# FROM QUARTZ CURVATURE TO LATE HOLOCENE MOBILITY AT SPRING CAVE, WESTERN CAPE, SOUTH AFRICA

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#### 1 Abstract

### 2

3 The late Holocene was a period of cultural change along the west coast of South Africa, with widespread 4 archaeological evidence for shifts in settlement patterns and economic activity. With these changes we expect 5 variability in the movement patterns of resident populations. In this proof-of-concept paper, we use lithic 6 assemblages from Spring Cave near Verlorenvlei to evaluate changes in mobility during the late Holocene. 7 These assemblages are dominated by bipolar-reduced quartz, which is notoriously difficult to assess using 8 geometric approaches given high levels of fragmentation and variability in product dimensions. We use 9 measures of curvature on cortical pieces to estimate original nodule size, and then use this to calculate the cortex 10 ratio, a measure of mobility. Ratios indicate differences in mobility and place use through time that mirror 11 earlier observations about shifts in land use. These observations warrant more extended analysis of other late 12 Holocene contexts throughout the west coast.

13

### 14 Keywords

15 Mobility, lithic technology, Western Cape, quartz, cortex ratio

16

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### 20 Conflicts of interest/Competing interests

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# 23 Availability of data and material

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- 25

# 26 Code availability

- 27 Analysis was conducted using the R programming platform (https://www.r-project.org/). Code used in this
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- 29

## 30 Author contributions

- 31 BD, MJD, DRB, JP, MJP, and JTF designed the research; BD, MJD, and DRB performed the research; BD and
- 32 MJD analyzed the data; BD, JP, and MJD wrote the paper with contributions from all authors.

- 33 Introduction
- 34

Mobility plays a key role in human adaptation both past and present (Kelly 2013; Meekan et al. 2017). The capacity to move affords humans opportunities to exploit wider pools of resources, maintain broader social networks, and avoid local hazards. Conversely, the decision not to move in response to changing social and ecological circumstances may necessitate other actions to prevent misfortune (Gould 1991). Changes in human mobility are strongly linked with environment and population dynamics, and such transitions are frequently associated with shifts in subsistence practices and social organization (Ruff et al. 2015). Demonstrating such

- 41 changes is therefore important for developing human evolutionary narratives (Braun et al. 2021).
- 42

43 During the late Holocene, the west coast of South Africa saw a series of dramatic changes in the lifeways of 44 local human populations. A well-resolved archaeological record shows evidence for major shifts in subsistence 45 practices (Dewar and Orton 2013; Jerardino et al. 2013; Lander and Russell 2018; Sadr 2015; Sealy and van der 46 Merwe 1988; Smith 2009), including an intensification of coastal foraging and the introduction of domesticated 47 stock, occurring in rapid succession. These changes would likely result in reorganizations of ecological 48 relationships within the region, including those mediated by mobility.

49

50 Identifying shifts in past mobility can be accomplished in many ways, but the record of stone artifacts provides 51 one of the most ubiquitous and continuous records of human activity. Stone artifacts and their attributes can 52 reflect the organization of technology around human lifeways at different scales (Nelson 1991; Clarkson 2008; 53 Barton and Riel-Salvatore 2014). For example, refitting of stone artifacts provides an avenue for investigating 54 human movements by showing the physical separation of parts of an original stone nodule, indicating which 55 parts of a reduction sequence are immediately discarded and which are transported (e.g., Close 2000). Refitting 56 can provide important information about ethnographic scale movements but can be difficult to implement at 57 large scales or applied to long time periods. Alternative approaches capitalize on the accumulative, time-58 averaged nature of assemblages to show shifts in settlement patterns and occupational intensity (Rezek et al. 59 2020). This includes measures like the cortex ratio that utilize the geometric properties of stone nodules (e.g., 60 surface area and volume; Dibble et al. 2005), indicating whether flaked material has been added to, or subtracted 61 from, a given assemblage, thus suggesting movement of components of a lithic reduction sequence (Douglass et 62 al. 2008; Douglass 2010; Davies 2016; Lin et al. 2015). Because measures like the cortex ratio do not rely on 63 formal types and work on a range of raw materials, they can be applied widely and used to make comparisons 64 between different technocomplexes (Ditchfield et al. 2014; Phillipps 2012; Holdaway and Davies 2019; Lin et 65 al. 2016; Reeves 2019; Shaw et al. 2019).

