Modelling erosional sensitivities of archaeological sites using DEM's from low altitude UAV imagery

S J. Chambers

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Abstract
In South Africa, archaeological sites that are open and exposed are often subject to degradation via erosion, allowing the archaeological material throughout these landscapes to be displaced resulting in a loss of archaeological context over time. As erosional sensitivities become higher, the condition of these sites continue to degrade, and artefacts and artefact deposits can be eroded from their in-situ positions and integrated into the landscape. This in turn reduces the integrity of the archaeological deposits at a site resulting in a loss of information. Providing an erosional risk-based assessment using the Revised Universal Soil Loss Equation (RUSLE) demonstrating the destructive processes operating at a site and the material most at risk, can allow for the integrity of archaeological clusters and material to be assessed. Providing easily interpretable outputs using GIS based analyses that clearly demonstrate the destructive processes operating at a site based on a method that is adaptable, can allow for research in the area to be tailored to regions of higher and lower importance, whilst providing information about past and potential artifact migration patterns in the landscape. This project aims to generate Digital Elevation Models (DEMs) and maps that illustrate and quantify this potential erosion and possible loss of integrity across two open-air sites along the Doring River in the Western Cape of South Africa. By combining Unmanned Aerial Vehicle (UAV) acquired imagery with GNSS RTK collected survey data, accurate representations and DEMs of each site could be produced and a baseline for assessing the integrity of the existing archaeological material and deposits could be created. From this, erosion risk was mapped and an urgency matrix developed to identify material most at risk across a site, as well as which archaeological deposits are most susceptible to erosion. This provides insight into areas that are most prone to erosion and are therefore most vulnerable to loss of information and context, which is particularly important in the current setting. The results of the project can not only illustrate destructive processes acting at each of the sites, but also provide information about formation processes and geomorphology of each of the archaeological sites and Doring River region.

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Modelling erosional sensitivities of archaeological sites using DEM’s from low altitude UAV imagery

Sherrie Jessica-Rose Chambers

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The information in this thesis is entirely the result of investigations conducted by the author, unless otherwise acknowledged, and has not been submitted in part, or otherwise, for any other degree or qualification.

Signed:  

[Signature]

Sherrie Chambers

3/3/2019
Abstract

In South Africa, archaeological sites that are open and exposed are often subject to degradation via erosion, allowing the archaeological material throughout these landscapes to be displaced resulting in a loss of archaeological context over time. As erosional sensitivities become higher, the condition of these sites continue to degrade, and artefacts and artefact deposits can be eroded from their in-situ positions and integrated into the landscape. This in turn reduces the integrity of the archaeological deposits at a site resulting in a loss of information. Providing an erosional risk-based assessment using the Revised Universal Soil Loss Equation (RUSLE) demonstrating the destructive processes operating at a site and the material most at risk, can allow for the integrity of archaeological clusters and material to be assessed. Providing easily interpretable outputs using GIS based analyses that clearly demonstrate the destructive processes operating at a site based on a method that is adaptable, can allow for research in the area to be tailored to regions of higher and lower importance, whilst providing information about past and potential artifact migration patterns in the landscape.

This project aims to generate Digital Elevation Models (DEMs) and maps that illustrate and quantify this potential erosion and possible loss of integrity across two open-air sites along the Doring River in the Western Cape of South Africa. By combining Unmanned Aerial Vehicle (UAV) acquired imagery with GNSS RTK collected survey data, accurate representations and DEMs of each site could be produced and a baseline for assessing the integrity of the existing archaeological material and deposits could be created. From this, erosion risk was mapped and an urgency matrix developed to identify material most at risk across a site, as well as which archaeological deposits are most susceptible to erosion. This provides insight into areas that are most prone to erosion and are therefore most vulnerable to loss of information and context, which is particularly important in the current setting. The results of the project can not only illustrate destructive processes acting at each of the sites, but also provide information about formation processes and geomorphology of each of the archaeological sites and Doring River region.
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Chapter 1: Introduction

1.1. Archaeological Background

Human evolved in Africa, and Africa thus has the longest archaeological record of any continent spanning more than 3 million years (Harmand et al. 2015). Because of this long record, Africa preserves important information about the biological and behavioural evolution of humans, including changes in stone tools and other artefacts that may signal the emergence of the enhanced mental abilities that define our species (Henshilwood & Marean 2003; Henshilwood et al. 2002, 2003, 2004, 2011; Vanhaeren et al. 2006; Bouzouggar et al. 2007; Wadley et al. 2011; Texier et al. 2013; Blegen 2017). The African archaeological record is commonly divided into three successive stages – the Earlier Stone Age (ESA), Middle Stone Age (MSA) and Later Stone Age (LSA) – each of which contains evidence of more complex behaviour.

The Western Cape of South Africa is well known for its rich deposits of archaeological material, and early evidence for the production of novel tool types and ornaments (Texier et al. 2013; Henshilwood & Marean 2003; Henshilwood et al. 2002, 2003, 2004, 2011). Most of this evidence is obtained from rock shelter sites located along or near the modern coastline (Bolus et al. 2015; Kendal et al. 2015; Blegen 2017). Along the Doring River (Figure 1) in the interior of South Africa, there are deposits of stone tools found both in rock shelters and on top of open-air sediment mounds, the latter of which are most common along the banks of the Doring River and its tributaries. As many as 16 of such mounds are currently known to exist along the Doring River, with documented artifact assemblages sometimes exceeding 10,000 pieces. These sites appear to be highly erosive in nature, which can create displacement of artefacts throughout the landscape leading to loss of integrity and preservation of the archaeological remains. This thesis will focus on two distinct sediment mound sites which seem to be highly erosional and have overlapping time-specific archaeology – known as Klein Hoek 1 (KH1) and Doring Bos 8 (DB8) – described in detail later in this chapter.

