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

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## Abstract

Africa’s Middle Stone Age preserves sporadic evidence for novel behaviours among early modern humans, prompting a range of questions about the influence of social and environmental factors on patterns of human behavioural evolution. Here we document a suite of novel adaptations dating approximately 92-80 000 years before present at the archaeological site Varsche Rivier 003 (VR003), located in southern Africa's arid Succulent Karoo Biome. Distinctive innovations include the production of ostrich eggshell artefacts, long-distance transportation of marine molluscs, and systematic use of heat shatter in stone tool production, none of which occur in coeval assemblages at sites in more humid, well-studied regions immediately to the south. The appearance of these novelties at VR003 corresponds with a period of reduced regional wind strength and enhanced summer rainfall, and all of them disappear with increasing winter rainfall dominance after 80 000 years before present, following which a pattern of technological similarity emerges at sites throughout the broader region. The results indicate complex and environmentally-contingent processes of innovation and cultural transmission in southern Africa during the Middle Stone Age.

## Introduction

Archaeological evidence from the African Middle Stone Age (MSA, 400-40 ka) defines our understanding of human behavioural evolution in the critical window between the emergence of our species and our subsequent global spread. Yet evidence for cultural innovation—the appearance of novel items such as distinctive stone tools, engravings, ornaments, and implements made from organic materials—occurs unevenly through the MSA in both space and time. In southern Africa, evidence for innovation appears to concentrate in two successive cultural units referred to as the Still Bay and Howiesons Poort, dating approximately 77-59 ka (1, 2). In the preceding periods of the MSA ('pre-Still Bay'), instances of cultural innovation tend to be temporally and geographically isolated (3). In the subsequent MSA ('post-Howiesons Poort'), several innovations appear to be lost, including a tradition of producing engraved ostrich eggshell (OES) water flasks that previously extended across 600 km of diverse habitats from the southern Cape coast to the deserts of southern Namibia (4, 5).

Explaining the complicated and apparently non-directional pattern of MSA cultural change is key to understanding controls on human behavioural evolution. Prominent explanations have included fluctuations in effective population size (6), the advent of territorial defense associated with exploitation of dense and predictable resources (7), and climatically driven phasing of cultural connectedness across the subcontinent (8). A significant biogeographic skew in the available archaeological dataset, however, makes these explanations difficult to test. Southern Africa is an ecologically diverse region with complex climate dynamics, yet evidence for MSA cultural innovation derives disproportionately from the relatively humid southern Cape coastal fringe (Figure 1). The archaeology of the arid regions of the west coast and interior remains notably understudied (9, 10). This skew may act to exaggerate both the appearance of cultural homogeneity and the periodicity of innovation by excluding ecosystems that required different behavioural adaptations to enable occupation at different times. It also complicates our understanding of cultural transmission dynamics—of when and under what conditions behaviours were transferred across biogeographic boundaries—and thus of the interplay between population connectivity and the development and persistence of innovations.

Here we present new data from excavations at the site of Varsche Rivier 003 (VR003), located 44 km from the Atlantic coast in the Knersvlakte bioregion, southern Namaqualand (Figure 1). Falling within the modern Succulent Karoo Biome, the Knersvlakte currently receives ~175±30 mm of rainfall per year (11, 12), almost all during the austral winter, and is characterised by a limited groundcover of xeric-adapted succulent shrubs and endemic 'stone plants' (13). While the MSA archaeology of the Succulent Karoo is largely unstudied, VR003 lies close to the modern limits of the Fynbos Biome. Characterised by evergreen shrubs and reeds, and closely related to winter rainfall regimes (14), the Fynbos Biome's current distribution encompasses many of southern Africa's most prominent MSA sites (15). Edaphic controls mean the Succulent Karoo / Fynbos Biome boundary is unlikely to have shifted substantially through the late Pleistocene (13, 16), though intensified winter rainfall may have supported periodic northward range expansion of some fynbos taxa (17).

Still Bay and Howiesons Poort assemblages occur in the upper strata at VR003 (18). Initial luminescence ages suggested that these occurrences were anomalously young; we redate the Howiesons Poort here to between 71.6-55.7 ka (SI Geochronology**,** Table S6), consistent with the majority of ages elsewhere, and supporting cultural linkages between VR003 and sites in the Fynbos during Marine Isotope Stage (MIS) 4. The character and cultural transmission dynamics of the MSA prior to the Still Bay in this region are, however, comparatively unknown. We thus focus on results from the deepest excavated layers at VR003, and their relationship to coeval MSA deposits elsewhere, to explore 1) evidence for innovative behaviours in this typically arid region, 2) the strength of cultural connectedness with sites to the south, and 3) relationships between innovation, cultural connectedness and environmental change.

**Results**

<u>Site formation and chronology</u>: VR003 is a north-facing rock shelter site in Neoproterozoic limestone of the Widouw Formation and located in the gorge wall of the Varsche River (Figure 1). Five excavation seasons since 2009 have focussed mainly on the upper slope deposits in front of the rock shelter (Main Area) and the accessible areas of the shelter itself (Shelter), linked by a narrow trench (Link Trench; Figure S1). The deep sounding in the Main Area excavation has attained a depth of 1.9 m below surface without encountering bedrock. No subsurface Later Stone Age (LSA) material is preserved in the Main Area, and the entire deposit so far excavated can be assigned to the MSA. Still Bay and Howiesons Poort horizons occur in stratum I-04 near the top of the sequence (Figure S1) (18), underlain by extensive MSA (strata I-05 to I-09). Having previously described the material through to I-07 (18), we concentrate here on the deepest excavated pre-Still Bay deposits in the Main Area, comprising two archaeological horizons **–** I-08 and I-09 **–** referred to for the purposes of this paper as the Lower Deposits.

The sedimentary sequence in the Main Area is composed of slope deposits with fine grained colluvium and coarser grained debris flow (Figure 2; for more detail see SI Geoarchaeology, Figures S2-5). Deposition of non-archaeological clasts on the slope by debris flow and colluvial processes is indicated by a lack of sorting or orientation and the fine coating of some coarse grained materials, though the low incidence of soil aggregates (Figure 2, inset B) and the lack of rounded rocks from the plateau above the shelter suggests overall limited transport distances. The regular occurrence of microscopic lithic knapping debris, and the high incidence and broad size distribution of microscopic bones (Figure 2, inset A, B) are typical for occupation layers suggesting their initial deposition on the slope. The presence of gypsum in the deposits indicates an arid environment with high evaporation rates. Fabric analysis of elongated bone and stone objects (n=353) reveals a predominantly planar distribution, suggesting that archaeological materials in the Lower Deposits were discarded on the slope (Figure S6). Object dip does not deviate from the surface slope or the overlying strata, and orientation does not differ significantly from a uniform distribution (Rayleigh test, $p = 0.0008$). Similarly, the dip of the 12 identified lithic refit sets, mainly comprising sequential flake removals (n=9), generally follows the deposit slope (Figure S7).

