Evaluating erosional impacts on open-air archaeological sites along the Doring River, South Africa: methods and implications for research prioritization

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Abstract
Open-air sites in arid and semi-arid landscapes are often subject to prolonged periods of exposure and episodes of erosion that can lead to the redistribution of artefacts and the loss of behaviorally significant spatial information. This is true along the Doring River, South Africa, where archaeologically rich sediment stacks with records exceeding 200,000 years are undergoing rapid erosion in response to modern climatic conditions and land use practices. This paper evaluates the impacts of past and future erosion on the disaggregation of artefacts from these open-air sites and the resulting loss of stratigraphic context and behaviorally significant spatial information. We use low elevation aerial images of the Klein Hoek 1 locality captured by an unmanned aerial vehicle (UAV) to develop a high-resolution local digital terrain model (DTM), which we use to model surface flow paths and quantify the potential for future sediment loss using the Revised Universal Soil Loss Equation (RUSLE). We compare the results of these analyses to the distribution of artefacts of different ages to assess artefact dispersion and to guide future research priorities at the locality. We find that some artefact clusters retain significant spatial integrity, whereas others are dispersed and likely out of primary context. The results also indicate that the geomorphic stability of a large part of Klein Hoek 1 has been compromised by erosion, with limited prospects for long-term survival given the present climate and land use practices.

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Abstract

Open-air sites in arid and semi-arid landscapes are often subject to prolonged periods of exposure and episodes of erosion that can lead to the redistribution of artefacts and the loss of behaviourally significant spatial information. This is true along the Doring River, South Africa, where archaeologically-rich sediment stacks with records exceeding 200 000 years are undergoing rapid erosion in response to modern climatic conditions and landuse practices. This paper evaluates the impacts of past and future erosion on the disaggregation of artefacts from these open-air sites and the resulting loss of stratigraphic context and behaviourally significant spatial information. We use low elevation aerial images of the Klein Hoek 1 locality captured by an unmanned aerial vehicle (UAV) to develop a high-resolution local digital terrain model (DTM), which we use to model surface flow paths, and quantify the potential for future sediment loss using the Revised Universal Soil Loss Equation (RUSLE). We compare the results of these analyses to the distribution of artefacts of different ages to assess artefact dispersion, and to guide future research priorities at the locality. We find that some artefact clusters retain significant spatial integrity, whereas others are dispersed and likely out of primary context. The results also indicate that the geomorphic stability of a large part of Klein Hoek 1 has been compromised by erosion, with limited prospects for long-term survival given present climate and landuse practices.

Keywords: Open-air sites; Southern Africa; Middle Stone Age; Later Stone Age; Revised Universal Soil Loss Equation (RUSLE); Archaeological GIS; Nearest-neighbour

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1. Introduction

Globally, open-air localities comprise the majority of archaeological sites. In Stone Age studies, however, there is often disproportionate emphasis on archaeological remains found in caves and rock shelters. This is particularly true in southern Africa, where erosional or slowly aggrading landscapes contrast with the relatively rapid accumulation and subsequent stability of sediments in rock shelters. Though a focus of considerable research attention, the Stone Age archaeological record of southern Africa is thus skewed in favour of those infrequent, sheltered locations in which the preservation of materials and stratified sequences is relatively good (though see (Sampson 1985; Fisher et al. 2013; Kandel and Conard 2013; Oestmo et al. 2014; Sampson et al. 2015; Hallinan and Parkington 2017)).

This focus on rock shelters in the region reflects pragmatic research practice. Research funds are finite, and locations with stratified deposits in which organic materials are preserved provide a far higher informative return on expenditure of time and money than deflated, diffuse scatters lacking organic items. To the extent that archaeologists are optimal information foragers, we should rank such sites highly. This approach, however, creates a problem: if the bulk of the record occurs in the open, and yet our research focus is on rock shelters, we are necessarily sacrificing the majority of available information in our reconstructions of the past. We are also making the problematic assumption that this focus on samples from rare and geologically-specific contexts is not introducing systematic bias in those reconstructions.

The archaeology of the Doring River in the Western Cape of South Africa exemplifies this problem. Though the area has many archaeologically-rich rock shelters (Saktura et al. In Prep; Högberg and Larsson 2011; Will et al. 2015; Mackay et al. 2019) and open-air localities (Shaw et al. 2019) with records extending into the Pleistocene, there is a persistent mismatch between the open-air and rock shelter records which suggests that neither on its own retains a representative subset of past behaviours (Mackay et al. 2014, 2018).