Artefacts currently visible on the Doring River sediment mounds may have been deposited in one of two ways: they may have accumulated on non-aggrading surfaces, or they may have eroded there from adjacent deposits. In both cases, these assemblages are palimpsests – clusters of artefacts with assorted ages that rest on a single geological surface (Bailey 2007). Because they contain material from a mix of depositional events, palimpsest often present a problem for
archaeological researchers wanting to understand past behaviour. Varying stages of occupation have been identified in sites along the Doring River based on the observed artefact types, and it has been suggested that the density, type and distribution of surface archaeology and time-specific artefacts can illustrate important information about the behaviour of populations (Mackay et al. 2014a). Hiatuses have also been identified, both in rock shelters and open-air sites such as KH1 and DB8, leading to the assumption that the populations either abandoned the region, or underwent patterns of significant spatial reorganisation when environmental conditions changed, particularly in the Winter and Year-round Rainfall Zone’s (WRZ/YRZ) (Figure 1) (Mackay et al. 2014a, 2014b).

Figure 1: Position of the Doring River (starred) within the Winter Rainfall Zone (WRZ) - dark grey shaded area. Light grey shading represents the Year Round Rainfall Zone (YRZ) and no shading illustrates the Summer Rainfall Zone (SRZ). Other sites include: Diepkoof (DRS), Hollow Rock Shelter (HRS), Ysterfontein (YFT), Peers Cave (PC), Blombos (BBC), Pinnalce Point (PP), Boomplaas (BMP), Nelson Bay Cave (NBC), Klasies River (KRM), Sehonghong (SHH), Sibudu Cave (SC), Border Cave (BC) (Mackay et al. 2014a).

As part of the Cape Fold Belt, geologically the region includes units such as the Table Mountain Group sandstone and Cape Supergroup shales. These units create large quantities of detritus in the form of scree and talus slopes along escarpments and cliff faces that are present at both KH1 and DB8. Being in the WRZ/YRZ the climate is Mediterranean and the vegetation is representative of dry scrubland and arid semi-desert. Much of the regional climate surrounding the Doring River is topographically influenced and geologically the Doring River region has been found to transition quickly from the Table Mountain Group sandstones in the west to younger Bokkeveld Group interbedded shales and sandstones in the east. The Cape Fold Belt mountain ranges are thought to have been folded and uplifted around 300 Ma ago (Quick and Eckardt 2015), with the Doring River incising into sandstone bedrock creating deep valleys and providing large amounts of sediment input. During periods of heavier precipitation, this catchment disperses sediment in larger quantities more readily to downstream reaches where flood deposits such as sediment mounds and terraces of fine-grained to coarse-grained sands and cobbles and boulder conglomerates can be observed flanking the sides of the river. The
farmland in the region is mostly cultivated along these flood plain reaches where rich, silty soils are prominent, and as a result many of the artefact bearing terraces and sediment deposits have been re-worked, compacted, moved and/or destroyed. The river and its tributaries are lined with boulders and sand or are incised into sandstone bedrock units. It is thought that these boulders making up parts of the Doring River floor may have provided ancient humans with the material used for making stone tools (Hallinan & Parkinton 2017).

Contention about the formation and geomorphology of the Doring River sediment mounds across various sites flanking the Doring River has recently arisen, including the future of the archaeological material on and within them (e.g. Phillips et al. 2018). It has been suggested the sediment mounds may have been formed by fluvial processes, however others suggest the mounds are aeolian derived. The Doring River has a low sinuosity meandering behaviour which contributed to formation processes at each of the sites, but due to the nature of the sediments and valley containments, also provides little information about its past behaviour. It was initially proposed these large and extensive sediment deposits were formed as a result of fluvial processes: point bars and cut bank deposits resulting from the meandering river (Mackay et al. 2014b), with occupation of these sites though to occur throughout the Stone Age (Hallinan & Parkinton 2017). However, those involved in the on-going research project have since revised this position, now proposing that these deposits were formed by both aeolian and fluvial process (Mackay A. C. pers. comm. 2018).
Questions about how these sedimentary features containing archaeology were formed, along with their relation to the river and other depositional influences, will be explored during this project. For example, were these sediment stacks deposited at a time of high river volume, or were they deposited as aeolian dune-like systems (i.e. loess or lunette systems) during extreme dryness and high winds; or are they a combination of similar processes; and if preservation rates in open-air sites decrease as a result of factors such as erosion and weather exposure. Some sediments preserve what seems to be in-situ collections of handaxes (Bleed et al. 2016), unlikely less than 250 ka (Herries 2011), invoking the suggestion that some of these sediment bodies are also that old. However, some appear to be recently active dunes, launching speculation about the periodicity of sediment accumulation between extremes of drought and rainfall. More recent dating techniques including Optically Stimulated Luminescence (OSL) are beginning to provide more accurate age estimates of the geomorphic units observed throughout these landscapes and sites (e.g. Mackay et al. 2014a).
It is important to understand present and past patterns of erosion on the Doring River sediment mounds as a means to better resolving their archaeological potential. As noted earlier, palimpsests are accumulations of mixed age deposits, from which behavioural information is hard to extract. However, if the current surface distribution of archaeology on these mounds is largely a result of recent erosional processes, it would imply that there are still buried deposits with in-situ archaeology that are not mixed. Estimates of potential erosion across the sites in this study and mapping the geomorphic units across that landscape can thus provide information about why some types of artefacts are more dispersed than other types (Figure 2). It has been observed that artefacts types with specific ages ranges are usually clustered together at varying heights across the sediment mounds (Will et al. 2015). Whether these clusters reflect lagged in-situ deposits or ancient palimpsests, and the age of these artefacts is important for understanding how and when technological changes occur throughout the region (Low et al. 2017). There has been much study into determining these rates of artefact dispersal, with studies such as Phillips et al. (2018) questioning how surface runoff and other climatic influences such as wind affect the migration of artefacts in the landscape. Open-air archaeological sites like many of those in this area are often subject to varying rates of erosion due to active destructive processes such as over-grazing and current climatic factors. These sites are exposed to sometimes extreme climatic variances that have the potential to rapidly degrade the site, most commonly by accelerated erosion.

