C, F, & G), and local areas

74   with a massive, well sorted pellet structure (Figure S4 E). However, the disturbed part does not

75   differ in its components from the intact part. In all three analysed thin sections, the material

76   composition can be divided into a fine silty, calcareous matrix with rare silty quartz grains, and

77   coarse grained (> 0.02 mm) geogenic and anthropogenic components. Geogenic components

78   include sand sized calcite crystals (e.g. Figure S3 A-C, & E), fine limestone gravel (e.g. Figure

79   S3 A&E), sand to fine gravel sized quartz (angular or rounded, Figure S3 F&G), rare sand to

80   fine gravel sized, rounded soil aggregates (Figure S3 A, D), fine gravel quartzite and gypsum

81   (Figure S4 D). Gypsum is present as accumulations of lenticular crystals as well as in rounded

82   rocks. The dominant anthropogenic component is bone fragments, which are sand to gravel

83   sized, subrounded to subangular (Figure S3 A-C, Figure S4 A&E, Figure S5 A, 6). Several bone

84   fragments show heating alterations, ranging from charring to superficial and complete

85   calcination (Figure S3 F, Figure S4 B, E, & G, Figure S5 G). The presence of microscopic

86   charcoal and dark amorphous staining, especially in the lowermost layer I-09, also indicates fire

87   use activities at the site, possibly related to the observed heat treatment of silcrete at the site.

88   Silcrete and quartz microdebitage, showing a particular 'flaked' shape compared to the

89   geogenic rounded minerals/rocks, are also present (Figure S3 C&G). OES is another common

90   anthropogenic component, and fragments show a subangular to rounded shape (Figure S3

91   A&E, Figure S4 C, Figure S5 A, C, & D). A few OES fragments show a dark colour, potentially

92   as the result of charring of their organic content, and others show internal fractures (Figure S4

93   C, Figure S5 D). Finally, one iron-rich rock fragment was observed, potentially presenting a

94   piece of ochre (Figure S5 B).

95   These micromorphological observations on the sediments allow us to reconstruct the

96   anthropogenic and natural formation processes of I-08 and I-09, the Lower Deposits of the deep

97   sounding. The calcareous matrix, calcite crystals and limestone originate from the weathering of

98   the bedrock and colluvial deposition on the slope. The fine coating on sand sized components,

99   the occurrence of rounding and of soil aggregates from the plateau above the site suggest

100   transport processes (2). However, the high frequency of microscopic bones and their broad size

101   distribution, the rarity of components from the plateau, and that the fine coating is composed of

102   typical slope material all indicate limited transport on the slope in front of the shelter and support

103   the integrity of the archaeological record at the site. Post-depositional processes affecting the

104   archaeological record are limited to impact fractures, possibly from trampling, local cementation,

105   and gypsum formation. The latter two result from circulating water and later evaporation. There

106   is little difference between I-08 and I-09, which show the same general composition and

107   structures, as well as depositional and post-depositional processes. One difference, however, is

108   a darker colour of I-09 compared to I-08, resulting from an increase in microcharcoal in this

109   layer. This increase in microcharcoal may indicate an intensification of fire use activities at the

110   site at this time, but may also just reflect a local phenomenon in this layer. Generally, fire use

111   activities appear to be of different fire intensity or duration as reflected in the variable heating

112   signal recorded in the bones. As we have not yet discovered any *in situ* combustion features,

113   fire use interpretation remains limited. Regarding the disturbed part in one thin section from I-08,

114   this most likely presents an ancient biogenic structure, possibly an underground nest structure.

115   The observed structure does not, however, resemble the published microstructure of termite

116   mounds (3-6) or of underground bee nests (7), which are both known in the area.

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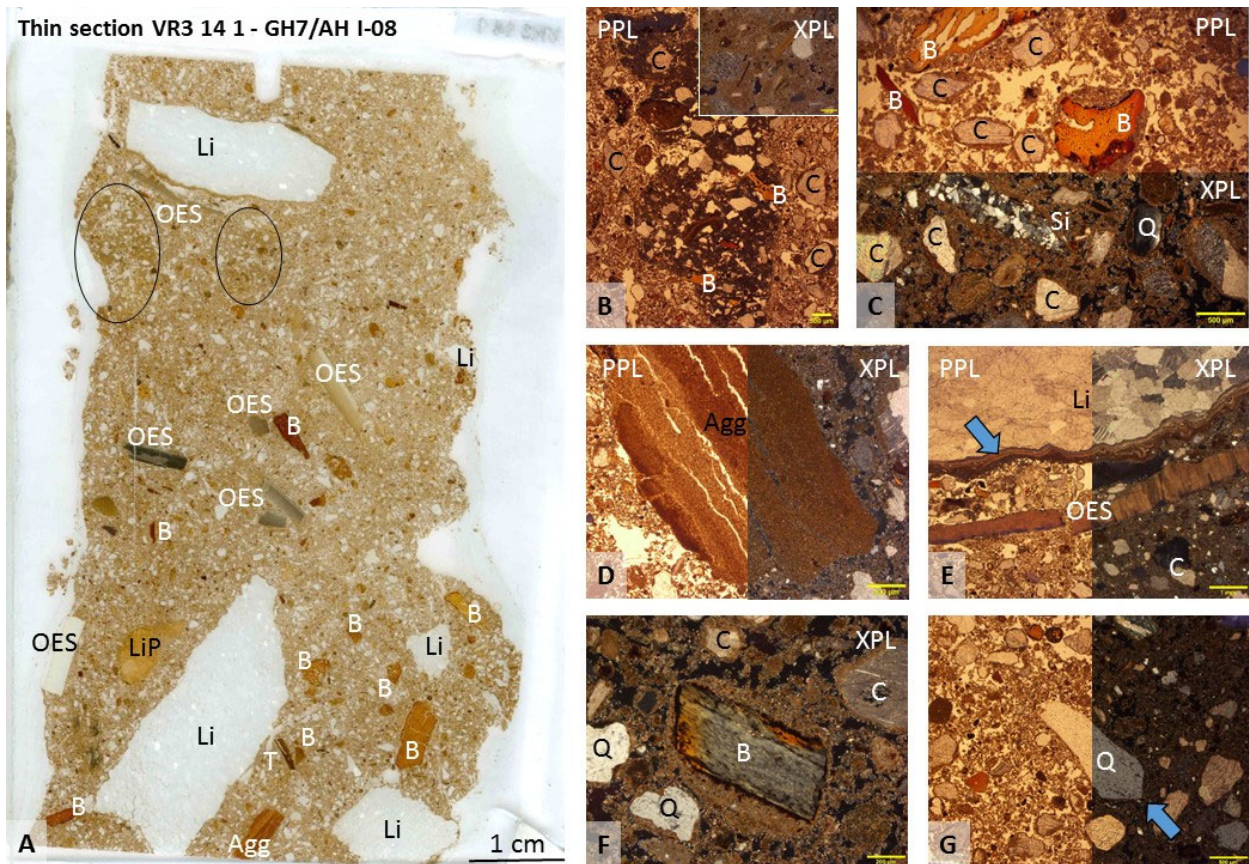
Figure S3. Micromorphology sample VR003 14 1 (I-08). (A) Scan of thin section VR 14 1 showing a homogenous appearance and random orientation of coarse grains. Coarse grains are mainly limestone and calcite crystals originating from limestone weathering (white grains) as well as quartz (also white grains, rarer than calcite), bones (almost all brown grains, larger ones labelled), ostrich eggshell and rarely teeth, speleothem pendants and aggregates. Two cemented areas are present (black circles), but only become visible at higher magnification (see B). (B) Cemented area showing a dark colour and clear boundaries to the surrounding matrix. The inlet at the upper right shows the dense microstructure in the cemented area, which otherwise does not differ from the surrounding matrix indicating *in situ* formation. Scale 500 µm, scale inlet 200 µm. (C) Sand to fine gravel sized grains, including bones, often exhibit a coating composed of fine material, a typical feature of slope deposits. The coating and the general matrix are composed of the same calcareous silt suggesting transport on the slope and not from the plateau above. Large grains such as limestone gravel, or elongated objects such as silcrete and ostrich eggshell, generally do not show coatings. Scale 500 µm. (D) A subrounded surface slack aggregate, enriched in organics and clay. This aggregate originates from the plateau above the site. Scale 500 µm. (E) *In situ* snapped ostrich eggshell below limestone. Note the coarse-crystalline nature of the limestone and a laminated pendant (arrow) formed on its surface. Scale 1 mm. (F) Calcined bone (grey colour). Scale 200µm. (G) Quartz microdebitage with elongated shape and acute edges (arrow), indicating that this quartz presents a knapping by-product. Scale 500µm. Abbreviations used here and in subsequent figures: Agg = Aggregate, B = Bone, C = Calcite, Ch = Charcoal, Gy = Gypsum, Ir = iron rich rock, Li = Limestone, OES = Ostrich eggshell, OIL = Oblique Incident Light, PPL and XPL= plane and Cross Polarized Light, Q = Quartz, Si= silcrete, T = Tooth, OIL plane and Cross Polarized Light, Q = Quartz, Si= silcrete, T = Tooth, OIL.

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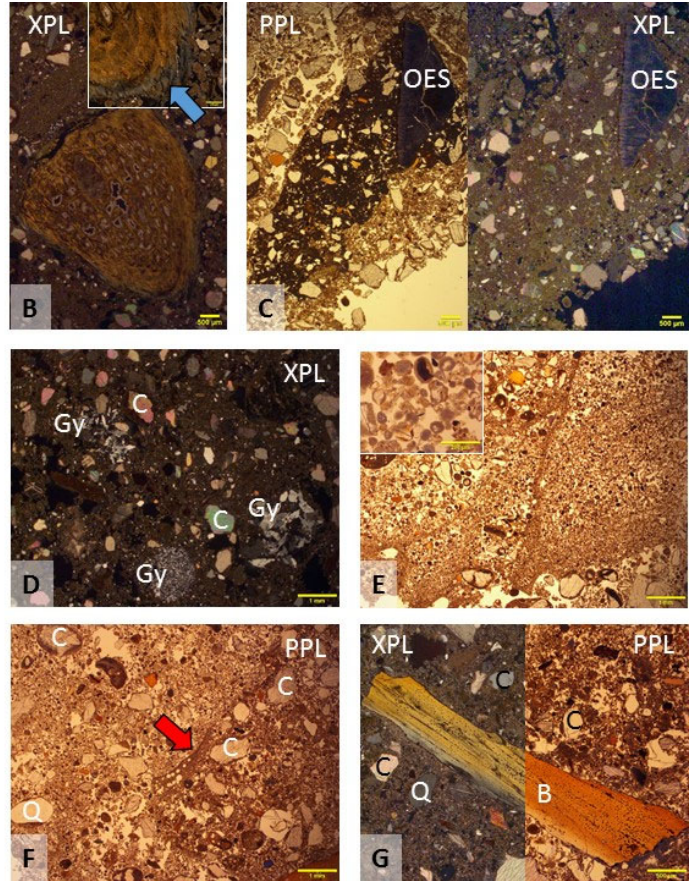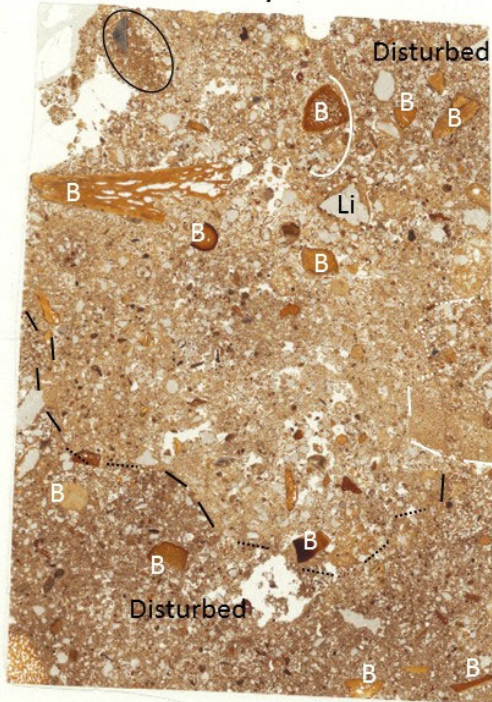
Figure S4. Micromorphology sample VR003 15 8 (I-09). (A) Scan of thin section VR3 15 8 showing local disturbances (dark coloured areas at bottom and upper right corner of slide). The contact is clear (marked by lines) and the intact part shows similar characteristics to thin section VR 14 1. Also here the deposit shows a calcareous matrix with limestone gravel, calcite crystals, fine gravel to sand sized bones (almost all brown grains) and a cemented areas (black circle) occurs. (B) Superficially calcined bone (blue arrow in inlet indicating grey, calcined phase), suggesting short exposure to a high temperature fire. Scale 500 µm, inlet 200 µm. (C) Cemented area with dark colour and clear boundaries to surrounding matrix, but showing same composition with calcareous silt (see XPL) and calcite crystals, bones and ostrich eggshell. Note also the internal fractures in the ostrich eggshell. Scale 500 µm. (D) Gypsum is present in variable forms with accumulations of lenticular crystals to rounded aggregates/rocks. Scale 1 mm. (E) Disturbed area with pellet structures, sorted for very fine sand, and fine coating of the wall, indicating a biogenic origin. Scale 1 mm. (F) Clear contact of the disturbed part with the intact part. Note a silty crust with vesicles here. Scale 1 mm. (G) Superficially calcined bone (grey colour) in the disturbed part of the thin section. Scale 500 µm.
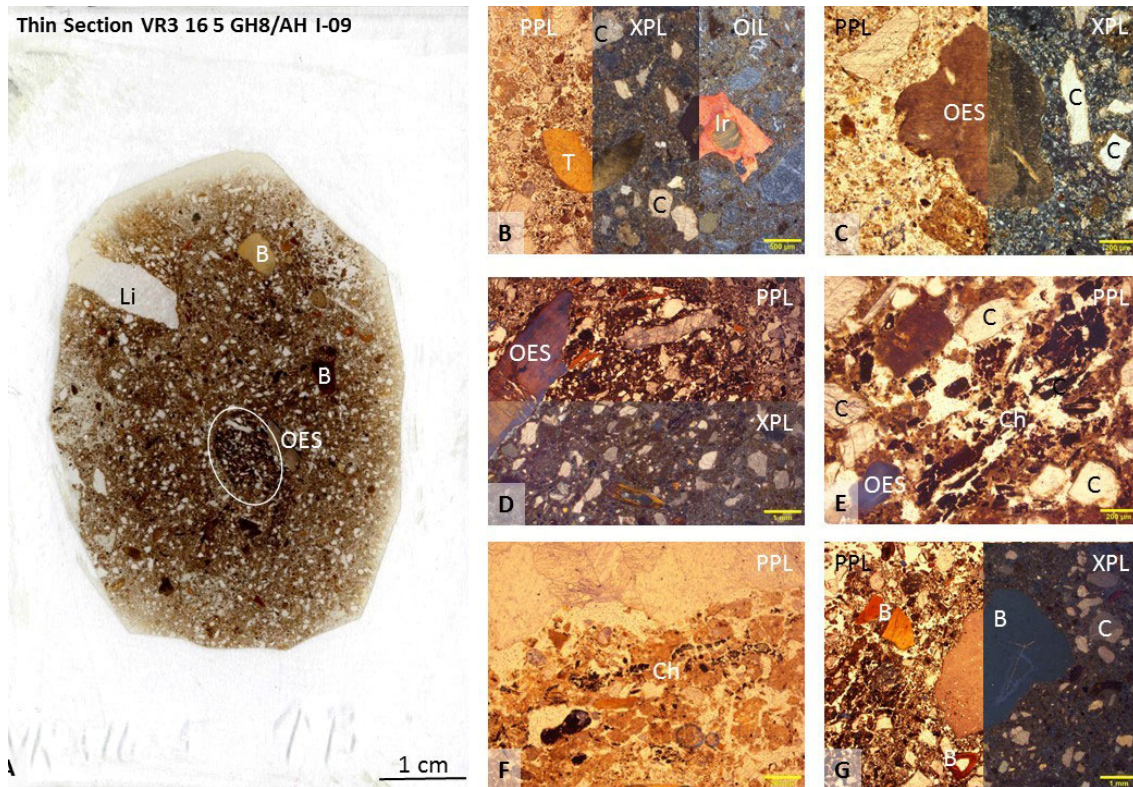
Figure S5. Micromorphology sample VR003 16 5 (I-09). (A) Scan thin section VR16 5 showing darker colour compared to the upper thin sections, resulting from microscopic charcoal and amorphous black staining in the matrix here (see E and F). Otherwise, the deposits show similar characteristics, with limestone and calcite crystals, many microscopic bones, a cemented area (white circle) and a homogenous, porphyric appearance. (B) Tooth (T) and an iron rich rock fragment, possibly ochre. Scale 500 µm. (C) Rounded ostrich eggshell suggesting transport. Scale 200 µm. (D) Cemented area next to an ostrich eggshell with internal fractures/dissolution traces. The fine material appears darker here due to increased density and black amorphous staining. Note also the bones in the cemented area. Scale 1 mm. (E) Details of cemented area with microscopic charcoal. Scale 200 µm. (F) Microscopic charcoal in the general matrix. Scale 200 µm. (G) Bone fragments, some heated (central grey) and others without heating alterations (brown). Scale 1 mm.

170   **Fabric analysis**. During excavation, elongated lithics and bones axis were plotted with two

171   spatial points to record their orientation and slope. The three-dimensional plunge and

172   bearing of each artefact was plotted in a Benn diagram along with comparative data for

173   geological processes modelled by (8). Confidence intervals (p = .95) in the Benn diagrams

174   were calculated using a permutation test developed by (9), which involves resampling the

175   assemblage 10000 times and plotting contour lines that accounts for 95% of the resampled

176   indices. Rayleigh and Kolmogorov-Smirnov tests were used to determine if the orientation

177   (bearing) and slope (plunge) of artefacts differed significantly from a uniform distribution, and

178   were run using the CircStats package in R. Mean slope values for the two-point objects

179   (10.8°) do not deviate substantially from the low to moderate slope of the Lower Deposit

180   sediments, and the artefacts show no preferential pattern in orientation.

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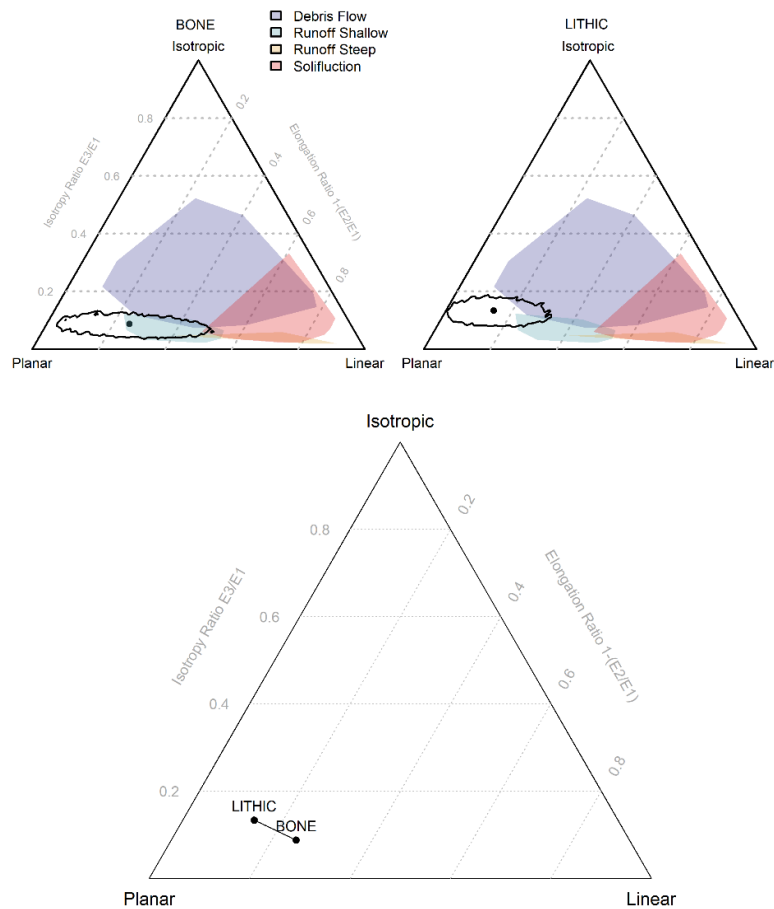
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184   **Figure S6.** Benn diagrams for two-point lithics and bones from I-08 and I-09 against expectations for
185   various depositional processes.

186

187   9

188   **Refits**. Refit analysis of lithic artefacts was used principally as a means of assessing the
189   integrity and slope of the archaeological deposits. Only silcrete and chert artefacts were
190   included, as these materials are visually diverse and distinctive, particularly when compared
191   to the other major materials in the assemblage (quartz, quartzite, and hornfels). A total of 12
192   refit sets was found in I-08 and I-09, comprising nine instances of sequential flake removals,
193   two sets of conjoining flake fragments, and one instance where two pieces of heat shatter
194   could be refit. Refits over short distances occur at various orientations (Figure S7). Refits
195   over long distances typically follow the slope of the surface and lower strata.
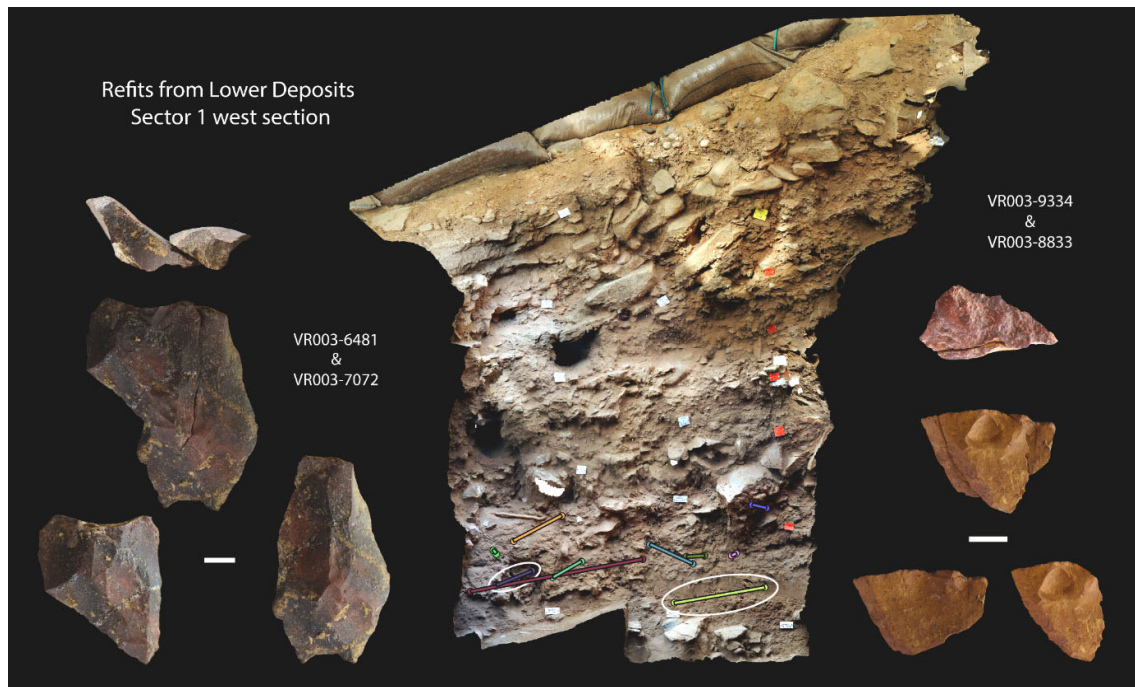
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197   **Figure S7.** Distribution and orientation of lithic refit sets in I-08 and I-09, with indicative examples of
198   refitting flakes.

Geochronology

Luminescence dating

Sample collection and preparation. Samples were collected during the excavation of VR003 by hammering metal tubes into cleaned section faces. These tubes were sealed with adhesive tape and wrapped in opaque plastic bags for transportation. Five samples were taken from Sector III (inside the shelter), with the aim of replicating previously published ages for the Howiesons Poort levels at VR003 (10). These published ages were younger than might be expected based on the affinities of associated material, though the chronology for these technocomplexes is contested (11, 12). A further four samples were taken from strata I-08 to I-09 in Sector I (Main Area), the lowermost VR003 levels excavated so far, to establish the age of this portion of the site.

In the laboratory, samples were processed under subdued red light. Sunlight exposed material was removed from each end of the sample tube and retained for dose rate measurement. Quartz and K-feldspar were extracted from the portion of each sample which had not been exposed to sunlight since burial. Samples were initially wet-sieved to isolate the 212-180 μm size fraction. This removes large bedrock clasts from the sample before acid treatment, meaning that the possibility of incorporating grains liberated by dissolution of the bedrock was minimized. Carbonates and organic matter were subsequently removed from the 212-180 μm fraction using 1M HCl and H_2O_2 respectively. The resulting material was re-sieved at 180 μm. Density separations at 2.72, 2.62, 2.58 and 2.53 g/cm^3 (13) were used to isolate quartz (2.62-2.72 g/cm^3) and K-feldspar (2.53-2.58 g/cm^3). The quartz fraction was etched in HF (23M HF for 60 min followed by a 10M HCl rinse) and sieved at 150 μm to remove partially dissolved feldspars. Samples were stored in opaque containers prior to measurement.