The Lower Deposits have been dated using single-grain luminescence (pIRIR) on feldspar, and by U-series dating on ostrich eggshell (OES) fragments (Figure 2). Potassium feldspar extracted from four sediment samples distributed from near the top of I-08 to the base of I-09 yielded stratigraphically consistent ages ranging from 80.8±4.6 ka (1σ, ±9.2 ka 2σ) to 89.9±5.0 ka (1σ, ±10.1 ka 2σ) (Table S7). U-series dating on three fragments of OES from lower I-08 and upper I-09 used a novel approach termed $^{230}$Th/U burial dating (19). As OES fragments were not typically piece-plotted during excavations we used two samples from bucket aggregates that also yielded OES artefacts (VR003-9300, VR003-6612) (see below), and one well-preserved piece-plotted fragment (VR003-9085) (Figures S11-S15). OES fragment VR003-9300 yields a $^{230}$Th/U burial age of 88.3 ±3.2 ka (2σ error). OES fragment VR003-9085 yields concordant sub-sample ages consistent with rapid U uptake, defining a mean age of 90.7 ±0.7 ka in good agreement with the age determined for VR003-9300. VR003-6612 also yields concordant sub-sample ages, however, their mean age of 74.5 ±1.4 ka is significantly younger than ages obtained for the two other OES, though it is within error of the luminescence ages at 2σ. This may imply mixing either in the bucket aggregate from which the sample derived or via disturbance processes such as bioturbation (SI Geoarchaeology). A probability density function provides a combined age range for the Lower Deposits of 92-80 ka at 1σ (SI Geochronology).

<u>Archaeology</u>: Phytoliths were analysed from nine samples distributed across stratigraphic units from I-09 to I-03 (SI Phytolith analysis, Tables S9 & S10, Figure S17). Abundance varies between samples, with highest concentrations in the Lower Deposits corresponding

with high proportions of Poaceae (grasses) relative to Restionaceae and non-graminoid (woody and shrubby) vegetation compared to overlying strata (Table S10). The ratio of $C_4$ (warm growing season) to $C_3$ (cool growing season) to grass phytoliths is low (<20.8), consistent with the region's winter rainfall regime. However, higher proportions of warm growing season $C_4$ grasses in the Lower Deposits (18.7±3.4) compared with the overlying strata (6.7±2.3) suggest a decrease in summer rain after ~80 ka. The decline in $C_4$ grasses—and grasses in general—is concurrent with a two-fold increase in Restionaceae and woody phytolith percentages. Combined these results are consistent with the marked increase in wind strength and upwelling along the west coast that began in MIS 5a (Figure 3) and the weakening of tropical systems in the southern continental interior under decreasing orbital eccentricity (20). These factors would have limited the incursion of summer rainfall systems in the region, resulting in increased rainfall seasonality (21). As Restionaceae is strongly linked to winter rainfall in the Cape, this may be further evidence for an overall shift toward a more dominant winter rainfall regime (see SI Phytoliths).

The preserved vertebrate sample of the Lower Deposits is small (NISP=524; SI Vertebrates, Table S11, which includes scientific names for the taxa mentioned below) and dominated by tortoises (n=352), most of which are angulate tortoises that feed on grasses, annual herbs, and succulents in sandy, coastal habitats and succulent scrublands (22). Bovids of all sizes are present, although only eland and grysbok/steenbok could be identified to taxon. Eland can tolerate a wide variety of habitats, including those with limited surface water, by consuming browse and grass (23). Steenbok are browsers that are adapted to open areas with some tall grass, bushes or scrub for shelter; grysbok may have extended this far north, but generally prefer denser cover (23, 24). Cape zebra was a grazer that would have consumed grasses in open areas (25). Consistent with the phytoliths, the faunal communities imply a relatively open, arid to semi-arid environment, offering graze and browse in diverse habitats. These taxa are also found higher in the sequence, along with springbok, wildebeest/hartebeest, and blue antelope, indicating that grasses persisted in the region; small sample sizes limit detailed comparisons.

In addition to mammals and reptiles, the Lower Deposits preserve 26 shellfish fragments. Limpets account for 77% of these, with granite limpets the dominant taxon, along with two black mussel fragments (SI Molluscs; Table S12, which includes scientific names). Other than a few isolated overlying examples, the majority of all marine shells at VR003 cluster in a band in the Lower Deposits (Figure 2). Given the luminescence and U-series results, relative sea level during the formation of the Lower Deposits would have been 25-40 m below present (26), though due to off-shore topography this would not have substantially increased VR003's distance to shore (27). The molluscs were thus likely obtained at least 45-50 km from site. While limpets and mussels appear as an important food resource in other South African coastal MSA assemblages (28), they are rarely transported as food packages beyond 10 km (29), raising questions about whether the VR003 individuals were transported as food or as empty shells. The shells from the Lower Deposits are fragmented, but no ochre residues nor anthropogenic modifications were observed on them.

OES is abundant at VR003, consisting mainly of unworked fragments, most of which appear to have been heated (SI Ostrich eggshell, Table S9). Surface preservation is typically poor, and engraved OES is limited to one piece with parallel striations from a Howiesons Poort context in the Link Trench (Figure S1). From approximately halfway through the Lower Deposits, however, we recovered 21 flaked OES fragments (Figures 2 & 4; SI Ostrich eggshell, Table S14). All pieces show flaking in the form of precise percussive initiations that were truncated when the piece broke. Typically three or more initiations were used to form an arc consistent with a circular aperture of approximately 23.6 mm (±6.1 mm) that likely reflect circular perforations initially made on whole OES (Table S14). Such perforations are consistent in size, if not form, with laterally perforated ostrich eggshell flasks from the Holocene (30). Pieces with only one or two initiations may reflect the early stages of this perforation process (SI Ostrich eggshell).

Main Area excavations have produced 27 772 flaked stone artefacts; 3062 of these were recovered from the Lower Deposits (SI Lithics) in addition to a small sample of pigments (SI Pigments). Distinctive artefact markers for the Still Bay and Howiesons Poort are limited to the upper strata, mainly I-04 (Figure S1). Quartz accounts for 60.0% of all artefacts from I-07 to I-03 (range: 54.2-65.4%), and silcrete for 10.9% (range: 7.2-16.1%) (18). In the Lower Deposits the proportion of quartz (29.8%) halves while silcrete (41.6%) becomes the dominant raw material for the only time in the sequence (Table S16). This change is most evident in the distribution of silcrete cores (Figure 2) which account for 61.5% of cores in the Lower Deposits.

These silcrete cores are small (max dimension mean=43.7±10.2 mm), typologically diverse (Table S22), and exclusively produced small flakes and blades (scar length mean=17.4±6.9 mm). Cores with prepared platforms and no obvious management of the flaking surface are the most common identifiable type, though opportunistic and minimally worked cores account for about a quarter of the total. The average number of flake scars on silcrete cores is 3.1, suggesting generally short reduction chains. Blade removals are not numerous but are concentrated on some cores (Figure 5, Figure S24), and with an average scar length of 15.2 mm could be classified as bladelets. Blade production, however, generally seems to have been opportunistic (SI Lithics, Tables S17 & S18).

Heat shatter is unusuually common in the Lower Deposits at VR003 (SI Lithics, Table S24, Figure S22), accounting for 24.2% of all silcrete artefacts (Tables S16); 62.3% of silcrete cores were made on such heat shattered fragments. Among those cores the mean scar count is only 2.3. Thus, the majority of silcrete cores in the Lower Deposits result from heat shattering of unworked pieces that were retrieved and used to produce a limited number of small flaking products prior to discard (Figure 5). Given the short reduction chains it is less likely that heat was used to improve the flaking characteristics of the rock than as an expedient means of creating small, angular core blanks.