However, the open-air localities in the Doring River catchment are highly erosional under present conditions, and experimental evidence suggests that even brief periods of surface exposure under these conditions will result in rapid disaggregation of scatters, particularly for the smaller-sized artefacts (Phillips et al. 2018). In order to develop a full depiction of the human past in the Doring River catchment, we need to make use of the available open site data, but first we need to understand which scatters retain integrity, which have been dispersed, and which are under imminent threat of disaggregation.

Answering these questions will not only allow us to understand the quality of the information that is preserved, but will provide insight into localities and the scatters within them that need to be prioritised given finite research time and impending loss of further information.

In this paper, we employ a range of methods to assess the integrity of surface-exposed material at the open-air locality Klein Hoek 1 and its sensitivity to current and future erosional processes. Following Howland et al. (2018), we use imagery derived from low elevation unmanned aerial vehicle (UAV) flights to construct a high-resolution local land surface model for the locality. We apply classification algorithms to remove vegetation from the UAV-derived point cloud, resulting in a digital terrain model (DTM) to which we first apply stream network analysis to assess likely flow paths of artefacts across the surface, and subsequently the Revised Universal Soil Loss Equation (RUSLE) to evaluate erosional sensitivities. In the context of these surfaces and processes, we assess the clustering and dispersion patterns of like-aged artefacts using nearest neighbour analysis of mapped cores and tools. Finally, we aggregate the data from these approaches to evaluate the likely past
2. The archaeology of Klein Hoek 1

The Doring River is a large seasonal river located in the Western Cape of South Africa (Figure 1), in what is currently the Winter Rainfall Zone (Chase and Meadows 2007). The lower reaches of the river follow a narrow gorge deeply incised into the local sandstone and shale geology, with the surrounding plateaux 250-350 m higher than the river valley. The catchment of the Doring River is semi-arid, with rainfall typically <250 mm per year. Local vegetation is relatively sparse, consisting of low shrubs and succulents of the Fynbos and Succulent Karoo biomes, the boundary of which falls within the catchment (Mucina and Rutherford 2006). As the major regional water source, the Doring River has been a focus of human occupation since at least the Middle Pleistocene (Shaw et al. 2019).

![Fig 1 Location of the Klein Hoek 1 study area: (A) Klein Hoek 1 archaeological survey area and the surrounding landscape; (B) Doring River catchment and the location of Klein Hoek 1; (C) Regional context of the Doring River watershed and Klein Hoek 1](image)

Archaeological material occurs along the Doring River on a series of isolated sediment stacks produced by aeolian and fluvial processes, and comprising a mix of loose sands, indurated sands, and calcrete horizons in various stages of development. Available OSL and uranium series ages on the sands and carbonates place the formation of sediment units between ~200 ka and the last century (Mackay et al. 2014; Shaw et al. 2019), though periods of accumulation were likely discontinuous. Archaeological material on these stacks covers all known phases of the archaeological record in this part of southern Africa, and extends into the Middle Pleistocene in some cases (Bleed et al. 2017). Many of these sediment stacks are highly erosional at present, and an experiment we conducted in 2014-2016 suggest that surface exposure of artefacts over even brief periods of time would likely result in disaggregation of assemblages and their relocation over tens of metres (Phillips et al. 2018).

In spite of this erosion, archaeological material on the Doring River sediment stacks occasionally exhibits remarkable clustering, consistent with recent exposure of previously buried behavioural aggregates (Barton and Riel-Salvatore 2014). A particularly good
example of this distributional pattern is present at the locality Klein Hoek 1 or KH1. KH1 is
located at the western (downstream) end of a long point bar on the Doring River (Figure 1).
The basal landform is a cobble bed that formed prior to downcutting of the current river
channel, and which likely protected the subsequently accumulating aeolian sediments from
eroison during channel migrations. Overlying the cobble bed is a series of loose and
indurated aeolian sands pushed up against the scree of the lower gorge, which in some
places forms a reasonably consistent slope from the scree to the overbank area of the
current river channel (Figure 2). The presence of colluvium on the sediment stack,
particularly at the western end, reflects the connection of the sediment stack and the
adjacent slope in the past, although an incised drainage channel at the southwest margin
now separates these two landforms. Archaeological material is dense across the surface of
KH1, with the only exceptions being the remnant vegetated areas that preserve loose upper
dune sands. The link between grazing, vegetation loss and erosion here is clear:
immediately east of the exposed archaeology is a fence-line beyond which the vegetation is
intact, erosion is limited, and no archaeology is visible. Given these observations, we can
infer that at least some of the erosion that has exposed and begun to destroy the
archaeological integrity of KH1 postdates the fence-line and is relatively recent.