Environmental dose rate calculation. For HF acid etched sand-sized quartz grains, the environmental dose rate consists of external beta, gamma and cosmic ray components. The dose rate to unetched sand-sized K-feldspar also contains an external alpha component and an internal beta component.

External alpha, beta and gamma dose rates were determined using alpha counting, beta counting and field gamma-spectrometry respectively. Alpha and beta counting was performed on dried, homogenised sub-samples of the light-exposed material removed from the sample tube prior to extraction of the dating sample. Uranium and thorium concentrations were calculated for each sample using thick-source alpha counts obtained using Daybreak Model 583 alpha counters. External alpha dose rates were calculated from these data using standard conversion factors (14) and assuming secular equilibrium in the U and Th decay series. Beta

dose rates were measured with a Risø GM-25-5 low-level beta counting system (15) using MgO and Volkagem (16) loess standards. Gamma dose rates were measured with an EG&G Ortec digiDart-LF gamma-spectrometer using the "threshold" method. External dose rates were corrected for moisture content (10±5%), attenuation of alpha (17) and beta (18) radiation due to grain size and alpha efficiency, using an a-value of 0.11±0.03 (19). The internal dose rate to K-feldspar grains was calculated assuming a K concentration of 12±1% and a K/Rb concentration ratio of 270:1 (20). The assumed K concentration encompasses (at 2σ) nearly the full range of K concentrations (9-14%) measured for single-grains of K-feldspar emitting detectable luminescence signals (21-25) and is consistent with the widely adopted value of 12.5±1.0% (26). Cosmic ray dose rates for the Main Area (Sector I) samples (the K-feldspar samples) were calculated using site location (31.5°S, 18.5°E, 50 m elevation) and present day sediment burial depths, assuming a sediment overburden density of 1.8±0.1 g/cm^3. However, calculation of the cosmic dose rates to the Sector III samples (the quartz samples) was complicated by their location behind the present-day dripline. For the purposes of calculation the cave was approximated to have an opening 120° wide and a roof consisting of a 3.5 m thickness of rock with a density of 2.5 g/cm^3. The dose rate at the surface of the sediment 1 m behind the dripline (the approximate sampling location) was then calculated using the cos$^2\Phi$ zenith angular distribution of cosmic rays (27). For each sample, this surface cosmic dose rate was modified according to the present-day burial depth using an overburden density of 1.8±0.1 g/cm^3. Total dose rates were calculated using the DRAC dose rate calculator (28). Dose rates are presented in Table S1. Here and throughout the luminescence Supplementary Information, uncertainties are given at 1σ except where otherwise stated.

Table S1. Sample depths and dose rates for VR003 samples. Depths are given below present-day sediment surface.

Stratum	Sample (mineral)[a]	Sample depth (m)	External dose rate (Gy/ka)[b]				Total dose rate, D$_r$ (Gy/ka)
			Alpha	Beta	Gamma	Cosmic	
Sector III 'Inside the Shelter'							
17	8238 (Q)	0.67±0.1[c]	-	0.70±0.08	0.68±0.07	0.11±0.01	1.49±0.11
17	2885 (Q)	0.67±0.1[c]	-	0.87±0.10	0.66±0.07	0.11±0.01	1.64±0.12
18	2883 (Q)	0.72±0.1[c]	-	1.01±0.12	0.68±0.07	0.11±0.01	1.80±0.14
20	2881 (Q)	0.80±0.1[c]	-	0.98±0.12	0.70±0.07	0.11±0.01	1.78±0.14
20	8235 (Q)	0.80±0.1[c]	-	1.03±0.12	0.94±0.09	0.11±0.01	2.08±0.15
Sector I 'Main Area'							
7/8	2432 (KF)	1.2±0.2	0.06±0.01	0.70±0.05	0.57±0.04	0.18±0.02	2.30±0.11[d]
8	8710 (KF)	1.4±0.2	0.06±0.01	1.09±0.08	0.64±0.05	0.17±0.02	2.74±0.13[d]
9	8678 (KF)	1.7±0.2	0.06±0.01	1.15±0.10	0.60±0.04	0.17±0.02	2.76±0.14[d]
10	11918 (KF)	1.9±0.2	0.05±0.01	0.67±0.05	0.50±0.04	0.16±0.02	2.17±0.11[d]

[a] Q = quartz, KF = K-feldspar. [b] External dose rates after correction for sample moisture content (10±5%) and, where appropriate, corrected for attenuation due to grain size and alpha efficiency. [c] Depth below sediment surface, excluding the 3.5 m cave roof thickness [d] Total dose rates are the sum of external dose rates plus an internal dose rate contribution of 0.79±0.08 Gy/ka.

Luminescence measurement equipment. Luminescence measurements were made on quartz extracted from Sector III samples, while K-feldspar was used for Sector I material. This approach was adopted since the Sector I samples were presumed to be considerably older than those from Sector III. K-feldspars are able to absorb far larger radiation doses than quartz before "saturation" occurs, enabling them to yield older ages before the upper limit of the technique is reached.

Individual grains of quartz or K-feldspar were mounted in aluminium discs drilled with 100 holes, each 300 µm deep and 300 µm in diameter. All luminescence measurements presented in this study were carried out using a Risø TL/OSL-DA-15 automated dating system (29), fitted with a dual laser single-grain attachment (30, 31). Individual grains were stimulated using either a focused 10 mW Nd:YVO$_4$ solid-state diode-pumped green (532 nm) laser for quartz OSL or a 140 mW TTL modulated infra-red (IR, 830 nm) laser with a Schott RG 780 longpass filter mounted in the beamline for K-feldspar pIRIR. Simultaneous illumination of all grains on a disc was carried out using either blue (470 nm) or IR (870 nm) light emitting diodes (LEDs). Luminescence was detected using an Electron Tubes Ltd 9235QB15 photomultiplier tube shielded by Hoya U-340 filters when measuring quartz and Schott BG3 and BG39 filters when measuring K-feldspar. Irradiation was carried out using a 1.48 GBq ^{90}Sr/^{90}Y beta source. This source is calibrated relative to the National Physical Laboratory, Teddington ^{60}Co γ-source (Hotspot 800) (32). Due to the spatial inhomogeneity of beta emitters across the active face of our ^{90}Sr/^{90}Y beta source, it was necessary to calibrate the dose rate to each individual grain position on a single-grain disc (33). All single-grain discs were placed into the Risø instrument at the same angle relative to the ^{90}Sr/^{90}Y beta source. For the instrument used in this study, the sample discs rotated 0.04±0.03° per measurement cycle within the single-aliquot regenerative-dose method (see below). Consequently, it is possible to accurately correct for the effects of inhomogeneity in our ^{90}Sr/^{90}Y beta source by applying a grain position correction to each equivalent dose. Position-corrected equivalent doses were used in all age calculations.

The single-aliquot regenerative-dose method applied to quartz and K-feldspar. Equivalent doses (D_e) were determined using the single-aliquot regenerative-dose (SAR) method (34). This method allows an independent estimate of D_e to be generated for each aliquot or mineral grain measured, though in practice single-grain measurements suffer a high rejection rate. The SAR technique involves making a series of paired measurements of luminescence intensity. The first measurement in each pair gives the natural (L_n) or regenerated (L_x) luminescence intensity, while the second measurement (T_x) gives the luminescence intensity in response to a fixed test dose. T_x is used to monitor changes in

303 sensitivity (luminescence per unit dose) during the measurement sequence. By dividing the

304 natural or regenerated luminescence intensities by their respective test dose intensity (i.e.

305 L_n/T_n or L_x/T_x), a sensitivity-corrected luminescence response is determined. All single-grain

306 quartz measurements presented in this study were made using the SAR procedure and

307 experimental conditions detailed in Table S2.

308

309 **Table S2.** The SAR measurement sequence used to produce single-grain equivalent dose estimates
310 from quartz from VR003.

Step	a) Single-grain quartz OSL
1	Give regenerative dose, D_i[a]
2	Preheat 1 (260 °C for 10 s)[b]
3	Green laser stimulation (125 °C, 2 s), L_x[c]
4	Give test dose, D_t (~10 Gy)
5	Preheat 2 (220 °C for 10 s)
6	Green laser stimulation (125 °C, 2 s), T_x
7	Return to step 1

311 [a] In the first cycle, where the natural luminescence intensity is observed, D_i = 0 Gy. [b] The suitability of
312 preheat 1 and 2 temperatures for measuring quartz from VR003 was assessed by performing single-
313 grain dose recovery tests (35) on 600-800 grains per sample. All samples yielded dose recovery
314 ratios (measured D_e/given dose) consistent with unity at 2σ, implying that the measurement conditions
315 used were appropriate. [c] The luminescence signal (L_x or T_x) was that recorded during the first 0.3 s of
316 stimulation, with a background signal from the last 0.3 s of stimulation subtracted.

317

318 **Table S3.** The SAR measurement sequence used to produce a) single-grain equivalent dose estimates
319 and b) fading rates from K-feldspars from VR003.

Step	a) Single-grain K-feldspar pIRIR	b) K-feldspar pIRIR fading rates
1	Give regenerative dose, D_i[a]	Give regenerative dose (~50 Gy)[c]
2	Preheat 1 (255 °C for 60 s)	Preheat 1 (255 °C for 60 s)
3	IR diode stimulation (60 °C for 200 s)	Pause[d]
4	IR laser stimulation (225 °C, 2 s), L_x[b]	IR diode stimulation (60 °C for 200 s)
5	IR diode stimulation (225 °C for 500 s)	IR diode stimulation (225 °C for 200 s), L_x[e,f]
6	Give test dose, D_t (~50 Gy)	Give test dose, (~50 Gy)
7	Preheat 2 (255 °C for 60 s)	Preheat 2 (255 °C for 60 s)
8	IR diode stimulation (60 °C for 200 s)	IR diode stimulation (60 °C for 200 s)
9	IR laser stimulation (225 °C, 2 s), T_x[b]	IR diode stimulation (225 °C for 200 s), T_x[e]
10	IR diode stimulation (225 °C for 500 s)	IR diode stimulation (290 °C for 150 s)
11	Return to step 1	Return to step 1

320 [a] In the first cycle, where the natural luminescence intensity is observed, D_i = 0 Gy. [b] The luminescence
321 signal (L_x or T_x) was that recorded during the first 0.3 s of stimulation, with a background signal from
322 the last 0.3 s of stimulation subtracted. [c] Prior to the first measurement cycle, aliquots were illuminated
323 for 150 s at 290 °C to remove any residual signal remaining after completion of the single-grain
324 measurement sequence. [d] For each aliquot, ten measurements were made, of which three were prompt
325 (no pause), three were made after a 1 hour pause, and two were made after 10 and 100 hour pauses.
326 [e] The luminescence signal (L_x or T_x) was that recorded during the first 50 s of stimulation, with a
327 background signal from the last 50 s of stimulation subtracted. [f] The optical wash incorporated into the
328 single-grain measurement sequence was omitted here since IR diodes illuminate the disc more evenly
329 than the single-grain laser, minimising the potential to carry signal over into the test dose measurements
330 (36).

331

332 K-feldspars were measured using a post-infrared, infrared stimulated luminescence (pIRIR)

333 measurement sequence (Table S3a). In this sequence, the sample is illuminated using IR

334 diodes for 200 s prior to measurement of the signal (L_x or T_x) from individual grains using an

335 IR laser. This procedure removes luminescence signals which are prone to "fading", which

336 could otherwise lead to underestimation of D_e (37, 38). In addition, samples underwent an

337 elevated temperature (225 °C for 500 s) IR diode stimulation after measurement of L_x or T_x, to

338 prevent carry-over of charge from one measurement to the next (36). Although VR003

339 samples yielded limited K-feldspar, dose recovery tests (39) were performed on three

340 multigrain aliquots of each of samples VR003-8678 and VR003-8710, and 600 individual

341 grains of sample VR003-2432. These tests yielded dose recovery ratios (measured D_e/given

342 dose) of 1.01±0.03, 0.98±0.03 and 0.99±0.01 respectively, implying that the measurement

343 conditions used were appropriate.

344

345 It has been observed widely that a large proportion of quartz and K-feldspar grains either do

346 not yield a measureable luminescence signal, or display luminescence characteristics which

347 indicate that they are unsuitable for age determination. Consequently, most dating studies

348 adopt rejection criteria which exclude these grains. In the present study we adopted rejection

349 criteria based on those used to analyse the very large single-grain dataset from Denisova

350 Cave, southern Siberia (24). In this analysis, grains were rejected where one or more of the

351 following conditions were met:

352   a) The initial T_n signal is less than 3σ above the corresponding background count, or the
353   relative error on T_n is >20%.
354   b) The recycling ratio (34) differs from unity by greater than 2σ.
355   c) The IR-depletion ratio (40) is more than 2σ below unity (this criterion excludes feldspar
356   grains, and was only used for analysing quartz datasets).
357   d) Recuperation is high. This criterion was met where L_x/T_x for the 0 Gy regeneration point
358   is greater than 5 % of L_x/T_x for the maximum regenerative dose.
359   e) The L_x/T_x ratios are too scattered to be reliably fitted with a curve. This criterion is met
360   where the figure-of-merit (FOM) value (41, 42) exceeds 10%. The FOM is defined as:

361
$$FOM(\%) = \frac{\sum_{i=1}^{n} |y_i^o - y_i^f|}{\sum_{i=1}^{n} y_i^f}$$

362   where y_i^o and y_i^f denote the ith observed and fitted values respectively.

363   f) The L_n/T_n ratio is statistically consistent with, or higher than, the saturation level of the
364   corresponding dose response curve (DRC), so that a finite D_e value and error cannot
365   be obtained.
366   g) The D_e value is obtained by extrapolation of the fitted DRC, rather than interpolation
367   among the regenerative dose signals.
368   h) The grain has a negative D_e value consistent with zero. This criterion was used to
369   identify modern contaminants introduced during sampling, and was only applied to the
370   quartz datasets.

371 Application of the rejection criteria was achieved using the function calSARED() provided in

372 the R package *numOSL* (43, 44), with DRCs fitted using a general-order kinetic fit (45). For

373 each accepted grain, the standard error associated with the D_e determination was estimated

374 using a 1000 iteration Monte Carlo simulation. Rejection criteria were applied to grains in the

375 order listed above, and only one cause for rejection was noted per grain (Tables S4 and S5).

376

377 **Table S4.** The number of quartz grains which were measured, rejected after application of rejection
378 criteria, and accepted for inclusion in the calculation of the burial dose.

Sample (VR003-...)	8238	2885	2883	2881	8235
Stratum	III-17	III-17	III-18	III-20	III-20
Total number of grains measured[a]					
	2800	2800	2800	2500	2800
Grains rejected for the following reasons					
a) T_n signal <3*background or relative error >20%	2362	2285	2071	1927	2201
b) Poor recycling ratio	66	108	129	165	83
c) IR-depletion ratio	36	23	31	18	39
d) 0 Gy dose >5% of L_x/T_x for the maximum dose	4	9	6	3	7
e) FOM >10%	19	28	16	29	12
f) L_n/T_n>DRC	68	62	138	145	159
g) D_e obtained by extrapolation	24	41	122	33	90
h) Negative D_e value consistent with zero	13	14	20	8	29
Sum of rejected grains					
	2592	2570	2533	2328	2620
Acceptable individual D_e values					
	208	230	267	172	180

379 [a] Gives the number of grain positions measured i.e. 100 per single-grain disc. Discs were not inspected
380 after use to assess the proportion of unoccupied grain positions, but a value ~3% has been reported by
381 the same operator (SJA) when measuring similar material.

382

383 **Table S5.** The number of K-feldspar grains which were measured, rejected after application of rejection
384 criteria, and accepted for inclusion in the calculation of the burial dose.

Sample (VR003-...)	2432	8710	8678	11918
Stratum	I-07/8	I-08	I-09	I-09
Total number of grains measured[a]				
	1200	1200	1600	1200
Grains rejected for the following reasons				
a) T_n signal <3*background or relative error >20%	843	912	1285	868
b) Poor recycling ratio	31	31	40	43
c) IR-depletion ratio	Omitted for K-feldspar			
d) 0 Gy dose >5% of L_x/T_x for the maximum dose	6	5	4	9
e) FOM >10%	71	74	127	61
f) L_n/T_n>DRC	0	1	2	0
g) D_e obtained by extrapolation	2	10	4	2
h) Negative D_e value consistent with zero	Omitted for K-feldspar			
Sum of rejected grains				
	953	1033	1462	983
Acceptable individual D_e values				
	247	167	138	217

385 [a] Gives the number of grain positions measured i.e. 100 per single-grain disc. Discs were not inspected
386 after use to assess the proportion of unoccupied grain positions, but a value ~3% has been reported by
387 the same operator (SJA) when measuring similar material.

388

389 To determine the age of a sample which has been measured using single-grain luminescence

390 techniques, it is first necessary to analyse the distribution of individual D_e values in order to

391 generate a single burial dose (D_b). Initially, the Central Age Model (CAM) (46) was used to

392 calculate D_b for both quartz and feldspar samples using the function calc_CentralDose() in the

393 R package *Luminescence* (47). The CAM generates D_b on the assumption that the dispersion

of measured D_e values is explained by the overdispersion parameter (OD, the relative standard deviation of the true paleodoses) and measurement uncertainties. This model is appropriate for samples where the luminescence signal of all constituent grains was fully bleached prior to deposition, and where no post-depositional mixing has occurred.

For the quartz (Sector III) Howiesons Poort and post-Howiesons Poort samples from inside the shelter, overdispersion values ranged between 30±2% and 55±2%, with a mean value of 45%. These values are higher than the <20-30% overdispersion typically reported for well-bleached unmixed quartz samples e.g. (48), implying that some degree of post-depositional mixing might have occurred. This inference is supported by the observation of minor bioturbation by roots and insects during micromorphological analysis of Sector III sediments (1). Consequently, D_b for these samples was determined using the Finite Mixture Model (FMM) (49). The FMM is appropriate for samples containing more than one population of grains, for example where bioturbation has occurred. The use of overdispersion alone to determine whether the FMM should be applied to a sample has been criticised (50) on the grounds that high overdispersion values can be caused by spatially variable β dose rates (beta microdosimetry) resulting from the presence of potassium feldspars. We discount beta microdosimetry as the main cause of the high overdispersion observed for VR003 quartz samples since this phenomenon is most pronounced where total dose rates are low (<1 Gy/ka) and the sediment is coarse grained, whereas the dated horizons have dose rates ranging from 1.5-2.1 Gy/ka (Table S1) and contain abundant silt-sized material (1). It has also been suggested that the FMM can identify dose components that do not result from post-depositional mixing, leading to the calculation of incorrect ages (51). This possibility has been discounted here both because it is contested (52) and because micromorphological analysis of Sector III sediments (1), implies that post-depositional mixing has occurred.

The FMM was run using two to six D_e components and an overdispersion value of 25%, the latter being sufficiently large to allow for the effects of beta microdosimetry (48). The minimum number of statistically supported D_e components was determined for each dataset by optimising the Bayesian Information Criterion (BIC) and the maximum log likelihood (llik) using the function calc_FiniteMixture() in the R package *Luminescence* (47). For the purposes of age calculation, D_b was the equivalent dose for the component containing the largest proportion of accepted grains. Equivalent dose distributions and FMM components for the quartz samples are shown in Figure S8 and Table S6.

For each quartz dataset, analysis using the FMM indicates that the majority of grains (74-94%) belong to the single population with the highest equivalent dose. One or more lower-dose

431   components are required, implying that post-depositional processes, presumably minor root

432   or insect bioturbation, have intruded a small proportion of younger grains. This inference is

433   consistent with the published micromorphological analysis of Sector III samples (10).

434

435   Since a number of grains were excluded from calculation of the burial dose due to natural

436   signal saturation (rejection criterion f, Table S4) it is necessary to demonstrate that the

437   omission of these data does not bias D_b (51). To test this possibility the quartz datasets were

438   reanalysed, this time using an additional rejection criterion. Briefly, luminescence data for each

439   grain were fitted using a single saturating exponential passing through the origin i.e. $L_x/T_x =$

440    $a[1\text{-}exp(\text{-}D/D_0)]$, where L_x/T_x is the sensitivity corrected luminescence intensity, a is the

441   saturation value and D_0 is a measure of the curvature of the dose response curve. Equivalent

442   doses (CAM and FMM) were then calculated after rejecting grains with D_0 below a threshold

443   value. This process was repeated with the D_0 threshold ranging from 0 Gy (no grains rejected

444   due to the D_0 criterion) to 150 Gy in 10 Gy increments. Two recent studies using this approach

445   (51, 53) have shown that dose recovery ratios increased as the D_0 threshold increased,

446   reaching a plateau consistent with unity, after which no further significant changes were

447   observed. Similarly, when performing this analysis on independently dated samples, D_b for the

448   plateau was consistent with the expected burial dose based on their known age (Thomsen et

449   al., 2016).

450

451   Plots of D_b (CAM and FMM) versus D_0 threshold are presented for each quartz sample in

452   Figure S9. For all samples, irrespective of the D_o threshold applied, D_b is consistent with that

453   calculated without application of the D_o rejection criterion at 2σ. Furthermore, only one sample

454   (VR003-2881) shows a systematic rise in D_b with increasing D_0 threshold, the pattern

455   suggested to indicate burial dose underestimation due to the onset of saturation in single-grain

456   datasets (Thomsen et al., 2016; Guo et al., 2017). In fact, the FMM calculated burial dose is

457   remarkably consistent with increasing D_o threshold despite an order of magnitude reduction in

458   the number of accepted grains (all samples) and a change in the minimum number of

459   statistically supported components (samples VR03-2885, -2883, -2881). A similar pattern is

460   noted with the CAM D_b values (not shown), though as outlined above, this is not expected to

461   yield the most accurate estimate of the true burial dose. Consequently, we find no evidence

462   that more accurate D_b values will be obtained by applying an additional grain rejection criterion

463   based upon a D_0 threshold. Hereafter, we calculate ages for the VR003 quartz samples using