## Discussion

Geoarchaeological work combined with refit analysis suggests that strata I-08 and I-09 at VR003 are intact slope deposits, and two different geochronometric techniques produce largely concordant ages suggesting accumulation within the interval ~92-80 ka. Phytolith assemblages in these Lower Deposits indicate higher proportions of summer rain and limited fynbos taxa, giving way to an increasingly dominant winter rainfall regime across the MIS 5/4 transition. Corresponding with these environmental changes, the archaeological assemblages in the Lower Deposits are distinctive both from those overlying them, but also from documented MSA assemblages elsewhere in southern Africa.

Though it is not possible to confirm that the flaked OES pieces are fragments of flasks, no comparable flaked OES artefacts have been reported from other MSA assemblages with large samples of OES (e.g., (9, 31, 32)). Potential OES flasks occur in the Howiesons Poort at Apollo 11 (33) and Diepkloof (4), but have not been reported from pre-Howiesons Poort contexts. The flask apertures at Diepkloof are also ground rather than flaked, consistent with LSA flasks. Thus, if the flaked OES from VR003 were flasks they were produced differently to other flasks from either MSA or LSA, and if they were not flasks then they reflect some other novel behaviour. In either case, use of OES as a raw material for artefact manufacture appears to be quite deep-rooted in the MSA.

Evidence for exploitation of edible shellfish species (e.g. limpets and mussels) occurs along the southern Cape coast as early as 164 ka (34); however transport of such species over >45 km is rare during the MSA and suggests movement of people between coastal and interior southern Namaqualand during MIS 5b. Long-distance transportation of a small sample of shellfish during the MSA has been noted from Apollo 11 and Pockenbank, which are ~140 km and ~120 km from the modern coast respectively (35, 36); they are both located in southern Namibia, suggesting that this behaviour may have been widespread through arid regions of southern Africa. Elsewhere limited transport of marine shell over ~15 km is found in the MSA at Diepkloof (31) and at Sibudu Cave (37).

The major component of the Lower Deposits lithic technology is characterised by focussed procurement of silcrete, use of heat shatter to create core blanks, and short core-reduction chains producing small flakes and blades. Comparable technological systems have not been described in the MSA elsewhere (for reviews see 1, 38, 39, and SI Lithics), including at the six Fynbos Biome sites that lie within 100 km of VR003 (Figure 1; SI Lithics, Table S24). Assemblages at those nearby sites are generally dominated by locally available quartzite or hornfels with systematic use of silcrete only after 75 ka (40-45). The exception is in MSA-Lynn at Diepkloof, which exhibits an increase in heat-treated silcrete and dedicated bladelet production leading in to the Still Bay (3). Heat shatter is rare in that assemblage, however, and none of the documented reduction processes feature the systematic use of core blanks made from heat shatter. The presence of bifacial and unifacial points in MSA-Lynn also suggests continuity with the overlying Still Bay, something that did not occur at VR003.

Results from VR003 suggest that the southern Succulent Karoo fostered a different set of adaptations to those characteristic of more humid areas to the south, including the manufacture of OES artefacts (possibly flasks), long distance transportation of marine shell, and the primary use of heat treatment to create core blanks for production of small flakes and blades. This package corresponds to a specific set of environmental conditions, and terminates around 80 ka with an apparent strengthening of regional winter rainfall systems. Though it lacks *fossile directeur* implements, the archaeological signature of the Lower Deposits is as distinctive in the VR003 MSA sequence as the Howiesons Poort or Still Bay. The difference between these phases is not in their innovativeness *per se*, but in their differing geographic extent. While the Howiesons Poort and Still Bay extend across much of southern Africa, the Lower Deposit package at VR003 appears to be a localised and environmentally-contingent adaptation.

These observations carry four significant implications for models of human behavioural evolution. First, they support arguments that the productive environments of the southern Cape coastal plains were not the sole locus of human innovation in southern Africa (9). Indeed, conversely, marginal environments likely required novel or at least distinct technological solutions to enable persistent survivorship (46). Second, and following from the first, research emphasis on biogeographically limited regions of southern Africa has probably acted to exaggerate the extent of cultural similarities through the MSA (SI Lithics).

Third, cultural connectedness in southern Africa, if measurable by similarity in stone tool assemblages, was variable through the late Pleistocene. While VR003 is culturally in phase with sites across the Fynbos Biome at least after 71 ka, it was not between 92-80 ka. Fourth, arguments that widespread cultural interaction was a primary driver of innovation in southern Africa (e.g., (8)) are not supported. It is possible that strong cultural connections pertained across the arid and interior regions of the sub-continent during MIS 5, however available data are insufficient to substantiate this proposition. In any case, Still Bay and Howiesons Poort assemblages occur across these regions as well as more humid parts of southern Africa (2). More interesting is the apparent loss of innovations (production of OES artefacts, systematic use of heat shatter to create core blanks) at VR003 after 80 ka, preceding the spread of the Still Bay. In some cases at least, innovation was responsive to environmental conditions and neither driven by interaction nor inherently cumulative (47).

Though the suite of adaptations identified at VR003 is currently unique, the pattern of transient innovations is consistent with the broader evidence from the African MSA. This can be read in one of two ways. It could imply a pre-modern condition in which the capacity for innovation was latent but cultural behaviour itself was yet to become a major selective force (48). Subsequent developments may reflect stabilisation of high-fidelity information transmission in the human niche (49, 50), potentially supported by transformations in language efficacy (51). Alternatively, it may partly reflect the out-sized role played by durable materials in models of human behavioural evolution. Flask fragments are rare even in large LSA OES assemblages, and their identifying characteristics are—in contrast to the possible VR003 examples—quite subtle; ground surfaces representing fragments of apertures <15 mm (30). In the small, fragmented OES assemblages from pre-Still Bay MSA contexts (9) and/or where surface preservation is poor (as at VR003) such artefacts would easily be masked. Thus, even if the flaked OES from the Lower Deposits are the remains of flasks, their disappearance does not necessarily reflect the loss of that capability but potentially its shift into a form that is less robust and visually obvious. Similarly, while the long-distance transportation of durable items is evident in the MSA by 200 ka (52); evidence for long-distance transport of perishable items, as with the shellfish at VR003, first appears much later for reasons that we consider more probably taphonomic than behavioural. Such preservation problems currently confound all models of human behavioural evolution (49, 53, 54). Ultimately the archaeology of human behavioural evolution reflects the intersection of four factors: capability to innovate (55), motivation to innovate (46), stabilisation of innovations (56, 57), and preservation of innovations (58). The record from VR003 speaks to the first two, highlighting the importance of obtaining data from diverse ecological regions. Disentangling the last two remains a key challenge going forward.

## Methods

**Excavation.** Excavations at VR003 proceeded within stratigraphic units. Only selected items were individually piece plotted during excavations in 2009/2011, with most items recovered in 11 L buckets aggregates. In 2014, 2015, and 2016, during which seasons the Lower Deposits were excavated, all artefacts >20 mm and bones >25 mm were piece plotted. Elongate items were plotted with 2 points where possible to allow for fabric analysis. Modified OES was plotted regardless of size in these seasons. All bucket aggregates were sieved on site through nested 3 mm and 1.5 mm mesh sieves.

