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

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54

55

56 **Abstract**

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

71 **Introduction**

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

85

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

102

103 Here we present new data from excavations at the site of Varsche Rivier 003 (VR003),
104 located 44 km from the Atlantic coast in the Knersvlakte bioregion, southern Namaqualand
105 (Figure 1). Falling within the modern Succulent Karoo Biome, the Knersvlakte currently
106 receives $\sim 175 \pm 30$ mm of rainfall per year (11, 12), almost all during the austral winter, and is
107 characterised by a limited groundcover of xeric-adapted succulent shrubs and endemic

108 'stone plants' (13). While the MSA archaeology of the Succulent Karoo is largely unstudied,
109 VR003 lies close to the modern limits of the Fynbos Biome. Characterised by evergreen
110 shrubs and reeds, and closely related to winter rainfall regimes (14), the Fynbos Biome's
111 current distribution encompasses many of southern Africa's most prominent MSA sites (15).
112 Edaphic controls mean the Succulent Karoo / Fynbos Biome boundary is unlikely to have
113 shifted substantially through the late Pleistocene (13, 16), though intensified winter rainfall
114 may have supported periodic northward range expansion of some fynbos taxa (17).

115

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

127

128 **Results**

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

142

143 The sedimentary sequence in the Main Area is composed of slope deposits with fine grained
144 colluvium and coarser grained debris flow (Figure 2; for more detail see SI Geoarchaeology,

145 Figures S2-5). Deposition of non-archaeological clasts on the slope by debris flow and
146 colluvial processes is indicated by a lack of sorting or orientation and the fine coating of
147 some coarse grained materials, though the low incidence of soil aggregates (Figure 2, inset
148 B) and the lack of rounded rocks from the plateau above the shelter suggests overall limited
149 transport distances. The regular occurrence of microscopic lithic knapping debris, and the
150 high incidence and broad size distribution of microscopic bones (Figure 2, inset A, B) are
151 typical for occupation layers suggesting their initial deposition on the slope. The presence of
152 gypsum in the deposits indicates an arid environment with high evaporation rates. Fabric
153 analysis of elongated bone and stone objects (n=353) reveals a predominantly planar
154 distribution, suggesting that archaeological materials in the Lower Deposits were discarded
155 on the slope (Figure S6). Object dip does not deviate from the surface slope or the overlying
156 strata, and orientation does not differ significantly from a uniform distribution (Rayleigh test,
157 $p = 0.0008$). Similarly, the dip of the 12 identified lithic refit sets, mainly comprising
158 sequential flake removals (n=9), generally follows the deposit slope (Figure S7).

159

160 The Lower Deposits have been dated using single-grain luminescence (pIRIR) on feldspar,
161 and by U-series dating on ostrich eggshell (OES) fragments (Figure 2). Potassium feldspar
162 extracted from four sediment samples distributed from near the top of I-08 to the base of I-09
163 yielded stratigraphically consistent ages ranging from 80.8 ± 4.6 ka (1σ , ± 9.2 ka 2σ) to
164 89.9 ± 5.0 ka (1σ , ± 10.1 ka 2σ) (Table S7). U-series dating on three fragments of OES from
165 lower I-08 and upper I-09 used a novel approach termed $^{230}\text{Th}/\text{U}$ burial dating (19). As OES
166 fragments were not typically piece-plotted during excavations we used two samples from
167 bucket aggregates that also yielded OES artefacts (VR003-9300, VR003-6612) (see below),
168 and one well-preserved piece-plotted fragment (VR003-9085) (Figures S11-S15). OES
169 fragment VR003-9300 yields a $^{230}\text{Th}/\text{U}$ burial age of 88.3 ± 3.2 ka (2σ error). OES fragment
170 VR003-9085 yields concordant sub-sample ages consistent with rapid U uptake, defining a
171 mean age of 90.7 ± 0.7 ka in good agreement with the age determined for VR003-9300.
172 VR003-6612 also yields concordant sub-sample ages, however, their mean age of 74.5 ± 1.4
173 ka is significantly younger than ages obtained for the two other OES, though it is within error
174 of the luminescence ages at 2σ . This may imply mixing either in the bucket aggregate from
175 which the sample derived or via disturbance processes such as bioturbation (SI
176 Geoarchaeology). A probability density function provides a combined age range for the
177 Lower Deposits of 92-80 ka at 1σ (SI Geochronology).