464   D_b obtained from the FMM without application of a D_0 rejection criterion.

465
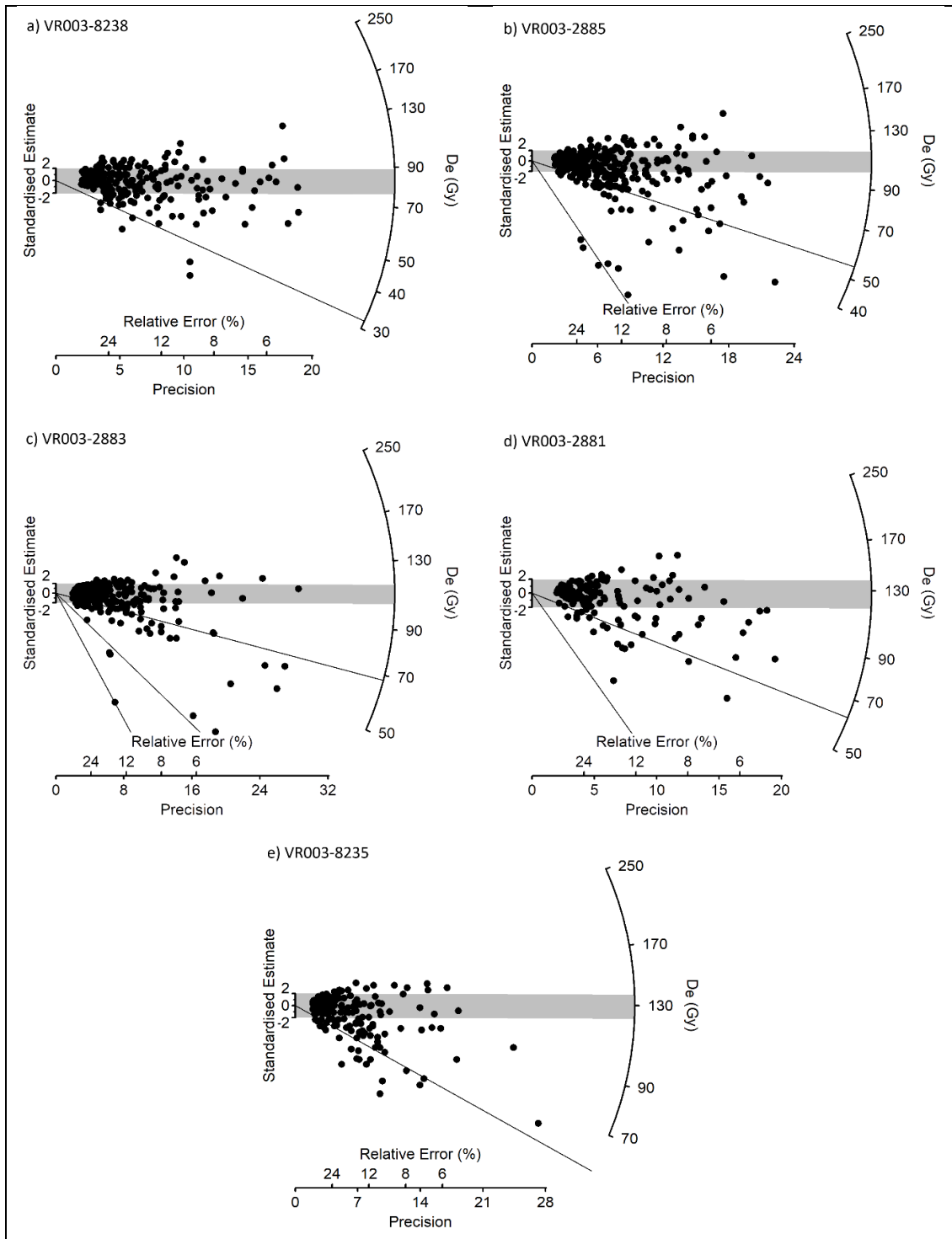
Figure S8. Single-grain quartz D_e distributions for a) VR003-8238, b) VR003-2885, c) VR003-2883, d) VR003-2881 and VR003-8235, associated with Howiesons Poort and overlying post-Howiesons Poort strata inside the shelter (see Figure S1 for locations). Each point represents an individual grain. The grey bars are centered on D_b, the FMM component containing the majority of accepted grains, and all points that lie within the bars are consistent (at 2σ) with this dose. One low-dose grain has been omitted from each of panels b (4.1±0.2 Gy) and d (6.4±0.4 Gy) to allow the main component to be displayed on an appropriately scaled radial axis.
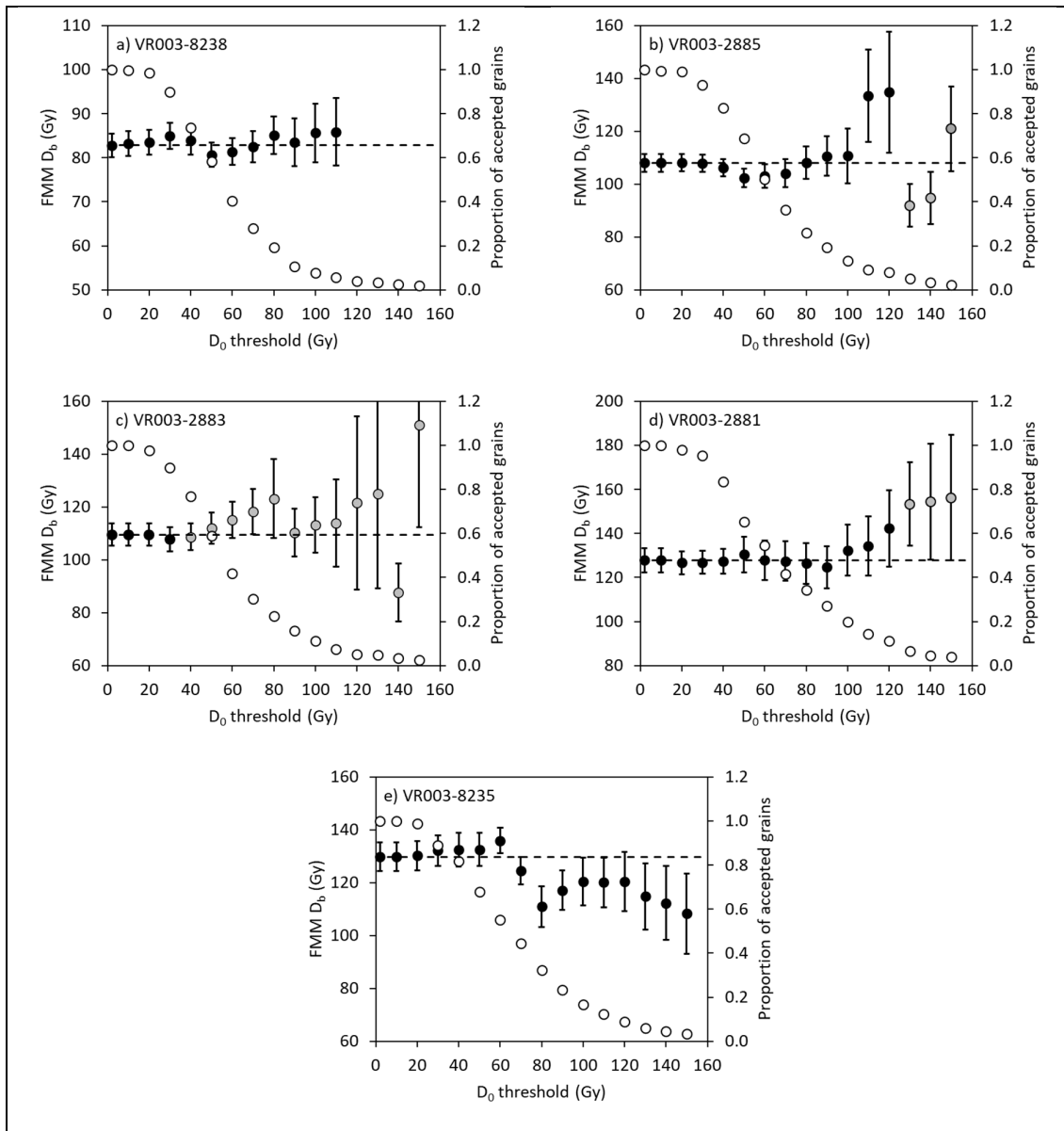
Figure S9. The main FMM component D_b (closed circles with 1σ uncertainties) and the corresponding proportion of accepted grains (open circles) plotted as a function of the D_0 threshold value. The proportion of accepted grains is calculated as the number of grains accepted using the threshold D_0 divided by the number accepted where no threshold is applied. Uncertainties on D_b are 1σ and do not include the instrument's beta source calibration error (3%) since these are common to all quantities being compared. Closed circles filled in black represent FMM D_b values where the minimum number of statistically supported components equals that where no D_0 rejection criterion is applied, whereas those filled in grey represent D_b values calculated where fewer components are recognised. For sample VR003-8235 the FMM yields two identical components when the D_0 threshold exceeds 110 Gy, implying that only one component is present. No data are plotted for these points. The dashed lines indicate D_b where no D_0 rejection criterion is applied, and is the value used to calculate burial ages for the quartz (Sector III) samples.

For the K-feldspar (Sector I) samples in the Main Area, overdispersion values ranged from 35±2% to 38±2%. These values are consistent with well-bleached unmixed K-feldspar

489   samples, so the CAM was deemed appropriate for calculation of D_b. Equivalent dose
490   distributions for the K-feldspar samples are shown in Figure S10.

491
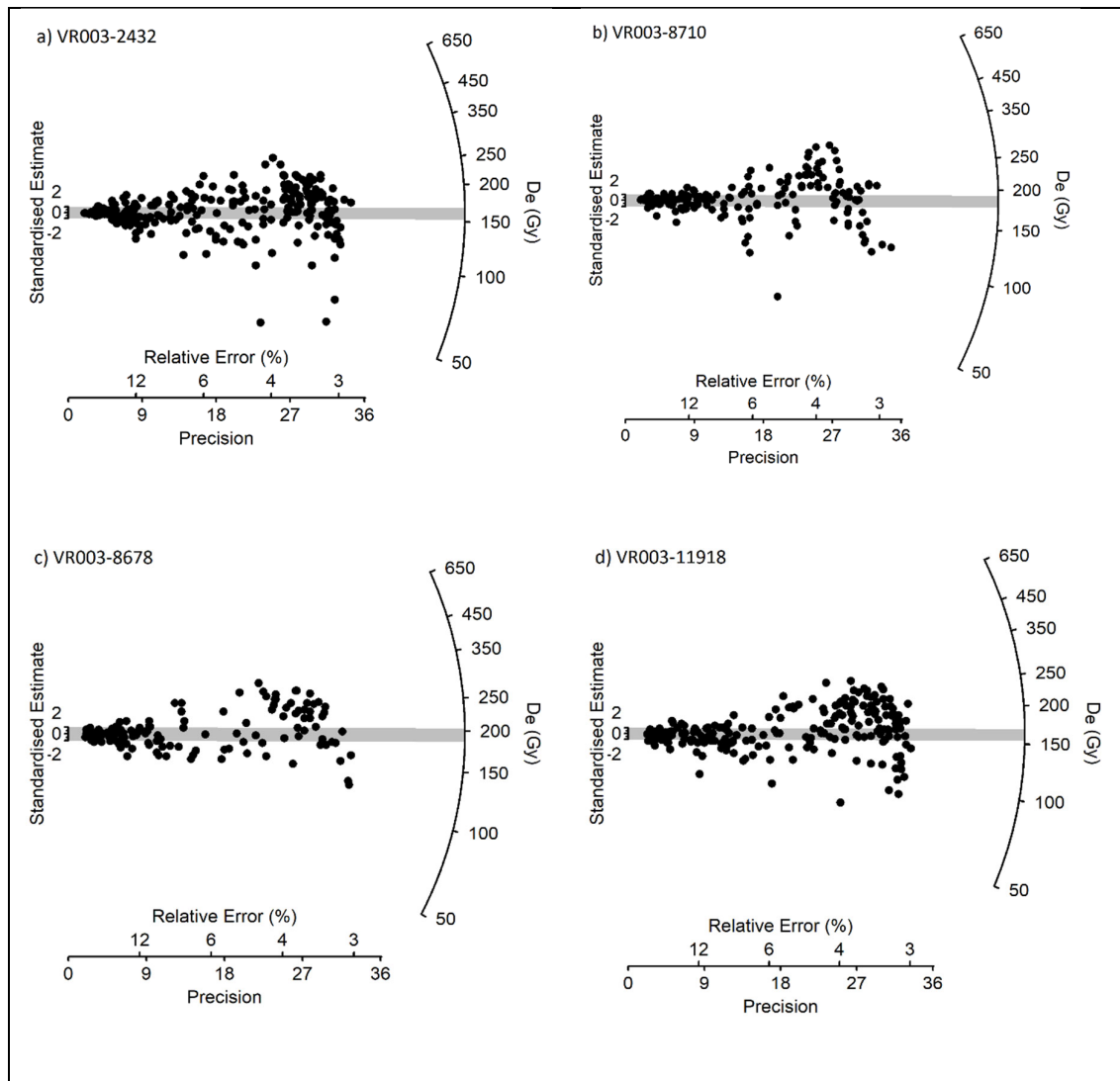
492   **Figure S10.** Single-grain K-feldspar D_e distributions for a) VR003-2432, b) VR003-8710, c) VR003-
493   8678 and d) VR003-11918 samples, taken from strata I-08 to I-09 in the Main Area. Each point
494   represents an individual grain. The grey bars are centered on the CAM D_b and all points that lie within
495   the bars are consistent (at 2 σ) with this dose.

496

497   **Fading correction and ages.** Luminescence ages are calculated by dividing the burial dose,
498   D_b by the total dose rate D_r. For quartz samples, the resulting age requires no subsequent
499   correction. However, where feldspars exhibit measurable fading, it is necessary to correct this
500   initial age. Fading rates were assessed using the measurement sequence outlined in Table
501   S3b. These measurements were made on a subset (n=32) of the sample discs after
502   completion of D_e measurements, but measurements and data analysis were conducted on
503   bulk signals from each disc rather than those from individual grains. Fading rates (g-values
504   normalised to t_c of 2 days) were calculated in Analyst v4.31.9 (54). Mean g-values for each

505 sample were consistent with the mean for all measured aliquots (1.9±0.1 %/decade), and this

506 value was used to correct each K-feldspar age. Fading corrections (55) were performed using

507 the calc_FadingCorr() function in the R package *Luminescence*. CAM burial doses, dose rates

508 and fading-corrected ages for the K-feldspar samples are presented in Table S7, while FMM

509 components, equivalent doses, dose rates and ages for the quartz samples are presented in

510 Table S6.

511

512 **Table S6.** Single-grain FMM components, burial doses, dose rates and ages for the Sector III quartz
513 samples taken inside the shelter.

Stratum	Sample (VR003…)	Mineral[a]	Component[b] (number/%)	D_e (Gy)[c]	D_r (Gy/ka)	Age (ka)[d]
17	8238	Q	**1/94**	**82.8±2.7**	1.49±0.11	55.7±4.4 (8.8)
			2/6	31.8±6.8		
17	2885	Q	**1/77**	**108±3**	1.64±0.12	66.1±5.3 (10.6)
			2/21	54.6±6.1		
			3/2	5.0±0.6		
18	2883	Q	**1/76**	**110±4**	1.80±0.14	60.8±5.2 (10.4)
			2/21	68.1±6.1		
			3/2	19.6±2.6		
			4/1	4.0±1.2		
20	2881	Q	**1/81**	**128±5**	1.78±0.14	71.6±6.2 (12.4)
			2/18	62.8±7.1		
			3/1	10.2±2.0		
20	8235	Q	**1/74**	**130±5**	2.08±0.15	62.5±5.1 (10.2)
			2/26	56.4±4.4		

514 [a] Q = quartz, KF = K-feldspar. [b] Component number ranked from highest to lowest D_e. [c] The bold D_e for
515 each sample is the burial dose (D_b) used to calculate the age. [d] Ages, with 1σ uncertainties and 2σ
516 uncertainties in parentheses.

517

518 **Table S7.** Single-grain CAM burial doses, overdispersion, dose rate and ages for the Sector I K-feldspar
519 samples in the Main Area.

Stratum	Sample (VR003-…)	Mineral[a]	OD (%)[b]	D_b (Gy)[c]	D_r (Gy/ka)	Age (ka)[d]
I-07/08	2432	KF	38±2	162±4	2.30±0.11	84.7±4.7 (9.4)
I-08	8710	KF	37±2	185±6	2.74±0.13	80.8±4.6 (9.2)
I-09	8678	KF	35±2	196±6	2.76±0.14	84.9±5.0 (10.3)
I-09	11918	KF	36±2	163±4	2.17±0.11	89.9±5.0 (10.1)

520 [a] Q = quartz, KF = K-feldspar. [b] OD = overdispersion. [c] D_b is the measured value and has not been
521 corrected for the effects of fading. [d] Fading corrected ages, with 1σ uncertainties and 2σ uncertainties
522 in parentheses.

523

524 **Discussion.** The K-feldspar ages from the Lower Deposits at VR003 are stratigraphically

525 consistent, and indicate that sediments from I-08 to I-09 accumulated in late MIS 5. The quartz

526 ages from Sector III inside the shelter are also stratigraphically consistent, ranging from

527 55.7±4.4 ka (VR003-8238 in III- 17) to 71.6±6.2 ka (VR003-2881 in III- 20). However, these

528 ages are older than published ages (10) for Sector III strata III-17 (42.3±2.7 ka) and III-20

529 (41.7±2.9 ka). Insufficient information is available for the published dataset to allow a complete

530 comparison, but some useful observations may be made.

531

532   Firstly, the directly comparable datasets for the III-17 and III-20 ages were produced using the
533   CAM (10) and FMM (this study). Since our analysis implies post-depositional incorporation of
534   younger grains into all Sector III samples, the CAM will yield lower D_b values and therefore
535   younger ages than the FMM in the absence of complicating factors. For the present dataset,
536   the CAM yields D_b values 16±4 % lower than the FMM, and the discrepancy between the
537   published equivalent doses and those presented here for III-17 and III-20 is consistent with
538   this value. Steele et al. (1) justify the use of the CAM for their III-17 and III-20 samples on the
539   grounds that the observed overdispersion (28 and 36% for their samples) is best explained as
540   the result of inhomogenous (beta) dose rates at the single-grain level (56). This inference is
541   defensible, and if correct it justifies the use of the CAM. However, use of the CAM on datasets
542   with relatively high (~>20-25%) overdispersion is unconventional and we regard our approach
543   as more appropriate, particularly since micromorphological investigation of these sediments
544   implies some degree of bioturbation.

545

546   Secondly, the published environmental dose rates (2.05±0.10 Gy/ka for III-17 and 2.73±0.15
547   Gy/ka for Layer 20) are higher than those presented here, which would result in a younger
548   calculated age for a given D_b. Inter-sample variation in dose rates is possible, even over short
549   distances within a single archaeological layer. The published sediment water contents and
550   cosmic dose rates are consistent with those presented here. Calculation of the beta and
551   gamma contributions for the published samples suggests that both are partly responsible for
552   the discrepancy with the values in this study. It is possible that both sets of dose rates are
553   accurate, and no grounds exist for dismissing either as erroneous. Because the same
554   techniques were used to calculate dose rates for both the K-feldspar and quartz samples, and
555   the former are in good agreement with independent [230]Th/U burial dating of ostrich eggshell,
556   we regard the values presented in this study as reliable.

557

558   Based on the above reasoning, we believe that the quartz luminescence ages presented
559   above (Table S6) represent the most reliable age estimates for Sector III. Our revised
560   chronology for these units, which contain a Howiesons Poort assemblage, is consistent with
561   the published (57) start (62.2-71.1 ka, 95% CI) and end (54.5-62.0 ka, 95% CI) ages for this
562   technocomplex (their preferred "Estimate B"). Our chronology is also consistent with the longer
563   Howiesons Poort chronology obtained at Diepkloof Rock Shelter (12). Consequently, our
564   revised chronology for Sector III confirms that the Howiesons Poort assemblage at VR003 is
565   contemporaneous with similar material elsewhere in southern Africa.

566

567

U-series Dating of Ostrich Eggshell

^{230}Th/U burial dating. Ostrich eggshells (OES) consist of ~2 mm-thick, low-Mg calcite containing 1-3 wt.% organics and are suitable for ^{230}Th/U dating, a technique capable of producing accurate, precise ages (~0.1%, 2σ) with a useful limit of >500 ka. Similar to other biominerals of higher animals, modern OES contain extremely low concentrations of primary U (c. 1 ppb or less); accordingly, most U in ancient OES is secondary. Until recently U-series dating of eggshells has been carried out without consideration of the effects of prolonged secondary uptake of U. In contrast, "^{230}Th/U burial dating" of OES, which we employ herein, explicitly accounts for U uptake by OES from soil water after burial. In a previous study, we documented U uptake patterns in archaeological OES, showed that the effects of prolonged U uptake could be mitigated by applying a simple diffusion model to ages measured on OES subsamples, and demonstrated that resulting model ages termed ^{230}Th/U burial ages were concordant with ^{14}C ages measured on splits of latest Pleistocene to Holocene OES (58). Further work has shown that ^{230}Th/U burial dating can be successfully used to date Pleistocene archaeological sites >100 ka, i.e., well beyond the ~50 ka ^{14}C limit (59).

Laser ablation. U concentrations of archaeological OES, when profiled normal to their surface via laser ablation, exhibit characteristic asymmetric patterns controlled by the layered crystalline structure of OES (58). U profiles may therefore be used to identify OES suitable for ^{230}Th/U burial dating and to select optimal locations of subsamples for U-series analysis. OES fragments from VR003 exhibit such U profiles (Figures S11-S13). Beginning at the outer surface, U typically falls rapidly in the first hundred microns or so, defines a flat or gently sloping plateau in the center of the eggshell, falls rapidly to a minimum value, and then rises rapidly with scattered values near the inner surface of the OES. Such a pattern indicates that U concentrations across most of the eggshell, from the outer surface to the U minimum, are controlled by U uptake at the outer surface. These patterns are associated with OES that yield ^{230}Th/U burial ages concordant with ^{14}C ages on splits of the same eggshell (58).

^{232}Th/U profiles of VR003 OES were also carried out via laser ablation (see Figures S11-S13 as above). These data identify OES calcite with high common Th (^{232}Th), an indicator of associated initial ^{230}Th, which can degrade the accuracy and precision of ^{230}Th/U ages. ^{232}Th/U ratios generally decrease away from OES surfaces where eggshell calcite may be visibly contaminated by detritus from host sediment (58). The OES from VR003 follow this pattern, with ^{232}Th/U ratios of c. 0.1 near their outer surfaces, while further inward rather pure OES calcite with much lower ^{232}Th/U ratios occurs.

604

605   Combining information from U and ^{232}Th/U profiles, the most suitable calcite for U-series dating

606   can be identified. It occurs in the central part of the OES where the crystalline structure

607   consists of radially-oriented, macroscopic columnar calcite crystal bundles of the palisade

608   layer. There, relatively high U and low ^{232}Th/U ratios coincide. For example, in sample VR003-

609   9085, mean [U] in the palisade layer ranges from ~ 62 to 16 ppb (median = 42.7 ppb); in

610   sample VR003-6612, mean [U] ranges from ~34 to 19 ppb in the palisade layer (median =

611   25.0 ppb); and in sample VR003-9300, [U] ranges between ~ 57 and 32 ppb in the palisade

612   layer (median = 56.2 ppb) (Figure S13; Table S5). In the palisade layer of all three VR003

613   samples, favorable ^{232}Th/U ratios of c. 0.01 or lower are observed, providing highly suitable

614   material for U-series dating.

Table S8. All isotope ratios are activity ratios. Uncertainties are 2 standard deviations. Uncorrected ages are calculated from measured ratios. Ages were corrected for U and Th from detritus using $(^{232}Th/^{238}U)$ = 1.21 ± 0.60, $(^{230}Th/^{238}U)$ = 1.0 ± 0.1, and $(^{234}U/^{238}U)$ = 1.0 ± 0.1. Decay constants are those of (60) for ^{238}U and (61) for ^{230}Th and ^{234}U. Initial $(^{234}U/^{238}U)$ is back-calculated from the measured ratio and the corrected age.

Sample Name	Sample wt (mg)	U (ppb)	^{232}Th (ppb)	$(^{230}Th/^{232}Th)$	$(^{232}Th/^{238}U)$	± (2σ, %)	$(^{230}Th/^{238}U)$	± (2σ, %)	$(^{234}U/^{238}U)$	± (2σ, %)	Initial $(^{234}U/^{238}U)$	± (2σ, ab.)	Uncorrected age ka	± (2σ), ka	Corrected age ka	± (2σ), ka	Burial age or *minimum age* **ka**	**± (2σ), ka**
VR003-6612 inner	120.16	15.641	0.2925	136.9	0.0056	1.17	0.83050	1.76	1.6094	0.60	1.753	0.011	75.3	1.9	75.0	1.9	***74.5***	***1.4***
VR003-6612 outer	102.47	19.800	0.3661	138.0	0.0056	0.83	0.82690	1.33	1.6157	1.26	1.759	0.022	74.4	1.9	74.1	1.9		
VR003-9300 inner	102.65	49.731	0.8685	157.6	0.0055	0.56	0.89620	0.86	1.6271	0.49	1.7904	0.0090	82.3	1.2	82.0	1.2	***88.3***	***3.2***
VR003-9300 outer	95.83	49.836	0.4700	300.7	0.0029	0.87	0.92404	1.51	1.6245	0.50	1.7958	0.0099	86.0	2.0	85.9	2.0		
VR003-9085-inner	169.08	36.974	0.4197	264.6	0.0034	0.35	0.97754	0.50	1.6488	0.48	1.8389	0.0087	91.2	1.0	91.0	1.0	***90.7***	***0.7***
VR003-9085-outer	176.02	52.418	0.7833	199.6	0.0047	0.40	0.97089	0.64	1.6465	0.44	1.8342	0.0081	90.6	1.0	90.3	1.1		

620

621 **^{230}Th/U ages of OES.** Three fragments of OES from layer I-09 were dated. U-series analytical

622 data and ages are given in Table S8, above. Measured U concentrations of OES calcite range

623 from ~15 to 50 ppb, ^{232}Th/^{238}U ratios are all <0.006, and corrections for initial ^{230}Th from detritus

624 are small (median = 0.25 ka)**,** indicating that the samples are geochemically suitable for

625 precise U-series dating. For OES fragment VR003-9300, we obtained an outer-shell age of

626 85.9 ±2.0 ka (errors are 2 σ) and an inner-shell age of 82.0 ±1.2 ka, consistent with prolonged

627 uptake of U originating from the outer surface of the eggshell. In such cases, we apply a simple

628 1-D diffusive uptake model to determine the time when the OES fragment was first exposed

629 to U in soil pore water. To do so, we plot the measured ages versus their distances from the

630 OES outer surface, normalized to the distance measured from the outer surface to the

631 minimum [U] observed in the laser ablation profile, which defines the limit of U derived by

632 uptake at the outer surface. Plotting ages of subsamples versus the square of their normalized

633 distance from the outer surface causes the expected relationship between age and distance

634 to become linear (58, 62). Accordingly, a linear extrapolation of the measured age-distance

635 relation to the outer OES surface, where U uptake was initiated, provides an estimate for the

636 age of initial U uptake, which we term the ^{230}Th/U burial age of the sample. Figure S13 shows

637 these relationships for OES fragment VR003-9300, leading to a ^{230}Th/U burial age of 88.3 ±3.2

638 ka, which we interpret as the best estimate for the depositional age of this OES.

639

640 Subsamples from two other OES fragments, VR003-9085 and VR003-6612, yield measured

641 ages that are within analytical errors; i.e., 91.0 ±1.0 and 90.3 ±1.1 ka for VR003-9085 and

642 75.0 ±1.9 and 74.1 ±1.9 ka for VR003-6612, indicating relatively rapid U uptake (Figure S14).