**Geoarchaeology**. Geoarchaeological analysis included grain size, loss on ignition, magnetic susceptibility, and micromorphology as well as fabric and refit analyses. Detailed results are presented in SI Geoarchaeology. Thin section analysis was conducted with a petrographic microscopic with magnification of up to 200x using oblique incidental (OIL), plane (PPL) and cross polarized (XPL) light. Micromorphological description follows terminology in (59, 60) and a detailed analysis is presented in SI Micromorphology. Fabric analysis was undertaken using the methods and code provided in (61).

**Single-grain luminescence dating**. Luminescence samples were obtained by hammering metal tubes into cleaned section faces. Samples were prepared under subdued red light at the Royal Holloway Luminescence Laboratory, yielding sand-sized quartz and potassium feldspar (K-feldspar) separates. All luminescence measurements were carried out using a Risø TL/OSL-DA-15 automated dating system, fitted with a dual-laser single-grain luminescence attachment. Quartz was measured using a standard single-aliquot regenerative-dose method whereas a post infrared, infrared stimulated luminescence procedure, intended to minimise the effect of “fading” (62) was used for K-feldspar. Individual grains were stimulated using either a focused 10 mW Nd:$YVO_4$ solid-state diode-pumped green (532 nm) laser for quartz 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-felspar. 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 Schott BG3 and BG39 filters. Irradiation was carried out using a 1.48 GBq $^{90}Sr/^{90}Y$ beta source calibrated relative to the National Physical

Laboratory, Teddington $^{60}Co$ γ-source (63). Data analysis was carried out using functions within the *numOSL* and *Luminescence* R packages. K-feldspar ages were corrected for a measured fading rate (g-value normalised to 2 days) of 1.9±0.1 %/decade (64).

**U-series dating of ostrich eggshell.** OES were analyzed in the Berkeley Geochronology Center's U-Daughter Lab. OES dating samples were screened using profiles of [U] and $^{232}Th/U$ obtained via laser ablation using a Photon Machines Analyte II excimer laser attached to a Thermo-Fisher NEPTUNE *Plus* inductively coupled mass spectrometer (ICP-MS). Selectively abraded subsamples of OES calcite from known positions in each OES fragment were analyzed in solution mode using the Thermo-Fisher NEPTUNE *Plus* ICP-MS. Laser ablation, solution analyses, data reduction, and calculation of $^{230}Th/U$ burial ages followed techniques similar to those described in (19). Activity ratios and ages were calculated using the half-lives from (65-67). Ages and uncertainties were calculated using (68).

**Phytolith analysis**. Nine sediment samples were processed for phytoliths, covering strata from I-09 to I-03. Phytoliths were extracted from approximately 5 g of bulk fine fraction sediment. Samples were sieved through 125 μm mesh; 2 g of each <125 μm subsample was treated for carbonate digestion using 10% HCl, followed by clay deflocculation aided by $NaPO_3$. 10% KOH solution was used for digestion of organic matter, before another round of deflocculation. Samples were neutralized, centrifuged and decanted between all steps. Phytoliths were extracted by heavy liquid flotation, using a solution of sodium polytungstate (2.3 g/cm$^3$). Assemblages were pipetted onto coverslips, dried, and mounted to microscope slides using Entellan medium for identification and counting. Phytolith abundance was counted up to 300, with concentration per gram of sediment later estimated using the proportion of sample analysed and initial 2 g weight.

**Faunal analysis**. All faunal (vertebrate, mollusc, and eggshell) remains were examined, including those that were individually plotted (>25 mm) as well as those recovered from the 3 mm screens. The screened materials were rinsed with water before sorting. Specimens were identified using comparative material housed in the Department of Archaeology at the University of Cape Town and the Department of Anthropology and the Museum of Wildlife and Fish Biology at the University of California, Davis, and published manuals. Specimens of any size that could be identified to element and taxon were recorded in the MNISQL database program written by Richard G. Klein (Stanford University). All identified specimens were examined for surface modifications and preservation. Molluscs and eggshells were counted, weighed, and examined for surface modifications. Discoloration consistent with heating was also noted (69).

**Lithic analysis**. Basic methods of stone artefacts classification and analysis are described in (18). Additional data were acquired as follows. Core scars counts applied a scaled minimum scar size cut-off at 20% of core maximum dimension, and also a fixed value (15 mm) presented separately in SI. Heat treatment was identified visually using methods described in (70). Silcrete is common and physically diverse around VR003 (71), complicating development of reference collections. For this reason we rely principally on visually-obvious heat-induced non-conchoidal fractures (HINC) (72) to identify the presence of thermal effects.

**Data availability statement**

All data used in the present study are available from the corresponding author on reasonable request.

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**Author contributions**

TES & AM directed excavations at VR003; dating by SJA (luminescence) and EMN & WDS (uranium-series); geoarchaeology by MCS (micromorphology), IM & RR (sedimentology), AFB (fabric analysis), and MAL (lithic refit); KB prepared and analysed the phytolith samples with environmental context provided by BMC; faunal analysis by TES & SL; TES & PJM analysed the ostrich eggshell, and CFK analysed the Iziko comparative sample; NM analysed the pigments; AM and CAO'D analysed the stone artefacts; AM, TES, SJA, EMN, WDS, MCS, AFB, KB, BMC, SL, NM, PJM, IM & JO wrote the manuscript.

**Competing Interests Statement**

The authors have no competing interests as defined by Nature Portfolio, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

**Data Availability Statement**

The spatial, lithic, faunal and pigment data used in this paper are included in a supplementary file. Phytolith data are provided in tables in the Supplementary Information. The VR003 collections are curated at University of Cape Town and Iziko Museums Cape Town, and can be accessed by arrangement with TES and AM.

**Figure captions**

**Figure 1**. **(A)** Aridity map of southern Africa, with the Varsche Rivier 003 (VR003; white dot) and relevant MSA sites referred to in the text (yellow dots) indicated. Aridity index data from (73) with definitions according to (74). Red box shows location of inset map (B). **(B)** VR003 in relation to modern biome-bioregion boundaries from (75) and Fynbos Biome sites immediately south: DRS=Diepkloof, EBC=Elands Bay Cave, HRS=Hollow Rock Shelter, KFR=Klipfonteinrand 1, MRS=Mertenhof, PL8=Putslaagte 8. **(C)** Site photo of VR003 and the Varsche Rivier 003 valley, looking west. **(D)** Excavation plan at conclusion of most recent season in 2016. The original deep sounding is highlighted in red.

**Figure 2**. East section of deep sounding with key artefact type and location of geochronology samples. Per convention, luminescence ages are presented here at 1 sigma uncertainty, U-Th ages at 2 sigma. For artefacts, aggregate contexts refers to silcrete cores recovered during the initial seasons (2009, 2011) during which individual artefacts were typically not plotted. These cores were recovered from bucket aggregates and include up to two cores in some cases. Inset bottom left: Microphotographs showing the typical components and structure of I-08. **(A)**. Bone (B) fragments range in size from gravel to sand. Another typical anthropogenic component at the site is ostrich eggshell (OES). Note also the coarse crystalline limestone (Li), and calcite crystals (C) and fine coating of these coarse grains. **(B)** Microscopic silcrete (Si) knapping debris and rounded soil aggregates (Agg) from the plateau above the site in a calcareous matrix.