Mapping of artefacts at KH1 (methods discussed further in the next section) was undertaken
in 2018, concentrating on cores and tools (Ames et al. In Press; Shaw et al. 2019). In total
6747 artefacts were mapped, during which we noted that artefacts associated with different
periods of time displayed different patterns of distribution, including those from the Earlier
Stone Age (ESA), Middle Stone Age (MSA) and Later Stone Age (LSA). Artefacts from some
technocomplexes, such as the Still Bay (75-71 ka; Jacobs et al. 2008; Högberg and Larsson
2011) appeared to be very strongly clustered, while others, such as the post-Howiesons
Poort (58-50 ka) and Later MSA (50-25 ka), appeared more widely dispersed. This pattern of
variable clustering coupled with strong evidence for recent erosion led us to explore the
relationship between erosion and artefact clustering, the susceptibility of sediments to future
erosion, and the future research potential of artefacts on the sediment stack.

3. Methods

3.1 UAV Imagery and Ground Control Point Acquisition

Aerial imagery of KH1 was acquired in 2018 using a DJI Mavic Pro semi-autonomous drone
flying a pre-defined flight path at 40 m altitude above ground surface. These flights produced
99 geotagged images. Image acquisition took place at mid-day to prevent shadow, and on a
day with minimal cloud cover and low wind. Imagery covers the area of the sediment stack
that was subject to archaeological survey (see below) as well as the surrounding landforms.

Prior to UAV flight, we emplaced 11 ground control points (GCPs) across the study locality,
marked by a white cross that would be visible on the images. Four GCPs are permanent,
comprising a 3 mm wide and 2 mm deep depression drilled into the top of 300 mm long steel
reinforcing bar set into a 300 mm deep concrete plug, the top of which is level with the
current ground surface. The additional seven GCPs were temporary. The centre of each
white cross and the drilled depressions in permanent GCPs were recorded using a Real
Time Kinematic Digital Global Positioning System (RTK DGPS). Data was collected in
geographic (degrees, minutes, seconds) and projected (WGS84 UTM 34S) coordinate
systems, with GNSS heights converted to elevations using the SA2010 geoid model
(Chandler and Merry 2010). RTK DGPS base station coordinates were logged for >7 hrs,
post-processed using the Canadian Geodetic Survey of Natural Resources Canada’s web-
based Precise Point Positioning service (Natural Resources Canada, 2020), and used to
recompute the final RTK rover datasets in Trimble Geomatics Office Version 1.63.
Fig 2 Oblique view across Klein Hoek 1, looking south. The surveyed area is approximated with a white polygon and the basal cobble bed with a black polygon. Other relevant features such as the fence-line, scree slope and *heuweltjies* are also indicated.

3.2 Sediment unit mapping

KH1 is divided into five geomorphic zones: the scree slope in the south, the active river channel in the north, the basal cobble bed exposed at the northern boundary of the sediment stack, the exposed indurated sands, and the vegetated loose dune sands. Where exposed, the indurated sands are blanketed by stone artefacts, as well as scree gravels in the southwest portion of the study area. This artefact and rock pavement indicates that the sedimentary context of previously buried archaeology has already been lost in these areas. Geomorphic boundaries were mapped using the same RTK GPS system outlined above. Perimeters were recorded on foot with the RTK rover in continuous collection mode, recording points at 0.5 m intervals. After post-processing, the point dataset was edited into polygon features in ArcGIS Pro 2.3.3, and the boundaries checked against the UAV-derived orthomosaic.

3.3 Image processing, georectification, and DTM creation

The KH1 UAV photoset was screened for poor quality and duplicate images, then imported into Agisoft Photoscan Version 1.4.5 (now Agisoft Metashape). Images were aligned and the sparse point cloud generated. The coordinate for each visible GCP was corrected to its RTK-provided position and elevation. Next, a dense point cloud (DPC) was generated at high quality and bounded with an upper point limit of 60,000 and lower point limit of 6,000. An orthomosaic was created and a digital elevation model (DEM) generated from the DPC.
Where the DEM is generated from standard colour images, the computed elevation surface does not differentiate between ground surface and the top of the vegetation. At fine spatial scales, this issue creates artificially complex local topographies that confound the modelling of erosional sensitivities. Consequently, we used image classification to remove the vegetation from the original DEM, resulting in a ground-only DEM or a Digital Terrain Model (DTM). Image classification was undertaken in ArcGIS Pro with a total class number of 12, as this facilitated the identification of even very sparse and low-lying shrubs. The process was refined by merging the output polygonal classes representing vegetation and removing classified areas <0.05 m². Vegetated areas were then deleted from the original DEM and Inverse Distance Weighting (IDW) interpolation applied to produce a continuous, smoothed DTM.