For the archaeological deposits scattered over the surface, this leads to loss of integrity as the artefacts are eroded from their in-situ positions and transported down slope, mixing archaeological information across the site while losing context. The climate of the region is arid to semi-arid, with highly concentrated winter rains and strong winds providing the context for dramatic sediment erosion rates. As open-air sites and landscapes are often significantly and rapidly impacted by these potential erosional sensitivities, it is essential to attempt to quantify the amount of erosion experienced at an archaeological site not only to better understand their formation, but to ascertain the future prospects for survival as archives of archaeological data.
1.2. Modern methods for estimating landscape change

Contemporary technological advancements in mapping have paved the way for new methods of close-range surface scanning and analysis using low altitude imagery of significant areas and landscape features, such as geological outcrops and ancient archaeological remains. Further advancements in software and hardware, such as the development of small and versatile Unmanned Aerial Vehicles (UAVs; also known as drones) and powerful Geographic Information System (GIS) software such as that produced by the Environmental Systems Research Institute (ESRI; e.g. ArcGIS), have allowed rapid development of more sophisticated analytical approaches in archaeology including both site-based approaches and landscape-scale methods (e.g. Bruno et al. 2010; Remondino et al. 2011). These semi-autonomous devices allow high resolution imagery of archaeological sites to be developed by coupling the acquired data with photogrammetric analysis techniques such as Structure from Motion (SfM) image processing and Image Based Modelling (IBM) techniques (Green et al. 2014; Howland et al. 2018). The UAV machines can also be coupled with other scanning technologies, such as small LiDAR scanners, capturing hyper-spectral imagery important for assessing geological and landscape change over time. In archaeology, the data acquired, and outputs produced by such means provide the ability to assess and illustrate surface elevations, sedimentary features, and archaeological deposits in exceptionally high detail. The imagery can be analysed at a landscape-scale, site-scale, and/or excavation-scale. These outputs can also benefit from geomorphological analyses when attempting to ascertain long-term landscape evolution and formation processes, which provide valuable context about ancient landscapes and land-use patterns.

A major priority for researchers is site preservation rates of both the artefact deposits and their in-situ positions within the landscape. Archaeological site degradation and disturbance is prevalent in most parts of the world as a result of deforestation, over-farming and climate fluctuations and looting. These effects have the ability to severely degrade a site via erosion and cause significant, if not total, loss of archaeological information as the remains and artefacts are displaced and mixed throughout the landscape. The impacts of site degradation can also vary across archaeological sites. For example, open-air sites - those exposed to the elements - have the potential to degrade as a result of erosional sensitivities much more rapidly than sites contained in rock shelters. Erosion is known to be the most pervasive form of site degradation, and as such it is necessary to attempt to quantify rates of erosion and its past and future potential effects on archaeological deposits across the landscape, to assist with management of these
important heritage resources. The effects of a changing climate can also be assessed where an increase or decrease in precipitation, severe storms and droughts can influence erosional processes acting on open-air sites and landscapes. As erosion rates can vary due to a variety of factors such as rainfall, soil surface composition and slope, it is necessary to quantify the impact of varying rates of erosion on the archaeological integrity of sites and deposits when attempting to assess artefact displacement patterns, the likelihood of \textit{in-situ} artefact displacement, and the time before all \textit{in-situ} archaeological information will be lost.

A study into the effects of erosion on archaeological sites was conducted by Howland et al. (2018) using low altitude aerial imagery and GIS software to produce maps of potential erosion at a site, as well as the predicted displacement and further degradation of artefact deposits caused by surface run-off. The study found that the use of these technologies and analytical techniques significantly improved analytical results, providing further information about associations between displaced artefacts and their point of origin (Howland et al. 2018). However, discussion about the accuracy and precision of the outputs created by UAV surveys continues since many of these 3D models and digital terrain models retain a high amount of error. De Reu et al. (2014) found that if the kinetic and propagating errors experienced when surveying sites with UAVs are combined with highly accurate RTK collected ground control points it significantly reduces the total error within the models while validating both forms of data. Nevertheless, many studies now promote the use of UAV derived information for both landscape-scale and site-scale analysis when combined with other forms of GIS analysis, such as GNSS RTK surveys (Karkanas et al. 2015; Nikolakopoulos et al. 2017).

This project aims to generate DEM’s and maps that illustrate and quantify the potential erosion and possible loss of integrity across two open-air sites along the Doring River in the Western Cape of South Africa, KH1 and DB8. This region is important due to the quantity of archaeological material present in both buried archives and across the surface of the landscape. Open-air sites have been identified as highly erosional, with the potential for rapid loss of archaeological context and associated information in the very near future (Phillips et al 2018). It has been noted that without open-air sites our understanding of the archaeological record will remain incomplete (Mackay et al 2014b).
1.3. Project Aims and Objectives

**Brief:** The aim of this project is to determine rates of erosion across open-air archaeological sites, whilst providing a baseline for assessing the sensitivity of a site to erosion and the potential for loss of archaeological information to occur. The study will also attempt to ascertain formation processes using accurate Digital Elevation Models (DEMs) and 3D models.

In early 2018 as part of Directed Studies in Earth and Environmental Sciences (EESC329) I compiled three-dimensional (3D) Digital Elevation Models (DEMs) using low-altitude Unmanned Aerial Vehicle (UAV) imagery to depict a number of eroding, open-air archaeological sites along the Doring River, South Africa. This honours project aims to firstly assess errors and georectify these previously generated DEMs to control points collected using Real-Time Kinematic (RTK) GNSS positioning at the same time as site survey, so that this baseline data source is accurate and precise to location. Next, the Revised Universal Soil Loss Equation (RUSLE) will be applied to these DEMs to estimate the potential soil loss from each of the sites in tonnes per hectare per year (t/ha.year). Thirdly, sedimentary features and bodies, such as sediment stacks and surface aggregates, will be mapped and overlain on the corrected DEMs in an attempt to ascertain possible formation processes at each site, and relating these features to elevation along the Doring River. This information will then be combined with artefact data, endeavouring to provide a better understanding about both active geomorphological processes and past formation processes operating at each site and affecting archaeological deposits and across the landscape.

Artefact types collected by my supervisors Dr Alex Mackay and Dr Chris Ames and their team (methods for which are not elaborated in this thesis) will be assessed for their distribution and likelihood of disposition based on erosional processes. These results can provide a basis for assessing the importance of a site, relating both to the current coherence of material at the site as measured by cluster of like-aged artefacts, and how quickly those clusters will need to be studied before losing archaeological integrity. Using these DEMs in conjunction with sedimentary and archaeological data, sites and features containing archaeological deposits can be assessed to determine the extent they are likely to be impacted by erosion in the near future. To achieve this, an urgency matrix will be formulated that compares the sensitivity of the landscape to potential erosion to the integrity of archaeological material at each of the sites.
Clusters of like-aged artefacts that are not dispersed throughout the site show high integrity, and if they are in locations assessed as being prone to high erosion rates, they will have a high urgency to be studied. Alternatively, clusters that are dispersed across the surface and have lost their integrity will, therefore, not be of immediate priority.