**Figure 3**. Comparison of primary factors determining long-term regional climate dynamics with VR003 phytolith data for 1) $C_4$:$C_3$ grass ratios and 2) the percentage of Restionaceae

and woody taxa, a classification reflecting the abundance of fynbos vegetation (Cordova et al., 2013; Esteban et al., 2017). Data for orbital parameters is from Laskar et al. (2004) and the SE Atlantic wind strength composite is as calculated by Chase et al. (2019) using the data of Farmer et al. (2005), Little et al. (1997), Pichevin et al. (2005) and Stuut et al. (2002). The phytolith data are depicted as uncertainty spaces defined by the multiplication of probability density functions derived from 1) stratigraphic unit ages and errors for the Lower Deposits and Howiesons Poort layers and 2) aggregated phytolith data and the associated standard deviation of sample values from these units (see SI for more detail).

**Figure 4**. Flaked OES fragments from the Lower Deposits. Artefacts 9220 and 7693 have simple perforations like those made by hyenas (76), but 9340, 7974, and 9300 show apparent elaborations of similar perforations through more extensive flaking. The artefacts in the central column may thus represent production stages leading to more finely 'finished' pieces in the left two columns. The 'hypothetical fit' in the top right is an indicative photo montage of VR003 samples 6147, 7833, 8415, 8348, and 6307. These pieces do not actually refit. Artefact AA8438 (bottom right) is from the Ethnographic Collection at Iziko Museums, and was recovered from Ysterfontein Village by G.E. Loedalf in June 1968 and donated to the museum in December 1968.

**Figure 5**. A selection of silcrete cores from the Lower Deposits (see also Figure S24). White arrows indicate location of HINC surfaces; yellow arrows indicate location of flaking initiations. All artefacts shown except 2815 were made on heat shatter. 1421: Minimal core on heat shatter. Inset (a) shows the contact between the smooth post-heat removal and the scalar features on the older shatter surface. 1462: Simple prepared platform core on heat shatter. 1520: Minimal core on heat shatter. 3450: Single platform core with small laminar removals on heat shatter. 5391: Prepared core on heat shatter with one laminar removal. 7379: Multiplatform core on heat shatter. 2815: Unheated single platform core with small laminar removals.

## References cited

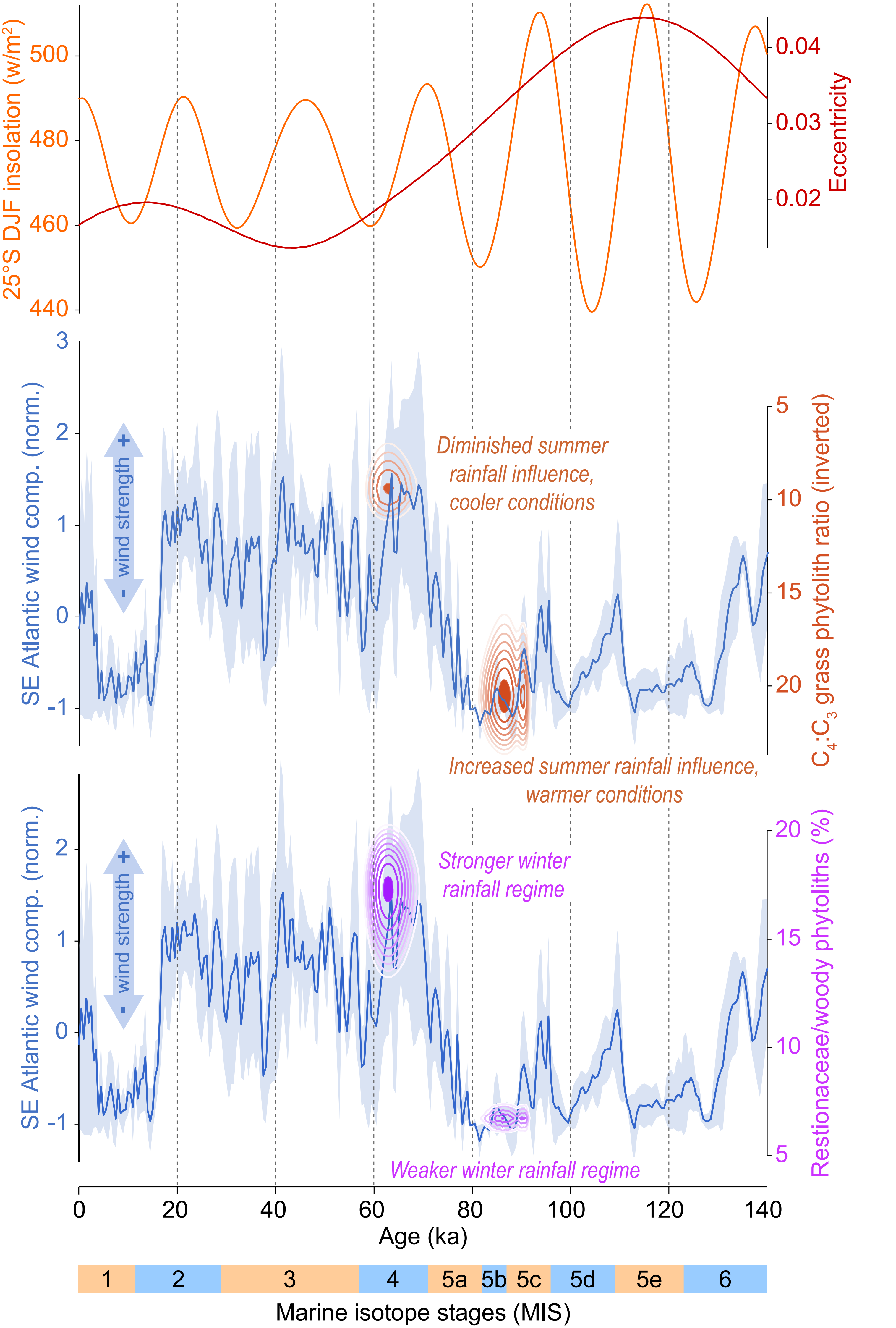

1. Lombard M*, et al.* (2012) South African and Lesotho Stone Age sequence updated. *South African Archaeological Bulletin* 67(195):120-144.
2. Kandel AW*, et al.* (2015) Increasing Behavioral Flexibility? An Integrative Macro-Scale Approach to Understanding the Middle Stone Age of Southern Africa. *Journal of Archaeological Method and Theory*.
3. Porraz G*, et al.* (2020) Experimentation as a driving force for innovation in the Pre-Still Bay from Southern Africa. *EcoEvoRxiv, ch53r, ver. 3, peer-reviewed and recommended by PCI Archaeology*.

