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

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Abstract

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

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

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Conflicts of interest/Competing interests

Not applicable

Availability of data and material

All data used in this manuscript are available at https://doi.org/10.5281/zenodo.6247712

Code availability

Analysis was conducted using the R programming platform (https://www.r-project.org/). Code used in this manuscript is available at https://doi.org/10.5281/zenodo.6247712

Author contributions

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

Introduction

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

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

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

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

Background

Verlorenvlei is an estuarine lake at the mouth of the Verlorenvlei River (alt. Verloren River) at Elands Bay (Fig 1). The Atlantic coastline north and south of the vlei is mainly sandy beaches with occasional rocky sandstone outcrops. Moving eastward from the shore, the area immediately around Verlorenvlei comprises linear coastal dunes flanked by strandveld vegetation communities. Further inland, the strandveld gives way to low, undulating sandveld fynbos punctuated with sandstone inselbergs, eventually rising to the foothills of the Cederberg Mountains where the main tributaries originate.

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

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

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

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

[1] Radiocarbon determinations in this study are presented as median values of calibrated ages before present, with raw radiocarbon ages presented in parentheses, e.g. ~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

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 reliant on foraging (Sadr 2003). In either case, the introduction of novel subsistence practices would almost certainly have resulted in further reorganization of ecological relationships within the region (Parkington et al. 1986; Orton 2006; Jerardino et al. 2009).

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

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.

Materials and methods

Spring Cave

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 1B). The location provides a commanding view of the vlei and coast north of Baboon Point (Fig 1C). The lithic composition of the shelter is primarily Piekenierskloof conglomerate, with quartz pebbles eroding actively from 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 ΔR offsets for the west coast of South Africa (Dewar et al. 2012).

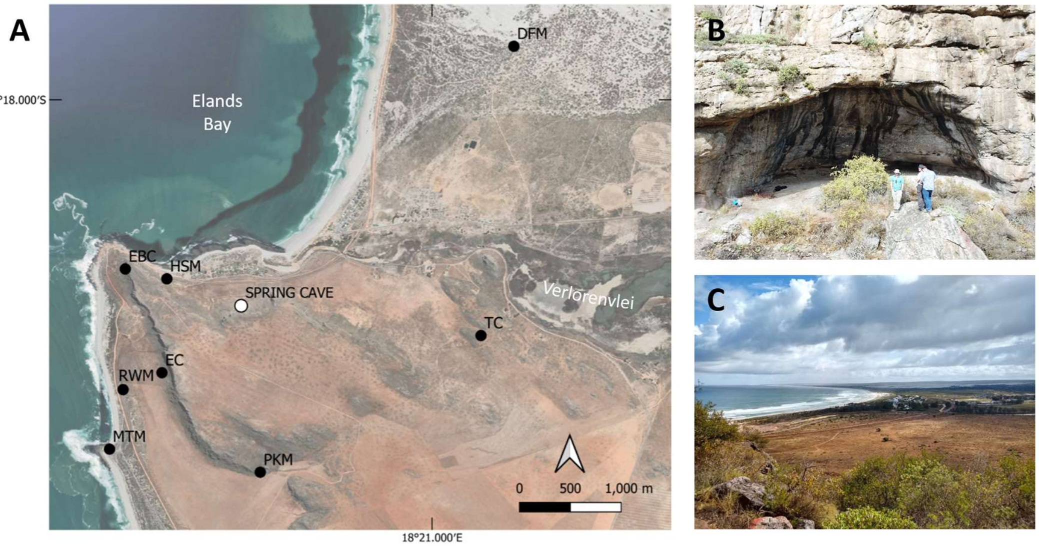

Figure 1 A) Location of Spring Cave in relation to other Verlorenvlei sites (*DFM* Dunefield Midden, *EBC* Elands Bay Cave, *EC* Eagle Cave, *HSM* Hailstorm Midden, *MTM* Mike Taylors Midden, *PKM* Pancho's Kitchen Midden, *RWM* Railway Midden, *TC* Tortoise Cave); B) Front view of Spring Cave; C) North facing view from Spring Cave

Excavations at Spring Cave were undertaken by a team from the University of Cape Town in 1984 in 2 non-adjacent 1 m^2 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.