**Objectives**

- Accurately and precisely represent the sites, features and their respective elevations in a series of 3D models, orthomosaics and DEMs.
- Determine rates of erosion acting upon each site, including the potential for a site to erode in the future.
- Ascertain possible formation processes and geomorphology of each site and the surrounding landscape.
- Provide a baseline for assessing the integrity of existing archaeological material and the sensitivity of each site to erosion through the use of an urgency matrix.

**1.4. Thesis Outline**

Presented as a series of chapters, this thesis is structured as follows: Chapter 2 contains background of the archaeology of southern Africa and the thesis study sites as a literature review. This section also introduces questions about the region that are currently being examined, and that will be explored in this study. The methodology for the production and compilation of maps, DEM’s and 3D models will be outlined in Chapter 3. Chapter 4 will present results and outputs, while Chapter 5 will discuss these results in detail and in context of the study objectives and other uncertainties, and other research. Conclusions of the thesis will be drawn, and future research recommendations are outlined in Chapter 6.
Chapter 2: Literature review and study background

2.1. Introduction: Archaeology of western South Africa

The Western Cape of South Africa is well known for its rich deposits of archaeological material, providing information about the behavioural evolution of early modern human populations through the late Pleistocene (Marean 2010). The composition of these deposits, typically comprising materials such as bone, shell, and stone tools (lithics), vary spatially and temporally throughout southern Africa (Mackay et al. 2014a). Situated within the Fynbos Biome, the study region with which this thesis is concerned is important for the study of early humans due to the evidence of complex tools and modes of manufacturing, indicating complex cognitive and behavioural traits (Mackay et al. 2015, 2018). Throughout the areas and sequences that contain artefact deposits are signs of rapid and dramatic environmental changes suggested to coincide with Marine Isotope Stage (MIS) fluctuations (Marean 2010, 2015; Meadows et al. 2015).

It is thought adaptations surrounding early human behaviour, population migration and modes of tool manufacturing coincide with these environmental changes and the social changes that are experienced by a group, rather than a population as a whole (Mackay et al. 2014a; Marean 2010, 2015). Marean (2015) suggested that complex social structures arose from the inheritance of knowledge, and that understanding of materials and manufacturing techniques may have promoted social identity in communities. Social identity among these early populations is also documented in the form of rock art symbols painted with ochre and ornamental artefacts created from ostrich or mollusk shells (see e.g. Texier et al 2013; Marean 2010). However, the distribution of time-specific artefacts can help determine how humans occupied the region in the past, and how and by what means they shared information, and how climate and landscape change processes attributed to their behavioural changes (Mackay et al. 2014a).
Across the western region of South Africa, variances in lithic artefact manufacturing techniques through time can provide a structure for estimating the age of specific artefact types when found in undated or un-dateable contexts (Table 1) (Lombard et al. 2012; Mackay et al. 2018). This variation is often resolved by archaeologists in terms of successive ‘Industries’, which are assemblages of similar artefacts. Such industries occur throughout at least the last 2 million years of occupation in southern Africa, though the tempo of industrial change seems generally to increase through time. Thus, while the ESA – which spans more than 1.5 million years, is divided into just three industries, the succeeding MSA - lasting less than a fifth of that time, is divided into as many as eight industries. A further five industries are identified in the LSA, which lasts 40,000 years – or a sixth of the MSA. Studies in surrounding regions of the Doring River area, including the Doring, Olifants, and Varsche Rivers, show that many of these industries can be found on both land surfaces and in excavated deposits (Hallinan & Parkinton 2017; Mackay et al. 2018). A number of these industries were also identified during early non-systematic surveys at KH1 and DB8 (Figure 3). Among other observations, this information suggests that these two mounds were sometimes occupied during overlapping periods in the past.

Figure 3: Still Bay artefacts from Klein Hoek 1. These artefacts have been reworked (Mackay et al. 2018).
**Table 1: The Southern African industrial Sequence illustrating each lithic (artefact) industry, age and characteristic (from Lombard et al. 2012).**

<table>
<thead>
<tr>
<th>Industry</th>
<th>Age</th>
<th>Date (ka)</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceramic Final LSA</td>
<td>LSA</td>
<td>0-2</td>
<td>Pottery.</td>
</tr>
<tr>
<td>Final LSA</td>
<td>LSA</td>
<td>0-4</td>
<td>Highly variable.</td>
</tr>
<tr>
<td>Wilton</td>
<td>LSA</td>
<td>4-8</td>
<td>Bladelets, backed tools, small scrapers.</td>
</tr>
<tr>
<td>Oakhurst</td>
<td>LSA</td>
<td>7-12</td>
<td>Flakes, large scrapers.</td>
</tr>
<tr>
<td>Robberg</td>
<td>LSA</td>
<td>12-18</td>
<td>Bladelet production, no tools.</td>
</tr>
<tr>
<td>Early LSA</td>
<td>LSA</td>
<td>18-40</td>
<td>Highly variable, bipolar flaking.</td>
</tr>
<tr>
<td>Final MSA</td>
<td>MSA</td>
<td>20-40</td>
<td>Highly variable, some point production.</td>
</tr>
<tr>
<td>Post-Howiesons Poort (pHP)</td>
<td>MSA</td>
<td>45-58</td>
<td>Unifacial points and scrapers, some blades.</td>
</tr>
<tr>
<td>Howiesons Poort (HP)</td>
<td>MSA</td>
<td>58-66</td>
<td>Blades, backed tools, notched blades, fine-grained rock.</td>
</tr>
<tr>
<td>Still Bay</td>
<td>MSA</td>
<td>70-77</td>
<td>Bifacial points.</td>
</tr>
<tr>
<td>Pre-Still Bay</td>
<td>MSA</td>
<td>72-96</td>
<td>Highly variable.</td>
</tr>
<tr>
<td>Mossel Bay</td>
<td>MSA</td>
<td>77-105</td>
<td>Levallois blade and point production.</td>
</tr>
<tr>
<td>Klasies River</td>
<td>MSA</td>
<td>105-130</td>
<td>Large blades with small platforms.</td>
</tr>
<tr>
<td>Early MSA</td>
<td>MSA</td>
<td>130-300</td>
<td>Highly variable.</td>
</tr>
<tr>
<td>Fauresmith</td>
<td>ESA</td>
<td>200-600</td>
<td>Small handaxes and blades.</td>
</tr>
<tr>
<td>Acheulean</td>
<td>ESA</td>
<td>300-1500</td>
<td>Handaxes and choppers</td>
</tr>
<tr>
<td>Oldowan</td>
<td>ESA</td>
<td>1500-2000</td>
<td>Cobble core tools.</td>
</tr>
</tbody>
</table>
2.2. Archaeology of the Doring River