4. Texier PJ*, et al.* (2010) A Howiesons Poort tradition of engraving ostrich eggshell containers dated to 60,000 years ago at Diepkloof Rock Shelter, South Africa. *Proc Natl Acad Sci U S A* 107(14):6180-6185.
5. Henshilwood CS*, et al.* (2014) Klipdrift Shelter, southern Cape, South Africa: Preliminary Report on the Howiesons Poort layers. *Journal of Archaeological Science* 45:284-303.
6. Powell A, Shennan S, & Thomas MG (2009) Late Pleistocene demography and the appearance of modern human behavior. *Science* 324(5932):1298-1301.
7. Marean CW (2016) The transition to foraging for dense and predictable resources and its impact on the evolution of modern humans. *Philos Trans R Soc Lond B Biol Sci* 371(1698).
8. Mackay A, Stewart BA, & Chase BM (2014) Coalescence and fragmentation in the late Pleistocene archaeology of southernmost Africa. *Journal of Human Evolution* 72:26-51.
9. Wilkins J*, et al.* (2021) Innovative Homo sapiens behaviours 105,000 years ago in a wetter Kalahari. *Nature*.
10. Dewar G & Stewart BA (2012) Preliminary results of excavations at Spitzkloof Rockshelter, Richtersveld, South Africa. *Quaternary International* 270:30-39.
11. Cowling RM & Pierce S (1999) *Namaqualand: A Succulent Desert* (Fernwood Press, Vlaeberg, South Africa).
12. Hijmans RJ, Cameron SE, Parra JL, Jones PG, & Jarvis A (2005) Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25(15):1965-1978.
13. Mucina L*, et al.* (2006) Succulent Karoo Biome. *The vegetation of South Africa, Lesotho and Swaziland,* Strelizia, eds Mucina L & Rutherford MC (SANBI, Pretoria), Vol 19.
14. Rebelo AG, Boucher C, Helme N, Mucina L, & Rutherford MC (2006) Fynbos Biome. *The Vegetation of South Africa, Lesotho and Swaziland,* Strelizia, eds Mucina L & Rutherford MC (SANBI, Pretoria), Vol 19.
15. Marean CW*, et al.* (2014) Stone Age people in a changing South African Greater Cape Floristic Region. *Fynbos: Ecology, Evolution, and Conservation of a Megadiverse Region*, eds Allsopp N, Colville JF, & Verboom GA (Oxford University Press, Oxford), pp 164-199.
16. Carr AS, Chase BM, & Mackay A (2016) Mid to Late Quaternary Landscape and Environmental Dynamics in the Middle Stone Age of Southern South Africa. *Africa from MIS 6-2: Population Dynamics and Paleoenvironments,* Vertebrate Paleobiology and Paleontology Series, eds Jones S & Stewart BA (Springer, Dordrecht), pp 23-47.
17. Chase BM & Meadows ME (2007) Late Quaternary dynamics of southern Africa's winter rainfall zone. *Earth-Science Reviews* 84(3-4):103-138.
18. Steele TE*, et al.* (2016) Varsche Rivier 003: A Middle and Later Stone Age site with Still Bay and Howiesons Poort assemblages in southern Namaqualand, South Africa. *PaleoAnthropology* 2016:100-163.
19. Sharp WD*, et al.* (2019) 230Th/U burial dating of ostrich eggshell. *Quaternary Science Reviews* 219:263-276.
20. Chase BM*, et al.* (In Press) South African speleothems reveal influence of high- and low-latitude forcing over the last 113.5 kyr. *Geology*.
21. Chase BM*, et al.* (2015) Influence of tropical easterlies in southern Africa's winter rainfall zone during the Holocene. *Quaternary Science Reviews* 107:138-148.
22. Manning J (2008) Namaqualand. (Briza Publications, Pretoria).
23. Skinner JD & Chimimba CT (2005) *The Mammals of the Southern African Subregion* (Cambridge University Press, Cambridge) 3rd edition Ed.
24. Skead CJ (1980) *Historical Mammal Incidence in the Cape Province. Volume 1: The Western and Northern Cape* (Department of Nature and Environmental Conservation, Cape Town).
25. Churcher CS (2006) Distribution and history of the Cape zebra (Equus capensis) in the Quaternary of Africa. *Transactions of the Royal Society of South Africa* 61:89-95.