643 In such cases, we interpret the weighted mean of the subsample ages as the best estimate of

644 the depositional age of the OES; i.e., 90.7 ±0.7 and 74.5 ±1.4 ka for VR003-9085 and VR003-

645 6612, respectively. The different U uptake histories inferred for the OES fragments studied

646 herein may result from distinct conditions in their host sediments including the availability and

647 U concentrations of soil pore waters in contact with each of the OES fragments.

648

649 As discussed in the text, we interpret the age of OES VR003-6612 as a minimum age and

650 infer an age for stratum I-09 of 90.2 ±3.2 ka (2σ error), equal to the weighted mean ages of

651 OES VR003-9300 and VR003-9085.

652

VR003-6612
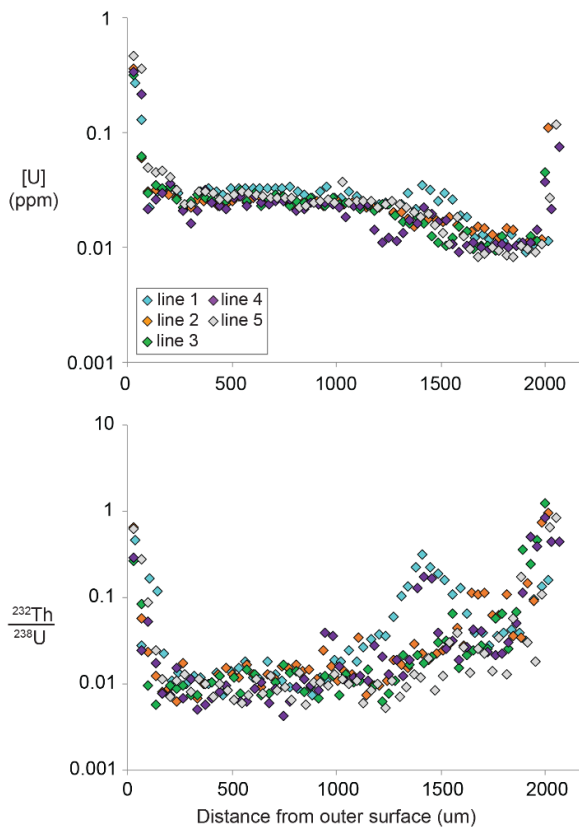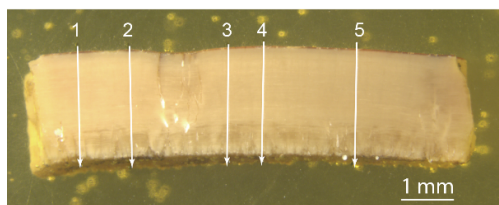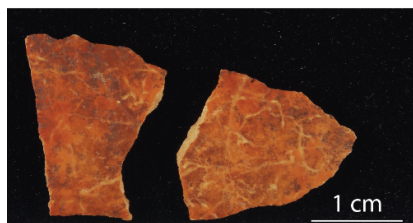
653

654 **Figure S11**. OES VR003-6612. Photo of analyzed OES fragment (upper left); photomicrograph of
655 laser ablation mount showing laser ablation tracks (lower left); and plots of laser ablation results
656 showing [U] and ^{232}Th/U versus distance from outer surface of OES.

657

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VR003-9085
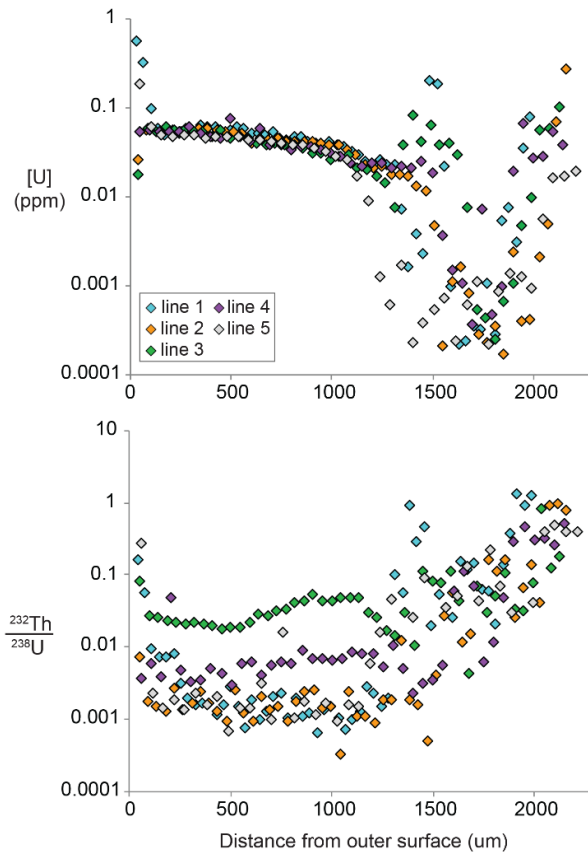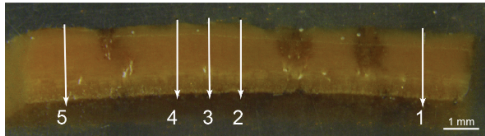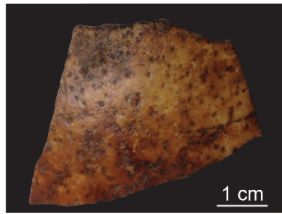
Figure S12. OES VR003-9085. Photo of analyzed OES fragment (upper left); photomicrograph of laser ablation mount showing laser ablation tracks (lower left); and plots of laser ablation results showing [U] and ^{232}Th/U versus distance from outer surface of OES.

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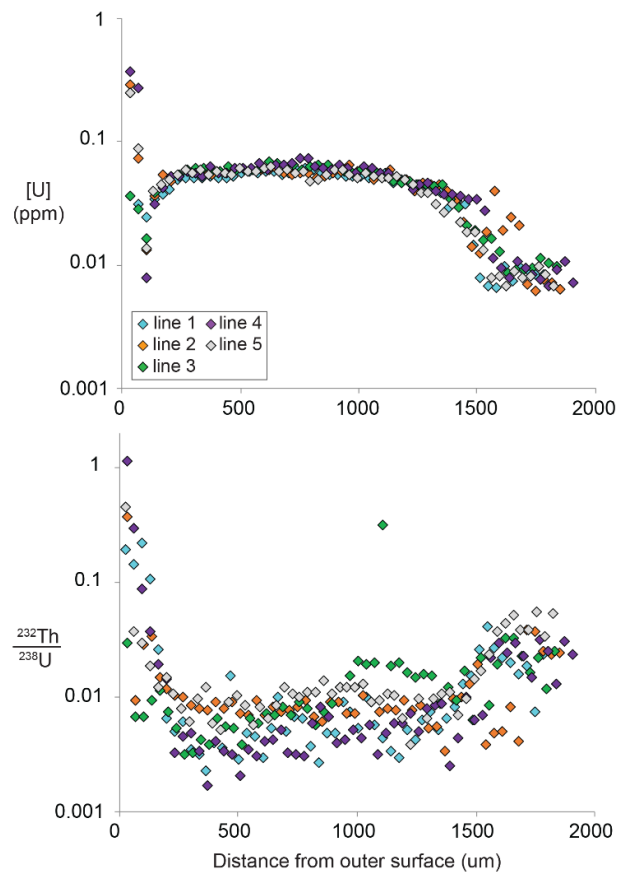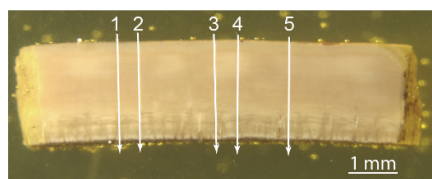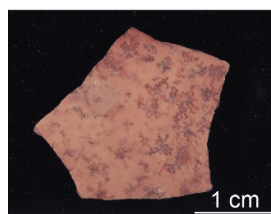
VR003-9300

Figure S13. OES VR003-9300. Photo of analyzed OES fragment (upper left); photomicrograph of laser ablation mount showing laser ablation tracks (lower left); and plots of laser ablation results showing [U] and ^{232}Th/U versus distance from outer surface of OES.
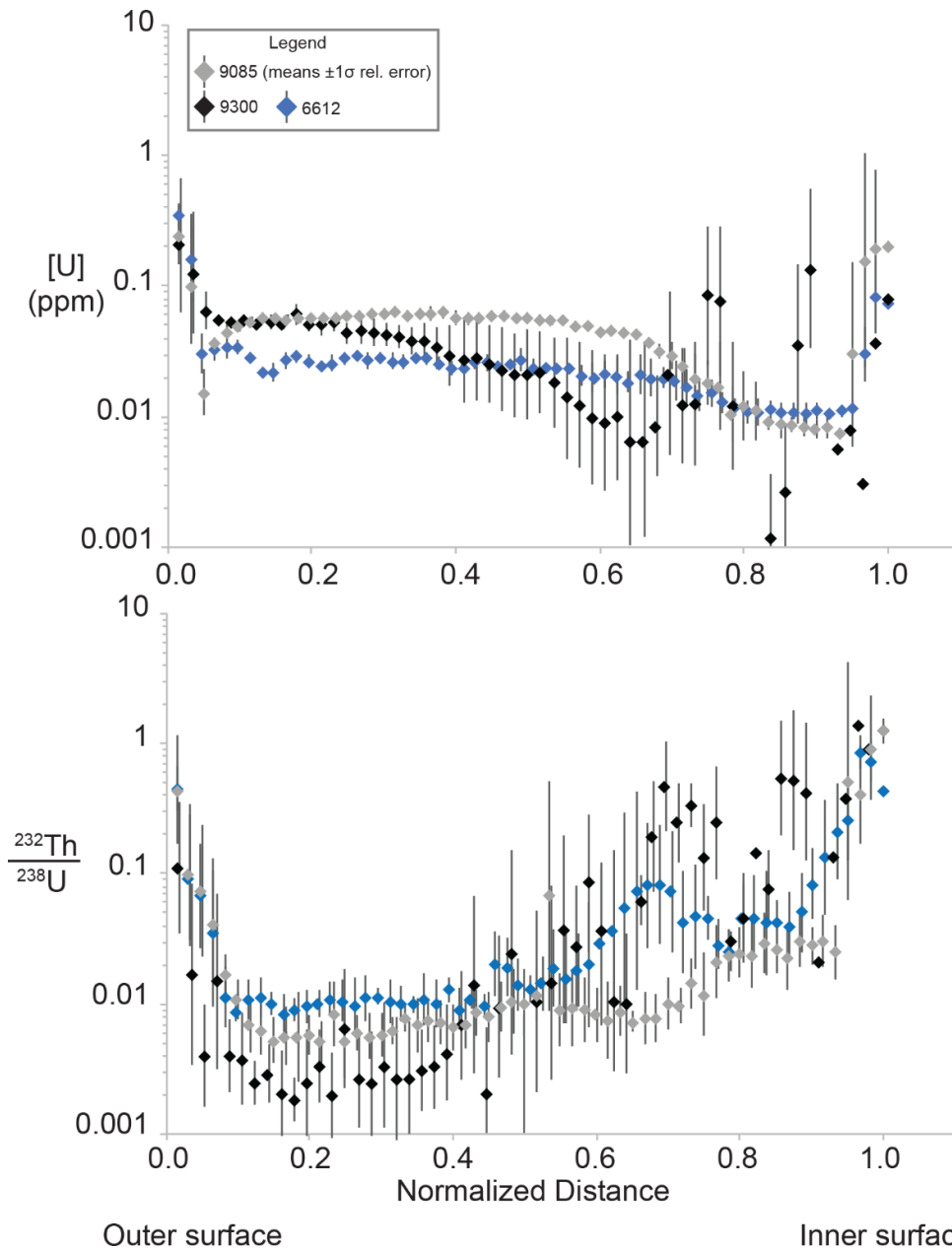
Figure S14. Plots comparing laser ablation results for the dated OES fragments. Points show the mean [U] or ^{232}Th/U at each position, computed by averaging values measured along five parallel laser ablation tracks across each OES. Mean [U] and ^{232}Th/U values are plotted versus distance from OES outer surfaces; vertical lines on points show 1σ errors.
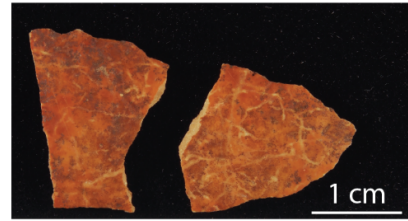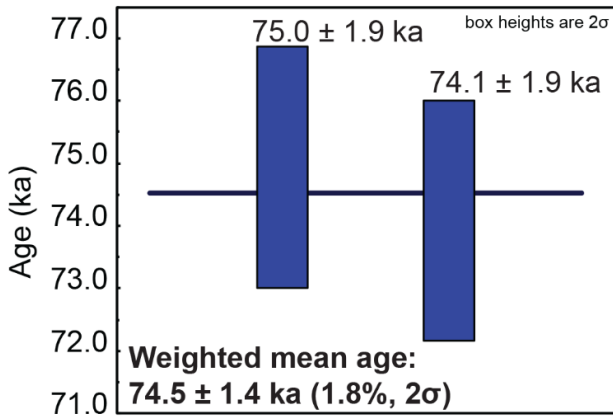
VR003-6612

VR003-9300
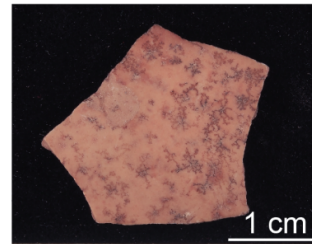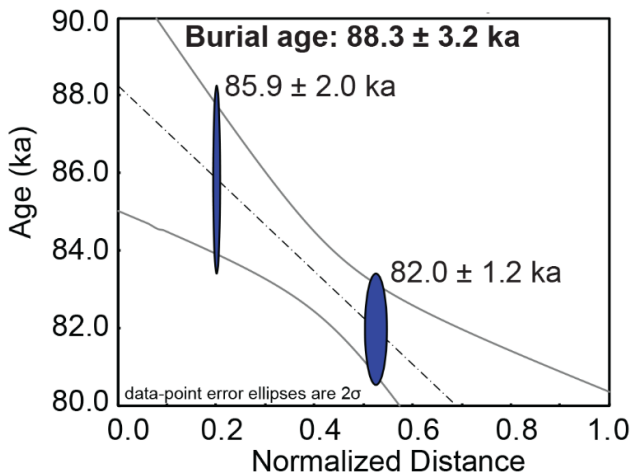
VR003-9085
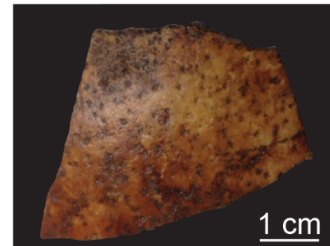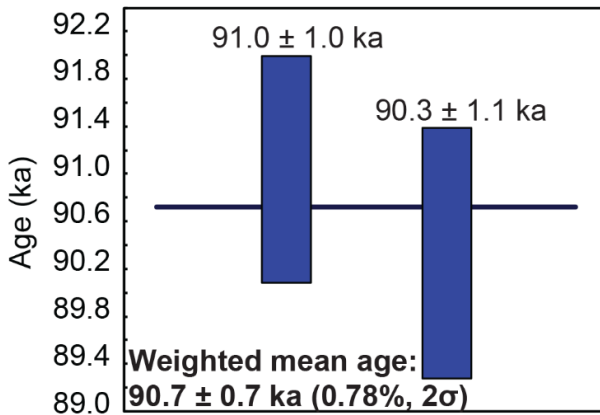
676

677 **Figure S15**. Photos of dated OES fragments (right) and plots of measured U-series ages (left). OES
678 fragment VR003-6612 yields concordant U-series ages for two samples that define a weighted mean
679 age; OES fragment VR003-9300 yields distinct U-series ages for two subsamples that define a
680 ^{230}Th/U burial age; and VR003-9085 yields concordant U-series ages for two samples that define a
681 weighted mean age.

682 **Establishing age estimates for depositional units**

683 To establish age estimates for the cultural/stratigraphic units identified at VR003, the OSL

684 and ostrich eggshell U/Th ages were combined in weighted probability density functions

685 (pdf$_{age}$) to define age estimates that reflect the ages and errors associated with each sample.

686 These, with weighted optima and one sigma errors, are shown in Figure S16 below. Age

687 ranges for the units based on optimum values and one sigma errors from these results are:

688 Lower Deposits = 86±6; Howiesons Poort = 63+8/-6; post-Howiesons Poort = 57+12/-4.

689 Strata I-07, I-06 and I-05 were not directly dated but they are constrained stratigraphically by

690 adjacent dated layers, and are thus estimated to date to between ~79-71 ka.
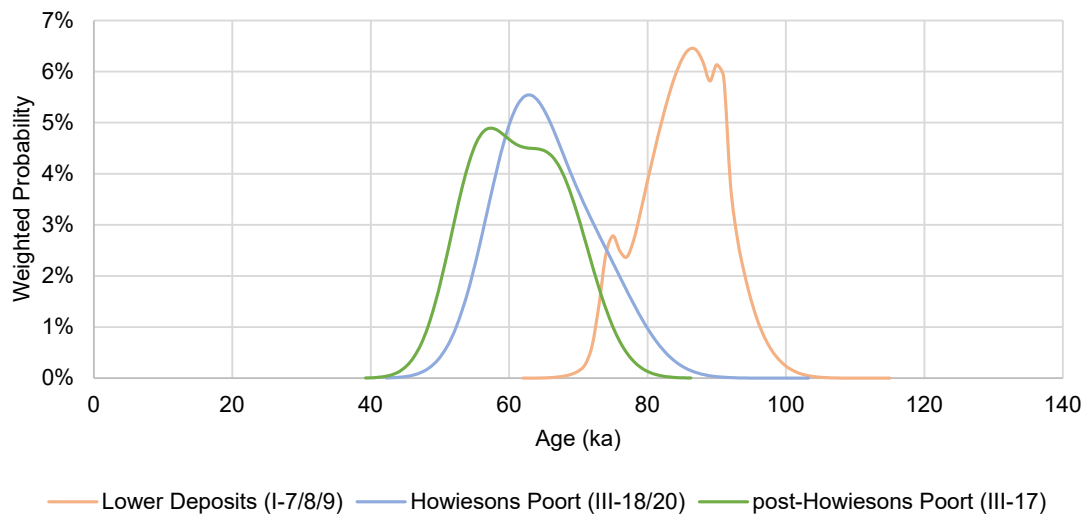
691

692 **Figure S16**. Probability density functions defining estimated ages of cultural/stratigraphic units
693 identified at VR003 based on optically stimulated luminescence and ostrich eggshell U/Th ages
694 (Tables S6, S7 & S8).

695

696

Archaeological data

Phytolith analysis

Phytoliths at archaeological sites will accumulate as a result of natural processes and human transport. The Main Area at VR003 is open to sunlight and naturally vegetated, though we cannot preclude an anthropogenic signal in the phytolith assemblages. We thus focussed our analysis on markers of rainfall seasonality (C_3:C_4 grasses), and the related prevalence of fynbos taxa such as Restionaceae, though recognising particularly in the latter case that humans may have selectively introduced such elements for purposes such as lighting fires and/or construction of bedding.

Phytolith classifications and definitions. Phytolith counts were divided broadly into graminoid and non-graminoid groups, with classification based on the revised nomenclature (63) as well as previous studies (64, 65). Graminoid groups include morphotypes characteristic of Poaceae (grasses), Cyperaceae (sedges), and Restionaceae (Cape reeds) families. Restionaceae (or, restios) includes reniform, paddle-like, and various spheroidal morphotypes. Restios are endemic to southern Africa and are characteristic of the fynbos vegetation of the winter rainfall zone of the southwestern Cape (66, 67). Poaceae includes short cells distinct to various grass subfamilies, such as the C_4 Chloridoid (short saddle) and Panicoid grasses (wide bilobates, crosses), as well as various C_3 subfamilies. Papillates were present, although these could be attributed either to Cyperaceae or to Proteaceae shrubs (68). Other non-specific graminoid morphotypes were also present, such as blocky and elongate, but they cannot be attributed to a particular group. Non-graminoid phytoliths representative of woody and shrubby vegetation were also present in relatively high concentrations (spheroidal, tracheary, among others). Spheroidal phytoliths from both Restionaceae and non-graminoids were counted together due to their considerable morphological similarity. The combination of these two groups is frequently used in contrast with grass phytoliths as an indicator of fynbos vegetation (64, 65).

Classification of short cell phytoliths. The classification of Poaceae short cell phytoliths in this study follows closely that of (69), which is modified from (64, 70). This classification is aligned with the recent ICPN 2.0 nomenclature (63), as well as recent literature (65, 71). Short cells in this study have been identified by morphology and classified by taxonomic (Chloridoids, Panicoids) and bioclimatic (C_3 and C_4) groups (Figure S17).

Phytolith data. The total collected phytolith count and classification for all samples is presented here as Table S9. Results are given as a standardized concentration per gram of

733   sediment. This is followed by a breakdown of the assemblage by ecologically significant

734   taxonomic and bioclimatic groups, particularly Poaceae subfamilies as well as the

735   Restionaceae and woody morphotypes in Table S10.

736

737   **Table S9**. Total phytolith concentration (#/gram), sample depths, archaeological unit attribution and
738   morphotype classifications.

Morphotype	I-09 180-185 cm	I-08b 155-160 cm	I-08a 125-130 cm	I-07 100-105 cm	I-05/06 75-80 cm	I-04b 50-55 cm	I-04a 40-42 cm	I-03/04 30-32 cm	I-03 20-22 cm
Rondel	22.4	13.6	21.8	7.4	7.6	14.3	9.8	27.1	12.6
Crenate	16.8	16.6	9.8	1.6	3.5	0.6	0	2.1	0
Trapezoid	76	99.5	55.7	20.5	10.1	8.6	5.7	18.1	6.8
Polylobate	0	0	1.1	0	0	0	0	0	0
Plateau saddle	1.1	3	1.1	0	0.5	0	0.6	0.7	0.5
Round saddle	1.1	0	0	0	1	0.6	0	0	0
Flat bilobate	5.6	1.5	6.6	1.1	0	0.6	0	0	0
Trapezoidal bilobate	5.6	7.5	8.7	0	1.5	0	0.6	0	0
Cross	0	1.5	0	0	0	0	0	0	0
Short saddle	14.5	28.7	21.8	1.1	1.5	1.7	1.7	2.8	1
Wide bilobate	2.2	0	0	0	0	0.6	0	0	0
Narrow bilobate	1.1	0	0	0	0	0	0	0	0
Tower	11.2	6	9.8	1.1	0	0	0.6	1.4	1
Total short cells	**157.6**	**177.9**	**136.4**	**32.8**	**25.7**	**27**	**19**	**52.2**	**21.9**
Flabellate bulliforms	0	1.5	2.2	0	0	0	0	0	0
Blocky	29.1	70.9	19.7	31.1	19.7	6.3	8.6	27.1	15
Elongate entire	99.5	84.5	99.4	15.8	10.6	12.6	5.2	24.3	6.8
Elongate sinuate	2.2	12.1	12	1.6	1	0	0	0	0
Elongate dentate	2.2	4.5	4.4	0.5	0	0	0	0	0
Acute bulbosus	6.7	12.1	7.6	0	4	0	1.1	2.8	0
Other grasses	13.4	18.1	19.7	7.4	2	6.3	3.4	16.7	9.2
Papillates	4.5	15.1	7.6	3.2	3	2.9	5.2	9.7	4.8
Spheroidal	14.5	21.1	15.3	9.5	17.1	9.7	7.5	36.2	7.7
Reniform	4.5	4.5	6.6	0.5	1	0.6	0	1.4	0.5
Paddle-shape	2.2	3	3.3	1.6	1.5	1.1	0	0.7	0
Tracheary	1.1	3	0	0	4.5	0.6	2.9	22.2	5.3
Sheet	0	0	0	0	0	0	0	4.2	0.5
Other non-graminae	0	0	0	0	0	0	4	0	0
Total phytoliths	**337.5**	**428.3**	**334.2**	**104**	**90.1**	**67.1**	**56.9**	**197.5**	**71.7**

739

740   **Table S10**. Phytolith indicator ratios and proportions from ecologically significant taxonomic and
741   bioclimatic groups.