2.2.1. Introduction

Situated in the Cederberg Mountains near Clanwilliam in the Western Cape, the Doring River drains a 28,000 km$^2$ basin, long providing important resources for modern humans (Figure 2). Along the sinuous river system, extensive pockets of sediments representing side bars and fluvial sediment stacks contain thousands of lithic artefacts some of which are thought to be more than 500,000 years old (Bleed et al. 2017). These deposits have been found mainly on and in these sediment stacks, occurring on the inner side of river bends. In contrast, the opposite side of these river bends may be incised into bedrock, with the steep cliff terrain providing an extensive colluvial drape containing less dense deposits of artefacts. These areas have been identified as hot spots for stone tool production, raising important questions about behavioural patterns and manufacturing techniques of modern humans. The Winter Rainfall Zone (WRZ) creates a semi-arid to arid climate for the region, receiving more than half its annual precipitation between April to September. It is thought that overgrazing in the current climate may have led to the degeneration of the sites via erosion, although the climate may have also promoted preservation of artefact deposits under sheets of aeolian sediment (Figure 1 and 2) (Jones B. G. pers. comm. 2019; Mackay et al. 2014a, 2014b).

Excavations of rock shelters and open-air sites in the Doring River valley allows local refinement of the characteristics and timing of the regional sequence discussed above, but also validated its general utility as a framework (Mackay 2010; Texier et al. 2013; Mackay et al. 2014b; Mackay et al. 2015; Porraz et al. 2016; Schmid et al. 2016). Low et al. (2017), however, noted the limitations of this approach as it does not adequately represent the variability in systems of early humans, and their social and environmental relationships need to be considered within a landscape framework. Nonetheless, this technique for sediment dating remains broadly applicable across much of the last 75,000 years.
2.2.2. Open-air sites and rock shelters along the Doring River

Throughout southern Africa generally and in the Doring River specifically, there has been much emphasis on a site-based approach to understanding the past, focusing on archaeological sequences from rock shelters. Rock shelters throughout the area - including Klipfonteinrand, Mertenhof Rock Shelter, and Putslaagte 8 – provide information about occupation in the area and behavioural traits such as heat-treating silcrete (Schmidt and Mackay 2016). However, they do not reasonably explain occupational hiatuses found throughout the archaeological record. It was noted by Phillips et al. (2018) that this is exacerbated in areas where rock shelters are more prominent, whereas by employing a landscape approach incorporate sites from across the entirety of the region, it is possible to examine broader assumptions about ancient human behaviours and occupational time-frames. For example, it was previously suggested based on rock shelter sequences that a decline in ancient human populations during the late MSA (50-25 ka) led to abandonment of the region as seen by the identified rock-shelter hiatuses. Conversely, information from open-air sites suggest high rates of artefact discard during precisely these periods where rock shelter occupation is sparse (Mackay et al. 2014b; Phillips et al. 2018).

Although, surface archaeology at open-air sites can also be discontinuous and hiatuses in open-air sites have been linked to periods where occupation of rock shelters was prominent (Mackay et al. 2018; described in detail in Will et al. 2015). Fully understanding the meaning of these discrepancies requires a better understanding of not only the kinds of industries present on open-air sites, but also their formation and preservation (Figure 4). Thus, it may be that these sites have prominent deposits from certain industries because conditions at those times were more favorable for site formation or preservation, and that the absence of certain industries can be explained in the opposite terms (Table 2).

Table 2: The age of each of the lithic types found across each of the KH1 and DB8 study sites. Lower Stone Age (LSA) artifacts are the earliest assemblages found, with Middle Stone Age (MSA) assemblages also occurring. Robberg and Post-Howiesons Poort (pHP) assemblages overlapping across each of the sites.

<table>
<thead>
<tr>
<th>Locality</th>
<th>LSA</th>
<th>Wilton</th>
<th>Oakhurst</th>
<th>Robberg</th>
<th>Final MSA</th>
<th>pHp</th>
<th>HP</th>
<th>Still Bay</th>
<th>Early MSA</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>DB8</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>KH1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
2.3. Questions of site formation and preservation

2.3.1. Questions of formation and preservation of open-air sites along the Doring River

The formation and geomorphology of the Doring River and its associated sediment bodies is currently under discussion, particularly whether these are formed by aeolian or fluvial processes. These processes potentially imply different environmental and climatic conditions during deposition, which in turn can reflect differences in the timing of deposition. That is, aeolian conditions creating depositing may be expected to be more common during dry, windy phases while large scale fluvial events may be more common when the region is more humid. Variances in formation can be reflected in changing elevations relative to the Doring River; if the deposits are principally alluvial then deposits of similar ages can be expected to occur at similar elevations across each of the sites relative to the elevation of the river. If the deposits are aeolian derived, then they can be expected to occur at any elevation across the sites.

Sediment mounds and other features observed across the region are also produced and maintained by biological processes, most notably termites. Large termite mounds - known locally as *heuweltjies* - have cemented sediments in patches across the Western Cape landscape (Moore and Picker 1991). The induration of sediment bodies caused by these termites may differentially improve their prospects for preservation owing to induration of the sediment. Along the Doring River, *heuweltjies* may have acted as agents for cementation of existing aeolian/fluvial sediments, making them more resistant to surface erosion. Other features have been initially proposed to have formed by fluvial processes: side bars, cut bank deposits and back-flow deposits resulting from the migration of the river (Mackay et al. 2014b). However, those involved in the on-going research project have since revised this position, suggesting these deposits may have formed by both aeolian and fluvial process (Mackay A. C. pers. comm. 2018).
As the formation of the sites also depends on the local geology, a study by Grenfell et al. (2014) around Gordonville, in the south-eastern region of southern Africa, found that local geological constraints on meandering river systems did not impact the morphology of the river so much as climatic changes. That is, increased precipitation led to flooding in the region but sporadic river flows did not allow adequate sediment transportation in floodplain reaches of the river systems, hence sediment accumulation occurred preferentially at the upstream end of the floodplain and on the inner bank of the meander (Grenfell et al. 2014). Theories akin to this may provide a basis for understanding the geomorphology of the Doring River, but do not provide insight into the possibility of aeolian and slope-driven sediment transport at a site-based scale.