66

67 Many late Holocene assemblages from the west coast feature high numbers of debitage and informal tools 68 (Orton 2006, 2013; Jerardino et al. 2021), which makes measures like the cortex ratio valuable for identifying 69 shifting land use patterns in the late Holocene of the west coast. However, assemblages from this part of South 70 Africa are dominated by quartz reduced using bipolar reduction, which creates unique challenges to the 71 application of the method. Here, we present a proof-of-concept analysis of geometric attributes from quartz 72 lithic assemblages from Spring Cave at Verlorenvlei, an estuary on the west coast of South Africa near Elands 73 Bay (Fig 1). Using a lens clock (two-legged spherometer) to assess curvature from cortical fragments (Douglass 74 et al. 2021), we reconstruct the size of nodules used to produce each assemblage. With this information, we 75 derive the expected surface area for the assemblages under study and compare these values with observed 76 cortical surface to assess relative degree of addition or subtraction of surface area from the assemblages. We 77 interpret these results in terms of differences in mobility between the respective archaeological study locations. 78 These findings present a unique complement to existing information about land use and mobility in the late 79 Holocene and suggest the need for more extensive investigation of similar archaeological contexts within the 80 west coast of South Africa.

81

82 Background

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84 Verlorenvlei is an estuarine lake at the mouth of the Verlorenvlei River (alt. Verloren River) at Elands Bay (Fig 85 1). The Atlantic coastline north and south of the vlei is mainly sandy beaches with occasional rocky sandstone 86 outcrops. Moving eastward from the shore, the area immediately around Verlorenvlei comprises linear coastal

87 dunes flanked by strandveld vegetation communities. Further inland, the strandveld gives way to low,

88 undulating sandveld fynbos punctuated with sandstone inselbergs, eventually rising to the foothills of the

89 Cederberg Mountains where the main tributaries originate.

90

91 The vlei itself is approximately 13km long and about 1.5km at its widest extent, and an important freshwater 92 habitat on the semi-arid west coast. Local paleoenvironment reconstructions suggest a complex interaction 93 between climate and sea level influencing the foraging habitats of the surrounding area. Fossil wood charcoal 94 assemblages from Elands Bay Cave suggests that early Holocene conditions were generally wetter than present, 95 with vegetation communities sharing similarities to present day conditions on the foothills to the east (Cowling 96 et al. 1999). Wetter conditions at this time are also suggested by various lines of faunal evidence, including size 97 clines in dune molerats (Bathvergus suillus) and the presence of hedgehog (Erinaceus frontalis) (Klein and 98 Cruz-Uribe 2016). Sediment cores from Klaarfontein Springs containing pollen and other biomarkers indicate a 99 shift after 4000 BP, when the influence of marine incursions into the vlei reduced and conditions overall became 100 more arid (Carr et al. 2015).

101

102 The period between 8000 and 4500 BP at Verlorenvlei is noteworthy for the sparseness of the record, a pattern 103 first identified in the long sequence from Elands Bay Cave (Parkington 1980). Few sites in the area contain 104 occupation layers dating to this period, and those that do indicate ephemeral occupations (Jerardino et al. 2013). 105 After 4500 years ago, the archaeological record underwent several notable changes. Deposition rates at multiple 106 occupation sites increase during the period between 4500 and 3000 BP, with many showing a wide range of 107 material culture and food waste (Parkington 2016). Toward the end of this period, and increasingly between 108 3000 – 2000 BP, numerous shell middens appeared along the coast, larger than any previously recorded marine 109 shell aggregates by several orders of magnitude (Jerardino 1996, 1998). The appearance of these middens 110 coincides with an apparent decline in evidence for human activity at inland sites (Jerardino et al. 2013), though 111 many inland sandveld sites remain undated and understudied (Parkington et al. 2020). These middens show 112 variability between them in size and composition but are noteworthy for their generally larger size than previous 113 or later shell aggregates, and for the overwhelming presence of black mussels (Choromytilus meridionalis) 114 contributing to their matrices.