	I-09 180-185 cm	I-08b 155-160 cm	I-08a 125-130 cm	I-07 100-105 cm	I-05/06 75-80 cm	I-04b 50-55 cm	I-04a 40-42 cm	I-03/04 30-32 cm	I-03 20-22 cm
Total phytoliths	337.5	428.3	334.2	104	90.1	67.1	56.9	197.5	71.7
Total short cells	157.6	177.9	136.4	32.8	25.7	27	19	52.2	21.9
Grass %	92.1%	89.1%	90.2%	85.8%	69.9%	77.8%	65.6%	62.3%	73.8%
C3 grass %	38.1%	33.1%	31.4%	29.4%	26.9%	36.8%	29.3%	24.3%	27.8%
C4 grass %	5.3%	7.1%	6.5%	1.1%	1.7%	3.4%	3.0%	1.4%	1.4%
Restio+woody %	6.3%	6.7%	7.5%	11.2%	21.8%	17.0%	13.2%	19.4%	11.4%
C4:C3 grasses	13.84	21.31	20.80	3.59	6.20	9.31	10.18	5.83	5.03
Restio+woody:Poaceae	0.13	0.16	0.18	0.35	0.76	0.42	0.39	0.73	0.37

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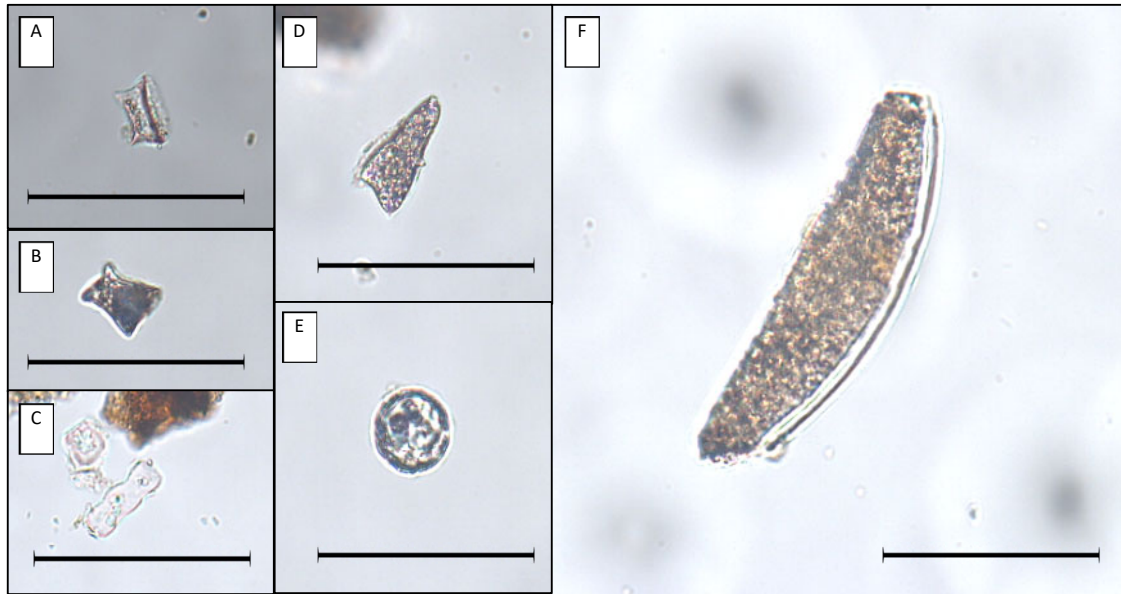
Figure S17. Selected phytolith morphotypes at 400x magnification. All bars 50 µm long. (**A & B**), short saddles (Poaceae); (**C**), crenate (Poaceae); (**D**), paddle-like (Restionaceae); (**E**), spheroid (Woody non-graminoid); (**F**), boomerang (Restionaceae).
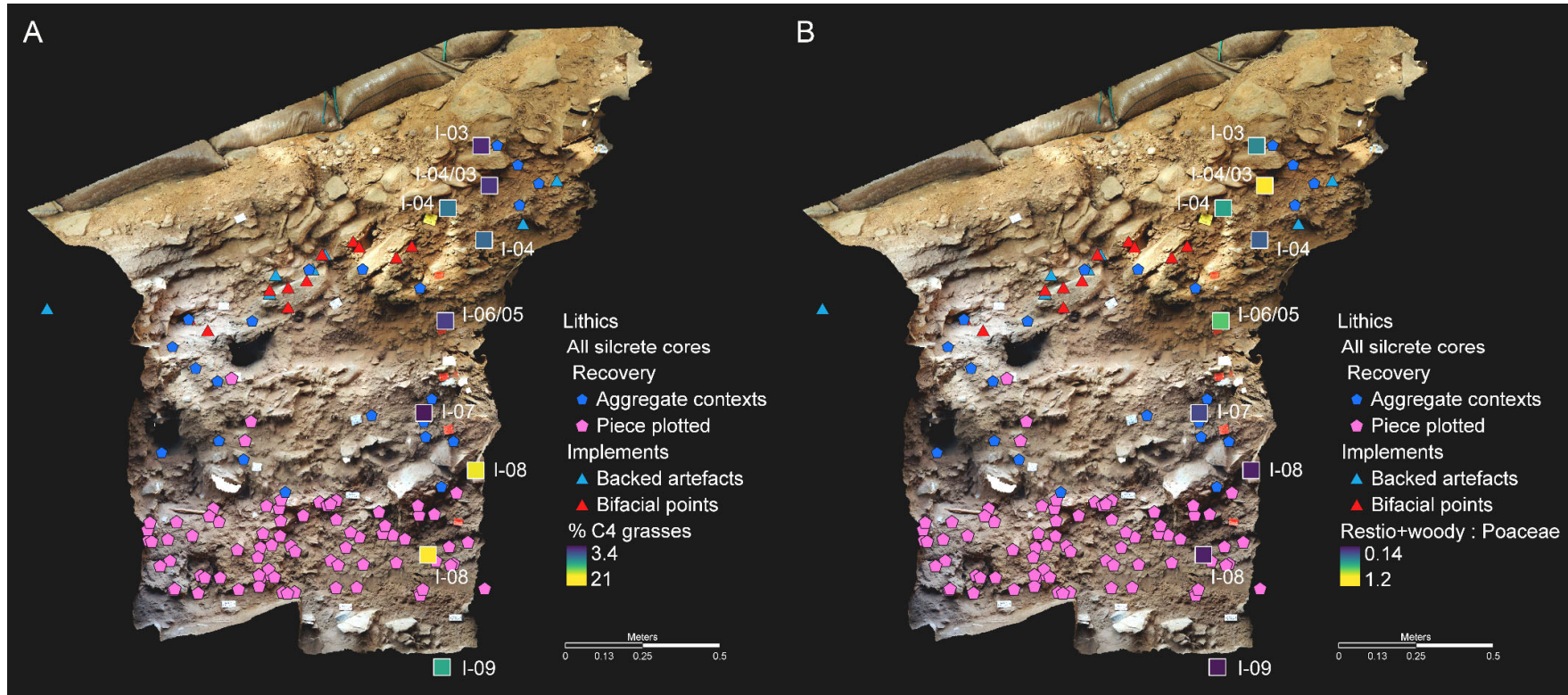
Figure S18. East section of VR003 showing sampling locations for phytoliths relative to key artefacts markers for the Lower Deposits, Still Bay and Howiesons Poort, and **(A)** % C_4 among grasses, and **(B)** the ratios of Restionaceae and woody taxa to grasses.

774 **Establishing an age-depth relationship for the phytolith data.** While the phytolith

775 samples are assumed to respect a stratigraphic order consistent with progressive

776 accumulation of sediments, the scatter of the OSL and ostrich eggshell U/Th ages does not

777 enable modelling of a robust age-depth relationship for each sample. As such, to

778 chronologically constrain the phytolith data, samples from the dated layers were compiled

779 and mean values with standard deviations were calculated for each layer. This was done for

780 the two primary metrics considered in this paper: C_4:C_3 grass ratio and the percentage of

781 Restionaceae and woody phytoliths that have been associated by (60) and (61) with fynbos

782 vegetation.

783 To define and depict aggregate phytolith sample values for the archaeological units

784 considered, the sample values for each unit were combined to establish probability density

785 functions for each unit (using the standard deviation of the sample values as the error)

786 (pdf$_{phyto}$). Pdf$_{age}$ (defined above) and pdf$_{phyto}$ for each layer were multiplied to create the

787 uncertainty spaces used in Main Text Figure 3 (Figure S19).
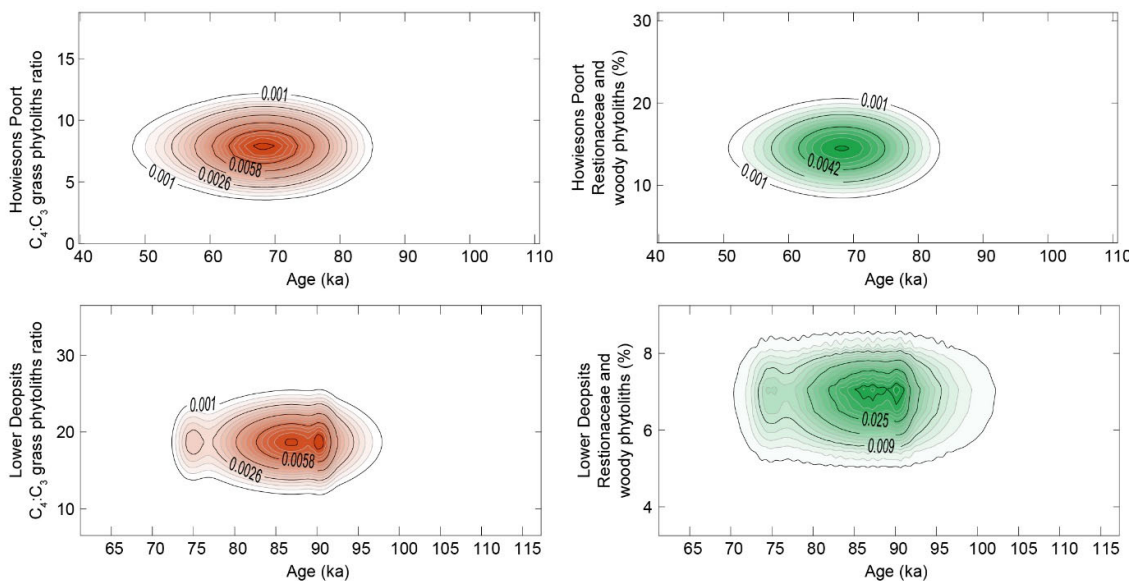
788 **Figure S19**. Uncertainty spaces defined by chronological and phytolith data for the Lower deposits
789 and Howiesons Poort units of the VR003 sequence.

790

791 **Evaluation of significant bioclimatic and taxonomic groups and community**

792 **composition in a regional context.** In this study we employ phytoliths to assess the impact

793 of putative changes in rainfall seasonality and oceanic and atmospheric circulation dynamics

794 that are thought to have occurred across the MIS 5/4 transition (72, 73). These changes

795 include a general depression of regional temperatures, an equatorward displacement of the

796 westerly storm track (bringing more winter rain to the southwestern Cape) (72-74) and an

797 intensification of the Southeast Atlantic Anticyclone (73, 75, 76), which would have restricted

798 the incursion of summer moisture-bearing systems associated with tropical easterly flow (77-

799 79).

800

801 In southern Africa, phytoliths have proven to be valuable for inferring changes in rainfall

802 seasonality and vegetation composition (64, 65, 69). Two primary metrics are presented

803 here as ecologically significant indicators of change: the ratio of C_4 to C_3 grasses, and the

804 percentage of Restionaceae and woody phytoliths.

805

806 The differing physiologies of C_4 and C_3 afford distinct competitive advantages as a function

807 of prevailing climates and atmospheric CO_2 concentrations ($_pCO_2$), with C_4 (C_3) grasses

808 being favoured under warmer (cooler) conditions (80-83). With decreasing $_pCO_2$, C_4 grasses

809 gain a competitive advantage over C_3 grasses (81, 82). Under modern annual average

810 atmospheric CO_2 concentrations of 416 ppm (84), the crossover temperature is calculated to

811 be ~27.7°C for the warmest month with sufficient rainfall to sustain plant growth (following

812 81, 82; Figure S19). At the VR003 site, sufficient precipitation is received only in the austral

813 winter months, when temperatures are generally <16°C (Figure S20; (85)), explaining the

814 dominance of C_3 grasses in the region, both today (86) and in the VR003 sequence (Table

815 S9, S10). With no change in rainfall seasonality or amount, regional winter temperatures

816 would need to rise by at least 11.7°C for C_4 grasses to become favoured over C_3 grasses.

817 Under the lower $_pCO_2$ of the 60-90 ka period (~190-240 ppm; (87, 88)), the crossover

818 temperature for C_4 advantage may have dropped to ~9°C or even lower (Figure S19, 81,

819 82). Considered in concert with southern African palaeotemperature reconstructions, which

820 can be used to estimate temperature depressions on the order of 2-4°C for MIS 4/5 (89, 90),

821 it may be predicted that changes in $_pCO_2$ would drive a significant increase C_4 grass

822 phytoliths in the VR003 assemblage, particularly during MIS 4. Results indicate, however,

823 that this was not the case, with C_3 morphotypes dominating the grass phytolith assemblage,

824 particularly during MIS 4, when they reach levels as high as 94.1%. From these results we

825 infer that while $_pCO_2$ may have some influence on the competitive advantage of C_4 over C_3

826 grasses (77, 78), it is primarily climate that drives the variability observed in the VR003

827 sequence.

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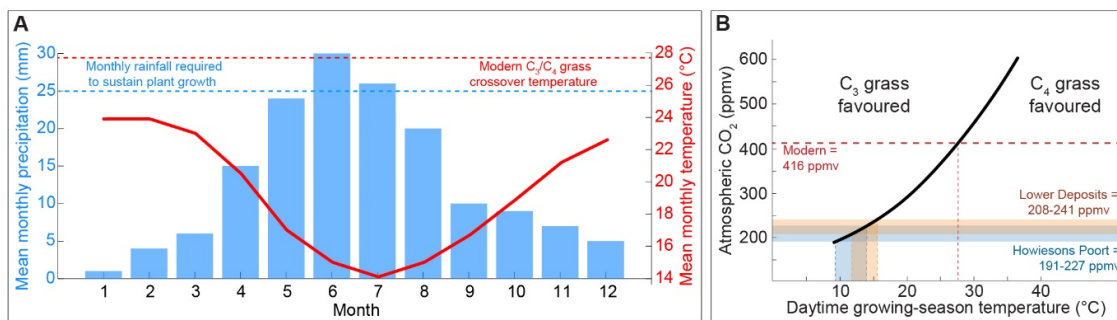
829

830 **Figure S20. (A)** Modern mean annual precipitation and temperature at the VR003 (data from 80).
831 Dotted lines indicate the threshold monthly precipitation requirement to sustain plant growth and the
832 C_3/C_4 crossover temperature under modern atmospheric CO_2 concentrations (77, 78). **(B)** Modelled
833 competitive advantage afforded C_3 and C_4 grasses as a function of atmospheric CO_2 concentration
834 and growing season temperature (adapted from 78). Atmospheric CO_2 concentrations are from (84)
835 for modern values and (82) and (83) for the VR003 units.

836

837 Interpreted thus in terms of climate variability, we consider that the relatively high $C_4:C_3$ ratio

838 in samples from the Lower Deposits (92-79 ka) most likely reflect changes in rainfall

839 seasonality, with an increase in summer rainfall, enabling at a minimum a greater presence

840 of drought-adapted species of C_4 Chloridoideae (such as *Cladoraphis spinosa*). The

841 transition from MIS 5 to MIS 4 is marked by a clear decrease in C_4 grass phytoliths, which

842 we interpret to be an indication of reduced summer rainfall and a more seasonal rainfall

843 regime. These findings are consistent both with prevailing conceptual models, which invoke

844 equatorward expansions of the westerly storm track and southern African winter rainfall zone

845 during periods of increased Antarctic sea-ice extent (72-74, 91) and with evidence indicating

846 a marked increase in South Atlantic Anticyclone intensity (Main Text Figure 3; as calculated

847 by (92) using the data of (73, 75, 76, 93), which would have limited the

848 incursion/development of summer rainfall systems in the region.

849

850 As mentioned, the percentage of Restionaceae and woody phytoliths has - contrasted with

851 grass phytoliths - been used as an indicator of fynbos vegetation (64, 65), which is

852 characteristic of the Fynbos Biome that is today primarily restricted to regions south of

853 VR003 (Main Text Figure 1; (94)). In contrast, phytoliths from the vegetation of the Succulent

854 Karoo Biome (currently encompassing the VR003 site) are uncommon and/or largely non-

855 diagnostic, but do contain relatively higher levels of Chloridoideae (C_4) phytoliths compared

856 with fynbos (69, 95). At VR003, percentages of the Restionaceae and woody phytolith group

857 more than double across the MIS 5/4 transition (from 6.8% to 16.5%). Considering the

858 anthropogenic nature of archaeological sediments, and the noted use of Restionaceae for

859 bedding (96), human agency cannot be discounted as the driver behind this change, but as

860   it coincides with shift towards more C$_3$ grass presence we consider it more parsimonious

861   that the increase in Restionaceae and woody phytoliths reflects environmental change and a

862   northward expansion of fynbos vegetation.

863

864   In summary, we conclude that variability in the VR003 phytolith record is consistent with data

865   from independent regional records that indicate significant changes to regional climate

866   systems across the MIS 5/4 boundary. Cooler global temperatures, expanded Antarctic sea-

867   ice extent and steeper intrahemispheric temperature gradients would have combined to drive

868   an increase in winter rain at VR003 while concurrently limiting the influence of summer rain

869   systems. The result would have been greater affinities with the Fynbos Biome, and weaker

870   environmental boundaries between VR003 and contemporaneous archaeological sites to the

871   south.

872

873

Fauna

Vertebrates. Early explorer records can be an important source for reconstructing historic faunal communities, and Skead has provided the most comprehensive reviews of accounts for south-western Africa (97, 98). However, information specific to the Knersvlakte is rare, and we must look towards descriptions of Namaqualand more generally. This may be suitable, because Namaqualand belongs to the Succulent-Karoo Biome and as such it appears that historically at least the Olifants River created an ecological boundary between this semi-desert of the north and the grassy, Fynbos Biome to the south (97), and VR003 is to the north. Following (97), (99), and (100) in Namaqualand's recent past red hartebeest (*Alcelaphus buselaphus*), gemsbok (*Oryx gazella*), and springbok (*Antidorcas marsupialis*) grazed the coastal plains, while black rhinoceros (*Diceros bicornis*) likely browsed in the scrubbier areas with surface water. Klipspringer (*Oreotragus oreotragus*), grey rhebok (*Pelea capreolus*), and mountain zebra (*Equus zebra*) were found in rockier up-lands, probably alongside hyrax (*Procavia capensis*), which are present on VR003's farm today. Eland (*Taurotragus oryx*) and quagga (which is often considered a sub-species of Plains zebra, *Equus quagga*) were also seen in the region historically, but like many of the other large bodied taxa, eland have been extirpated from the region while quagga are extinct. Steenbok (*Raphicerus campestris*), common duiker (*Sylvicapra grimmia*), Cape porcupines (*Hystrix africaeaustralis*), and ostrich (*Struthio camelus*) continue to be seen throughout the region, as well as small animals such as hare (*Lepus* sp.) and a variety of tortoises: mostly commonly the angulate or South African bowsprit tortoise (*Chersina angulate*), but also speckled padloper (*Homopus signatus*) and tent tortoise (*Psammobates tentorius*). A variety of large carnivores exploited the region, including hyenas (brown [*Hyaena brunnea*] and spotted [*Crocuta crocuta*]), jackals (*Canis mesomelas*), caracals (*Caracal caracal*), leopards (*Panthera pardus*), and even lions (*Panthera leo*), alongside many smaller carnivores. Cape fur seal (*Arctocephalus pusillis*), penguin (*Spheniscus demersus*), and other shore birds would have been found along the coast.

However, Late Pleistocene faunal communities are often distinct from the historic ones. For example, further south in the Fynbos Biome the elevated abundance of grazers indicates that more grasses must have been present in the Late Pleistocene (101). Locally however, until our project on the Varsche Rivier Farm, no archaeological samples were known, either MSA or LSA, from the Knersvlakte, so no local Late Pleistocene comparisons are possible (102). Late Pleistocene faunal samples have been described from northern Namaqualand, including the MSA deposits from Spitzkloof Rockshelter (103) and the hyena den sample from Boegoeberg 1 (104).

910

911   The Lower Deposit faunal assemblage (Table S11) has a substantial proportion of tortoise

912   remains (n= 352, 67% of total NISP) and counts of distal humeri indicate at least 21

913   individuals present; when carapace and plastron pieces are identifiable to species they are

914   predominately from angulate tortoises; one humerus was not an angulate but the alternative

915   species could not be confidently assigned. Mammals comprise the other major component of

916   the assemblage, primarily bovids of all size classes as well as zebras. Based on

917   identifications of dental remains, among the small bovids, grysbok/steenbok were confirmed,

918   and among the large bovids, eland were identified. While no identifiable dental remains of

919   small-medium and medium-large bovids were preserved in the Lower Deposits, in other Late

920   Pleistocene contexts at VR003, small-medium bovids are represented by springbok

921   (*Antidorcas marsupialis*) and large-medium bovids are represented by alcelaphines

922   (wildebeest and hartebeest; *Alcelaphus* and *Connochaetes*) and the now extinct blue

923   antelope (*Hippotragus leucopheus*). When comparing to the historic data, many of the taxa

924   identified in the Lower Deposits of VR003 were seen in Namaqualand historically. This

925   includes hyraxes, porcupines, honey badgers and the abundant tortoises. A few taxa require

926   further discussion (again, following (97, 99)). Overall, terrestrial species representation

927   suggests a relatively open, arid to semi-arid environment, with both graze and browse

928   available in diverse habitats. More grass would have been available than was present in the

929   region during the late Holocene, including historically. While the phytolith data show variation

930   through the sequence, a comparable signal of change through time is harder to identify in

931   the faunal record; small sample sizes limit detailed comparisons.

932

933   VR003 is close to the boundary where Cape dune mole-rats exist to the south and Namaqua

934   dune mole-rats (*Bathyergus janetta*) exist to the north. Our identification is based on our

935   specimen's larger size, because the Cape species is larger than the Namaqua one;

936   however, Cape dune mole-rat body size varies with precipitation (105), and it may be

937   possible that Namaqua dune mole-rats did, too. In either case, mole-rats indicate flat sandy

938   substrates, which necessary for their burrowing, and they can survive independent of water,

939   obtaining sufficient moisture from the plants that they eat.

940

941   Skead (97) highlights the challenges of trying to determine which small cats were referenced

942   in the historic accounts, and although references specific to wild cats are not known for

943   Namaqualand, they were presumed to be present because of their recent wide geographic

944   range; furthermore, the black-footed cat (*Felis nigripes*) might be possible. We identified the

945   VR003 specimens as wild cat based on their size, because black-footed cats are

946   significantly smaller.

947

The Cape zebra was a horse-sized zebra that grazed a broad range of southern eastern and north-eastern Africa during the Pleistocene (106). The Cape zebra disappeared from southern Africa by 12,000 to 9,500 years ago, apparently because grazing opportunities declined with the onset of the Holocene, further indicated by the increase in smaller browsing taxa in Holocene and historic faunas (107-109). In this assemblage, we identified our specimen as Cape zebra instead of quagga based on its large size.

Eland were present but apparently sparse in Namaqualand historically. They have a wide geographic distribution, because they are mixed-feeders taking advantage of grazing and browsing based on local availability. Importantly, they are not tied to surface water and therefore can take advantage of a wider variety of habitats. Therefore, their presence in the Lower Deposits of VR003 are not surprising, and other sites show that MSA people frequently hunted them (110, 111).

Finally, based on the specimens preserved, we were unable to distinguish steenbok from grysbok (both small bovids of the genera *Raphicerus*). Steenbok are common in Namaqualand today; they are browsers who prefer open areas with some tall grasses or shrubs for protection. Grysbok were probably also in the area, at least in the southern part adjacent to the mountainous fynbos. They are also a browser, but they prefer denser cover than steenbok. During the Late Pleistocene grysbok appear to have been much more widespread, and therefore we cannot confidently argue that our specimens are more likely to be one species over the other (112). However, in the Richtersveld of northern Namaqualand, steenbok but not grysbok have been identified in the Late Pleistocene deposits of Spitzkloof (103) and Boegoeberg 1 (104), indicating open environments.

Analysis of bone modifications was limited due to high fragmentation and poor preservation of the assemblage, and signs of hominin butchery and carcass processing may be obscured by some root etching, minor weathering damage, and the more common presence of concretions on many of the specimens. No cutmarks or percussion marks were observed but evidence of green breakage on a small portion (n=7) of bovid long bones could indicate cracking of fresh bone to access marrow. All major taxonomic categories (tortoises, bovids, small mammals/carnivores, birds) show some evidence of burning. No chew-marks, gastric etching, or other evidence of carnivore consumption were observed.

983 **Table S11.** The faunal remains from the Lower Deposits, I-08 and I-09. The Number of Identified
984 Specimens (NISP) are presented, along with the Minimum Number of Individuals (MNI). The bovid
985 species counts are based on dental remains, and those counts are not included in the body-size
986 categories. When possible to identify more specifically, the Testudinidae are *Chersina angulate*, with
987 the exception of one humerus which was not. The birds and snakes were not identified to more
988 specific taxa. Mammalian nomenclature based on (99).