2.3.2. Questions of preservation of open-air sites in context of a changing climate

Open-air archaeological sites like many of those in southern Africa are often subject to varying post-depositional processes which actively accelerate erosion. These open-air artefact deposits are discontinuous and rapidly erode from the sediment mounds as a result of wind, precipitation and sheetwash; loss of information and archaeological context can be severe in the highly arid climates experienced along the Doring River, especially where there is active farming and large variability in erosion. Soil erosion in southern Africa is known to be a major contributor to land degradation (Le Roux et al. 2008), and many open-air archeological sites are subject to erosion that possesses the potential to rapidly degrade the site. Anthropogenic processes contribute to accelerated erosion in the region, and can often be acting as active destructive processes, where drivers such as over-grazing contribute increasing rates of erosion (Le Roux et al. 2008; Howland et al. 2018; Phillips et al. 2018). Phillips et al. (2018) suggested that this is a key challenge experienced by archaeologists studying open-air sites in the region, since preservation rates are often significantly reduced. Conversely other natural agents may be acting across the landscape to preserve lithic deposits, such as heuweltjies (termite mounds), providing sediment cementation and therefore reducing erosion. These features are common throughout the landscape and can often exceed sizes of 3 m in diameter. As open-air sites and landscapes are often significantly and rapidly impacted by these potential erosional sensitivities, it is essential to attempt to assess the erosional risk at an archeological site to ascertain the impeding future of the site.
The sites in this study, KH1 and DB8, are both open-air sites with complex surface topography that can reflect a combination of formational, erosional and biological (i.e. possible heuweltjies) processes. Each of the sites is dissimilar in morphology, however based on surface artifacts there may be sediments which have possibly been deposited around similar time periods. Archaeological materials upon these surfaces can provide additional information about the formation and destructive processes acing upon each of the sites, allowing the relationship between lithic density and artefact type to be explored in further detail.

2.3.3. Questions about patterning of artefact clusters and dispersal

Estimates of potential erosion across each of the sites and mapping the geomorphic units that can be observed across that landscape can provide information about why some types of artefacts are more dispersed than other types. It has been observed that artefacts with specific ages (based on artefact types and industries) may be clustered together at varying heights amongst the sediment mounds (Bailey 2007; Will et al. 2015). However, artefact clusters in open-air sites are generally characterised by large numbers of artefacts scattered across the surface of the site, but these may have also been displaced as a result of slope (involving aspect and inclination), climate effects (including surface runoff and rain splash), anthropogenic influences (such as livestock herding and cultivation), and wildlife influences (for instance: baboon interference) (Phillips et al. 2018; Howland et al. 2018). Whether this clustering is based on behavioural processes (artefacts occurring at different ages were discarded in horizontally discreate patches) or post-depositional (artefacts of similar ages erosion form similar-aged deposits), the age of these artefacts is important for understanding how and when technological changes occurred throughout the region (Low et al. 2017). Studies into determining rates of artefact dispersal in the landscape have considered the effects of variables, including but not limited to slope, surface aspect and runoff, and climatic variances. They concluded that, in periods of lower precipitation, artefact migration rates may be influenced by wind and wildlife (e.g. Phillips et al. 2018). Furthermore, estimating the effects of erosion on artefact deposition and migration patterns can provide a better understanding of landscape use patterns and early human behavioural changes (Karkanas et al. 2015; Phillips et al. 2018).
2.3.4. *Introduction to Klein Hoek 1 (KH1)*

Situated on the inner bed of the meander towards upper reach of the floodplain, KH1 comprises a range of sediment units. Seemingly placed atop an alluvial terrace and further cobble bedding, thousands of artefacts lay over the surface of the open-air sediment mound site. Although, the formation of the site is still under question, it can be presumed that the splays of artefacts have either eroded and lagged to the surface and now occur as palimpsest deposits. Various degrees of sediment consolidation occur across the site, with some areas void of artefacts and other areas containing hundreds to thousands (Figure 5). Approximately three sediment mounds across the site may be a result of cemented *heuweltjies*, but could also be relict dunes deposited by fine sands being blown from the western and northern edges of the site by the predominant north-westerly winds. Clusters of like-aged (based on industry) artefacts, including Robberg, pHP and Still Bay clusters (Table 2), have also been observed where some of these artefacts may be being transported across the site through erosional processes (Figure 5).

*Figure 5:* (A) depicts the 3 sediment mounds observed across KH1 with their positions circled in yellow. (B) illustrates all the artefacts tagged at the site and their positions in the site. There are clear gaps on the deposit noticeable from this figure. Industry based artefacts can be observed in (C), where each cluster either splays downslope (purple arrows; green circle: pHP) or clusters together in depressions (red circle: Robberg artefacts and pink: Still Bay artefacts).
2.3.5. Introduction to Doring Bos 8 (DB8)

DB8 presents a more complex site when compared to KH1, which can be observed in Figure 6 below. The site seems to mainly have been deposited by fluvial processes creating terracing on both the southern and northern sides of the site. A tributary split the site into two, where this feature is incising onto sandstone bedrock. Erosional processes are observed to be highly active on this site, but their extent and effect on artefact deposits is relatively unknown. The site contains fewer surface artefacts, although the present industry-based deposits do seem to concentrate within a small distance of each other (Figure 6). Notable present at this site are artefacts of Robberg, pHp, HP and Still Bay age (Table 2). Lobe-like features can be observed to the west of the site and are possibly a result of side bar sediment deposition. Cemented termite mounds appear to be less common at this site.