115

116 Debate persists as to how the signals of change occurring during this part of the late Holocene are reflective of 117 shifts in settlement patterns. The presence of large coastal middens with a concurrent decline of evidence for 118 occupation at inland sites is suggestive of a period of intensive use of marine resources and a re-orientation of 119 human activity around coastal environments, potentially in response to increasing population densities 120 (Jerardino et al. 2013; Jerardino 2021). In terms of mobility, this would suggest more residential occupations 121 with fewer long-distance relocations to inland areas. Conversely, the middens may be viewed as a product of 122 field processing necessitated by regular movement between coastal and more distant areas (Parkington et al. 123 2020, 2021). In particular, observed differences in the concentrations of material culture classes between large 124 middens and sites from periods before and after their proliferation challenge the interpretation of the middens as 125 sites of residential occupation. Stable isotope analyses on human skeletons from the west coast show greater 126 consumption of marine foods during the 3rd millennium BP (Sealy and van der Merwe 1988) and are suggestive 127 of population growth and territoriality during the late Holocene (Sealy 2016). However, whether this increase is 128 consistent with diets consisting of large amounts of shellfish has been questioned (Parkington et al. 2020).

129

130 Approximately 2000 years ago, the practice of herding livestock appeared on the west coast (Sadr 2015). The 131 earliest, directly dated evidence of domestic caprine remains from the region is found at Spoegrivier Cave in 132 Namaqualand dating to ~2031 BP<sup>1</sup> (2105±65 bp; Sealy and Yates 1994; see also Coutu et al. 2021), with

<sup>&</sup>lt;sup>1</sup> Radiocarbon determinations in this study are presented as median values of calibrated ages before present, with raw radiocarbon ages presented in parentheses, e.g.  $\sim$  530 BP (550 ± 50 bp). Calibrations were completed using the rcarbon 1.4.1 package (Crema and Bevan 2020) for the R statistical computing platform (R Core

133 domestic stock and other signals like ceramics appearing a few centuries later at sites such as Kasteelberg on the

- Vredenburg Peninsula (Sadr et al. 2017), Die Kelders near Walker Bay (Horsburgh and Rhines 2010), and
- Blombos Cave on the southern Cape coast (Henshilwood 1996). Direct evidence for herding in Verlorenvlei can
- be found at Tortoise Cave beginning ~1533 BP (Pta-3312 1680±50 bp; Robey 1987), with evidence for pottery

preceding this by a few centuries (Orton 2002). It has been long debated whether herding groups were distinct

- from foragers, maintaining a social distance that facilitated adjacent but parallel lifeways (Smith 1998) or if populations operated along a subsistence spectrum, with some more reliant on food production and others more
- populations operated along a subsistence spectrum, with some more reliant on food production and others more
   reliant on foraging (Sadr 2003). In either case, the introduction of novel subsistence practices would almost
- 141 certainly have resulted in further reorganization of ecological relationships within the region (Parkington et al.
- 142 1986; Orton 2006; Jerardino et al. 2009).
- 143

144 Lithic assemblages recovered from Verlorenvlei sites are overwhelmingly manufactured from quartz using 145 bipolar reduction techniques (Orton 2006:25). The relative abundance of 'exotic' raw materials in stone artifact 146 assemblages is often used to demonstrate shifts in settlement patterns of late Holocene west coast populations 147 (e.g. Parkington et al. 1988; Wahl 1994). The term 'exotic' may be variably defined (Orton 2004:93); here it is 148 understood to mean materials not readily available within a few hours' walk from a site. At Steenbokfontein and 149 Tortoise Cave, Jerardino et al. (2009) noted decreasing proportions of silcrete and hornfels in assemblages 150 dating after 3500 BP, suggesting that this pattern is indicative of intensified occupation of local, quartz-rich 151 areas and limited interaction with places where other materials are found more readily. Orton (2004:231) 152 likewise notes an increasing quartz component after 2000 BP in a number of Elands Bay localities (excluding 153 Elands Bay Cave), potentially indicating limited access to exotic raw materials following the introduction of 154 pastoralism to the area.

155

While approaches based on raw material abundances connect movement to the spatial distribution of geological sources, the actual locations of these sources are not always known (Orton 2006). At the same time, the overall numbers of exotic artifacts are low in many late Holocene deposits, making it difficult to make meaningful assessments of long-term trends. To build on these interpretations, we use the geometry of artifacts to assess local mobility by way of the cortex ratio: a measure of the separation of cortical surface relative to volume. This approach, described below, allows us to take advantage of the higher numbers of quartz artifacts found in Verlorenvlei assemblages in order to assess late Holocene settlement patterns as expressed across the landscape.

- 164 Materials and methods
- 165166 *Spring Cave*

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Spring Cave is a rock shelter located on a steep, north-facing slope on the Bobbejaansberg kopje approximately
500m from the Verlorenvlei estuary and about 500m from the Elands Bay coast (Fig 1A). A water seep allows
for some vegetation growth within the cave. The shelter itself measures about 20m wide and about 5m high (Fig

171 1B). The location provides a commanding view of the vlei and coast north of Baboon Point (Fig 1C). The lithic

172 composition of the shelter is primarily Piekenierskloof conglomerate, with quartz pebbles eroding actively from173 shelter walls.