Scientific name	Common name	NISP	MNI
Procavia capensis	rock hyrax (dassie)	1	1
Bathyergus suillus	Cape dune mole-rat	1	1
Hystrix africaeaustralis	Cape porcupine	1	1
Felis silvestris libyca	African wild cat	8	1
Mellivora capensis	honey badger (ratel)	1	1
Equus capensis	Cape zebra	1	1
Taurotragus oryx	eland	5	2
Raphicerus sp(p.)	grysbok/steenbok	4	1
	small bovid(s)	63	1
	small-medium bovid(s)	34	1
	large-medium bovid(s)	32	1
	large bovid(s)	15	1
Aves	birds	3	1
Testudinidae	tortoises	352	21
Serpentes	snakes	3	1
	Total	**524**	

989

990 **Molluscs**. The West Coast of South Africa is well-known for its important fisheries. The

991 coast supports a high biomass of animals and plants, due to the near-shore upwellings that

992 bring cold, nutrient-rich waters to the surface (113). Humans have taken advantage of this

993 productive coastal ecosystem from today into the deeper past. Along the West Coast, LSA

994 shell middens are abundant and well-documented from the coastal fynbos region south of

995 our study area: particularly from Lambert's, Elands, and Saldanha Bays and the Vredenburg

996 Peninsula (114, 115). In northern Namaqualand, numerous LSA shell middens are

997 documented along the coastal regions of the Buffels, Swartlinjies, and Spoeg Rivers (116-

998 119). MSA shell middens are rarer, but a few are documented: Boegoeberg 2 in the far north

999 and Ysterfontein 1, Hoedjiespunt 1 and 3, and Sea Harvest to the south (114). Sites are

1000 known from along the coast west of VR003, but few have been well-investigated (120).

1001 Nearest to VR003 are samples from Brandsebaai, where five LSA and one MSA shell

1002 middens have been analyzed in detail (121), highlighting that shellfish should have been

1003 available along the more local coast while VR003 was occupied.

1004

1005 The LSA and MSA shell middens document that coastal occupants consistently exploited

1006 limpets and mussels from the rocky shoreline. Three limpet species are most common in

1007 archaeological samples from the West Coast: granite (*Cymbula granatina*), granular

1008 (*Scutellastra granularis*), and Argenville's (*Scutellastra argenvillei*). Granite limpets live and

1009 graze on rocks in the upper part of the inter-tidal zone (the Upper Balanoid), often in high

1010 densities in Namaqualand, making them readily accessible to foragers during low-tide;

1011 granular limpets also live in this zone, often even higher in the inter-tidal than granite limpets

1012 (113, 122). Despite their increased accessibility, granular limpets are often passed over at

1013 first as foragers focus their harvesting on larger granite limpets (121, 123). Argenville's

1014 limpets can also occur at high densities and are the largest of the three, but they occur

1015 lowest in the inter-tidal (122); they are most accessible during spring low tides, which may

1016 have restricted their exploitation in the past despite their large size. Black mussels

1017 (*Choromytilus meridionalis*) are commonly found alongside these three limpets in

1018 archaeological assemblages, although their relative proportions can vary considerably. This

1019 variation may reflect local rocky shore morphology, because limpets prefer sheltered areas

1020 as heavy waves may dislodge them, while mussels, as filter feeders, prefer surfaces

1021 exposed to wave action. Black mussels primarily live in the lower inter-tidal, but will extend

1022 up to the more accessible reaches; storms may dislodge and wash up rafts or mats of

1023 mussels, which humans can be readily harvest, if found fresh. The mollusc sample from the

1024 Lower Deposits of VR003 is consistent with the other archaeological samples noted above

1025 and contains mostly granite limpets (NISP=13), but Argenville's limpet (NISP=3) and

1026 unidentifiable limpet (NISP=4) fragments are also present, along with fragments of black

1027 mussels (NISP=2) (Table S12). The shells are fragmented, but no ochre residues nor

1028 anthropogenic modifications were observed on them.

1029

1030 What is surprising about the VR003 Lower Deposits mollusc sample is that they were

1031 transported at least 44 km from the coast to the site. Ethnographic work with modern

1032 shellfish foragers shows that they rarely transported shellfish meant for consumption more

1033 than 10 km (2 hours walk) from the coast, and usually they stay much closer; the locations of

1034 recent shell middens (when sea levels would have been near what they are today) supports

1035 this (124-127). From the MSA, two exceptions are known: Diepkloof Rock Shelter and

1036 Sibudu Cave. Diepkloof is 14 km from the modern coast. The MSA assemblages span from

1037 the pre-Still Bay through the post-Howiesons Poort, although the molluscs are concentrated

1038 in the upper deposits; granite limpets (1,565.1 g) and black mussels (809.0 g) are most

1039 common, consistent with other shell middens from the West Coast (128). Sibudu also span

1040 from the pre-Still Bay through the post-Howiesons Poort and preserves mostly brown

1041 mussels (*Perna perna*; NISP=296), but also some other molluscs and a few fish remains;

1042 Sibudu is ~15 km from the modern coast of KwaZulu-Natal (129). These two examples may

1043 represent the extreme end of the distribution of variation in transport distances for edible

1044 shellfish or they may represent transportation for other purposes. At least in the younger

1045 MSA deposits, Diepkloof's sample is large enough that it suggests consistent consumption

1046 of shellfish, and therefore may reflect the ease of transportation along the flat landscape of

1047 the Verlorenvlei (128).

1048

1049 More extreme is the evidence for long-distance transportation during the MSA of small

1050 samples of marine shellfish noted from Apollo 11 and Pockenbank Rock Shelter, which are

1051 ~140 km and ~120 km from the modern coast respectively. Apollo 11 preserves two granite

1052 limpet fragments and Pockenbank has provided granite limpet and black mussel fragments

1053 [T. Steele, personal observation] (130, 131). Transportation beyond 10-15 km is more typical

1054 of the LSA, including small samples of shells that were found in the LSA deposits of VR003

1055 and three LSA sites on the same farm (1, 132-134). The reason for the transportation of the

1056 VR003 Lower Deposits marine shells is unclear, and further investigations are needed to

1057 help determine if they may have been transported for use as containers, tools, or other

1058 purposes; however, we have identified no residues or anthropogenic modifications on them.

1059 In the pre-Still Bay deposits of Blombos Cave, a large abalone (*Haliotis midae*) shell was

1060 found that had been used as a container for processing ochre (135). As far as we are aware,

1061 marine shells tools have not yet been documented in the MSA, although they are known

1062 from the Middle Paleolithic (such as in Grotta dei Moscerini, Italy) and from more recent

1063 periods (136). Finally, at the Pinnacle Point 13B and the Contrebandiers Cave (Morocco),

1064 MSA people transported larger shells (helmet or lipped cask shell, *Phalium labiatum*, and

1065 predatory sea snails *Charonia lampas*, respectively) into these coastal sites for unknown

1066 reasons; the taphonomy of the shells indicates that they were collected after the gastropod

1067 inside had died, so they were not first used as a food resource (137). The MSA African

1068 record does show that smaller shells that were often used as ornaments were regularly

1069 transported for 40-50 km (from the modern shore), with one example of 200 km (138),

1070 although the largest assemblages come from near-shore contexts.

1071

1072 **Table S12.** The marine shell remains from I-08 and I-09. The Number of Identified Specimens (NISP)
1073 are presented, along with the Minimum Number of Individuals (MNI); weight in grams and number of
1074 burnt specimens are also included. When MNI counts exceed one, they are based on the apices of
1075 the limpets.

Scientific name	Common name	NISP	MNI	Weight (g)	# Burnt
Choromytilus meridionalis	black mussel	2	1	0.3	1
Cymbula granatina	granite limpet	13	2	45.2	0
Scutellastra argenvillei	Argenville's limpet	3	1	12.7	2
	limpet	4	1	1.5	4
	mollusc	4	1	1.2	1
Total		26			

1076

1077 **Ostrich eggshell (OES).** Fragments of OES recovered from the screens during excavation

1078 were sorted into categories based on colour, representing the temperature of heat exposure

1079 consistent with that described by (139) (Table S13). Counts and weights were recorded, and

1080 all fragments were examined for evidence of anthropomorphic alteration, including beads in

1081 various stages of manufacture, intentional engraving, and any indication of deliberate or

1082 repeated percussive modification (i.e., flaking) (Table S14). Occasionally worked pieces

1083 were identified during excavation (n=5 as in Table S14). These were individually plotted, and

1084 then quantified in terms of count, colour, and weight; they are included in Table S13.

1085

1086 OES identified as possibly flaked were examined using a Nikon SMZ 1000 stereomicroscope

1087 with a magnification range of 8x to 80x. A Nikon D7100 was attached for microphotos that

1088 captured images at a magnification range of 16x to 160x. Flaking initiations can be seen, for

1089 example, on fragments VR003-6147, VR003-7833, and VR003-7114, indicating repeated

1090 application of downward percussive force in a series of precisely-aimed blows (Main Text

1091 Figure 4). A few samples preserved only simple notches from single blows (e.g., VR003-

1092 9220, VR003-7693) that could be carnivore perforations (140); in other cases such notches

1093 appear to reflect either errant blows or early stages of flaking (e.g., VR003-7974, VR003-

1094 9300, VR003-7340) prior to refinement of the flaking arc. Perforation notches may potentially

1095 reflect initial stages of flask opening.

1096

1097 **Table S13**. OES divided into categories of heat exposure, including number of fragments

1098 and total weight in grams (g).

I-08 & I-09	OES < 200°C		OES 200°C - 350°C		OES > 350°C		Total OES	
	n=	Wt (g)	n=	Wt (g)	n=	Wt (g)	n=	Wt (g)
Aggregate samples	2719 17%	1605.4 21%	3479 22%	2692.1 36%	9511 61%	3262.4 43%	15709	7559.9

1099

1100

1101

1102 **Table S14**. Details of flaked OES fragments recovered from I-08 and I-09. Concave refers to concavities formed by repeated flaking in an arc; notched refers
1103 to a concavity formed by a single flaking initiation. Arc radius and circle diameter estimated for concave flaked margins only.

Sample ID	Recovery	Max. dimension (mm)	N initiation	N margins flaked	Initiation from exterior?	Initiation from interior?	Concave (C) and/or notched	C Width (CW)	C Depth (CD)	CD / CW	N width	N depth	Est. radius	Est. diam.
5698	screen	41.3	>3	1	1	0	C	9.3	0.6	15.50			18.32	36.64
6147	plot	24.6	>3	1	1	0	C	14.8	1.8	8.22			16.11	32.22
7833	plot	30	>3	1	1	0	C	18.8	3.1	6.06			15.80	31.60
7114	screen	18.8	>3	1	1	0	C	11.3	1.1	10.27			15.06	30.12
7693	screen	17.6	>3	1	1	0	C	10.6	1	10.60			14.55	29.09
5910	screen	23.7	>3	1	1	0	C	12.6	1.7	7.41			12.52	25.05
8415	plot	30.5	>3	1	1	0	C	13.4	2.1	6.38			11.74	23.48
6307	plot	38.4	>3	1	1	0	C	13.3	2.1	6.33			11.58	23.16
9300	screen	17.9	3	1	1	0	C,N	11.8	1.7	6.94	5.8	1.2	11.09	22.18
7974	screen	29.7	>3	1	1	0	C,N	14.1	2.6	5.42	6.3	2	10.86	21.72
8417	screen	13.1	>3	1	1	0	C	6.4	0.5	12.80			10.49	20.98
8348	plot	27.6	>3	1	1	1	C	11.3	1.8	6.28			9.77	19.53
8100	screen	23	>3	1	1	0	C	8.9	1.1	8.09			9.55	19.10
6060	screen	22	>3	1	1	0	C	8.5	1.1	7.73			8.76	17.52
6199	screen	28.2	>3	1	1	0	C	8.8	1.2	7.33			8.67	17.33
6612	screen	17.7	>3	1	1	0	C	6.7	0.7	9.57			8.37	16.73
9340	screen	17.9	2	1	1	0	C,N	8.4	1.3	6.46	4.5	1.2	7.43	14.87
8344	screen	32.7	1	1	0	0								
5169	screen	22.3	2	2	1	0								
9220	screen	19.2	1	1	1	0	N				5.1	2.9		
7693	screen	18.9	1	1	1	0	N				4.9	1.6		

1104

1105

49

Pigments

Data recorded on all pigments >5 mm from the Lower Deposits include nodule morphology, weathering, friability, hardness, magnetism, texture, luster, and type of inclusions. It was noted whether or not each pigment nodule was washed before analysis in case of ambiguous traces. Macroscopic observations were made using a Nikon SMZ 1000 stereomicroscope with a magnification range of 8x to 80x. A Nikon D7100 was attached for microphotos, capturing images at magnifications from 16x to 160x. For pigment nodules that were anthropogenically modified, modification form, proportion, number of facets, and profile type were recorded. Pigment nodules were tested for streakability on a ceramic plate. If nodules did not streak or exhibited poor staining power, they were excluded from the final count. Pigment streak colour was assessed using a Munsell CAPTURE Color Matching Tool, directly applied to the ceramic plates following device protocols. Munsell colour values were captured multiple times to ensure accuracy. If multiple values were obtained, the value that was captured more often was used. Munsell colour values were then converted to the RGB colour model using the xyY-to-sRGB formula at https://pteromys.melonisland.net/munsell/.

The Lower Deposit pigment assemblage comprises 78 pieces (Table S15) featuring considerable variation in morphology and mineralogy (including pieces rich in hematite, limonite, and manganese). Nodules masses range from 0.05g to 12.01g with the vast majority <1g. Pigment nodules have varying morphologies that include irregular chunks (n=48), rounded lumps (n=16), flakes (n=6), chips (n=6), a tabular piece, and a prismatic (crayon-like) one (Table S15). Nodules described as chunks exhibit an irregular thick morphology with sharp edges (Figure S21), while chips and flakes are thin portions derived from larger nodules. Chips are rounded in outline, while flakes are angular. Nodules exhibit some weathering with almost all having some amount of sediment adhering to them (n=75) and many with indications of rounding (n=38). A small number of pigments nodules were either burned (n=2; Figure S21) or have ash adhering to the surface (n=1). Nodules are generally well or moderately cemented, though three nodules are friable to the touch. Many nodule colors are represented in this assemblage including pink, red, purple, black, grey, greenish brown, yellow, and orange; nodules streak in a wide variety of colors and hues from dark reds and reddish browns to light reds and pale browns with reddish yellows, strong browns, and medium reds in between (Figure S21). Three of the specimens appear to be massive hematite nodules, which generally are substantial, smooth, dark, and glossy in appearance. While many similar objects such as these did not produce a color when streaked on a ceramic tile, the three included in this dataset exhibited relatively good staining power in colors such as very pale brown and yellowish red. The majority of the

pigment nodules are unmodified, but eight are ground, scraped, and/or polished (Figure S21; Table S15). Two of the modified nodules have multiple wear facets including the prismatic piece which has nine separate facets. The modified nodules streak a variety of colors including pink, red, yellowish red, greyish red, and very pale brown when tested on a ceramic tile (Figure S21).

Table S15. Number of pigment modified and unmodified nodules by morphology, I-08 & I-09.

Pigment nodule morphologies	Number of pigment nodules	Number of modified nodules
Chunk	23	4
Flake	6	0
Lump	4	0
Prismatic	1	1
Tabular	1	1
Small chip	6	0
Small chunk	25	2
Small lump	12	0
TOTAL	78	8
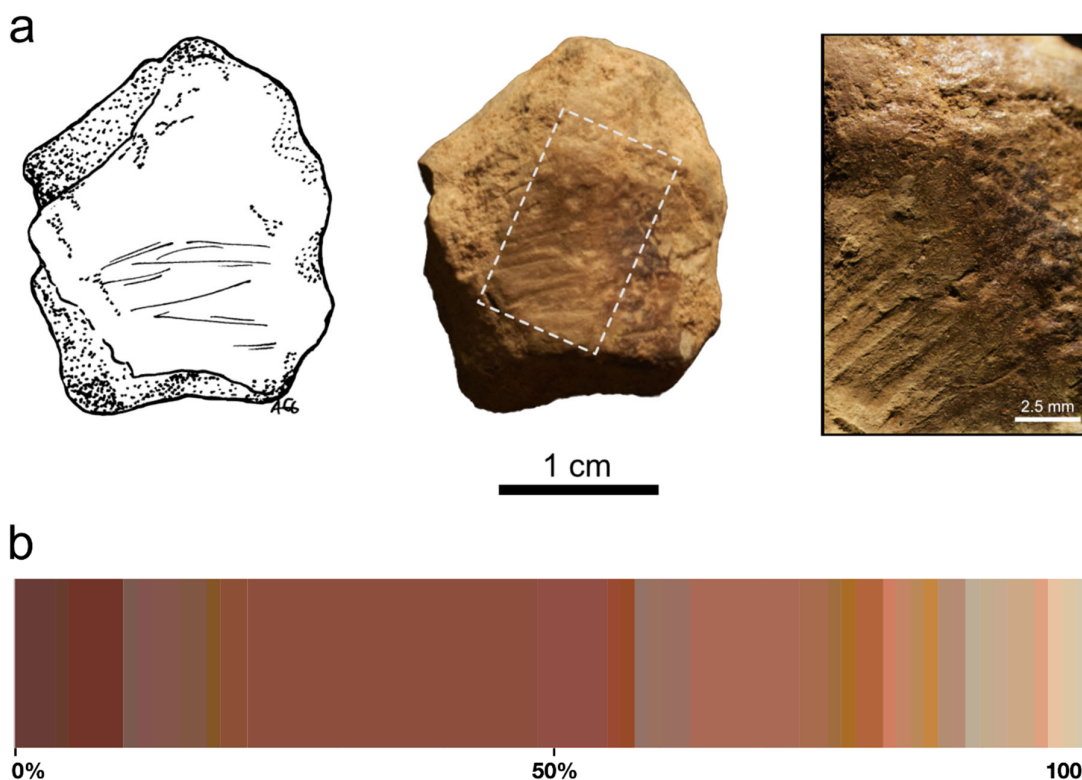
Figure S21. (A) Pigment nodule VR003-8511 (I-08) with anthropogenic modifications including polish and grinding with minor burning on the surface. This nodule is characterized as a chunk, weighs 4.18g, measures 24.74 x 19.9 x 9.97mm, and streaks a very pale brown color (Munsell color system: 10YR 7/3). (B) Proportion of pigment colors from Lower Deposits when streak on a ceramic tile.

1157 **Lithics**

1158 We begin this section by providing a detailed description of the Lower Deposits lithic
1159 assemblage before providing an overview of potentially comparable MSA assemblages from
1160 across southern Africa. We conclude by evaluating whether the characteristic technologies
1161 of the Lower Deposits are similar to any other published datasets.

1162

1163 **Lower Deposits lithic data**. The analysed assemblage from the Lower Deposits comprises
1164 3062 flaked artefacts >15 mm; artefacts below this cut-off were not analysed individually.
1165 The breakdown of primary classes by raw material is given in Table S16. Silcrete is the
1166 single most common rock type in the sample (41.6%), followed by quartz (29.8%) and
1167 quartzite (20.9%); between them these three lithologies account for more than 90% of the
1168 artefacts. The fine-grained rocks hornfels and chert account for a further 6.2% of artefacts,
1169 followed by the 'other' category which includes sandstone, shale, ironstone, limestone and
1170 unidentified igneous lithologies. The raw material composition of the Lower Deposits is
1171 interesting relative to previously published strata from the site: in all other units which we
1172 have analysed, quartz was the dominant rock (>50% of total) and silcrete never exceeded
1173 17% (1).

1174

1175 **Table S16**. Breakdown of flaked lithic assemblage from I-08 and I-09 by raw material and artefact
1176 class.

	silcrete	quartz	quartzite	hornfels	chert	other	total	%
flakes	813	712	554	76	66	26	2247	73.4
retouched flakes	29	44	18	10	4	1	106	3.5
cores	72	25	13	3	4	0	117	3.8
flaked pieces	67	119	26	4	7	8	231	7.5
heat shatter	313	9	20	8	5	6	361	11.8
total	1294	909	631	101	86	41	3062	
%	41.6	29.8	20.9	3.3	2.9	1.4		100.0

1177
1178 Flakes are the most common of the primary artefact classes (73.4%), with cores (3.8%) and
1179 retouched flakes (3.4%) having similarly low frequencies. Heat shattered pieces – pieces
1180 formed by heat-induced fracture – account for 11.8% of the total. This abundance is driven
1181 principally by silcrete among which it accounts for nearly a quarter (24.2%) of all artefacts,
1182 including many large pieces (Figure S22). Among all other raw materials combined heat
1183 shatter accounts for 3.0% of artefacts, with hornfels (8.8%) having the highest value after
1184 silcrete. This pattern might partly be explained by the relative identifiability of heat effects on
1185 different lithologies. The characteristics of heat shatter are generally visually-obvious on fine-
1186 gained sedimentary/metamorphic rocks such as silcrete, chert and hornfels, and to an extent

1187   on the coarse-grained rocks such as quartzite, but can be hard to identify on crystalline

1188   rocks like quartz which often exhibit non-conchoidal fracture. This does not, however,

1189   explain the differences observed here for heat shatter frequencies between silcrete, chert

1190   and hornfels. Chert should be more sensitive to shatter than silcrete (141).

1191

1192   Notable variation is also observed in the prevalence of other primary artefact classes by raw

1193   material. Silcrete, for example, contributes the majority of the cores (61.4%) but only 27.4%

1194   of the retouch flakes. Indeed, silcrete is only the lithology in which cores exceed retouched

1195   flakes. Among other rock types the retouched flake to core ratio varies from 1 (chert / other)

1196   to 3.3 (hornfels); for silcrete the value is 0.4. These base data suggest differences in the

1197   delivery and treatment of silcrete vs non-silcrete artefacts in the Lower Deposit assemblage.

1198   Complete flakes were classified into three shape types: flakes, blades and points (Figure

1199   S23). We define blades here as any flake with elongation (percussion length / maximum

1200   percussion width) of 2 or greater. We do not distinguish blades and bladelets, and given our

1201   cut-off of 15 mm many of the latter would have been missed during analysis. 'Points' we

1202   define as flakes with a consistent taper through at least their distal two-thirds. The type

1203   'flakes' refers to any shape that does not conform to these other types. Where points are

1204   elongate the type 'point' was selected over the type 'blade'.

1205

1206   **Table S17**. Numbers of different flake types in the Lower Deposits divided by raw material, complete
1207   flakes only.

	silcrete	quartz	quartzite	hornfels	chert	other	total	%
flakes	434	323	269	37	35	14	1111	88.7
blades	36	14	20	10	3	0	83	6.6
points	24	8	20	3	4	0	59	4.7
total	494	345	309	50	42	14	1253	

1208
1209   Flakes dominate the sample (88.7%) with both blades and points relatively uncommon (6.6%

1210   and 4.7% respectively) (Table S16). Values for both are consistent across raw material

1211   classes with the exception of hornfels, where blades comprise an anomalous 20%,

1212   potentially implying different reduction patterns for that rock type. Only 18 (21.7%) of the

1213   blades related to laminar (unidirectional or bidirectional opposed) reduction systems,

1214   suggesting that the presence of the blades in the assemblage was largely incidental.

1215   Consistent with this, evidence for formal establishment and/or maintenance of blade

1216   removals is minimal; following Soriano, Villa and Wadley (142) most of the blades fail to

1217   conform to standard types (Table S18). The single class 'C' (maintenance) crested blade we

1218   identified is only partially crested, with the crest in lateral position. This artefact is made from

1219   silcrete and the proximal area of the left lateral reflects an episode of thermal fracture that

1220   occurred before the flake was struck (Figure S23 e). The scars that comprise the crest are

1221 smooth and lustrous, and consistent with working after heat treatment. Thus, the flake was

1222 struck from a core that had been heated to the point of fracture.

1223

1224 **Table S18**. Blade types from I-08 and I-09 following (142). Empty columns (i.e., those with null
1225 values: classes B3, B5, B11, B13, B14, D1) are excluded. Class A blades reference initial phases of
1226 production (cortical blades); class B blades derive from the optimal phase; class C blades are those
1227 used for maintenance of core morphology; class D blades are those that do not conform with any of
1228 the standard definitions.

	A1	A2	A3	B1	B2	B4	B6	B7	B8	B9	B10	B12	C2	D2
silcrete	1	2	2	5				2	1	1			1	20
quartz				2	2	1	1		1	1				6
quartzite	2			2			1		1	1		1		11
hornfels				1	1	2	1		1		1			3
chert	1									1				1
total	4	2	2	10	3	3	3	2	4	4	1	1	1	41

1229
1230 Like blades, point production in our assemblage mostly seems opportunistic or incidental

1231 (Table S18). Only seven of 59 (11.8%) exhibit platform and dorsal scar configurations

1232 suggestive of Levallois reduction; across the entire sample this amounts to 0.6% of complete

1233 flakes. A further ten points (16.9%) appear to relate to discoidal flaking patterns. One of

1234 these was made from chert and refits to an earlier flake (Figure S7), suggesting that at least

1235 some of these points were made on site. As we note, though, there is nothing in the flake

1236 component to suggest that manufacture of points was an objective of reduction at the site.