Figure 6: Although there are 3 large sediment mounds across the site – denoted by the yellow circles in (A), there is a much larger spread of artefact deposit which covers a large portion of these mounds (B). Clusters of industry based (time-specific) artifacts have been outlined in (C).
Chapter 3. Methodology

At the beginning of 2017 a major research project (named DRPLP) led by Dr Alex Mackay (UOW) was initiated to understand the occupational history of the South Africa by focusing on formation processes, lithic type stage distributions and lithic type density patterns. Archaeological data was collected as part of the larger DRPLP project, including lithic attributes, such as type, integrity and possible industrial affiliation (based on comparison with other excavated samples). The attributes ‘industry type’ – recorded for approximately 10% of artefacts - was the most relevant for this study.

The methods described below were applied to each of the sites, KH1 and DB8. These sites were chosen for their complex and variances in terrain, completeness of archaeological data – including clustering variances, extensiveness of surface erosion and observable potential of erosion affecting lithics across the sites. DB8 has been identified as a possible slack water deposit, whereas KH1 illustrated an aeolian derived deposit overlaying fluvial sediments and bedding (Mackay et al. 2014b). The sites are located on closed access, active farmland where entry was provided by strict permission of the land owners.

3.1. Primary data acquisition

The data used for this study were collected during the 2018 field season in South Africa. As UAV’s have the potential to be operated manually, semi- autonomously or fully autonomously, this system was selected due to its versatility and high resolution of data capture. A series of images were collected in .jpg format for each of the 4 sites using a small, multi-rotor UAV (DJI Mavic Pro) fitted with the standard 4 K, 12 MP camera (model FC220, focal length 4.7 mm, and resolution 4000 x 3000, image pixel size 0.00156425 x 0.00156425), mounted on a 3 pitch gimbal (3 axis stabilisation and movement capabilities: pitch at up to - 90° and + 30°, yaw and roll at 0° and 90° horizontally and vertically) (www.dji.com/mavic/info). Battery power lasted no longer than 20 min for each flight, allowing 99 images to be captured during each flight pass. For an altitude (height of flight) of 40 m, 1 flight was sufficient to capture each site in detail including the latitude, longitude and elevation of each image. Operated semi-autonomously, the aircraft was linked to an Apple IPad Mini to set flight parameters prior to take-off; including altitude and image overlap and monitor the active flight pass. For each flight, a set of flight paths and flight parameters (constant across each site; Appendix 1) were defined the day before. Images were acquired during favourable conditions for each location - minimal cloud, minimal sun azimuth and minimal winds - allowing a window of between ~2 -
4 hours each day during the middle of the day. The images used for model generation were chosen based on a defined set of requirements, where images that were of poor quality (blurry, out of focus, poor lighting, and duplicates) or did not match in the alignment phase of pre-processing were rejected from the set. During image acquisition up to 99 images were captured for each and assessed based on these criteria.

3.2. Pre-processing and georectification using RTK

Ground Control Points (GCPs) were laid across the sites during the 2018 field season and their locations recorded with a Real Time Kinematic Digital Global Positioning System (RTK DGPS). For the purpose of this study (and other studies), two types of GCPs were established. These included short term spray painted white crosses (specified as: Drone GCP xx) on the surface of the ground and more permanent, long term concrete fixtures dug into the surface (specified as: DRPLP xx). There was no particular order to the placement of GCPs, however the more GCP’s placed around may produce more accurate results although must be placed a sufficient distance from each other whilst being a fair distance from the boarder of the site. The data for these points was then corrected to the preferred geoid (WGS 84 UTM Zone 34S) and manually converted to decimal degrees (DMS) (as the points were collected as eastings and northings) via open source online conversion tools and Microsoft Excel. As GCPs and RTK DGPS points must be in the same coordinate system, conversions to either data can be done to ensure the data correlates and; as a result any models produced prior to georectification will need to be converted to the correct coordinate system as the importing data (e.g. from WGM 84 to WGS 84 UTM Zone 34S). The file was then saved in the required file type (CSV,) to allow other software to recognise the contained data (such as latitude (X) values, longitude (Y) values and elevation (Z) values).

The images were loaded into Photoscan and aligned into sequential order (pre-determined by the software), forming the base tie points for the model to be generated from. The csv. file was then imported, and all images unchecked in the reference window, excluding the image metadata from further processing. Each marker point was corrected to its exact position in each corresponding image, confirming the marker point position in the images for each recognisable GCP. This process will correct the final DEM to the actual elevation and coordinate system as recorded by the RTK. Once all GCPs were marked the dense point cloud (DPC) was compiled at high quality and bounded with an upper point limit of 60,000 and lower-point limit of 6,000. This allows for a high quality and high resolution output, in addition to setting the initial structure and polygons for the 3D model to be generated from. Next, DEMs were constructed
from these DPCs, and further an orthomosaic (stitch) of the images produced an overall 2D image of each site. A detailed method and flowchart including parameters for model generation is provided in Appendix 1 (Figure 7).

*Figure 7: This flowchart outlines the method undertaken to georectify the DEMs using RTK GCPs, which can be applied across all sites in this study.*

### 3.3. Classification of a DPC with Photoscan

Photoscan provides a valuable array of tools for spatial analysis, although these tools are quite limited in processing power and accuracy as they are relatively novel for the software. Nevertheless, the tools were attempted, and the following section outlines these endeavours.

To produce a ground-only surface model from the DPC for slope analysis, removal of the vegetation from ground across the sites was necessary. First, grouping points into classes such as vegetation or ground allowed for the DPC to be separated based on these classes. Using the DPC tool set available, the “classify points” option was chosen and executed with the parameters specified in Table 3. These parameters were determined to be most optimal based on multiple tests run and data collected from the site of KH1. When classifying other sites, it may be best to tailor parameters to the landscape being classified where a number of tests to ensure the correct and best parameters are being utilised for the landscape are required. Once the classification process was complete, each unidentified group was assigned to its appropriate class (i.e. vegetation and ground). To achieve this, each group of points defined by the tool was collected (lassoed) and assigned the relevant class using the “assign class” option. Once completed, these classes can be specified when generating the DEM in the “Build DEM” dialogue box, and a ground-only DEM could be produced without vegetation.