3.4 Assessing flow paths

To assess the likely dispersion paths of artefacts being moved downslope by erosion, we created a stream network map from the DTM. Sinks were first identified and filled up to a maximum of 0.485 m. Flow direction and flow accumulation surfaces were calculated from the resulting depressionless DTM, from which smoothed stream paths were generated. Strahler classes are used to measure complexity of drainage development.

3.5 Calculating RUSLE

The Revised Universal Soil Loss Equation (RUSLE) was used to estimate the sensitivity of the KH1 landscape to further erosion. We implemented RUSLE \( A = R \times K \times LS \times C \times P \) in a GIS environment following procedures that combine elements in Howland et al. (2018), Farhan et al. (2013), Renard and Freimund (1994), Renard et al. (1997), and Goldman et al. (1986). In the above equation, \( R \) represents the erosive potential of local, annual rainfall. \( K \) quantifies the erodibility of the land surface based on soil and sedimentological properties. The \( LS \) factor is a dimensionless variable that combines slope and overland flow distance to account for surface topography. Cover \( (C) \) and erosion control practice \( (P) \) are dimensionless and address variable land cover/use and any erosion prevention initiatives, respectively. We operationalized the equation using the raster calculator in ArcGIS Pro, using a constant for \( R \) and derived raster images for \( K \), \( LS \), and \( C \). Because erosion control measures are non-existent at KH1, \( P \) is not incorporated into the analysis. Refer to the electronic supplementary material (Online Resource 1) for methods of parameter characterisation for the RUSLE equation.

All incorporated variables \((R, K, LS, \text{and } C)\) were multiplied in the raster calculator to produce a continuous surface of erosional sensitivity in tonnes per hectare per year (t/ha/yr).

\[
A = 225.29 \times K_{\text{raster}} \times LS_{\text{raster}} \times C_{\text{raster}}
\]

The result was reclassified into five erosional risk categories of minimal (0-5), low (5-15), moderate (15-25), severe (25-50), and extreme (>50) (Farhan et al. 2013; Howland et al. 2018).

3.6 Archaeological data acquisition and nearest neighbour clustering analysis

Archaeological survey of KH1 was conducted in 2018 as part of the Doring River Archaeology Project. Detailed survey methods are described elsewhere (Ames et al. In Press; Shaw et al. 2019) and are only summarised here. Targeted sediment stacks, such as KH1, were surveyed by two people walking in parallel transects 2-3 m wide. Transects were demarcated by black nylon string to ensure complete surface coverage and prevent duplication. The total surveyed area at Klein Hoek 1 was 18 835 m². All cores, retouched implements, and pottery fragments within this area were recorded regardless of size, along with fragments of ochreous rock >30 mm. The position of all artefacts was recorded on a Trimble Juno 3B mobile device enabled with ESRI ArcPad 10.2. Attributes recorded included raw material, artefact class, implement type, core type, clast shape, clast maximum size.
dimensions, cortex coverage, cortex type, and a range of taphonomic indicators such as patination, edge rounding and discolouration. In addition to these more observational data, we recorded where possible the likely epoch to which the artefacts belonged—whether ESA, MSA, LSA or Khoi (herders with pottery)—and the technocomplex with which they were most likely associated. For detailed survey protocols, classification parameters, and our efforts to reduce inter-observer variability see Shaw et al. (2019).

At KH1 we were able to assign 30.9% (n=2088) of the 6747 recorded artefacts to an epoch, and 7.5% (n=506) to a technocomplex. While the proportion assigned to technocomplexes may seem relatively low it needs to be borne in mind that the Doring River and the scree

Fig 3 (A) DTM elevation and stream network symbolised by stream order (Strahler classes). (B) Oblique 3D view of KH1 looking southeast with simplified stream network and major geomorphic features indicated
adjacent KH1 are major sources of the dominant raw materials used in the catchment (Shaw et al. 2019). Artefacts are thus often in early stages of reduction/production on the sediment stacks (Lin et al. 2016; Low et al. 2017; Low and Mackay 2018), and consequently may lack derived flaking characteristics. Many core types, most notably Levallois cores, are also specific to epochs but transgressive across technocomplexes, while others, such as bipolar cores, typically cannot be assigned in respect to either variable.