1237

1238 Almost half of all flakes (46.5%) – including flakes, blades and points – have cortex (Table

1239 S19). Presence and prevalence of cortex between raw materials is quite consistent, varying

1240 from 41.2% (chert) to 56.8% (hornfels). Notably less well-represented lithologies present the

1241 outlying values, possibly reflecting sample-size effects. Within the main raw materials,

1242 variance is from 42.8% (silcrete) to 51.4% (quartzite). Similarly, proportions of flakes with

1243 cortical coverage across more than half of the dorsal and platform surfaces do not vary

1244 greatly between raw materials (7.5% (silcrete) to 10.3% (chert)). The main point of contrast

1245 in cortex between raw materials is in its form (Table S20). Quartzite and hornfels, which are

1246 both available in ancient cobble beds in the area, generally have fluvial cortex as their most

1247 common type (62.4% and 40.0% respectively); silcrete and quartz, the two flakable rocks

1248 that occur commonly as primary sources in the area, have very high proportions of outcrop

1249 cortex (83.8% and 74.1% respectively).

1250
1251 **Table S19**. Cortex classes for all complete flakes in I-08 and I-09.

	silcrete	quartz	quartzite	hornfels	chert	total	%
51-100	35	29	25	4	4	97	8.6

26-50	33	21	33	6	0	93	8.0
1-25	127	112	74	15	12	340	29.9
0	299	183	177	25	26	710	53.5
total	494	345	309	50	42	1240	

Table S20. Cortex types for all complete flakes in I-08 and I-09.

	silcrete	quartz	quartzite	hornfels	chert	total
outcrop	160	120	6	4	5	295
fluvial	9	11	82	10	2	114
crystal	0	5	0	0	0	5
unsure	26	28	44	11	9	118
total	195	164	133	25	16	533

The 103 retouched flakes in the Lower Deposits include 63 complete pieces that we discuss briefly here. Notched pieces – comprising simple notches formed by a single blow and complex notches formed by multiple removals from the same concavity – are the most common retouched artefact type. These are followed by denticulates, defined as artefacts with three or more adjacent notches along a single margin. A very high proportion (41.9%) of retouched pieces could not be assigned to any type. Among the major lithologies, these 'informal' retouched pieces are most common on silcrete artefacts (60%); quartz has the next highest proportion at 41.7%. The retouched silcrete artefacts include one denticulate made on a piece of heat shatter. This is one of only three examples of retouch on heat shattered fragments (see Table S23 below) (e.g., Figure S23 m).

Table S21. Retouch flake types in I-08 and I-09 by raw material.

	silcrete	quartz	quartzite	hornfels	chert	Other	total
Denticulate	2	5	2	0	0	0	9
Notch, simple	3	4	6	2	0	0	15
Notch, complex	2	1	0	1	0	0	4
Scaled piece	0	1	1	2	0	0	4
Scraper	1	3	0	0	0	0	4
Other	12	10	2	0	2	1	27
total	20	24	11	5	2	1	63

Silcrete cores have been discussed in some detail in the main text; here we discuss the core assemblage as a whole (n=91, Table S22). As noted in the main text, the types of cores found in the Lower Deposits is quite diverse. 'Other prepared' pieces – comprising those with preparation of the striking platform but no clear organisation of the removal surface – are numerically most common, along with cores that conformed to no type. Most of these latter pieces were opportunistic, 23 of 24 (95.8%) having three or fewer removals >20% of the core maximum dimension. The 'platform' groups includes cores that are not technically single platform – they may have one or two blows from from a second surface – but which

have a series of removals along a single dominant, and invariably linear platform. Bipolar

working is extremely rare across all materials (n=1).

Generally speaking the non-silcrete cores are similar many respects to the silcrete cores. Those made from quartz (n=20), chert (n=3), and hornfels (n=2) have similar maximum dimensions (mean=34.2, ±11.0 mm), numbers of removals (3.3), flake scar lengths (17.1 ±7.3 mm) and types as the silcrete cores. Quartzite cores (n=12) are appreciably larger than those on other lithologies (61.7 ±26.2 mm), with larger scars (26.9 ±9.4 mm), and more scars per core (4.4). Generally speaking, however, cores from all materials in I-08 and I-09 were dedicated to the expedient production of small flakes and blades.

Consistent with earlier observations on the flake component, evidence for blade production is rare: only 7 or the 91 (7.7%) complete cores retained one or more blade removal. Point removals were even less common (n=4, 4.4%). Of the blade removals recorded, most were extremely small, with a mean of 16.3 mm (±6.2).

Table S22. Core types by raw material, I-08 and I-09.

	silcrete	quartz	quartzite	hornfels	chert	Other	total
Bipolar	0	1	0	0	0	1	2
Discoidal	3	1	1	0	0	0	5
Levallois, preferential	3	1	2	0	0	0	6
Levallois, recurrent	5	0	1	1	1	0	8
Other prepared	15	5	3	1	0	0	24
Platform	10	3	1	0	1	0	16
Rotated	4	1	1	0	0	0	6
No type	13	8	3	0	1	0	24
total	53	20	12	2	3	1	91

Heat effects are prevalent in the Lower Deposits, but as noted in the main text, most commonly on silcrete. To that end, we restrict discussion of heat effects here to that raw material. Like prior sections of this SI, we exclude incomplete pieces to avoid duplicate counts of what may have been individual artefacts. Heat effects are classified following (143, 144). Without a detailed reference collection the identification of post-heat removals is subjective, relying on the evaluation that flake scars are smoother and more lustrous than might be expected for unheated silcrete. The classification 'unsure' was thus used quite frequently during analysis, and the firm identification of heat treatment largely restricted to those pieces with clear texture contrast between adjacent and/or sequential removal events, including double patina and surfaces with heat-induced non-conchoidal (HINC) fracture (Table S23).

1305

1306 Overall, 39.4% of silcrete artefacts appear likely to have been heated and 35.8% might

1307 confidently be classified as 'heat treated' in the sense that they were thermally altered before

1308 being worked (ie., all heated excluding 'HINC – Flaked before' and 'HINC – Unsure'). Of

1309 those with clear signs of heat shatter (HINC fractures) at some point before or after discard,

1310 a very high proportion (79.8%) were flaked after shatter. Excluding those for which the

1311 sequence of shatter and flaking cannot be identified (HINC – Unsure) this value rises to

1312 96.3%.

1313

1314 Evidence for heat effects occurs unevenly between different artefact classes. Approximately

1315 two thirds of all unretouched flakes (65.4%) and half of all retouched flakes (48.4%) show no

1316 clear signs of heat effect. This is true of only 5.6% of cores. Types of heat effects differ just

1317 as starkly. Heat treated pieces with no evidence of HINC are twice as common as pieces

1318 flaked after shatter among complete flakes and complete retouched flakes; among cores

1319 pieces flaked after shatter are twice as common as those with no evidence of HINC. Most

1320 simply, this difference may reflect flakes removed from areas of a heated core from which

1321 HINC fractures were absent. It is also possible that these flaking products derive from a heat

1322 treatment system in which heat-induced fracture was less prevalent. Based on the evidence

1323 from the silcrete cores in the Lower Deposits, however, such activities may have taken place

1324 off site.

1325

1326 **Table S23**. Classification of heat effects on silcrete artefacts of different classes, I-08 and I-09.
1327 Double patina excludes pieces with HINC features. Flaked before, Flaked after, Both, and Unsure
1328 refers to the sequential relationship between the shatter event creating the HINC fracture and any
1329 flaking events evident on the piece.

Artefact class	No heat	Unsure	Heated							Total
			Post-heat removals	Double patina	HINC					
					Flaked before	Flaked after	Both	Unsure		
flakes	66	257	48	47	3	55	2	16		494
retouched flakes	1	8	1	5	0	3	0	1		19
cores	1	2	3	14	0	32	0	1		53
Total	68	267	52	66	3	77	2	17		553
					218					

1330
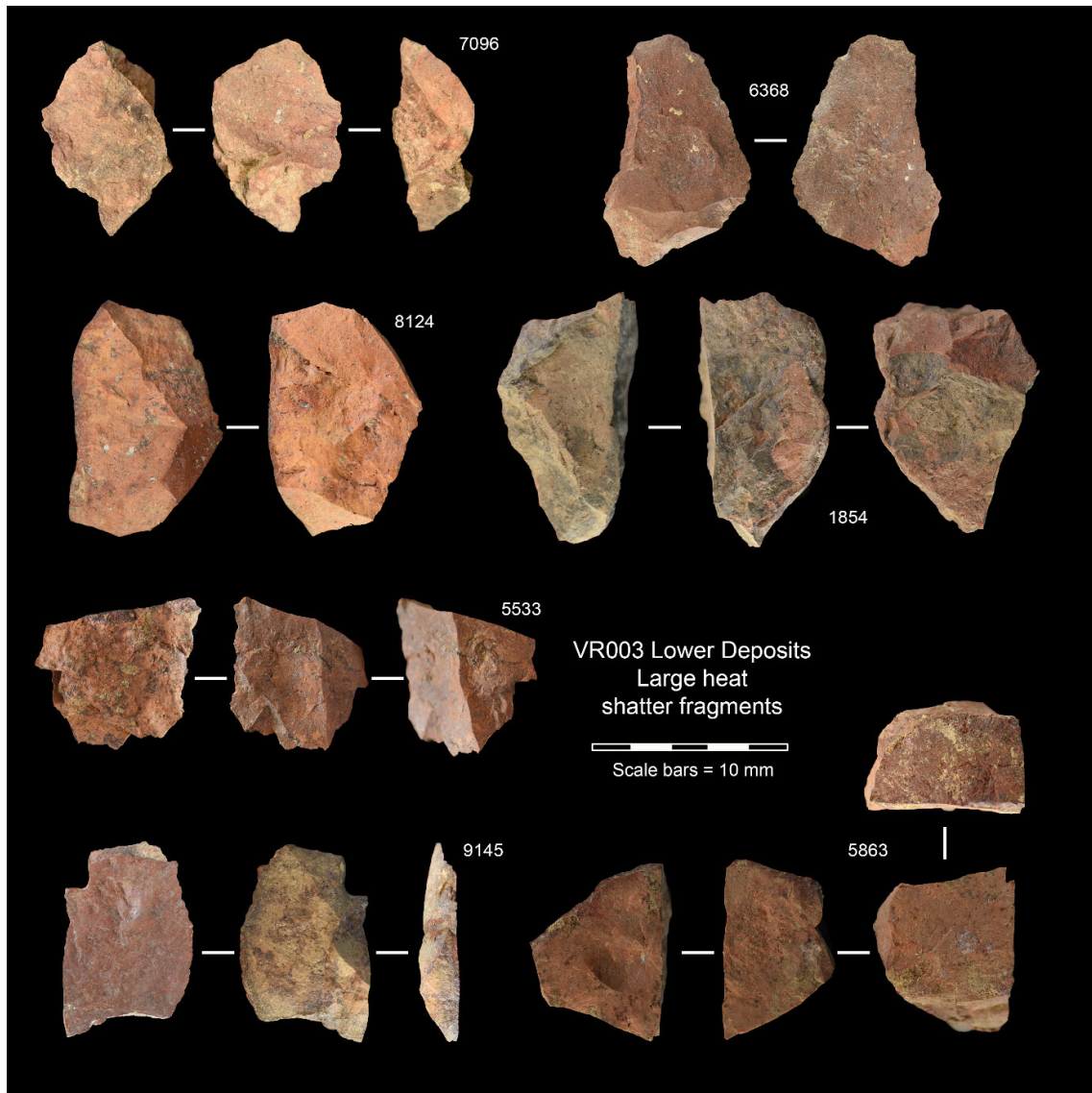
1331

1332 **Figure S22**. Large, blocky, unworked silcrete heat shatter fragments from the Lower Deposits.

1333

1334

Figure S23. Flakes and unretouched flakes from the Lower Deposits. White arrows are used to indicate locations of HINC fractures that have been truncated by subsequent removals. (a-c) silcrete blades; (a) was heat shattered after manufacture, as indicated by HINC (potlids) on the ventral surface. (d) silcrete point with double patina on the left side (dorsal view) – note the texture contrast between the proximal (later) and distal (earlier) scars. (e-f) silcrete blades, including (e) partially crested blade; (f) was struck from a ridge formed by heat shatter. (h) hornfels blade with pecussion-shattered bulb. (i) silcrete flake with HINC on distal right lateral, truncated by the ventral. (j-k) denticulate and notched (respectively) quartz flakes. (j) hornfels scaled piece. (m) silcrete notched piece with HINC fracture truncated by both the ventral and one retouch scar. (n) silcrete complex notch. (o) silcrete scraper, retouch has removed the platform.

VR003-6587
Platform installed at top, one lateral removal to prior flaking face. Unclear heating / flaking sequence.

VR003-6884
Single blow from existing ridge on upper surface onto dull lower surface.

VR003-6004
Single blow from upper surface cutting into a shatter face. Blow applied from a cortical surface.

VR003-9048
Single blow from upper shatter surface, truncating another shatter surface.

VR003 Lower Deposits
Silcrete cores made on fragments of heat shatter

Scale bars = 10 mm

VR003-6363
Two blows from upper shatter surface truncating shatter along left lateral.

VR003-7105
Single blow from upper shatter surface truncates shatter features on the core face. Two further small initiations from a lateral shatter surface.

VR003-1510
Series of laminar scars down one margin of shatter fragment. Initiations from and truncating shatter surfaces.

VR003-5383
Initiations from upper prepared platform to main flaking surface. One overshot flake truncates the rear shatter surface.

VR003-5532
Simple platform surface with three initiations. The left-most removal truncates an area of shatter on the lateral edge. Rear surface is shatter.

HINC surfaces →
removal initiations →
potlids →

1345

1346 **Figure S24**. Annotated figure showing silcrete cores made on fragments of heat shatter.

1347

1348 **The Lower Deposits lithic technology in context**. A wide variety of industry/techncomplex

1349 terms combined with a small number of consistently dated assemblages complicates

1350 reviews of the pre-Still Bay lithic technology of southern Africa. The term 'pre-Still Bay' itself

1351 presumes the existence of the Still Bay as a regional horizon marker, though it probably

1352 cannot function that way given: [1] Still Bay assemblages are quite rare (145), [2] there does

1353 not appear to be a Still Bay in some regions (146), [3] the bifacial points used to define

1354 discrete Still Bay horizons in the west and south-west of South Africa (147, 148) are a

1355 recurrent feature of assemblages in the east and north-east (149, 150), and [4] regional

1356 differences in bifacial point morphology (151, 152), coupled with chronometric

1357 inconsistencies (e.g., 12, 153, 154), precludes the assumption that all such bifacial point

1358 assemblages are related (155). The broader term 'Early MSA' is not obviously more useful.

1359 Some apply this to any assemblage inferred to be of MIS 5 age or greater (156); others

1360 restrict it to assemblages inferred to ante-date the MIS 5e highstand (157-160). In either

1361 case the Early MSA, like the pre-Still Bay, lacks unifying technological characteristics and

1362 doesn't provide an obvious mechanism for dealing with undated assemblages.

1363

1364 Given that our interests here are quite narrow, we approach this review through the lens of a

1365 specific question: what other MSA assemblages resemble those from the Lower Deposits at

1366 VR003? We define the technological characteristics of the Lower Deposit lithic assemblages

1367 as follows: [1] focussed procurement of silcrete, [2] use of heat fracture to create core

1368 blanks, [3] dedicated production of small flakes and blades across most raw materials, [4]

1369 short reduction chains in the dominant core component, [5] elevated rates of heat shatter, [6]

1370 rare and opportunistic production of blades and points, [7] relatively few retouched artefacts,

1371 [8] notches and denticulates as the most common implement forms, and [9] near-absence of

1372 bipolar reduction. Not all of these characteristics are reported on in published analyses of

1373 other sites, but enough information is available in most cases to make a reasonable

1374 assessment. Characteristic [1] is only applicable to silcrete-bearing regions around the

1375 southern and western coastal margins of South Africa (161); in other areas an equivalent

1376 characteristic could be redefined as 'predominance of a raw material that is otherwise rare in

1377 the sequence'. Further note that, so far, heat treatment in the MSA has only been

1378 demonstrated to have been applied to silcrete (162-165). Consequently characteristics [2]

1379 and [5] are also likely to be geographically constrained.

1380

1381 We take a two part approach to this review. We start by using the defining characteristics of

1382 the prevailing MIS 5 culture-historic taxonomies (ie., 'technocomplexes') in the region,

1383 including Klasies River / Mossel Bay / pre-Still Bay (158, 159, 166), and the recently re-

1384 emerging Pietersburg (167-169). Following (170) we appreciate that these culture-historic

1385 taxa are normative and typically act to supress inter- and intra-assemblage variation,

1386 creating the appearance of coherence where it may not exist (156). We thus document site-

1387 specific variance within these taxa where possible. Subsequently, we provide detailed data

1388 on assemblages likely to ante-date the Still Bay from the six MSA sites within 100 km of

1389 VR003 both from published sources and from our own analyses.

1390

1391 *Major technocomplex comparisons*. The foundational MSA culture-historic taxonomy

1392 proposed by Volman (171) remains influential but has recently been updated by Lombard

1393 and colleagues (159), and Wurz (158), with important further supplementary information in

1394 (172). We follow their naming conventions here. It is worth recalling, though, that Volman's

1395 original focus was on the southern Cape region that today largely falls within the Fynbos

1396 Biome. Regions to the north and east—those receiving predominantly summer rain and

1397 including the Grassland and Savanna Biomes—were not always well served by that system.

1398 With a recent resurgence of interest in the MSA of this area (167-169, 173, 174), the

1399 historical Pietersburg Industry has been somewhat revitalised as a regional MSA

1400 technocomplex tentatively assigned to MIS 5 (167, 168).

1401

1402 Klasies River. The Klasies River unit is assigned a putative age of 130-105 ka, and has been

1403 identified at sites including Klasies River and Pinnacle Point 13b (159) (Figure S25). Defining

1404 characteristics are "a recurrent blade reduction strategy", elongate flaking products with

1405 diffuse bulbs, low frequencies of retouch, and denticulated pieces. Further sites with

1406 assemblages in the age range of this taxon are Florisbad, Hoedjiespunt and Ysterfontein

1407 (59, 175, 176), though they appear to have different technological characteristics (158).

1408

1409 The relevant LBS member at Klasies River Main site has large cores dedicated to blade

1410 production, with almost all artefacts made from quartzite, and negligible silcrete ('non-local',

1411 a term used for rocks that include silcrete, totals 0.2-0.4% in these assemblages). Quartzite

1412 also dominates the LC-MSA 5e and East 5d assemblages from Pinnacle Point 13b, though

1413 silcrete accounts for a reasonably elevated 12.6% of artefacts. There are very few cores in

1414 these deposits (177), and neither the presence nor prevalence of heat treatment in the

1415 assemblages at either site has been documented.

1416

1417 Heat treatment does occur at Hoedjiespunt (163), where quartz is the main raw material,

1418 bipolar cores the dominant type, and silcrete cores absent (176). On the other hand, silcrete

1419 is common at Ysterfontein 1 both overall (51.3%) and among cores specifically (47.1%)

1420 (178), though heat treatment has not been studied. The assemblage is characterised by the

1421 production of small flakes and blades (179), with cores described as 'platform' and 'two

1422 volume' (179), the latter corresponding to discoidal and/or Levallois reduction.

1423

1424 Florisbad is the only site in this grouping to lie outside the modern Fynbos Biome. Unit F has

1425 an age of 121 ±6 ka and an assemblage of ~1669 artefacts, almost all made from dolerite

1426 (175). Pointed flakes are relatively common, though it is not clear if blades per se are

1427 present, and if so in what quantity. The most common implements are described as 'cutting

1428 tools' – flakes showing either minor retouch or use damage. The only other types present

1429 are burins and sidescrapers.

1430

1431   <u>Mossel Bay</u>. Lombard et al (159) assign the Mossel Bay taxon an age range of 105-77 ka,

1432   and identify it at Klasies River, Pinnacle Point, and potentially Melikane, with undated

1433   examples at Cape St Blaize and Nelson Bay. With the exception of Melikane, all of these

1434   sites are located within the modern Fynbos Biome. Wurz also assigns unspecified layers at

1435   Diepkloof to the Mossel Bay (probably MSA-Mike and earlier—see discussion below under

1436   *Individual site comparisons*), as well as Cave of Hearths, though we include the latter here

1437   under the Pietersburg. The Mossel Bay is defined by the production of points and blades by

1438   unipolar recurrent Levallois reduction, with low rates of retouch and few defined implement

1439   types (158, 159). Douze et al (172) extend this comparison to include the M3 unit at

1440   Blombos dating 98-82 ka (180), and provide seven characteristics that link all assemblages:

1441   "1) the dominant use of local raw material, 2) dominant parallel (Levallois-like) core reduction

1442   methods, 3) a combination of different core reduction methods for the production of blanks,

1443   4) a production of predetermined blanks, 5) a low percentage of retouched tools, 6) usually a

1444   dominance of notched or/and denticulated tools, and 7) the production of points" (p25). They

1445   consider the technocomplex to be a single coherent unit comparable to the Still Bay and

1446   Howiesons Poort.

1447

1448   In the Mossel Bay-assigned SAS Member at Klasies River, quartzite accounts for the

1449   majority of artefacts, and silcrete is again scarce ('non-local' ranges from 0.5% to 2.1%).

1450   Wurz (166: p1008) states that "The core reduction scheme in this sub-stage is clear, as

1451   almost all the cores and end products are uniformly patterned. Nearly all of the preparation

1452   of the core was directed at the production of Levallois-like points". Cores in this unit are

1453   made either on large primary flakes or cobbles, and while retouch was typically rare,

1454   notching and denticulation were the most common forms. A minor departure from this

1455   pattern is found in the Witness Baulk sample reported by (181) dating ~110-93 ka where,

1456   though quartzite accounts for 90% of artefacts, there is some dedicated production of small

1457   blades. In the M3 at Blombos silcrete is the most common raw material, but the

1458   technological elements are strongly similar to the typical Mossel Bay elements at Klasies

1459   River (172). Again, there has been no discussion of the role of heat treatment in these

1460   assemblages or their technological organisation.

1461

1462   At Pinnacle Point 5-6 quartzite is the major raw material in the stratigraphic aggregates YBS

1463   (96 ±6 ka), YBSR (89 ±5 ka) and LBSR (91 ±4 ka), though silcrete accounts for 25.7% of all

1464   artefacts and 45.7% of cores (182). Almost half of the silcrete cores produced blades or

1465   bladelets. Cores on heat shatter are not included in the extensive dataset provided by

1466   Wilkins and colleagues (182), though heat treatment was likely applied to silcretes in the

1467 LBSR unit at least (183). Bipolar cores are notably rare in these assemblages, despite a
1468 diverse core corpus geared towards the production of a range of blades, points, and flakes.
1469
1470 Inclusion in this technocomplex of Melikane, located in the modern Grassland Biome in
1471 Lesotho, seems questionable. The Phase IV assemblage there has ages of 83.2 ±6.2 ka and
1472 79.5 ±3.1 ka, but its technological characteristics feature the production of small blades from
1473 multi-directional cores made on locally-available chert pebbles, and their subsequent
1474 reduced by bipolar techniques (184). There is no evidence of heat treatment, though this site
1475 falls outside the 'silcrete belt' and as noted earlier, heat treatment has not yet been
1476 documented on lithologies other than silcrete in the region. The distinct nature of the
1477 technological systems at Melikane suggest regional diversity of technological responses in
1478 the interval covered by the Mossel Bay taxon.
1479
1480 pre-Still Bay. The 'pre-Still Bay' is not a coherent taxon, and is used in Lombard et al (159) to
1481 denote undescribed or anomalous assemblages either underlying or immediately antedating
1482 the Still Bay. With Blombos M3 reassigned to Mossel Bay, the two remaining sites in this
1483 grouping are Rose Cottage Cave and Sibudu, both located outside the Fynbos Biome, in the
1484 Grassland and Savanna Biomes respectively. Both have ages that would otherwise place
1485 them in the Mossel Bay, perhaps further emphasising that MIS 5 technological diversity
1486 increases when sites outside the Fynbos Biome are considered.
1487
1488 Description of the pre-Still Bay (more accurately 'pre-Howiesons Poort' (185, 186))
1489 technology at Rose Cottage Cave remains limited, though a summary of ages from layers
1490 KUA through LEN range from ~96-71 ka (187). Chert is the most common rock, as at
1491 Melikane, though "sandstone and tuffaceous rocks" are more common in the pre-Still Bay
1492 than elsewhere in the sequence (186). Neither pointed flakes nor blades appear to be
1493 particularly common, and unifacial points are the most common implement type, followed by
1494 'knives'.
1495
1496 At Sibudu the pre-Still Bay layers are denoted D-A, and are older than 77.2 ±2.1 ka with as
1497 yet no lower bounding age (174). Dolerite is the main raw material, comprising 83.9% of the
1498 published artefact sample. Fine-grained rocks hornfels and chert are rare (1.7% and 0.3%
1499 respectively), as is quartz (2.1%). Cores are also very uncommon (0.7%) though retouch
1500 (8.2%) is more frequent than at most MIS 5 assemblages. Reduction processes are geared
1501 towards the production of blades, and the main core type is given as 'platform', indicating
1502 typically unidirectional removals. Bipolar reduction is also common, however. As at Rose
1503 Cottage Cave, unifacial points are the most common implement type. This stands in contrast

1504   to all MIS 5 assemblages from the Fynbos Biome, with the exception of MSA-Lynn at

1505   Diepkloof (see below). Bifacial tools are the second most common implement type at

1506   Sibudu, followed by scrapers. Denticulates are present though infrequent.

1507

1508   Pietersburg. As with the 'pre-Still Bay', though it is long-established (188-190), whether the

1509   Pietersburg can be considered a coherent taxon is still unclear (168). Sites with published

1510   ages are few but include 227-77 ka at Border Cave (173), 150 ±14 ka at Olieboomspoort

1511   (169), 97 ±10 ka to 73 ±6 ka at Bushman Rock Shelter (167), and potentially 90 ka at

1512   Mwulu's Cave (191). Other sites that have been assigned to this grouping are Cave of

1513   Hearths and Lincoln Cave (172). All are located within the modern Grassland and Savanna

1514   Biomes.

1515

1516   de la Peña and colleagues (168) describe the Pietersburg as a technological succession,

1517   rather than an entity, from "triangular blanks/Levallois-like industries to bifacial/unifacial

1518   pieces/Levallois-like industries" (p25). Scrapers are also common in some sequence

1519   components (167), and denticulates in others (168). Almost all Pietersburg assemblages do

1520   appear to produce some bifacial points, however. Like other MIS 5 groupings, raw material

1521   selection appears to be highly localised, with quartzite the dominant rock at Mwulu's Cave

1522   and Olieboomspoort (168, 169), hornfels and quartz at Bushman Rock Shelter (167), and

1523   rhyolite, hornfels and basalt at Border Cave (173). There is no discussion of heat treatment

1524   in any Pietersburg sites, but it seems unlikely that any of the main raw materials would be

1525   suitable.