Team 2020). Terrestrial samples were calibrated using the SHCal20 curve (Hogg et al. 2020), while marine samples were calibrated using the Marine20 curve (Heaton et al. 2020) with  $\Delta R$  offsets for the west coast of South Africa (Dewar et al. 2012).



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Figure 1 A) Location of Spring Cave in relation to other Verlorenvlei sites (*DFM* Dunefield Midden, *EBC* 

Elands Bay Cave, EC Eagle Cave, HSM Hailstorm Midden, MTM Mike Taylors Midden, PKM Pancho's
Kitchen Midden, RWM Railway Midden, TC Tortoise Cave); B) Front view of Spring Cave; C) North facing
view from Spring Cave

180

Excavations at Spring Cave were undertaken by a team from the University of Cape Town in 1984 in 2 non-adjacent 1 m<sup>2</sup> squares (D9 and I9). The excavated squares revealed a sequence of occupation layers with the densest concentrations of material culture objects falling between 764-341 1 sigma cal BP (Pta-4062 840±60 BP; Pta-4062 460±40 BP) and 3833-2967 1 sigma cal BP (Pta-4027 3510±60 BP; Pta-4033 2970±60 BP). The former corresponds to the post-pottery, post-pastoralism period immediately preceding European colonization and the latter to the millennium prior to a the 'megamidden' period of intensified era of shellfish use.

187

188 The outcomes of the Spring Cave excavations were not formally published, but are frequently cited in regional 189 reconstructions of west coast settlement patterns (e.g. Miller et al. 1995; Orton 2004, 2006; Jerardino et al. 190 2013; Parkington et al. 1988; Parkington 2012). In particular, Orton (2004, 2006) studied the lithic artifacts at 191 Spring Cave in terms of technology and raw material use in the wider context of Late Pleistocene and Holocene 192 archaeology at Elands Bay. Findings from the 1984 excavations were reviewed by Jerardino and colleagues 193 (2021), including a detailed description of stratigraphy and an analysis of faunal remains from the site.

195 Spring Cave lithics were accessed and analyzed at the University of Cape Town Department of Archaeology in 196 late 2019. In keeping with other studies using geometric proxies, only artifacts larger than 10mm in maximum 197 dimension were included in the study. Assemblages were divided into 2 temporal groups: >3000 BP, and <1000 198 BP. Artifacts found between layers Echo (~1013 cal BP; Pta-4035 1150±50 BP) and UDF (~3086 cal BP; Pta-199 4033 2970±60 BP) and those beneath and including layer Next Black 4 (~4270 cal BP; Pta-6226 3860±60 BP) 200 were left out of the analysis as they could not be reliably assigned to one of these periods within the late 201 Holocene; however, only 15 artifacts over the minimum size threshold are associated with these intervening 202 layers.

203204 *Cortex ratio* 

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The cortex ratio is a comparison between the amount of cortex (outer weathered surface) present in an
 archaeological assemblage and the cortex expected from that assemblage if all products of reduction were
 retained there (see Dibble et al. 2005; Douglass et al. 2008 for detailed descriptions). Ratio values that deviate

from 1 indicate that the amount of cortex has either been increased or decreased by the addition or removal of artifacts, suggesting regular movement to or from the assemblage location. Values close to 1 indicate that the net addition and subtraction of artifacts is balanced. While it is possible that regular transport of lithic artifacts over time results in a balance between input and output, this is more easily achieved when most artifacts produced locally are also discarded locally, suggesting limited movement between discard events.

214

215 The cortex ratio and other geometric measures depend on estimates of the average size of raw material nodules. 216 To accommodate this, measures of core reduction intensity from cortex proportion, as well as flake scar 217 frequency and orientation, have been developed (Braun 2006; Douglass 2010; Douglass et al. 2018). Other 218 applications use upper quartiles of remnant cores (e.g., Phillipps and Holdaway 2015) or maximum flake lengths 219 (Lin et al. 2015) to estimate original nodule dimensions. Each of these approaches was developed for 220 application to a particular material and/or technology being studied. However, they share a perspective of flakes 221 and cores as objects generally distinguishable by higher and lower ratios of cortical surface area to volume, 222 respectively. For bipolar-reduced, quartz-dominated assemblages, the chunky, fragmented nature of reduction 223 products makes such distinctions less useful for estimating average nodule size using the methods described 224 above (Diez-Martin 2011; de la Peña 2015; Spry et al. 2021). An analysis of cortex ratio using bipolar quartz 225 assemblages must therefore rely on other fragment attributes to estimate average nodule size. Here, we draw on 226 recent experimental work using the curvature of cortical pieces to reconstruct nodule size (Douglass et al. 2021).