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

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

Cortex ratio

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.

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

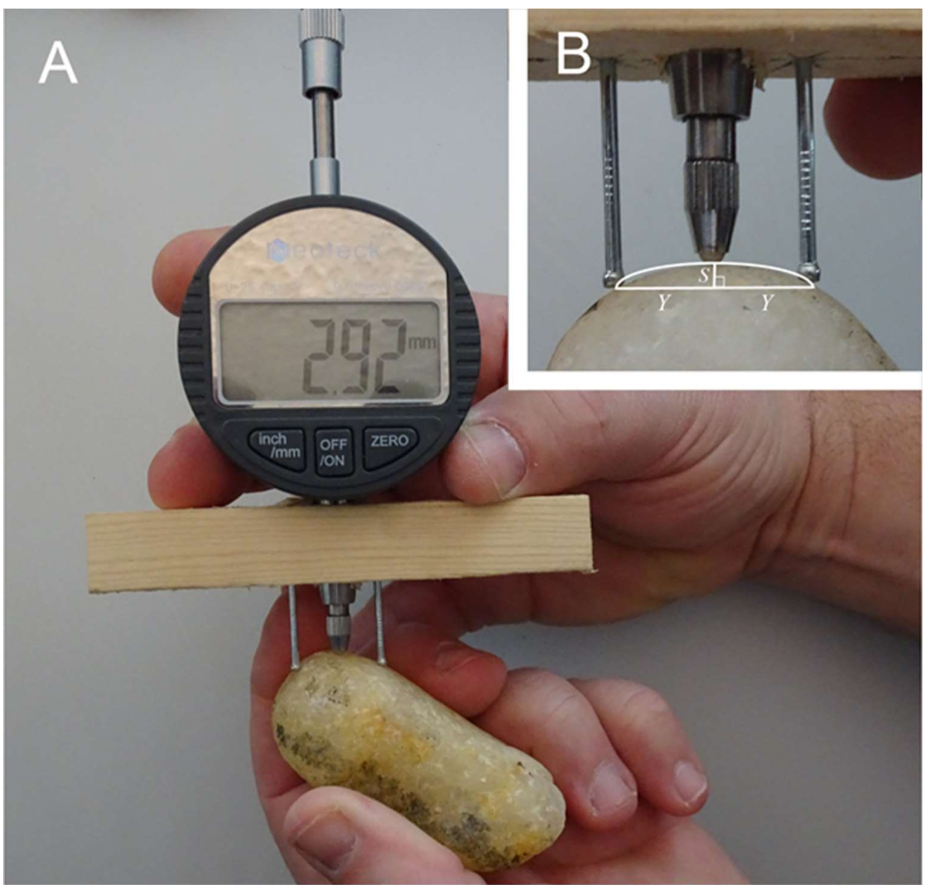

Figure 2. Illustration of lens clock use for measuring cobble curvature A) demonstrates measurement of cortical curvature with lens clock, note leg position indicating starting point of measure at nodule “end” B) close-up image showing derived measures from lens clock used to estimate radius of curvature.

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.

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

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

Where Y equals the distance between each leg and the probe tip (half the distance between legs) and S equals the difference 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 measures taken from cortical fragments in an assemblage are then averaged, the result being directly proportional to the radius of the cobble(s) from which it was produced. Experimental validation using irregular 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 Douglass et 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:

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

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:

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

The entire process, from artifact measurement to cortex ratio calculation, is as follows:

1. 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).
2. For artifacts with cortical surface large enough to measure (that is, with a maximum dimension greater than the distance $2Y$ 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), $2Y$ and S (distance travelled by digital indicator). See SI Appendix 1 for more details.
3. For each unique artifact measured with the lens clock, use the mean of the S values and half the value of $2Y$ 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.

5. For each artifact in the analytical group, multiply the 2D surface area (max. length x max. width) by the percentage of cortical surface to obtain the cortical surface area. Sum these values to obtain the observed cortical surface area for the analytical group. Divide observed cortical surface by expected cortical surface area to calculate the cortex ratio.