178

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

182 with high proportions of Poaceae (grasses) relative to Restionaceae and non-graminoid
183 (woody and shrubby) vegetation compared to overlying strata (Table S10). The ratio of C₄
184 (warm growing season) to C₃ (cool growing season) to grass phytoliths is low (<20.8),
185 consistent with the region's winter rainfall regime. However, higher proportions of warm
186 growing season C₄ grasses in the Lower Deposits (18.7±3.4) compared with the overlying
187 strata (6.7±2.3) suggest a decrease in summer rain after ~80 ka. The decline in C₄
188 grasses—and grasses in general—is concurrent with a two-fold increase in Restionaceae
189 and woody phytolith percentages. Combined these results are consistent with the marked
190 increase in wind strength and upwelling along the west coast that began in MIS 5a (Figure 3)
191 and the weakening of tropical systems in the southern continental interior under decreasing
192 orbital eccentricity (20). These factors would have limited the incursion of summer rainfall
193 systems in the region, resulting in increased rainfall seasonality (21). As Restionaceae is
194 strongly linked to winter rainfall in the Cape, this may be further evidence for an overall shift
195 toward a more dominant winter rainfall regime (see SI Phytoliths).

196

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

211

212 In addition to mammals and reptiles, the Lower Deposits preserve 26 shellfish fragments.
213 Limpets account for 77% of these, with granite limpets the dominant taxon, along with two
214 black mussel fragments (SI Molluscs; Table S12, which includes scientific names). Other
215 than a few isolated overlying examples, the majority of all marine shells at VR003 cluster in a
216 band in the Lower Deposits (Figure 2). Given the luminescence and U-series results, relative
217 sea level during the formation of the Lower Deposits would have been 25-40 m below

218 present (26), though due to off-shore topography this would not have substantially increased
219 VR003's distance to shore (27). The molluscs were thus likely obtained at least 45-50 km
220 from site. While limpets and mussels appear as an important food resource in other South
221 African coastal MSA assemblages (28), they are rarely transported as food packages
222 beyond 10 km (29), raising questions about whether the VR003 individuals were transported
223 as food or as empty shells. The shells from the Lower Deposits are fragmented, but no ochre
224 residues nor anthropogenic modifications were observed on them.

225

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

238

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

248

249 These silcrete cores are small (max dimension mean= 43.7 ± 10.2 mm), typologically diverse
250 (Table S22), and exclusively produced small flakes and blades (scar length mean= 17.4 ± 6.9
251 mm). Cores with prepared platforms and no obvious management of the flaking surface are
252 the most common identifiable type, though opportunistic and minimally worked cores
253 account for about a quarter of the total. The average number of flake scars on silcrete cores

254 is 3.1, suggesting generally short reduction chains. Blade removals are not numerous but
255 are concentrated on some cores (Figure 5, Figure S24), and with an average scar length of
256 15.2 mm could be classified as bladelets. Blade production, however, generally seems to
257 have been opportunistic (SI Lithics, Tables S17 & S18).

258

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

267

268 **Discussion**

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

277

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

287

288 Evidence for exploitation of edible shellfish species (e.g. limpets and mussels) occurs along
289 the southern Cape coast as early as 164 ka (34); however transport of such species over
290 >45 km is rare during the MSA and suggests movement of people between coastal and

291 interior southern Namaqualand during MIS 5b. Long-distance transportation of a small
292 sample of shellfish during the MSA has been noted from Apollo 11 and Pockenbank, which
293 are ~140 km and ~120 km from the modern coast respectively (35, 36); they are both
294 located in southern Namibia, suggesting that this behaviour may have been widespread
295 through arid regions of southern Africa. Elsewhere limited transport of marine shell over ~15
296 km is found in the MSA at Diepkloof (31) and at Sibudu Cave (37).