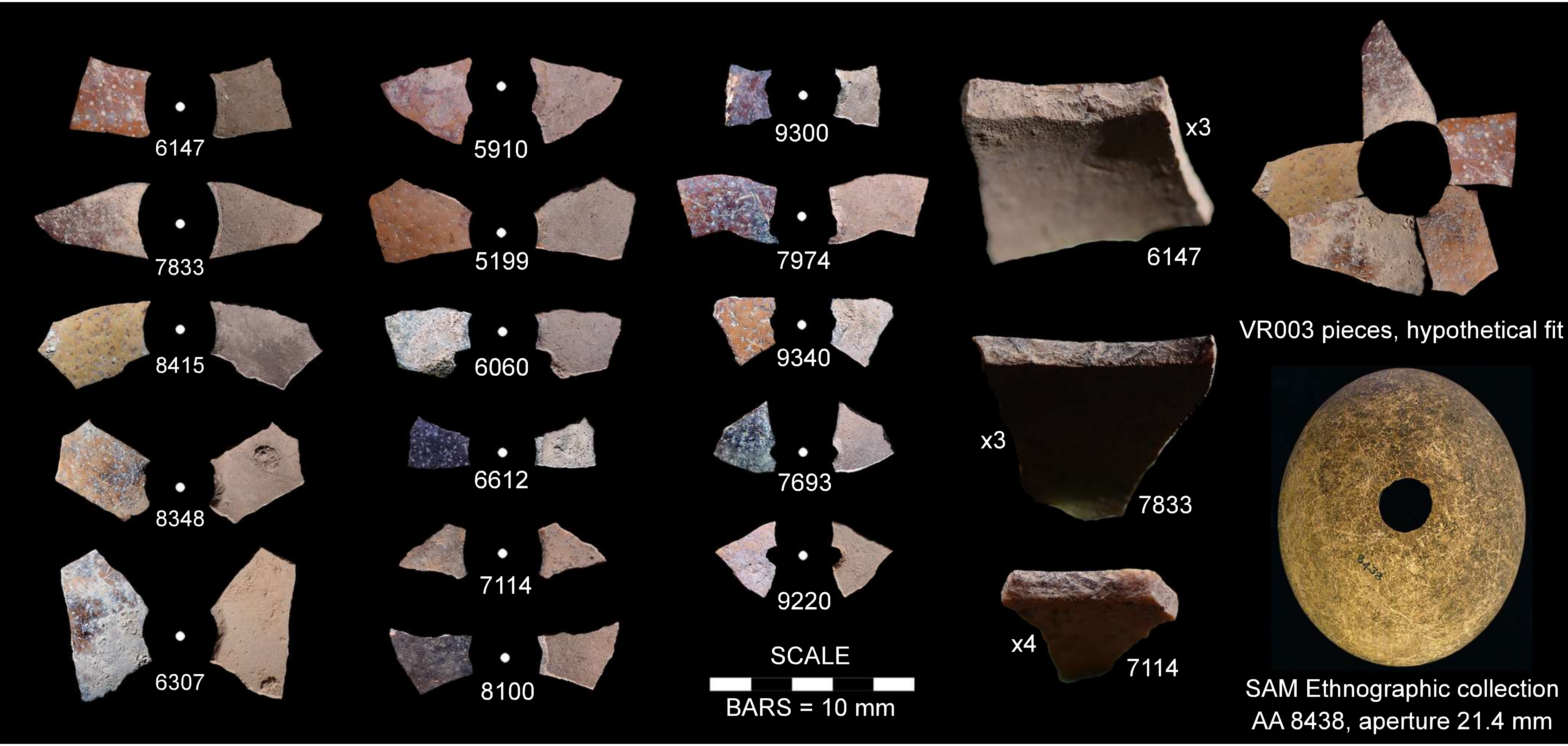
26. Spratt RM & Lisiecki LE (2016) A Late Pleistocene sea level stack. *Climate of the Past* 12(4):1079-1092.
27. De Wet W (2013) Bathymetry of the South African Continental Shelf. MSc (University of Cape Town).
28. Jerardino A & Marean CW (2010) Shellfish gathering, marine paleoecology and modern human behavior: perspectives from cave PP13B, Pinnacle Point, South Africa. *J Hum Evol* 59(3-4):412-424.
29. Marean CW (2010) Pinnacle Point Cave 13B (Western Cape Province, South Africa) in context: The Cape Floral kingdom, shellfish, and modern human origins. *J Hum Evol* 59(3-4):425-443.
30. Kandel AW (2004) Modification of ostrich eggs by carnivores and its bearing on the interpretation of archaeological and paleontological find. *Journal of Archaeological Science* 31:377-391.
31. Steele TE & Klein RG (2013) The Middle and Later Stone Age faunal remains from Diepkloof Rock Shelter, Western Cape, South Africa. *Journal of Archaeological Science* 40(9):3453-3462.
32. Klein RG*, et al.* (2004) The Ysterfontein 1 Middle Stone Age site, South Africa, and early human exploitation of coastal resources. *Proc Natl Acad Sci U S A* 101(16):5708-5715.
33. Vogelsang R*, et al.* (2010) New Excavations of Middle Stone Age Deposits at Apollo 11 Rockshelter, Namibia: Stratigraphy, Archaeology, Chronology and Past Environments. *Journal of African Archaeology* 8(2):185-218.
34. Marean CW*, et al.* (2007) Early human use of marine resources and pigment in South Africa during the Middle Pleistocene. *Nature* 449(7164):905-908.
35. Schmidt I*, et al.* (2016) New investigations at the Middle Stone Age site of Pockenbank Rockshelter, Namibia. *Antiquity* 90:e2.
36. Vogelsang R (1998) *Middle Stone Age Fundstellen in Südwest-Namibia. Africa* (Heinrich-Barth-Institut, Köln).
37. Plug I (2006) Aquatic animals and their associates from the Middle Stone Age levels at Sibudu. *Southern African Humanities* 18:289-299.
38. Wurz S (2013) Technological Trends in the Middle Stone Age of South Africa between MIS 7 and MIS 3. *Current Anthropology* 54(S8):S305-S319.
39. Volman TP (1981) The Middle Stone Age in the Southern Cape. PhD (University of Chicago).
40. Schmidt P & Mackay A (2016) Why Was Silcrete Heat-Treated in the Middle Stone Age? An Early Transformative Technology in the Context of Raw Material Use at Mertenhof Rock Shelter, South Africa. *Plos One* 11(2):e0149243.
41. Porraz G*, et al.* (2013) Technological successions in the Middle Stone Age sequence of Diepkloof Rock Shelter, Western Cape, South Africa. *Journal of Archaeological Science* 40(9):3376-3400.
42. Schmid V, Conard NJ, Parkington J, Texier PJ, & Porraz G (2016) The 'MSA 1' of Elands Bay Cave (South Africa) in the context of the southern African Early MSA technologies. *Southern African Humanities* 29:153-201.
43. Evans U (1994) Hollow Rock Shelter, a Middle Stone Age site in the Cederberg. *Southern African Field Archaeology* 3:63-73.
44. Mackay A, Jacobs Z, & Steele TE (2015) Pleistocene archaeology and chronology of Putslaagte 8 (PL8) rockshelter, Western Cape, South Africa. *Journal of African Archaeology* 13(1):71-98.
45. Saktura RB*, et al.* (In Prep) The Middle Stone Age sequence at Klipfonteinrand 1 (KFR1), Western Cape, South Africa. *Unspecified*.
46. Thompson JC*, et al.* (2018) Ecological risk, demography and technological complexity in the Late Pleistocene of northern Malawi: implications for geographical patterning in the Middle Stone Age. *Journal of Quaternary Science* 33(3):261-284.