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230 231 232

Figure 2. Illustration of lens clock use for measuring cobble curvature A) demonstrates measurement of cortical curvature with lens clock, note leg position indicating starting point of measure at nodule "end" B) close-up image showing derived measures from lens clock used to estimate radius of curvature.

A purpose-built lens clock (two-legged spherometer) was used to take curvature measurements on fragments
 with cortical surfaces. The lens clock used for our study was made using a Neoteck VTMNTK120 digital
 indicator consisting of a spring-pressured probe where the distance of plunge is displayed on a digital dial face

(resolution of 0.01mm, maximum measuring range 25.4mm). A drill press was used on a small block of wood to
make three holes, one through the block for inserting the probe and two of the same depth placed equidistant on
either side of the central hole into which small brad nails were placed (Fig 1). Combined, the holes are aligned
in a straight row and plumb to the wood block with the probe slightly higher than the two legs. When placed on
a round surface, the legs remain constant while the probe is plunged inward.

241

242 Measurements of curvature taken using a lens clock can be translated into a spherical radius estimate, which we
243 use here as a model of average nodule size. The equation for the radius of curvature is:
244

 $r = \frac{Y^2}{2S} + \frac{S}{2}$ 

246

263

Where *Y* equals the distance between each leg and the probe tip (half the distance between legs) and *S* equals thedifference in depth between the probe and the legs.

Lens clock readings were then taken over the cortical surface of cortex-bearing fragments in each assemblage.
 Measurements were taken at 1cm increments in a grid-like fashion, first oriented to the longest axis of the core
 or fragment and then perpendicular to this axis, to provide even coverage of the surface (see SI Appendix 1). All

252 measures taken from cortical fragments in an assemblage are then averaged, the result being directly

253 proportional to the radius of the cobble(s) from which it was produced. Experimental validation using irregular

254 quartz pebbles demonstrated close agreement (mean radius deviation ~15%) between the average radius of

unworked nodules and lens clock-derived estimates from cortical fragments following reduction (see Douglasset al. 2021 for additional details).

To calculate cortex ratios using this value, average radii obtained from measured fragments were converted into
 nodule volumes using the equation for a sphere:

$$V = \frac{4}{3}\pi r^3$$

260 The average of these volumes was then used as the average reconstructed nodule volume, and this was used to calculate the average reconstructed nodule surface area:

262 
$$A = \pi^{\frac{1}{3}} (6V)^{\frac{2}{3}}$$

- 264 The entire process, from artifact measurement to cortex ratio calculation, is as follows:
- For each artifact in the assemblage, record the identification number, horizontal unit, vertical unit, raw material, cortical surface percentage (estimated at 10% intervals), maximum length (mm), maximum width (mm), maximum thickness (mm), and weight (g).
- 268
  2. For artifacts with cortical surface large enough to measure (that is, with a maximum dimension greater than the distance 2*Y* in Fig 2), take lens clock readings at 1 cm intervals, first parallel to the axis of maximum dimension along transects spaced 1 cm apart; then, if possible, perpendicular to it, with the lens clock legs set astride the transect. For each lens clock reading, in a separate table, record identification number of artifact (corresponding to step 1), 2*Y* and *S* (distance travelled by digital indicator). See SI Appendix 1 for more details.
- For each unique artifact measured with the lens clock, use the mean of the *S* values and half the value of 2*Y* to calculate an average radius using Eq. 1 above. Use each r to calculate nodule volume estimates using Eq. 2. Take the mean of all volume estimates as the theoretical average nodule volume (*V*) and calculate the theoretical average nodule surface area (*A*) using Eq 3.
- 4. For each analytical group of artifacts (e.g. <1000 BP) take the sum of artifact weight values and divide by raw material specific density (e.g. 2.65 for quartz) to calculate assemblage volume. Divide this by the theoretical average nodule volume (V) to obtain the estimated number of nodules and multiply this by the theoretical average nodule surface area (A) to calculate expected cortical surface.</li>

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percentage of cortical surface to obtain the cortical surface area. Sum these values to obtain the 284 observed cortical surface area for the analytical group. Divide observed cortical surface by expected 285 cortical surface area to calculate the cortex ratio.