In our analysis, we use the epochs and technocomplexes to assess patterns of distribution relative to sediment bodies, flow paths and erosional sensitivities. We then assess the degree of clustering and mixing within and between technocomplexes as a guide to the integrity of their spatial location and sedimentary context. The functional assumption of our approach is that the technocomplexes are relatively age constrained—with some exceptions, the periodicity of change across the Late Pleistocene and Holocene is 5-10 kyr (Jacobs et al. 2008; Lombard et al. 2012)—and their artefacts have a reasonable likelihood of having initially been distributed in spatial proximity to one another (Haas and Kuhn 2019). One limitation of this approach is that sample size is quite small for many technocomplexes, precluding the use of many statistical techniques. Of necessity, our test processes were thus relatively simple, combining visual assessment of distribution patterns with nearest neighbour distance analysis. To assess clustering we compared the mean and median nearest neighbour distances for all artefacts within a given technocomplex; all else being equal, clustered technocomplexes should have lower average dispersion by this measure. To assess mixing, we compare the frequency with which artefacts from any given technocomplex occur nearest to an artefact of the same or other technocomplex; where assemblages are clustered and discrete, most nearest neighbours should be of the same technocomplex. While this approach is tailored to the limitations of the available data set, we emphasise that a range of statistical techniques could be used to evaluate spatial patterning.
4. Results

4.1 Erosional history and sensitivity of Klein Hoek 1

Vegetated loose sands are restricted to patches in the eastern and southeastern parts of the study area, with underlying indurated sands exposed elsewhere, particularly in the western half of the locality where no substantial vegetated patches remain. Reasonably well developed drainage networks (third and fourth order rivulets/streams) have also formed in this area (Figure 3). The DTM reveals the deeply incised drainage that now forms the south-western boundary of the locality, and the extent of erosional downcutting into the northwestern deposits. The basal cobble bed is visible in the DTM as a ledge along the northern edge of the stack over which the indurated sediments lie. A well-formed knick point has developed in the cobble bed through which the only fourth-order stream in the identified network runs; the visual similarities in scale to the southwestern drainage suggest that the western deposits will become unstable as the knick point progresses upslope.

The DTM also reveals the emergence of two erosion-resistant, broadly circular mounds towards the northern end of the sediment stack. These reflect areas of consolidated sediment approximately 25 m across and 2 m high, consistent with what are known locally as *heuweltjies*—indurated sediment patches that are common across the Western Cape landscape and result either from fine aeolian accumulation within dense vegetation communities, the activities of termites, or the interaction of both. *Heuweltjies* can be seen in...
Figure 2 as circular patches of light-coloured vegetation on the plateau above KH1, reflecting their landscape prevalence.

RUSLE values (Figure 4) show that erosional sensitivities are highest along the drainage in the southwest corner, below the slope of the basal cobble bed particularly around the knick point, and at the northern margins of the two sediment mounds. Notable is the low erodibility of the top of the cobble bed and the areas of loose, vegetated dune sand—the latter especially prominent east of the fence-line and where patches are preserved to the west. Other low erosion risk areas include the tops of the low mounds and the areas immediately upslope of them. The central portion of the locality has generally low to minimal risk of erosion, probably due to past sediment loss in these areas. A string of moderate to severe erosion risk values tracking southeast to northwest across the locality signals downcutting through already deflated areas into the uppermost western deposits, and aligns with the stream flowing across the site into the knick point. This flow emerges from the scree in the southeast corner and enters the locality with moderate erosive potential before dissipating. This dissipation likely occurs due to the decrease in slope steepness (Online Resource 1: Figure S2), the permeability of the loose, vegetated dunes sands in that area, and the concentration of flow into the aforementioned stream.

4.2 Distribution of Artefacts at Klein Hoek 1

Artefacts are generally abundant in those areas of KH1 from which vegetation and loose sands have been lost (Figure 5). There are notably acute concentrations around the periphery of the more western of the two mounds, on top of the more eastern mound, and in an erosional embayment below (northeast of) the eastern mound. Upslope towards the southern edge of the locality artefacts are more sparsely distributed. Only a few artefacts appear to have spilled onto the cobble bed along the northern edge.

The bulk of the epoch-assigned artefacts at KH1 relate to occupation during the MSA (92.4%, n=1929), with only a small number of LSA (n=129) and ESA (n=30) pieces. We found no artefacts at KH1 relating to the period after the arrival of herders in the region. While MSA artefacts occur across the locality, they are more heavily concentrated in the deflated areas on the western side, and in areas of low to moderate erosion risk associated with stream flow across the central western deposits (Figure 6, Figure 7). The more sparsely distributed ESA artefacts map reasonably well onto the MSA artefacts, being generally restricted to the western side. LSA artefacts, on the other hand, show a more constrained distribution concentrated on and around the mounds in the northeastern part of the surveyed area. While those artefacts situated on top of the more eastern mound are at minimal risk of erosion, those around the northern periphery of both mounds are in areas where erosion risk is more severe.