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

Results

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

Table 1 Raw materials for Spring Cave lithic assemblages (all fragment classes)

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

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

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^3)**	**Reconstructed nodule surface area (mm^2)**
Spring Cave	18	483	29.9 ± 15.2	58900	7321.6

The mean nodule radius derived from curvature estimates on archaeological fragments (29.9 mm) gives a diameter of 59.8 mm, which is in close agreement with previous assessments of raw materials available as clasts in the local Piernierskloof formation conglomerate (e.g., Rust 1967; Bordy et al. 2016). For example, Bordy and colleagues (2016) found an average clast size of 56 mm across sampling sites from Elands Bay to Doring Bay, with Elands Bay sites showing similar average values to that produced here. Among the measured fragments themselves, the maximum dimension was 54 mm, also falling within the range of average clast sizes for the region.

While the two Spring Cave assemblages had comparable numbers of artifacts, those from the <1000 BP window had nearly twice the volume of those from >3000 BP. This resulted in substantially different estimates for expected surface area observed between the two groups (Table 3). The <1000 BP group had a cortex ratio of 0.56, notably lower than the baseline value of 1, while the >3000 BP group had a cortex ratio of 1.00.

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

Assemblage	n_{quartz}	**Total Volume (mm^3)**	**Expected Surface Area (mm^2)**	**Observed Surface Area (mm^2)**	**Cortex Ratio**
<1000 BP	273	248947.2	30940.7	17451.9	0.56
>3000 BP	249	103698.1	12888.3	12724.2	1.00

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

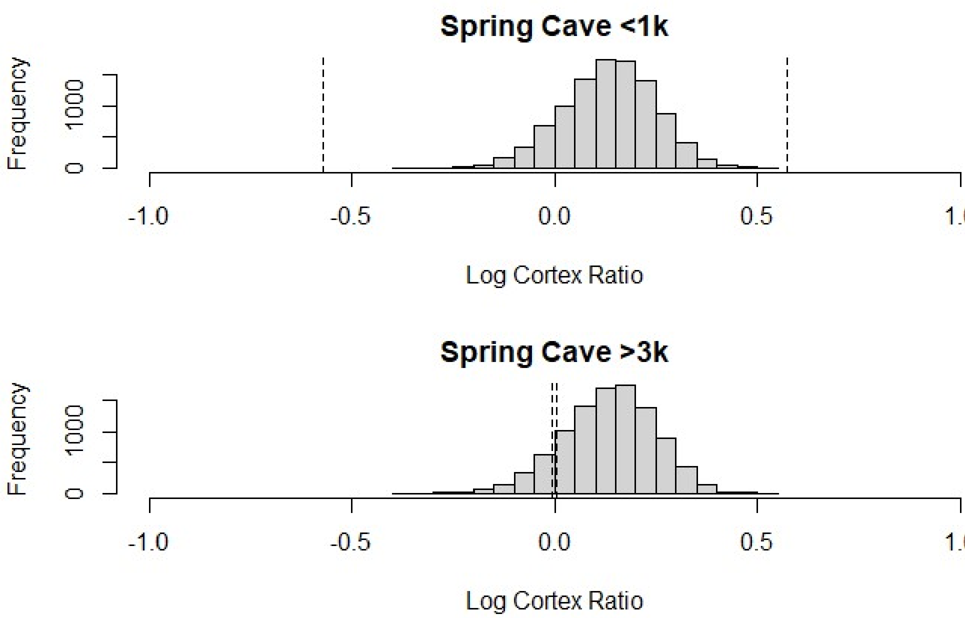

Figure 3 Histograms of log-transformed cortex ratios generated using randomly sampled artifacts from a "complete" experimental assemblage. Dotted line indicates difference between log-transformed observed cortex ratios and 0 for two-tailed probability.

To assess the likelihood that the artifact groups studied here were drawn from the same population, we used a Monte Carlo resampling routine where the combined artifacts from two layers are randomly divided into two groups equaling the number of artifacts in each layer. Cortex ratios are then calculated for each group, and the difference between the two is taken. This process is repeated 10,000 times to generate a sampling distribution, and the true difference between the two layers is compared, using *p*=0.05 as a threshold for significance. For Spring cave, the difference in cortex ratios between the two layers is 0.44, well outside that produced by the Monte Carlo resampling, with a corresponding *p*-value of less than 0.001.