5. For each artifact in the analytical group, multiply the 2D surface area (max. length x max. width) by the

287 Following the calculation of cortex ratios, a series of tests were conducted to assess statistical confidence (Lin et 288 al. 2015). All data analyses were conducted using the R statistical computing platform (R Core Team 2020). 289 Code and documentation can be found in an electronic supplement.

#### 291 Results

292

290

293 Analyzed assemblages consisted principally of chipped quartz, which can be sourced locally as conglomerate 294 pebbles, and smaller components of quartzite, silcrete, and hornfels (Table 1). While vein quartz sources are 295 available from Table Mountain Sandstone landforms in region, these are thought to be limited (Orton 2006), and 296 all of the quartz fragments studied here has maximum dimensions consistent with pebble reduction.

297

Group	Quartz	Quartzite	Silcrete	Hornfels	Other	Total
SC <1000 BP	273	46	6	2	1	328
SC >3000 BP	257	33	16	3	14	323

299

300

301 A total of 552 curvature measurements were taken from 48 quartz fragments that a) possessed cortical surface 302 and b) had enough surface area from which to take readings. Of the measured fragments, only those with 5 or 303 more curvature measurements (n=18) were used in the reconstruction of average nodule radius as lower 304 numbers of readings can produce extreme values (Douglass et al. 2021). Among the included fragments, a final 305 total of 483 measurements were used, and the mean number of readings for the included fragments was 26.83. 306 The values for mean curvature-derived radius, as well as volume and surface area estimates for reconstructed 307 nodules, are presented in Table 2.

308

309 Table 2 Cortical surface curvature estimates for Spring Cave artifacts

Site	No. of measured fragments	No. of curvature measurements	Mean curvature- derived nodule radius (mm)	Reconstructed nodule volume (mm <sup>3</sup> )	Reconstructed nodule surface area (mm <sup>2</sup> )
Spring Cave	18	483	$29.9 \pm 15.2$	58900	7321.6

310

311 The mean nodule radius derived from curvature estimates on archaeological fragments (29.9 mm) gives a

312 diameter of 59.8 mm, which is in close agreement with previous assessments of raw materials available as clasts 313 in the local Piernierskloof formation conglomerate (e.g., Rust 1967; Bordy et al. 2016). For example, Bordy and 314 colleagues (2016) found an average clast size of 56 mm across sampling sites from Elands Bay to Doring Bay, 315 with Elands Bay sites showing similar average values to that produced here. Among the measured fragments 316 themselves, the maximum dimension was 54 mm, also falling within the range of average clast sizes for the region.

317 318

319 While the two Spring Cave assemblages had comparable numbers of artifacts, those from the <1000 BP window 320 had nearly twice the volume of those from >3000 BP. This resulted in substantially different estimates for

321 expected surface area observed between the two groups (Table 3). The <1000 BP group had a cortex ratio of

322 0.56, notably lower than the baseline value of 1, while the >3000 BP group had a cortex ratio of 1.00.

323

Assemblage	<b>n</b> <sub>quartz</sub>	Total Volume (mm <sup>3</sup> )	Expected Surface Area (mm <sup>2</sup> )	Observed Surface Area (mm <sup>2</sup> )	Cortex Ratio
<1000 BP	273	248947.2	30940.7	17451.9	0.56
>3000 BP	249	103698.1	12888.3	12724.2	1.00

324 Table 3 Volume, surface area, and cortex ratio estimates for Spring Cave assemblages

325 326

327 Following Lin et al. (2015), we assessed these assemblages in terms of whether they deviate significantly from 1 328 and the extent to which they can be reliably shown to be different from one another. In the first case, we 329 generated 10,000 simulated assemblages from fragments randomly sampled from an experimental dataset of 20 330 quartz cobbles reduced using the bipolar technique, with cortex ratios calculated using the lens clock method 331 ("Heavy Reduced Quartz" in Douglass et al. 2021). Sample sizes were matched to the number of artifacts in 332 each temporal grouping. Given that the experimental data include all fragments from reduced cobbles, the cortex 333 ratios produced from these assemblages approximate 1. To achieve a two-sided probability, simulated and 334 observed cortex ratios were log transformed. The <1000 BP assemblages were found to be significantly 335 different from the mean of their corresponding simulated distribution at a 0.05 threshold. The >3000 BP 336 assemblage, with a cortex ratio of 1.00, could not be differentiated statistically from simulated "complete" 337 assemblages.