297

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

310

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

323

324 These observations carry four significant implications for models of human behavioural
325 evolution. First, they support arguments that the productive environments of the southern
326 Cape coastal plains were not the sole locus of human innovation in southern Africa (9).
327 Indeed, conversely, marginal environments likely required novel or at least distinct

328 technological solutions to enable persistent survivorship (46). Second, and following from the
329 first, research emphasis on biogeographically limited regions of southern Africa has probably
330 acted to exaggerate the extent of cultural similarities through the MSA (SI Lithics).

331

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

344

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

365 four factors: capability to innovate (55), motivation to innovate (46), stabilisation of
366 innovations (56, 57), and preservation of innovations (58). The record from VR003 speaks to
367 the first two, highlighting the importance of obtaining data from diverse ecological regions.
368 Disentangling the last two remains a key challenge going forward.

369

370 **Methods**

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

378

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

386

387 **Single-grain luminescence dating.** Luminescence samples were obtained by hammering
388 metal tubes into cleaned section faces. Samples were prepared under subdued red light at
389 the Royal Holloway Luminescence Laboratory, yielding sand-sized quartz and potassium
390 feldspar (K-feldspar) separates. All luminescence measurements were carried out using a
391 Risø TL/OSL-DA-15 automated dating system, fitted with a dual-laser single-grain
392 luminescence attachment. Quartz was measured using a standard single-aliquot
393 regenerative-dose method whereas a post infrared, infrared stimulated luminescence
394 procedure, intended to minimise the effect of “fading” (62) was used for K-feldspar. Individual
395 grains were stimulated using either a focused 10 mW Nd:YVO₄ solid-state diode-pumped
396 green (532 nm) laser for quartz or a 140 mW TTL modulated infra-red (IR, 830 nm) laser
397 with a Schott RG 780 longpass filter mounted in the beamline for K-feldspar. Simultaneous
398 illumination of all grains on a disc was carried out using either blue (470 nm) or IR (870 nm)
399 light emitting diodes (LEDs). Luminescence was detected using an Electron Tubes Ltd
400 9235QB15 photomultiplier tube shielded by Schott BG3 and BG39 filters. Irradiation was
401 carried out using a 1.48 GBq ⁹⁰Sr/⁹⁰Y beta source calibrated relative to the National Physical

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

405

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

415

416 **Phytolith analysis.** Nine sediment samples were processed for phytoliths, covering strata
417 from I-09 to I-03. Phytoliths were extracted from approximately 5 g of bulk fine fraction
418 sediment. Samples were sieved through 125 μm mesh; 2 g of each <125 μm subsample was
419 treated for carbonate digestion using 10% HCl, followed by clay deflocculation aided by
420 NaPO_3 . 10% KOH solution was used for digestion of organic matter, before another round of
421 deflocculation. Samples were neutralized, centrifuged and decanted between all steps.
422 Phytoliths were extracted by heavy liquid flotation, using a solution of sodium polytungstate
423 ($2.3 \text{ g}/\text{cm}^3$). Assemblages were pipetted onto coverslips, dried, and mounted to microscope
424 slides using Entellan medium for identification and counting. Phytolith abundance was counted
425 up to 300, with concentration per gram of sediment later estimated using the proportion of
426 sample analysed and initial 2 g weight.