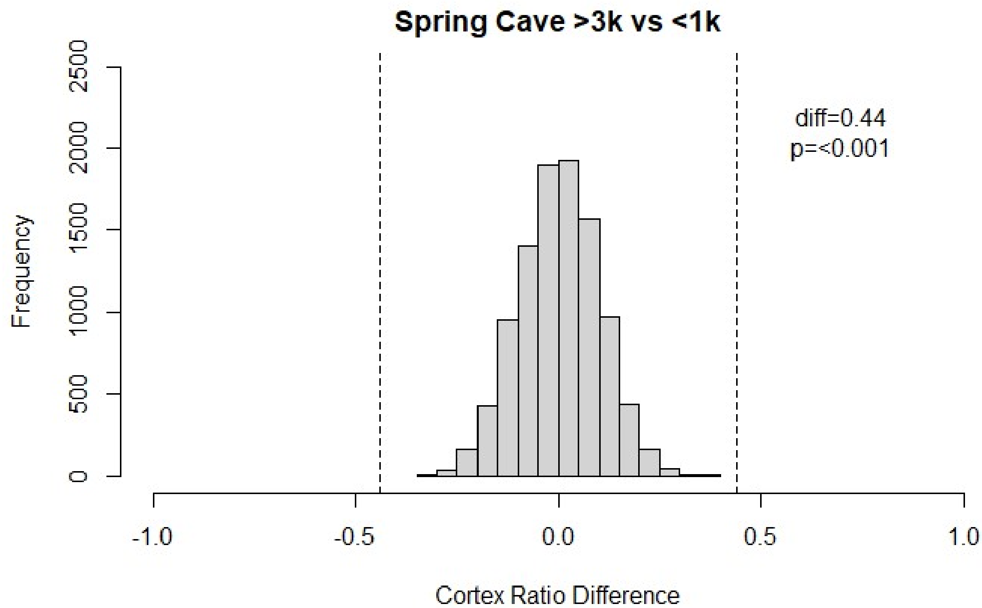

Figure 4 Histogram of differences in cortex ratios between Monte Carlo resampled lithic artifact groups from Spring Cave. Dotted lines indicate observed difference between groups for two-tailed probability (±0.44).

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.

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

During the later phase, the cortex ratio at Spring Cave drops to ~0.56, indicating that more cortex is leaving Spring Cave than is being brought into it, and suggests greater mobility relative to the >3000 BP period of occupation. There are several existing interpretive frameworks that might account for increased mobility during the last millennium. The arrival and growth of herding around or just after 2000 BP would likely have disrupted the lifeways of resident forager populations, potentially pushing them into marginal habitats (Smith 1998). It is also possible that fixed resource bases became either less accessible or less productive, necessitating a more opportunistic approach to resource acquisition that involved frequent movement (Jerardino et al. 2009;

Parkington 2016). In any of these cases, the result would almost certainly be more rather than less movement during this period. The evidence offered by the cortex ratio values from Spring Cave suggests that cortical material has been removed from the assemblage or non-cortical material has been carried into it (or both), which is consistent with increased mobility overall during this period.

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

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

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

The Spring Cave case study provides a proof-of-concept for a methodological approach that could be deployed more widely in areas where quartz lithic technology is predominant (Orton 2006), permitting comparative assessment of movement between many localities and time periods. For the west coast of South Africa in particular, this study lacks a sample occurring between 3000 and 2000 BP, which is considered to be the height of the megamidden phenomenon. Comparisons of cortex ratios between inland and coastal assemblages dated before, during, and after the period of intense midden-building could help to resolve questions related to changes in settlement patterns and socioeconomic organization (e.g. Parkington 2016; Parkington et al. 2020, 2021; Jerardino 2021; Jerardino et al. 2013). It is also easy to imagine how an approach such as this could be applied fruitfully to lithic scatters such as those found in deflation hollows that occur across the landscape north of Verlorenvlei (Manhire 1987) in order to explore spatial variability in movement patterns. This is to say nothing of the extensive Pleistocene record present throughout the region, for which this approach would also be useful for understanding settlement arrangements.

Conclusions

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

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