339

Figure 3 Histograms of log-transformed cortex ratios generated using randomly sampled artifacts from a
 "complete" experimental assemblage. Dotted line indicates difference between log-transformed observed cortex
 ratios and 0 for two-tailed probability.

343

344 To assess the likelihood that the artifact groups studied here were drawn from the same population, we used a 345 Monte Carlo resampling routine where the combined artifacts from two layers are randomly divided into two 346 groups equaling the number of artifacts in each layer. Cortex ratios are then calculated for each group, and the 347 difference between the two is taken. This process is repeated 10,000 times to generate a sampling distribution, 348 and the true difference between the two layers is compared, using p=0.05 as a threshold for significance. For

349 Spring cave, the difference in cortex ratios between the two layers is 0.44, well outside that produced by the

350 Monte Carlo resampling, with a corresponding *p*-value of less than 0.001.

351



Cortex Ratio Difference

352

357

Figure 4 Histogram of differences in cortex ratios between Monte Carlo resampled lithic artifact groups from
 Spring Cave. Dotted lines indicate observed difference between groups for two-tailed probability (±0.44).

#### 356 Discussion

Understanding mobility in the past, particularly as it relates to environments and subsistence changes, is fundamental for interpreting human evolution and cultural change. Building this understanding requires reliable indicators of movement in the past that can be applied across a wide range of archaeological contexts. The inferences derived from this study of lithic geometry provide a means to derive information about mobility from a widely available archaeological proxy (quartz artifacts) that complements data obtained from site densities and deposition rates, frequencies of exotic lithics, stable isotopes, etc.

364 365 The difference in cortex ratios from Spring Cave between >3000 BP and <1000 BP is striking, especially given 366 the otherwise similar qualities of the lithic assemblages. For the earlier window, a cortex ratio close to 1 is 367 suggestive of nearly complete quartz reduction sets. The period of greatest accumulation at Spring Cave during 368 that time is consistent with the onset of increased population and territoriality along the west coast generally 369 (Sealy 2016). Spring Cave, with its easy access to the productive coast, panoramic view, and ready source of 370 quartz for artifact manufacture, would make an attractive location for this kind of settlement. While movements 371 certainly occurred during this time, as indicated by the presence of mollusc shells and non-local lithic material 372 transported to the site, they may not have been occurring with enough frequency to remove or add substantial 373 amounts of cortical quartz.

374

375 During the later phase, the cortex ratio at Spring Cave drops to ~0.56, indicating that more cortex is leaving 376 Spring Cave than is being brought into it, and suggests greater mobility relative to the >3000 BP period of 377 occupation. There are several existing interpretive frameworks that might account for increased mobility during 378 the last millennium. The arrival and growth of herding around or just after 2000 BP would likely have disrupted 379 the lifeways of resident forager populations, potentially pushing them into marginal habitats (Smith 1998). It is 380 also possible that fixed resource bases became either less accessible or less productive, necessitating a more 381 opportunistic approach to resource acquisition that involved frequent movement (Jerardino et al. 2009; 382 Parkington 2016). In any of these cases, the result would almost certainly be more rather than less movement 383 during this period. The evidence offered by the cortex ratio values from Spring Cave suggests that cortical 384 material has been removed from the assemblage or non-cortical material has been carried into it (or both), which 385 is consistent with increased mobility overall during this period.

386

387 The cortex ratio is useful as a measure of movement because it is sensitive to the separation of volume and 388 cortical surface area in flaked stone assemblages. However, because the Spring Cave excavations are limited to 389 two square meter test pits, it is possible that artifacts from the remaining deposit might shift these values and 390 thus scuttle the above interpretation. The material from the excavations undertaken so far is not very useful for 391 evaluating intra-site spatial variability in assemblage composition: all of the pre-3000 BP quartz artifacts were 392 recovered from the I9 unit, and almost all of the post-1000 BP quartz artifacts were recovered from the D9 unit. 393 Kolmogorov-Smirnov tests comparing the small number of post-1000 BP quartz artifacts from the I9 unit 394 (n=20) with those from the D9 unit (n=253) detected no clear difference in terms of artifact weight (D = 395 0.27668, p-value = 0.1171) or cortical surface area (D = 0.24447, p-value = 0.2179). On a conceptual level, as 396 the assemblage size increases, the ratio value becomes more robust to the influence of individual artifact 397 contributions and reflects the 'average' of lithic discard behavior at a given location over the period of 398 accumulation (Parkington 1993; Davies et al. 2021). For artifacts from the unexcavated portion of the Spring 399 Cave deposit to shift the present cortex ratios to values that would change the interpretation, the character of the 400 unexcavated assemblage would have to be systematically different across a very small area.