KH1 contains artefacts assigned to seven different MSA and LSA technocomplexes. Numerical representation is highly variable, however. The late MSA (50-25 ka, n=230) and Still Bay (75-71 ka, n=183) are very well represented, while the post-Howiesons Poort (58-50 ka, n=32) and Robberg (22-14 ka, n=28) have modest numbers of artefacts. Only ten
artefacts each were assigned to the Howiesons Poort (71-58 ka), Early LSA (27-22 ka) and Wilton (8-2 ka) technocomplexes (Table 1).

Consistent with the relatively large number of artefacts, the Late MSA has the widest distribution, covering approximately 86% of the surveyed area (Figure 8E, Figure 9E). Late MSA artefacts are most common in the western parts of KH1, particularly in and around the deflated western depression, and around the margins of the western mound where erosion risk is moderate to severe. Many of these artefacts are entrained or becoming entrained in the drainage feature developing in this area. Mean nearest neighbour distances imply relatively strong clustering of Late MSA artefacts, though this needs to be considered against relative abundance of artefacts from that technocomplex (Table 1). Our measure of mixing suggests reasonable integrity of Late MSA artefacts, however, when we control for sample size the parameter appears to be non-significant (Online Resource 1: Table S3); that is, Late MSA artefacts occur near other Late MSA artefacts at a probability no greater than chance.

Despite similarly large numbers, the distributional pattern of Still Bay artefacts is quite different from that of the Late MSA. Still Bay artefacts were found across 43% of the locality, though most are exposed just above the cobble bed as a single cluster in an erosional feature created by a series of short drainage lines at the northeastern edge of the locality (Figure 8H, Figure 9H). Though RUSLE values here indicate minimal erosional risk in the central cluster, surrounding values are moderate to extreme. The intense clustering of Still Bay artefacts results in a mean nearest neighbour distance of 1.9 m and a median of only 0.5 m (Table 1)—considerably lower than the value for any other technocomplex (see also Online Resource 1: Figure S3). The Still Bay artefacts are also significantly less mixed than those from other technocomplexes (Online Resource 1: Table S3), reinforcing the integrity of this assemblage.

Robberg and post-Howiesons Poort artefacts have similar mean nearest neighbour distances (5.8 m and 5.9 m respectively) and similar total areas of distribution (3233.0 m² and 3485.8 m² respectively), but their patterns of spatial distribution are very different. Robberg artefacts almost exclusively occur in the northeastern area of KH1, and most cluster tightly on top of the eastern mound in an area with low and minimal erosion risk. Beyond this central cluster, Robberg artefacts are radially distributed in highly erosional contexts around the mound’s periphery, probably reflecting downslope dispersion of artefacts that became entrained in stream networks. A central cluster with only a few outlying displaced artefacts is supported by the much lower median nearest neighbour value of 2.6 m and the heavily right skewed nearest neighbour distances distribution, perhaps best described as a decay curve (Online Resource 1: Figure S3).
Fig 8 DTM elevation showing the (A) stream network and distributions of (B) Wilton artefacts, (C) Robberg artefacts, (D) Early LSA artefacts, (E) Late MSA artefacts, (F) Post-Howiesons Poort artefacts, (G) Howiesons Poort artefacts, and (H) Still Bay artefacts.
In contrast, downslope dispersion appears to be the dominant pattern for distribution of Post-Howiesons Poort artefacts—the mean (5.9 m) and median (4.4 m) nearest neighbour distances are relatively consistent (Online Resource 1: Figure S3). This pattern matches their position relative to the drainage network in the western part of the locality. Moreover, the post-Howiesons Poort shows significant mixing with artefacts from other technocomplexes (Online Resource 1: Figure S3), mainly the Late MSA and Howiesons Poort, implying deflation of sediments in this area and an accumulating lag deposit.

The smallest technocomplex groups—Wilton, Early LSA and Howiesons Poort—are all relatively dispersed, with mean nearest neighbour distances from 11.1–24.4 m and areal distribution across 12.3%–44.2% of the locality. The distribution pattern for Wilton-assigned artefacts is very similar to that of the Robberg, with a strong central cluster of seven artefacts situated on a mound with low erosional sensitivity, and the remaining three artefacts more widely dispersed (Online Resource 1: Figure S3). The median nearest neighbour distance for the Wilton (2.9 m) is significantly lower than the mean. Mixing values are high for both the Wilton and Robberg (Table 1), which is the result of their overlapping cluster distributions (Figure 8B & 8C, Figure 9B & 9C).