1526

1527   The assemblages underlying the Still Bay at Apollo 11 (192) are an uneasy fit with the

1528   Pietersburg, but have not been assigned to other technocomplexes. Volman (171)

1529   considered these assemblages most similar to those from Cave of Hearths. The artefacts

1530   include numerous large flakes and blades, but the retouched component is mainly

1531   denticulate with single unifacial point reported in (192). Consistent with the other sites

1532   considered in this review, raw material selection is localised, comprising quartzite and

1533   calcareous mudstone (combined >90%).

1534

1535   *Individual site comparisons*. We now review data from MSA sites located near to VR003,

1536   targeting the data most relevant to the identifying characteristics of the Lower Deposit

1537   assemblages. The sites relevant to this comparison are Putslaagte 8 (69.3 km) (193), Hollow

1538   Rock Shelter (76.3 km) (194, 195), Klipfonteinrand 1 (78.3 km) (171), Mertenhof (88.9 km)

1539   (196), Elands Bay Cave (91.3 km) (160, 171, 197), and Diepkloof (96.2 km) (147). All are

1540   located to the south of VR003 in what is today part of the Fynbos Biome, though Putslaagte

1541   8, Klipfonteinrand 1, Hollow Rock Shelter and Mertenhof all lie east of the Cederberg

1542   mountains close to the current boundary with the Succulent Karoo Biome (Figure 1). Elands

1543   Bay Cave and Diepkloof lie west of the mountains near the modern coastline. The data

1544   presented below are summarised in Table S24.

1545

1546   Putslaagte 8 has minor Howiesons Poort and Still Bay components, and the undated

1547   underlying MSA assemblage from layers FOBSS spits 6-14 is small. FOBSS6-8 and

1548   FOBSS9-14 had minor technological differences and are reported separately here. The

1549   prevailing raw materials across both units are hornfels and quartzite, which are locally

1550   abundant. Silcrete accounts for 1.4% of artefacts in FOBSS6-8 and 1.2% in FOBSS9-14

1551   later peaking at 21.9% during the LSA Robberg (CGBSS13-16). None of the 30 cores in

1552   FOBSS6-14 were made from silcrete. No observations were made on heat treatment,

1553   though heat shatter comprises 3.6% of artefacts in Mackay's dataset for FOBSS6-8 and

1554   1.4% for FOBSS9-14; only one of those pieces is silcrete. The FOBSS 6-14 assemblage –

1555   immediately underlying the putative Still Bay – contains some blades, but cores dedicated to

1556   blade or point production were not reported. In FOBSS 6-8 bipolar cores were reasonably

1557   common (n=4, 16.7%), as was retouch (4.8%) with scaled pieces (n=7) and denticulates

1558   (n=6) the most frequent types. In the underlying FOBSS 9-14 a few notches (n=2) and

1559   denticulates (n=1), along with one bipolar core (16.7%).

1560

1561   The shallow deposit at Hollow Rock Shelter has been excavated twice but the MSA

1562   component underlying the Still Bay has not been described in detail. In fact, it is unclear

1563   whether or not there is a pre-Still Bay component to the site, though an OSL age of 87 ±6

1564   was obtained from a sample 200 mm below surface. Consequently the site is not included in

1565   the summary Table S24, but some observations are made here. Bifacial points are rare in

1566   the two deepest layers—IIIA and IIIB—reported by (198), as is silcrete (194, 199). Silcrete

1567   samples from the potential pre-Still Bay layers were too small for meaningful analysis by

1568   (199), though 45% of silcrete cores in the Still Bay were made on heat fractured blanks,

1569   intimating persistence/recurrence of that technological behaviour in MIS 4.

1570

1571   Klipfonteinrand was excavated by Parkington in 1969 and Mackay between 2011-2012. The

1572   MSA component of the site has Howiesons Poort and underlying MSA. Volman (171)

1573   analysed Parkington's MSA sample, though found that excavation had cross-cut depositional

1574   layers, resulting in a mixed assemblage of which Volman made a relatively cursory

1575   assessment. Nevertheless, he assigned the pre-Howiesons Poort MSA to MSA 2b in his

1576   scheme, equivalent to Mossel Bay above, with high proportions of quartzite, high rates of

1577   retouch, and few denticulates.

1578

1579 Mackay's (unpublished, manuscript in preparation) re-excavation differentiated four MSA

1580 strata—LGSS, BS, GGLBS & PBSS—the upper two of which were Howiesons Poort and the

1581 lower two unassigned to any technocomplex. Silcrete peaks at 23% in the Howiesons Poort,

1582 a value comparable to peak values at Putslaagte 8 (21.5%), which is only 15 km north, and

1583 the Still Bay at Hollow Rock Shelter (18.8) 5 km to the west. The earlier, pre-Howiesons

1584 Poort MSA layers include 5422 analysed artefacts. Silcrete varies between 7.0% (GGLBS)

1585 and 1.2% (PBSS), though it accounts for only 1.4% of artefacts overall, and only 1 of 98

1586 cores. Quartzite and sandstone are the main raw materials, comprising 77.8% of all artefacts

1587 in GGLBS and 94.2% in PBSS. These raw materials also account for 84.6% (GGLBS) and

1588 91.8% (PBSS) of cores in those two layers. Only 0.6% of artefacts were classified as heat

1589 shatter – no other analysis of heat treatment has been completed. Blades and convergent

1590 flakes respectively comprise 4.7% and 8.4% of artefacts in GGLBS, and 3.5% and 8.1% of

1591 complete flakes in PBSS. Several of the blades in PBSS are notably large, ranging from 80-

1592 120 mm. Retouched pieces comprise 6.0% of all artefacts across both units, with

1593 denticulates (n=74) and notched flakes (n=31) as the most common implements, though as

1594 noted in (200) it is not clear that these two types are meaningfully different.

1595

1596 Mertenhof is located a further 10.7 km south of Klipfonteinrand, and was excavated by

1597 Mackay between 2013-2015. Few results have yet been published so far, and the site

1598 remains undated, though the sequence contains Late MSA, post-Howiesons Poort,

1599 Howiesons Poort, Still Bay, and pre-Still Bay units (201, 202). Published data are so far

1600 limited, and thus we provide summary results from O'Driscoll's ongoing PhD analysis of

1601 1401 pre-Still Bay artefacts. The pre-Still Bay component of the sequence (originally DBS) is

1602 subdivided into four units, from youngest to oldest: SL, LAS, GLB, and LMS. Silcrete peaks

1603 at 32.2% of artefacts in the Howiesons Poort (202); among the pre-Still Bay units the highest

1604 value is 4.7% in SL, and the overall proportion is 1.1%. The major raw materials are

1605 quartzite (65.4%), hornfels (16.3%), and sandstone (10.1%). There are only 29 cores in the

1606 assemblage, most of which are quartzite (51.7%) and none of which are silcrete. Though

1607 rare overall (5.8%), quartz accounts for 24.6% of cores; bipolar working (24.1%) is

1608 correspondingly common. Heat shatter comprises 1.2% of the analysed assemblage overall,

1609 though no heat shattered pieces of silcrete were recorded. Convergent (point-like) flakes are

1610 common, as are blades, the latter including pieces comparably large to those at

1611 Klipfonteinrand. Both blades and convergent flakes are most common in unit LAS. Retouch

1612 is common ranging from 7.3% to 14.0%, with notches and denticulates the most frequent

1613 types.

1614

1615 Elands Bay Cave was initially excavated by Parkington in 1970 (203), and again by Porraz in

1616 2011 (197). The sequence is dominated by Later Stone Age occupation, though there are

1617 Late MSA and 'Early MSA' components. The Late MSA has ages of 35 ±3 ka and 38 ±3 ka,

1618 and the Early MSA has ages of 83 ±14 ka and 236 ±26 ka (204). Porraz and colleagues

1619 conclude that the Early MSA assemblage formed in MIS 6 (197). The published Early MSA

1620 sample comprises 1518 artefacts, dominated by quartzite (98.7%) (160). Silcrete contributes

1621 only 3 pieces (0.2%) to the Early MSA total, but in subsequent phases of the LSA rises to

1622 almost 50% (197). No markers of heat treatment were identified in the Early MSA sample.

1623 Core reduction is organised around the morphology of locally available quartzite blocks, and

1624 directed primarily towards the production of flakes. Core blanks comprise slabs (67.2%),

1625 flakes (13.8%), and indeterminate forms (19.0%). The most common reduction systems are

1626 described as planar—where removals are directed across the broad face of the core—and

1627 orthogonal—where removals are directed down the shortest face of the core. Bipolar

1628 working is a common component of the orthogonal reduction system though no specific data

1629 are available. Pseudo-Levallois points (8.2%) are modestly common and blades (2.3%) are

1630 rare, though 5.2% of cores were organised around blade production. Retouched pieces

1631 comprise 7.3% of the assemblage, with notches and denticulates the most common

1632 implement types.

1633

1634 Diepkloof contains a long MSA sequence, including post-Howiesons Poort, Howiesons

1635 Poort, Still Bay, and two 'pre-Still Bay' units denoted MSA-Lynn and MSA-Mike (147, 205).

1636 MSA-Lynn has ages of 100 ±10 ka from Tribolo and colleagues (12), and bracketing ages of

1637 76.5 ±3.3 ka and 88.4 ±4.0 ka from Jacobs and Roberts (57). MSA-Mike has ages of 118-90

1638 ka (12), and 88.2 ±4.4 ka to 93.3 ±4.4 ka (154) from the same research groups.

1639

1640 The lithic assemblages from MSA-Lynn comprises 922 pieces >20 mm and has been

1641 extensively described by Porraz and colleagues (205). Quartzite (60.1%) and quartz (12.8%)

1642 are the dominant raw materials, though silcrete comprises a further 24.7%. This is elevated

1643 relative to other pre-Still Bay assemblages in the region, though lower than the peak value of

1644 65-66% during the Howiesons Poort at the site (147). Silcrete is over-represented in cores,

1645 accounting for 47.6% of the total (10 of 21). Heat treatment of silcrete is common (73-91%),

1646 though only 7.4% of pieces show HINC fractures. No specific data on proportions of heat

1647 shatter are presented, though Porraz et al ((205): p13) note "A few thermal fragments were

1648 recorded in the assemblage but whether heat shattering occurred as an accident during heat

1649 treatment or through post-depositional processes remains unclear in these cases". Mackay

1650 (206) analysed a column sequence from Diepkloof for his PhD, which included a small

1651 sample of layer Lynn (n=132) with silcrete proportions (28.0%) similar to those reported by

1652 Porraz (205). This sample included no heat shattered pieces.

1653

1654 Porraz et al (205) describe seven different lithic reduction sequences for MSA-Lynn. The first

1655 four relate to the production of flakes of different morphologies, though not all are

1656 represented by cores found at the site. The fifth sequence is directed towards the production

1657 of bladelets from silcrete cores, the bladelets having a mean bladelet length of 24.7 ±7 mm.

1658 Bladelet production involves preparation through overhang removal and production of

1659 crested blades, with 40% of silcrete cores dedicated to bladelet production. Despite

1660 extensive analysis of heat treatment markers, there is no discussion of the use of heat

1661 shatter in this or any other reduction sequence in MSA-Lynn. The final two reduction

1662 sequences correspond to bipolar working, which account for 52.4% of cores, and the

1663 production of bifacial pieces (5.6% of assemblage total, including 13 bifacial pieces and 39

1664 shaping flakes). Porraz and colleagues discount the possibility that these artefacts are

1665 intrusive from the overlying Still Bay, but rather consider them a precursor to the

1666 technological systems that follow. In contrast to other nearby pre-Still Bay assemblages,

1667 unifacial points (n=19) and bifacial points (n=13) are the most common implement types in

1668 the assemblage; denticulates (n=6) and notches (n=2) are relatively rare. Retouch accounts

1669 for 7.8% of artefacts in MSA-Lynn overall.

1670

1671 MSA-Mike has much higher proportions of quartzite (86.3%) and correspondingly lower

1672 proportions of silcrete (3.9%) than MSA-Lynn. The role of heat in this assemblage has not

1673 been described, and no data are available on the proportion of heat shatter in (147, 205).

1674 Mackay's PhD sample from layer Mike is small (n=46) but includes no heat shattered pieces.

1675 Including all layers from MSA-Lynn to the base of the Diepkloof sequence Mackay recorded

1676 only 6 heat shattered pieces, comprising 0.4% of all analysed artefacts with a range from 0%

1677 to 0.6% (n=2321).

1678

1679 In the larger dataset used by Porraz et al (205), points constitute ~17% of all flakes, with

1680 production via two different system. One system complies with the definition of Levallois

1681 reduction, while the other involved exploiting angular core edges to produce elongate points

1682 with a triangular cross-section. Blades comprise ~13% of the flake total, and were largely

1683 produced via a unidirectional production system. Retouch rates in MSA-Mike are relatively

1684 low (2.9%), with denticulates and notches combined accounting for 32% of retouched

1685 pieces.

1686

1687   *Summary*. Information about lithic assemblages is presented inconsistently between MSA

1688   sites, making any broad review difficult. In this case we attempted to use a combination of

1689   specific and general data to assess which other MSA assemblages most resemble those

1690   from the Lower Deposits at VR003. It seems reasonably clear that there is no ready fit with

1691   any of southern Africa's major technocomplexes as currently defined. Silcrete is common at

1692   some sites during MIS 5—most notably along the southern Cape coast—but we could not

1693   find evidence for the systematic use of heat treatment to create core blanks among those

1694   sites. A focus on small flake and blade production was rare, with the exceptions of

1695   Ysterfontein and the MSA-Lynn at Diepkloof, both of which also had high proportions of

1696   silcrete within the assemblage generally and within cores specifically. Ysterfontein has been

1697   consistently dated to ~120 ka, however, making it around 30 000 years older than the Lower

1698   Deposits at VR003. There is also no published evidence for heat treatment at that site. We

1699   return to the case of MSA-Lynn momentarily.

1700

1701   Perhaps the major pattern to emerge from our review of the technocomplexes is that MIS 5

1702   was technologically diverse both within regions, but perhaps more appreciably between

1703   regions (156). Local raw material procurement is a consistent characteristic across all sites

1704   in all technocomplexes, but implement types in the Fynbos Biome sites are different to those

1705   in the modern Savanna and Grassland Biomes, and flaking systems are highly variable both

1706   within and between regions. To the extent that taxa like Klasies River or Mossel Bay are as

1707   coherent as they have been argued to be, it is doubtful that they can be applied beyond the

1708   Fynbos Biome sites for which they were originally defined. And that may be the primary

1709   conclusion to reach from this section of our review: lithic assemblages may be different in

1710   different regions, so given we know essentially nothing about the MSA of what is today

1711   Succulent Karoo, is it any surprise that the assemblages there are different again?

1712

1713   The closest analogue to the Lower Deposit assemblage was found in the MSA-Lynn at

1714   Diepkloof. None of the other sites within 100 km of VR003 resembled these assemblages,

1715   despite much of the data being collected by the same analysts using the same or similar

1716   protocols. The MSA-Lynn has high proportions of silcrete both generally and among cores

1717   specifically, high rates of heat treatment, and the dedicated production of small blades from

1718   silcrete cores. In the Jacobs and Roberts chronology, the age interval for MSA-Lynn also

1719   overlaps that for the Lower Deposits. There are important differences between these

1720   assemblages, however. Primarily, despite detailed data being available, there is no evidence

1721   that heat shatter was abundant or habitually used to create core blanks in this part of the

1722   Diepkloof sequence. Given the analysis conducted by P. Schmidt (205), and the

1723   supplementary data available from (206), it seem likely that this absence of evidence is

1724   evidence of absence. A second difference concerns the nature of these sequences

1725   themselves. At VR003, silcrete peaks in the Lower Deposits before falling away again

1726   through I-07 to I-05, increasing subsequently in the Still Bay and Howiesons Poort (I-04). At

1727   Diepkloof, the increase in silcrete in MSA-Lynn is sustained thereafter through to the post-

1728   Howiesons Poort (147). Supporting this, the unifacial and bifacial pieces that appear in MSA-

1729   Lynn also persist into subsequent layers. It is for these reasons that Porraz and colleagues

1730   (205) view MSA-Lynn as an immediate precursor to the Still Bay. That cannot be the case at

1731   VR003 Lower Deposits, which lacks unifacial and bifacial points, and sits at least half a

1732   meter below the Still Bay. Thus, even one set of ages allow for overlap between the Lower

1733   Deposits and MSA-Lynn, they are technologically and sequentially distinct.

Site	VR003	PL8		KFR		MRS				EBC[a]	DRS[b]	
Layer	Lower Deposits	FOBSS 6-8	FOBSS 9-14	GGLBS	PBSS	SL	LAS	GLB	LMS	Early MSA	Lynn	Mike
Date	92-79 ka	-	-	-	-	-	-	-	-	83-236 ka	~100 ka or ~88-77 ka	118-90 ka or ~93-88 ka
% silcrete	41.6	1.4	1.2	7.0	1.2	4.7	0.6	0.6	2.7	0.2	24.7	3.9
% silcrete as ratio to site max.[c]	1.0	0.06	0.05	0.30	0.05	0.15	0.02	0.02	0.08	0.004	0.37	0.06
% silcrete heated	39-76	-	-	-	-	-	-	-	-	0	73-91	-
% heat shatter[d]	11.8	3.6	1.4	1.4	0.4	2.3	0.6	1.8	3.4	0	0-0.6	
% points	4.7	-	-	8.4	8.1	4.7	7.2	1.2	3.7	8.2	5.2	17.2
% blades	6.6	-	-	4.7	3.5	2.3	5.3	2.9	2.0	2.3	14.6	14.1
% retouch	3.5	4.8	1.4	7.1	5.8	14.0	7.3	12.4	8.8	7.3	7.8	2.9
Most common implements	notched, dentic.	scaled piece, dentic.	notched, dentic.	dentic., notched	dentic., notched	dentic.	notched, dentic.	dentic., notched	dentic., notched	notched, dentic.	Unifacial points, bifacial points	dentic., notched
% silcrete cores	61.5	0	0	0	1.2	0	0	0	0	0	47.6	0
% bipolar cores	2.2	16.7	16.7	0	1.1	0	27.3	33	21.4	-	52.4	-
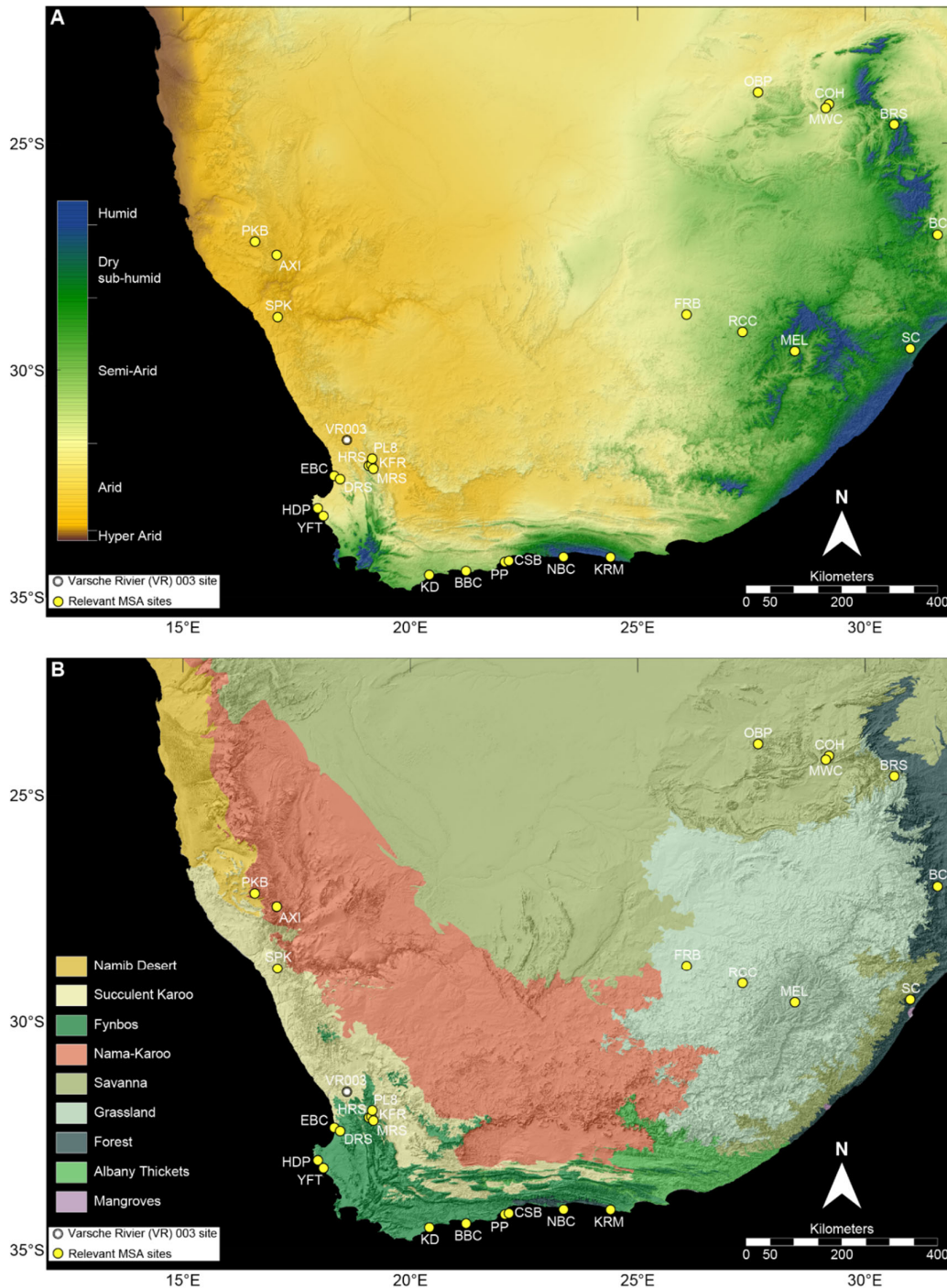
1746

Figure S25. (A) Aridity map of southern Africa, with the Varsche Rivier 003 (VR003; white dot) and relevant MSA sites referred to in the preceding review (yellow dots) indicated as follows: AXI=Apollo11, BBC=Blombos Cave, BC=Border Cave, BRS=Bushman Rock Shelter, CSB=Cape St. Blaize, COH=Cave of Hearths, DRS=Diepkloof, EBC=Elands Bay Cave, FRB=Florisbad, HDP=Hoedjiespunt, HRS=Hollow Rock Shelter, KD=Klipdrift, KFR=Klipfonteinrand 1, KRM=Klasies River Main site, MEL=Melikane, MRS=Mertenhof, MWC=Mwulu's Cave, NBC=Nelson Bay Cave, OBP=Olieboompoort, PP=Pinnacle Point site complex, PL8=Putslaagte 8, RCC=Rose Cottage Cave, SC=Sibuu Cave, VR003=Varsche Rivier 003, YFT=Ysterfontein. Aridity index data from (209) with definitions according to (210). **(B)** Modern biome-bioregion map of southern Africa with VR003 and other sites shown as in Pane (A). Biome-bioregion boundaries defined following (211, 212).

1757

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