427

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

439

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

448

449 **Data availability statement**

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

452

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467

468 **Author contributions**

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

476

477 **Competing Interests Statement**

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

480

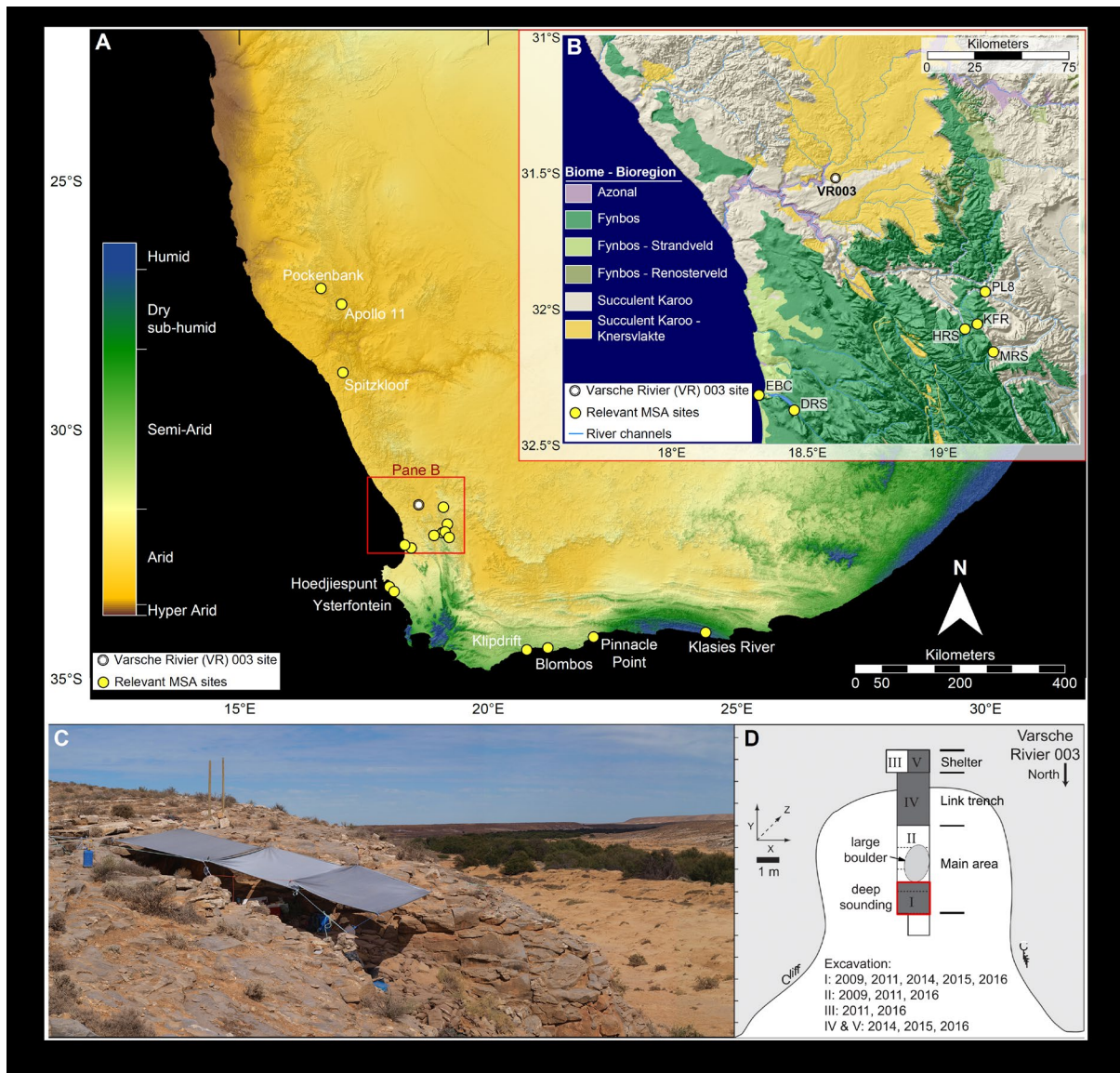
481 **Data Availability Statement**

482 The spatial, lithic, faunal and pigment data used in this paper are included in a
483 supplementary file. Phytolith data are provided in tables in the Supplementary Information.