Early LSA artefacts all occur on the lower slopes on or near the basal cobble bed and are widely spread, reflected in their low density, large nearest neighbour values, and relatively high degree of mixing. Perhaps more than any other technocomplex, artefacts from the Early LSA are distributed in areas of severe to extreme erosion risk. In many respects, artefacts from the Howiesons Poort show a generally similar pattern to those of the Early LSA, though they display greater mixing and lower sensitivity to current and future erosion.

5. Discussion

The combination of a high-resolution DTM, stream networks, erosional sensitivity, and artefact provenience data provides us with significant insights into the recent taphonomic history and future erosional risks of the sediment stack and archaeology at KH1. The DTM and RUSLE values reveal the preservational effects of the fence-line on the eastern boundary of the surveyed area, and the erosional effects of well-developed and incipient drainage lines on the western side of the locality. The presence of erosion-resistant indurated mound structures in the northern part of the locality, which we interpret as heuweltjies, appears to have helped protect sediment in this area, however, the increasing prominence of the northern flanks of these mounds places them under imminent threat of erosion.

The effects of variable erosional histories and sensitivities are clear in the distribution of archaeological materials. Consistent with the greater preservation of sediments in the east and upslope of the mounds, artefacts from the LSA are essentially restricted to this area. We interpret this to indicate the preservation of younger age sedimentary units here that may have been lost farther to the west, though we currently lack the ages to test this proposition. In contrast, ESA and MSA artefacts dominate in areas to the west where past erosion seems to have been most severe, likely reflecting their exposure since the advent of grazing at the locality.

Turning to the technocomplex data, the artefacts on the western side of the locality appear to have undergone significant loss of spatial and sedimentary context. The horizontal integrity of the Howiesons Poort, post-Howiesons Poort and Early LSA has been heavily compromised, and the resultant lagging has produced considerable mixing of artefacts from different periods. The Late MSA presents a somewhat different spatial configuration but ultimately a similar prognosis. The relative abundance of Late MSA artefacts at KH1 may reflect an intensive period of occupation, though it needs to be borne in mind that this technocomplex is currently less temporally constrained than the others (25 kyr vs 5-10 kyr).
Fig 9 RUSLE showing the (A) stream network and distributions of (B) Wilton artefacts, (C) Robberg artefacts, (D) Early LSA artefacts, (E) Late MSA artefacts, (F) Post-Howiesons Poort artefacts, (G) Howiesons Poort artefacts, and (H) Still Bay artefacts
That said, a similar pattern of broad distribution does seem to typify the Late MSA at a number of other localities in the Doring River (Shaw et al. 2019). Among other issues, the inferred loss of sediment in this part of the locality means that the chronometric ages of the artefacts—to which we currently assign age ranges based on potentially problematic assumptions (Shaw et al. 2019)—probably cannot be resolved.

The development of a knick point in the basal cobble bed immediately downslope of the late MSA, post-Howiesons Poort and Howiesons Poort concentrations is disconcerting, particularly given its similarities to the deeply incised drainage that currently defines the western edge of the locality. Further cutting back at this knick point has the potential to destabilise the western deposits completely, with consequent loss of the archaeological material from this area.

In the eastern half of the stack, future research potential is considerably better. Wilton and Robberg artefacts retain some spatial integrity as a result of the mound on which they are situated, though the effects of downslope sediment loss is fairly clear from the dispersed distribution of artefacts outside the major clusters. There is some potential for dating the deposits underlying the Robberg and Wilton, though assuming that the technocomplex assignments are correct, and given that the latter now rests on the same surface as the former, at least 6 kyr of stratigraphic context has potentially been lost. It is possible that there has been some mis-assignment of artefacts in this area, with Robberg and Wilton cores potentially being difficult to separate. This would explain the degree to which these two technocomplexes map onto each other. The presence of distinctive mid Holocene ‘thumbnail scrapers’ in this assemblage makes a Wilton assignment secure for those pieces; if the Robberg-assigned cores do indeed belong to the Wilton, the dating of these deposits may resolve this possibility and suggest that the mixing here has been overstated, rendering it more comparable to that of the Still Bay assemblages beneath them.

The contrast between apparent spatial integrity of the putative Wilton and Robberg artefacts and the high dispersion indicated by our nearest neighbour analysis requires some brief discussion. This technique did not appear to deal well with the highly heterogeneous distributions that characterised these technocomplexes, over-emphasising their dispersion. Alternative approaches to the visual and statistical treatment of clusters, such as the Getis-Ord statistic, would have been preferable but could not be applied to each technocomplex due to small sample sizes. Future work that explores these and other point pattern approaches to artefact distribution on the sediment stacks is in preparation (Ames et al. In Prep).