401

402 For this study, we developed an estimate of average nodule size using combined cortical fragments regardless of 403 their temporal associations. This gave us a larger sample of cortical fragments to use in our estimate but gives 404 the study an in-built assumption that raw material size is not a driving factor in the observed differences in 405 cortex ratios between time periods. Such an assumption may not always be warranted, especially for instances 406 where higher levels of mobility are suspected that might bring an individual into contact with a wider range of 407 raw material sources. This can be investigated by generating assemblage-specific estimates. While differences in 408 raw material sizes are suggested between the pre-3000 BP and post-1000 BP assemblages from Spring Cave, 409 their impact on the resultant cortex ratios is minimal (see SI Appendix 2). This provides additional support for 410 the outcome of the study and its wider applicability. In future studies using this method, the impact of temporal 411 variability in raw material characteristics should likewise be investigated.

412

413 While the current study is suggestive of changing use of the Spring Cave site between the two periods studied. 414 these are single instances from a continuum of underlying values expressed across the landscape, and the extent 415 to which these patterns are unique to Spring Cave or reflect the broader trends in the region is not yet known. 416 For example, the ratio value close to 1 recorded for the >3000 BP assemblage may be most parsimoniously 417 explained through limited transport of lithics, but it could be that this is an outlier among a distribution of values 418 from similarly aged deposits that is more consistent with frequent movement. Developing the picture of mobility 419 in the past will require expanding the analysis to a wider range of sites. The collective properties of cortex ratios 420 expressed across a landscape can be used to inform on broad-scale use of space (Rezek et al. 2020). An 421 instructive example comes from semi-arid Australia, where cortex ratios obtained from late Holocene surface 422 assemblages vary between values close to 0 and values greater than 1, but in aggregate exhibit regularities that 423 indicate repeated visitation and regular transport of cortical flakes (Holdaway et al. 2019). Computer 424 simulations have been used to contextualize these findings in terms of different configurations of mobility 425 (Davies et al. 2018; Holdaway and Davies 2019), showing that when cortex ratios are juxtaposed with density, 426 they can be used to differentiate between collections of assemblages generated by variable occupation intensity 427 or frequency of visitation (Davies et al. 2021).

428

429 The Spring Cave case study provides a proof-of-concept for a methodological approach that could be deployed 430 more widely in areas where quartz lithic technology is predominant (Orton 2006), permitting comparative 431 assessment of movement between many localities and time periods. For the west coast of South Africa in 432

particular, this study lacks a sample occurring between 3000 and 2000 BP, which is considered to be the height 433 of the megamidden phenomenon. Comparisons of cortex ratios between inland and coastal assemblages dated

434 before, during, and after the period of intense midden-building could help to resolve questions related to

435 changes in settlement patterns and socioeconomic organization (e.g. Parkington 2016; Parkington et al. 2020,

436 2021; Jerardino 2021; Jerardino et al. 2013). It is also easy to imagine how an approach such as this could be

437 applied fruitfully to lithic scatters such as those found in deflation hollows that occur across the landscape north

438 of Verlorenvlei (Manhire 1987) in order to explore spatial variability in movement patterns. This is to say

439 nothing of the extensive Pleistocene record present throughout the region, for which this approach would also be

440 useful for understanding settlement arrangements.

441

#### 442 Conclusions

443

452

444 This study illustrates the adaption of the cortex ratio to bipolar quartz assemblages using estimates of cortical 445 surface curvature and applies it to the late Holocene assemblages at Spring Cave. There are interesting parallels 446 between the cortex ratio values from Spring Cave and other indicators of mobility identified in the late Holocene 447 record from Verlorenvlei. In particular, the ratios suggest a shift from a less mobile coastal settlement prior to 448 3000 BP to a more mobile arrangement after 1000 BP. This interpretation is preliminary, and additional 449 assemblages will need to be assessed before this pattern can be determined to be meaningful for the area more 450 broadly. The approach presented here offers a means to address mobility in archaeological assemblages like 451 those from Verlorenvlei where bipolar-reduced quartz is a predominant feature.

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459 460

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