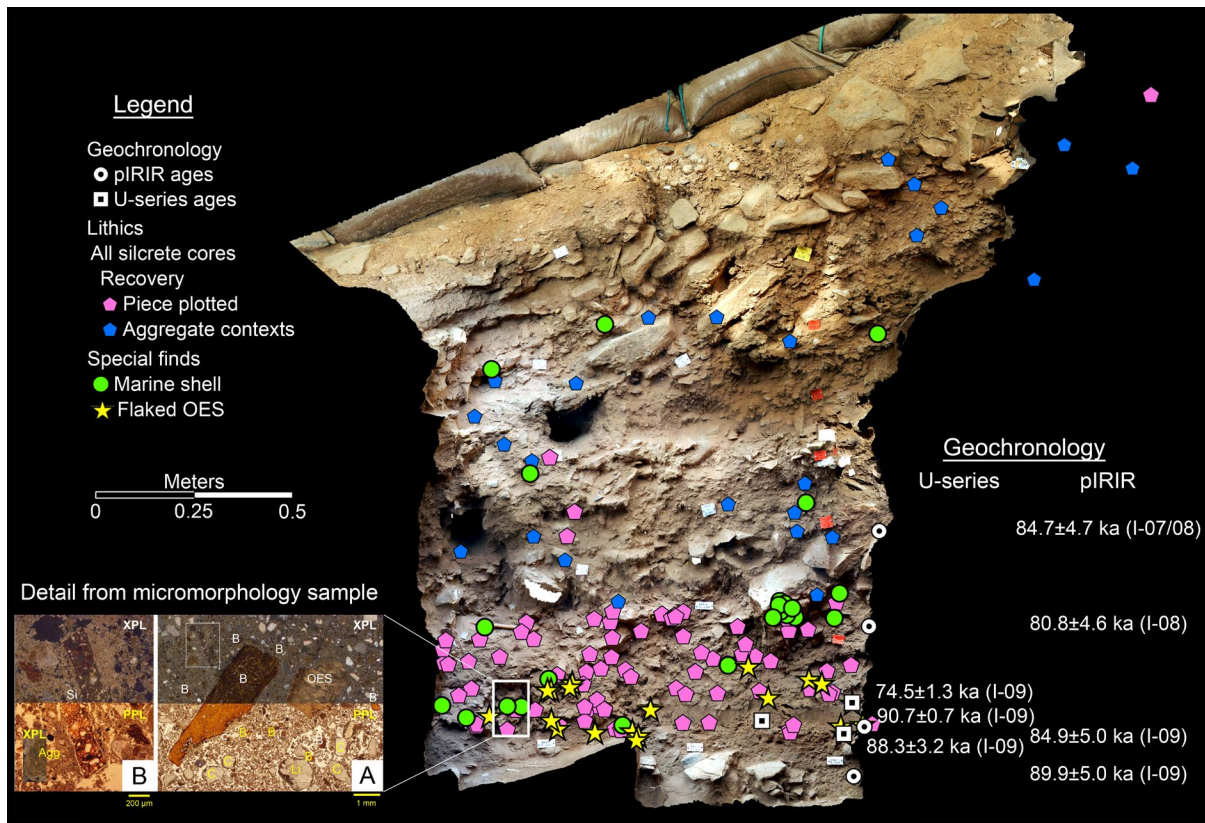
484 The VR003 collections are curated at University of Cape Town and Iziko Museums Cape
485 Town, and can be accessed by arrangement with TES and AM.