Considering the full suite of analyses presented here, the Still Bay has the most future research potential out of all of the technocomplexes we identified. With a large number of artefacts, and apparently very low dispersion and limited mixing in the main cluster, the Still Bay appears to have retained considerable spatial integrity. That the Still Bay artefacts occur towards the base of the sediment stack, at an elevation between the basal cobble bed and the easternmost mound suggests potential for excavation and chronometric age bracketing. However, those potential Still Bay deposits are also in some of the areas most susceptible to future erosion. In this sense, it is reasonable to assume that any neighbouring in situ Still Bay artefacts are at imminent risk of exposure and possible disaggregation from erosion of the eastern mound, as well as from the continuing development of the drainage features that exposed the Still Bay artefacts at this location. Further loss of surface vegetation in the eastern part of the locality will likely accelerate this process, in turn accelerating loss of potentially buried deposits and the dispersion of artefacts that are already surface-exposed. Work on the Still Bay at KH1 is thus a research priority.

6. Conclusions

Surface artefact scatters are often undervalued because of assumptions about their integrity and information potential. This is particularly true in arid and semi-arid landscapes where
sediment accumulation is slow and erosion is prevalent. However, by turning away from open-air sites we risk the permanent loss of information from what constitutes the bulk of the record. To return to an analogy from the start of the paper, by optimising our rate of information return we may be limiting the diversity of information we recover, something that is particularly problematic when dealing with the already fragmentary Pleistocene record. In this paper, we used a range of readily available and easily applied techniques to help us understand the quality of the information still available to us in open-air sites. This work demonstrates that the pattern of disaggregation is variable across the KH1 locality. Some areas have experienced considerable erosion resulting in the loss of stratigraphic context, leaving disaggregated lags of artefacts that span multiple periods of the Middle and Later Stone Age that now have reduced long-term research potential. Other areas have experienced less severe erosion, where surface artefacts are tightly clustered with relatively low rates of mixing. These latter areas offer significant future research opportunities; behavioural patterning of the surface material appears relatively intact, and the material sits atop or adjacent to remaining deposits likely to contain in situ remains. However, erosional sensitivity modelling indicates these remaining sediments are at imminent risk of continued erosion and subsurface exploration in these areas should be high priority. Overall, the combination of UAV-derived land surface modelling and nearest neighbour analysis of point-provenieneced archaeological surface distributions allows us to make better-informed decisions about future research priorities at open-air archaeological sites in arid and semi-arid environments.

**Tables**

**Table 1** Abundance and distribution data for artefacts assigned to technocomplexes

<table>
<thead>
<tr>
<th>Technocomplex</th>
<th>N</th>
<th>Convex hull area in m² and % of total survey area</th>
<th>Artefact density (n/m²)</th>
<th>Clustering¹</th>
<th>Mixing²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilton</td>
<td>10</td>
<td>2321.7 (12.3%)</td>
<td>0.004</td>
<td>11.1 (2.9)</td>
<td>70.0</td>
</tr>
<tr>
<td>Robberg</td>
<td>28</td>
<td>3233.0 (17.2%)</td>
<td>0.008</td>
<td>5.8 (2.6)</td>
<td>48.2</td>
</tr>
<tr>
<td>Early LSA</td>
<td>10</td>
<td>8330.9 (44.2%)</td>
<td>0.001</td>
<td>24.4 (15.5)</td>
<td>60.0</td>
</tr>
<tr>
<td>Late MSA</td>
<td>230</td>
<td>16245.0 (86.2%)</td>
<td>0.014</td>
<td>3.1 (2.1)</td>
<td>25.2</td>
</tr>
<tr>
<td>Post-Howiesons Poort</td>
<td>32</td>
<td>3485.8 (18.5%)</td>
<td>0.009</td>
<td>5.9 (4.4)</td>
<td>68.7</td>
</tr>
<tr>
<td>Howiesons Poort</td>
<td>10</td>
<td>4896.1 (26.0%)</td>
<td>0.002</td>
<td>17.7 (12.8)</td>
<td>100.0</td>
</tr>
<tr>
<td>Still Bay</td>
<td>183</td>
<td>8163.2 (43.3%)</td>
<td>0.022</td>
<td>1.9 (0.5)</td>
<td>12.0</td>
</tr>
</tbody>
</table>

¹Mean nearest neighbour distance (m) for all artefacts within a given technocomplex, with the median nearest neighbour distance (m) in brackets.

²Percentage of artefacts that have an artefact from a different technocomplex as a nearest neighbour.

**References**


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