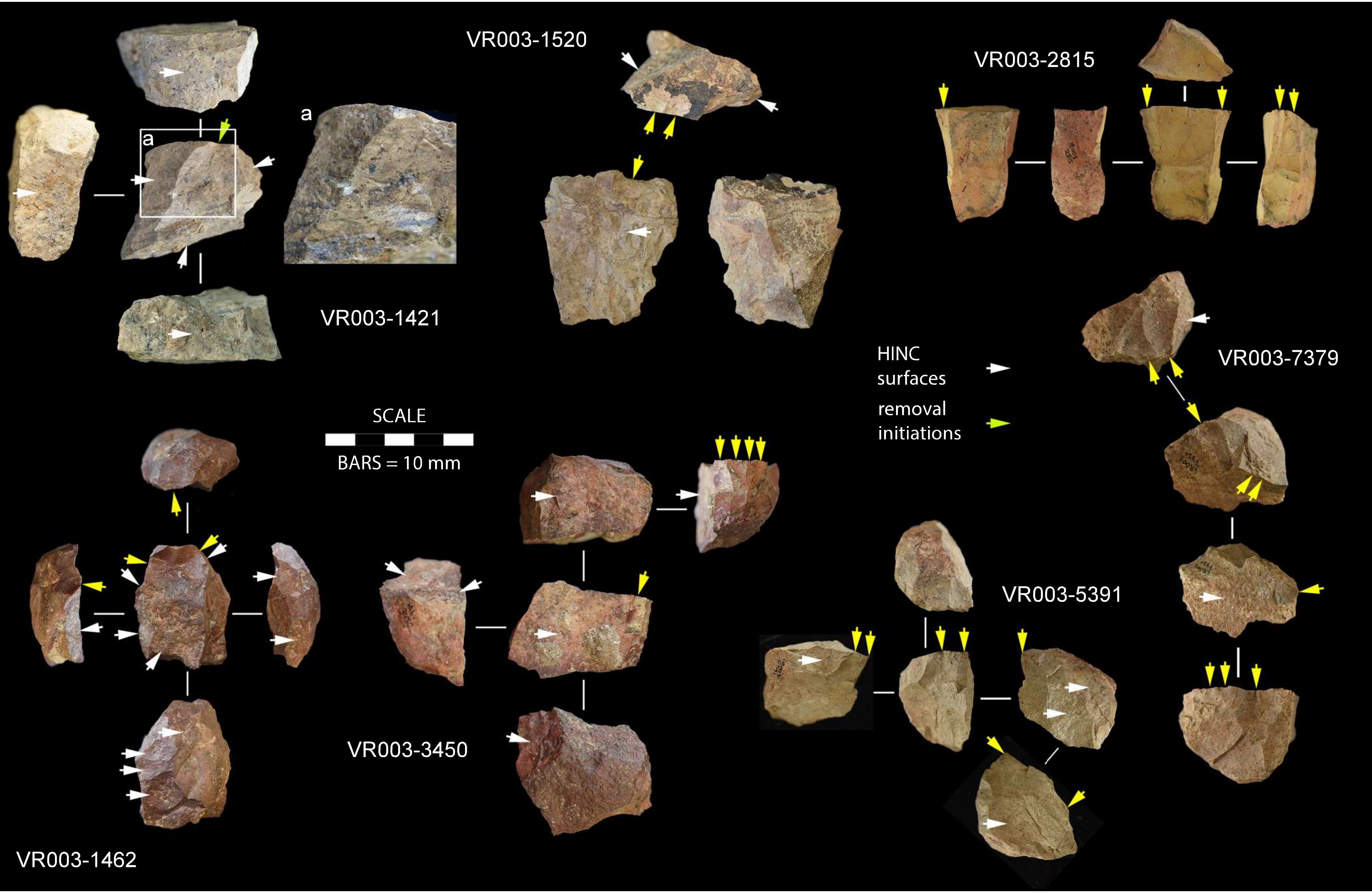
47. Vaesen K & Houkes W (2021) Is Human Culture Cumulative? *Current Anthropology* 62(2):218-238.
48. Boyd R, Richerson PJ, & Henrich J (2011) The cultural niche: why social learning is essential for human adaptation. *Proc Natl Acad Sci U S A* 108 Suppl 2:10918-10925.
49. Sterelny K (2011) From hominins to humans: how sapiens became behaviourally modern. *Philos Trans R Soc Lond B Biol Sci* 366(1566):809-822.
50. Gärdenfors P & Högberg A (2017) The Archaeology of Teaching and the Evolution of Homo docens. *Current Anthropology* 58(2):188-208.
51. Marwick B (2003) Pleistocene Exchange Networks as Evidence for the Evolution of Language. *Cambridge Archaeological Journal* 13(1):67-81.
52. Blegen N (2017) The earliest long-distance obsidian transport: Evidence from the ∼200 ka Middle Stone Age Sibilo School Road Site, Baringo, Kenya. *Journal of Human Evolution* 103:1-19.
53. McBrearty S & Brooks AS (2000) The revolution that wasn't: a new interpretation of the origin of modern human behavior. *J Hum Evol* 39(5):453-563.
54. Klein RG (2000) Archeology and the Evolution of Human Behavior. *Evolutionary Anthropology: Issues, News, and Reviews* 9(1):17-36.
55. Wynn T & Coolidge FL (2016) Archeological insights into hominin cognitive evolution. *Evol Anthropol* 25(4):200-213.
56. Derex M & Mesoudi A (2020) Cumulative Cultural Evolution within Evolving Population Structures. *Trends Cogn Sci*.
57. Sterelny K (2016) Adaptable individuals and innovative lineages. *Philos Trans R Soc Lond B Biol Sci* 371(1690).
58. Henshilwood CS & Marean CW (2003) The Origin of Modern Human Behavior: Critique of the Models and their Test Implications. *Current Anthropology* 44(5):627-651.
59. Stoops G, Marcelino V, & Mees F eds (2010) *Interpretation of Micromorphological Features of Soils and Regoliths* (Elsevier).
60. Stoops G (2003) *Guidelines for analysis and description of soil and regolith thin sections* (Soil Science Society of America, Madison, Wisconsin).
61. McPherron SP (2018) Additional statistical and graphical methods for analyzing site formation processes using artifact orientations. *PLoS One* 13(1):e0190195.
62. Thomsen KJ, Murray AS, Jain M, & Bøtter-Jensen L (2008) Laboratory fading rates of various luminescence signals from feldspar-rich sediment extracts. *Radiation Measurements* 43:1474-1486.
63. Armitage SJ & Bailey RM (2005) The measured dependence of laboratory beta dose rates on sample grain size. *Radiation Measurements* 39:123-127.
64. Huntley DJ & Lamothe M (2001) Ubiquity of anomalous fading in K-feldspars and the measurement and correction for it in optical dating. *Canadian Journal of Earth Sciences* 38:1093-1106.
65. Jaffey AH, Flynn KF, Glendenin LE, & Essling AM (1971) Precision measurement of half-lives and specific activities of $^{235}$U and $^{238}$U. *Physical Review C* 4:1889-1906.
66. Cheng H*, et al.* (2013) Improvements in $^{230}$Th dating, $^{230}$Th and $^{234}$U half-life values, and U–Th isotopic measurements by multi-collector inductively coupled plasma mass spectrometry. *Earth and Planetary Science Letters* 371-372:82-91.
67. Holden NE (1990) Total half-lives for selected nuclides. *Pure Applied Chemistry* 62:941-958.
68. Ludwig KR (2010) *Isoplot/Ex version 3.75: A Geochronological toolkit for Microsoft Excel* (Berkeley Geochronology Center Special Publication, Berkeley, California).
69. Collins B & Steele TE (2017) An often overlooked resource: Ostrich ( Struthio spp.) eggshell in the archaeological record. *Journal of Archaeological Science: Reports* 13:121-131.

70. Schmidt P (2017) How reliable is the visual identification of heat treatment on silcrete? A quantitative verification with a new method. *Archaeological and Anthropological Sciences* 11 713-726.
71. Roberts DL (2003) *Age, genesis and significance of South African coastal belt silcretes* (Council for Geoscience, South Africa).
72. Schmidt P*, et al.* (2015) A previously undescribed organic residue sheds light on heat treatment in the Middle Stone Age. *J Hum Evol*.
73. Trabucco A & Zomer R (2019) Global Aridity Index and Potential Evapotranspiration (ET0) Climate Database v2.
74. UNEP (1997) *World atlas of desertification* (United Nations Environment Programme, London) 2nd ed Ed.
75. Mucina L & Rutherford MC (2006) *The vegetation of South Africa, Lesotho and Swaziland* (South African National Biodiversity Institute, Pretoria).
76. Kandel AW & Conard NJ (2005) Production sequences of ostrich eggshell beads and settlement dynamics in the Geelbek Dunes of the Western Cape, South Africa. *Journal of Archaeological Science* 32(12):1711-1721.



25°S DJF insolation (w/m²)
500
480
460
440
Eccentricity
0.04
0.03
0.02
SE Atlantic wind comp. (norm.)
3
2
1
0
-1
+ wind strength -
Diminished summer rainfall influence, cooler conditions
Increased summer rainfall influence, warmer conditions
C4:C3 grass phytolith ratio (inverted)
5
10
15
20
SE Atlantic wind comp. (norm.)
2
1
0
-1
+ wind strength -
Stronger winter rainfall regime
Weaker winter rainfall regime
Restionaceae/woody phytoliths (%)
20
15
10
5
0
20
40
60
80
100
120
140
Age (ka)
1
2
3
4
5a
5b
5c
5d
5e
6
Marine isotope stages (MIS)


6147
7833
8415
8348
6307
5910
5199
6060
6612
7114
8100
9300
7974
9340
7693
9220
SCALE
BARS = 10 mm
x3
6147
x3
7833
x4
7114
VR003 pieces, hypothetical fit
SAM Ethnographic collection
AA 8438, aperture 21.4 mm



VR003-1520
VR003-2815
a
a
VR003-1421
HINC
surfaces
removal
initiations
VR003-7379
SCALE
BARS = 10 mm
VR003-5391
VR003-3450
VR003-1462