486

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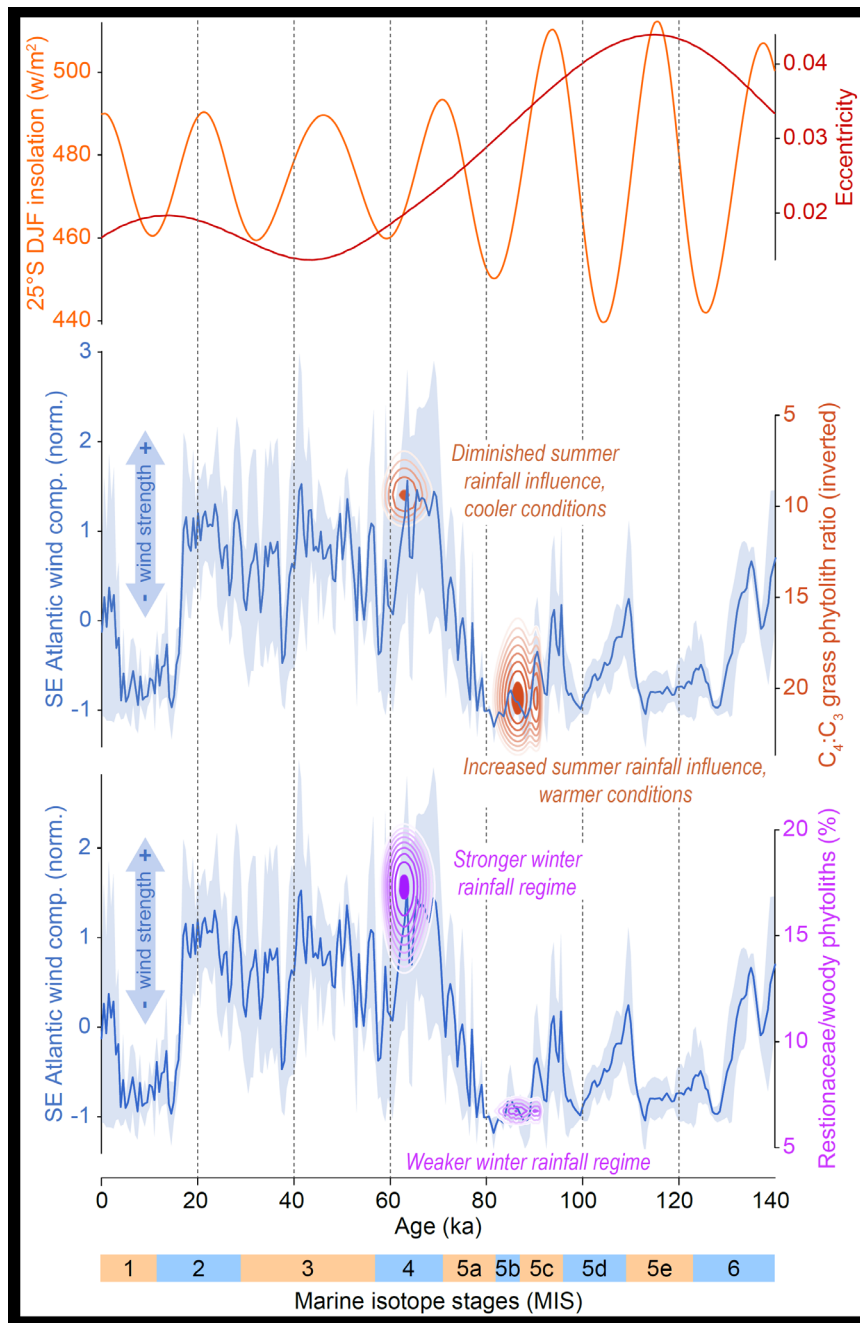


487
 488 **Figure 1. (A)** Aridity map of southern Africa, with the Varsche Rivier 003 (VR003; white dot)
 489 and relevant MSA sites referred to in the text (yellow dots) indicated. Aridity index data from
 490 (73) with definitions according to (74). Red box shows location of inset map (B). **(B)** VR003
 491 in relation to modern biome-bioregion boundaries from (75) and Fynbos Biome sites
 492 immediately south: DRS=Diepkloof, EBC=Elands Bay Cave, HRS=Hollow Rock Shelter,
 493 KFR=Klipfonteinrand 1, MRS=Mertenhof, PL8=Putslaagte 8. **(C)** Site photo of VR003 and
 494 the Varsche Rivier 003 valley, looking west. **(D)** Excavation plan at conclusion of most recent
 495 season in 2016. The original deep sounding is highlighted in red.
 496



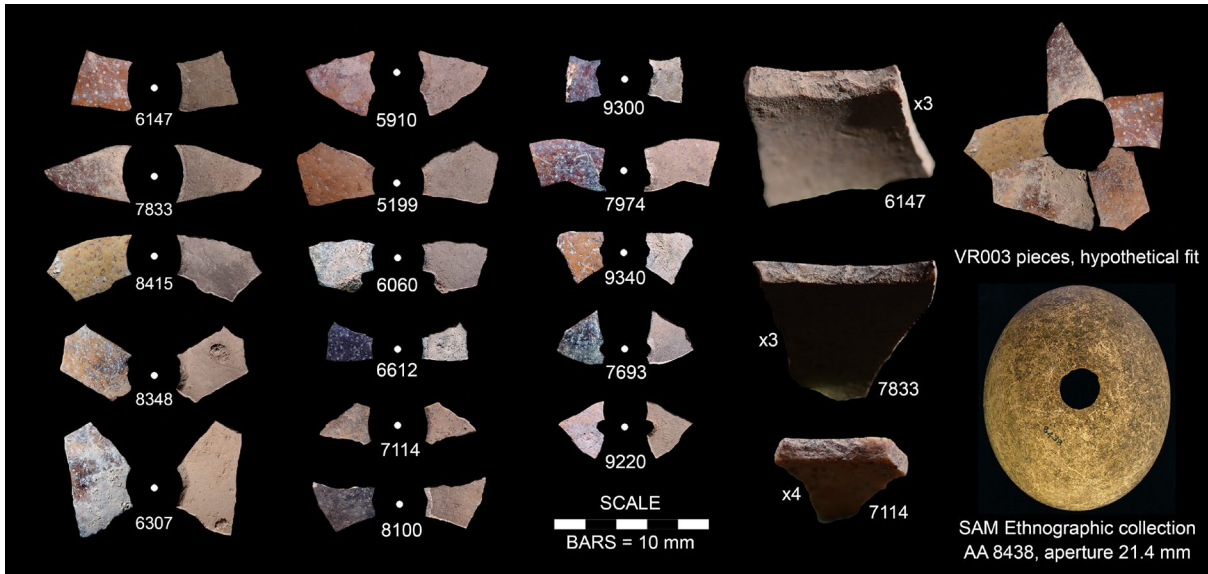
497

498 **Figure 2.** East section of deep sounding with key artefact type and location of
 499 geochronology samples. Per convention, luminescence ages are presented here at 1 sigma
 500 uncertainty, U-Th ages at 2 sigma. For artefacts, aggregate contexts refers to silcrete cores
 501 recovered during the initial seasons (2009, 2011) during which individual artefacts were
 502 typically not plotted. These cores were recovered from bucket aggregates and include up to
 503 two cores in some cases. Inset bottom left: Microphotographs showing the typical
 504 components and structure of I-08. **(A).** Bone (B) fragments range in size from gravel to sand.
 505 Another typical anthropogenic component at the site is ostrich eggshell (OES). Note also the
 506 coarse crystalline limestone (Li), and calcite crystals (C) and fine coating of these coarse
 507 grains. **(B)** Microscopic silcrete (Si) knapping debris and rounded soil aggregates (Agg) from
 508 the plateau above the site in a calcareous matrix.
 509



510

511 **Figure 3.** Comparison of primary factors determining long-term regional climate dynamics
 512 with VR003 phytolith data for 1) $C_4:C_3$ grass ratios and 2) the percentage of Restionaceae
 513 and woody taxa, a classification reflecting the abundance of fynbos vegetation (Cordova et
 514 al., 2013; Esteban et al., 2017). Data for orbital parameters is from Laskar et al. (2004) and
 515 the SE Atlantic wind strength composite is as calculated by Chase et al. (2019) using the
 516 data of Farmer et al. (2005), Little et al. (1997), Pichevin et al. (2005) and Stuu et al. (2002).
 517 The phytolith data are depicted as uncertainty spaces defined by the multiplication of
 518 probability density functions derived from 1) stratigraphic unit ages and errors for the Lower
 519 Deposits and Howiesons Poort layers and 2) aggregated phytolith data and the associated
 520 standard deviation of sample values from these units (see SI for more detail).



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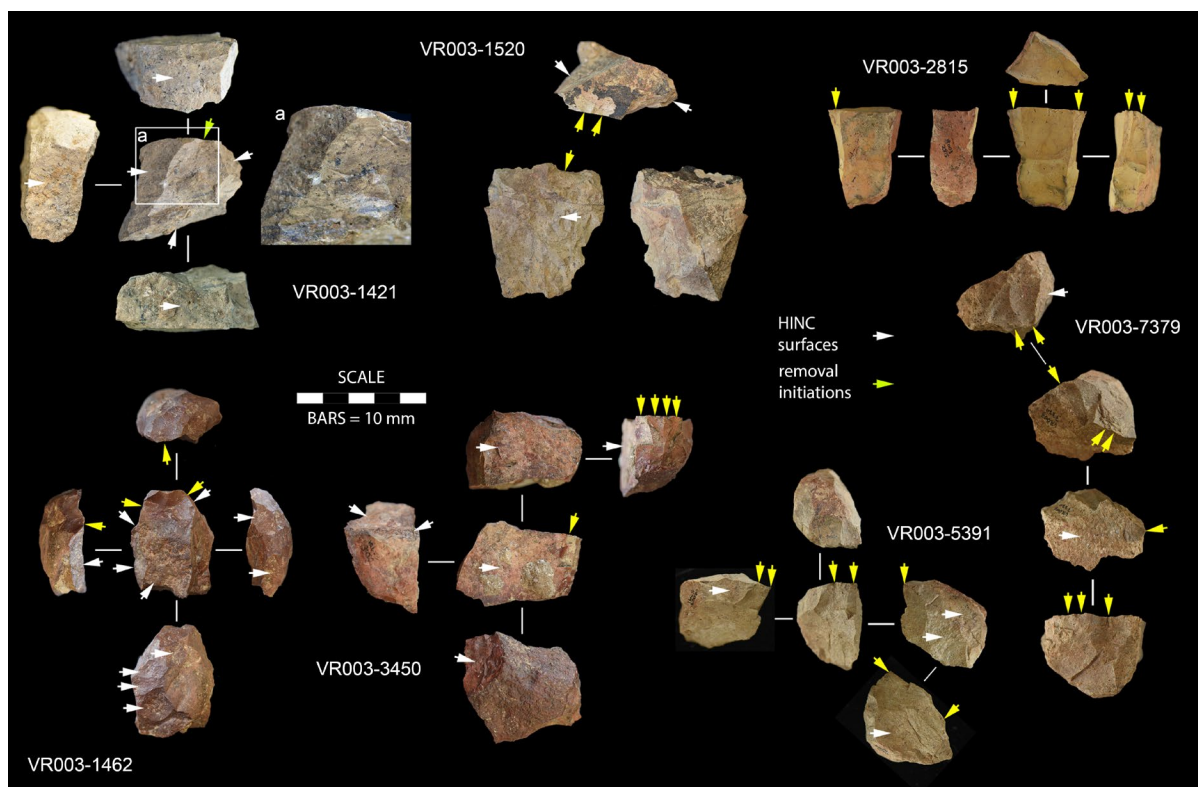
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Figure 4. Flaked OES fragments from the Lower Deposits. Artefacts 9220 and 7693 have simple perforations like those made by hyenas (76), but 9340, 7974, and 9300 show apparent elaborations of similar perforations through more extensive flaking. The 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.



532

533 **Figure 5.** A selection of silcrete cores from the Lower Deposits (see also Figure S24). White
 534 arrows indicate location of HINC surfaces; yellow arrows indicate location of flaking
 535 initiations. All artefacts shown except 2815 were made on heat shatter. 1421: Minimal core
 536 on heat shatter. Inset (a) shows the contact between the smooth post-heat removal and the
 537 scalar features on the older shatter surface. 1462: Simple prepared platform core on heat
 538 shatter. 1520: Minimal core on heat shatter. 3450: Single platform core with small laminar
 539 removals on heat shatter. 5391: Prepared core on heat shatter with one laminar removal.
 540 7379: Multiplatform core on heat shatter. 2815: Unheated single platform core with small
 541 laminar removals.

542

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