*Table 3: For KH1, these parameters were most suited to the site. However, they may need to be tailored for other sites to achieve accurate classification.*

<table>
<thead>
<tr>
<th>Parameters for automatic DPC classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max angle: 1.5     Max distance: 0.1  Cell size: 0.3</td>
</tr>
</tbody>
</table>
However, this process did not automatically collect all necessary points in the complex landscape presented by KH1. Another option was to select points based on colour, where the software will create a class based on that point colour and deviation from the colour (tolerance level). However, this resulted in suboptimal results if colour contrast between, for example ground and vegetation, was not strong enough (i.e. classifying ground as the colour class of vegetation being created). Although, if tolerance was set low enough and multiple iterations were executed, selecting coloured points and assigning them appropriately, most vegetation in the landscape was classed correctly without the need for lengthy manual classification. Tolerance values varied between 1-10 if points were not being collected, or too many points were collected (sometimes a result of tolerance being set too low/too high).

As this method also did not collect all vegetation point across the landscape (a few small bushes were not classed as vegetation), a manual classification approach was necessary to finish classifying the model proficiently. That is, using the manual classification option and lassoing points that were not assigned to the correct class. Once all points were collected and assigned to the correct class, the DEM was compiled of only the ground surface selecting either an interpolated build (smoothing model while filling holes), or interpolation disabled (will not fill holes or smooth surfaces, leaving spaces where other point classes were).

Each of these methods were amalgamated into each other as each process was conducted (Figure 8). That is, the points classified by each process are assigned to the class previously defined by the first automatic classification. However, a result of the lengthy time to classify the DPC using Photoscan (up to 1 week), it was determined this process would be more suited to less complex landscapes then that of KH1, such as agricultural fields where removing only a crop was necessary.
Figure 8: As automatic classification provided sub-optimal results, each of the classification processes Photoscan offers were combined in attempt to accurately classify the vegetation from the ground.

3.4. Classification of a DPC and orthomosaic using ArcGIS

The georectified DPC and orthomosaic that was built using Photoscan can be imported into ArcGIS Desktop for classification. This method was attempted in effort to reduce processing time and produce more accurate results. Before importing the data directly into ArcGIS, first a geodatabase (gdb.) was created in ArcCatalog and the data corrected to the right datum (WGS 84 UTM Zone 34S). Secondly, the colour values from the Photoscan metadata was converted to RGB values for ArcGIS to recognise for the classification process. Finally, each of the orthomosaics and point clouds produced from Photoscan were clipped to the site extent to reduce the overall size of the data.

Once this was completed, the project was loaded into ArcGIS to group vegetation and ground points into classes in order to separate them for production of the ground-only DEM with within this software suite. ArcGIS provides a wide array of spatial processing tools, and here the ENVI toolbox was utilised to firstly classify the orthomosaic in order to create a mask depicting the classified vegetation group, which was later applied to the DPC to remove the vegetation and create the smoothed, ground-only DEM. Using this toolbox, an “Unsupervised Classification With Cleanup” tool was used to classify the image (orthomosaic). To test the results and determine the best method to use for this project, a “Supervised Classification with Cleanup” process was then executed. The unsupervised classification method uses an ISO Maximum Likelihood function to produce the output, a multivariate classification approach based on bands in the image (i.e. RGB values for this project), where the classification tool doesn’t use
training classes as opposed to supervised classification (ArcGIS Help 2013). It was found that the unsupervised classification approach using a total class number of between 10 – 25 (this may need to be experimented with and visually assessed to ensure the class number sufficiently covers all present vegetation) produced the most accurate output, where this process collected even very sparse and low lying shrubs throughout the area (parameters for this process are outlined in Table 4). Although, and as a result of this precision, larger rocks were identified as vegetation however was deemed to not be an issue as the interpolation will rectify these points. Further, the classification file was converted from a raster file type to a polygonal shape file. Small areas of miss classification were identified (some larger gravel like rocks and artefacts were classified as vegetation), however as the classification was most probably based on colour, this could not be resolved as some rocks were the same colour as branches of vegetation.

**Table 4:** Parameters defined for the classification of the orthomosaic using the unsupervised classification tool.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classes</td>
<td>10 – 25</td>
</tr>
<tr>
<td>Smoothing</td>
<td>Enabled</td>
</tr>
<tr>
<td>Kernel Size</td>
<td>7</td>
</tr>
<tr>
<td>Aggregation</td>
<td>Enabled</td>
</tr>
<tr>
<td>Aggregation size</td>
<td>12</td>
</tr>
</tbody>
</table>

To create the file necessary for removing the vegetation from the DEM, the classified polygon layer was further refined using a process referred to as generalisation. This process has several steps and allows for groups of polygons in the classified layer to be merged together and essentially ‘smoothed’ while removing groups of pixels under or over a defined size (Figure 9) (ArcGIS Help 2013). From of the pre-defined classes, each class representing vegetation was recorded (and as such modified for each site) and using the “Feature Class to Feature Class” tool an algorithm following the format of the expression below was built:

\[
\text{(CLASS\_NAME} = \text{class } 1) \text{ OR (CLASS\_NAME} = \text{class } 2) \text{ OR (CLASS\_NAME} = \text{class } 3) ...
\]

![Figure 9: Before generalisation, the classification output can look noisy and patch. Generalisation cleans up this output, creating uniform output with less noise (ArcGIS Help 2013).](image-url)
This separates the larger polygons (of vegetation) from smaller polygons (where ground has been classified) and allows for export into new shape file (layer). As there were still many areas of bare ground that were classified as vegetation, only polygons above 0.05 cm were selected and a new vegetation class was created (again, polygons between 0.02 m and 0.05 cm were tested to ensure accurate ground and vegetation separation). Finally, to merge the multiple vegetation classes together to create a single polygon and fill any resultant holes in vegetation polygons form the generalization process, the “Dissolve” and “Union” tools were used generating a single polygon of vegetation. This vegetation file (layer) created by the generalization process was then overlaid onto the point cloud, and using the “Select by Location” tool with the invert option checked (leaving default parameters) and the defined vegetation points were removed from the point cloud leaving bare ground points only.

3.5. DEM generation using ArcGIS

The DEM of the ground-only surface was constructed using ArcGIS Pro as the total number of points in the DPC exceeded the maximum number of points for processing in ArcGIS Pro. The DPC was further clipped to the site extent, and the shapefile of vegetation extracted to create a vegetation only layer (retaining all x, y, and z values). As this process leaves holes in the DPC where the vegetation was, interpolation was then conducted to fill these holes and create a smooth surface DEM for slope analysis. To create the final interpolated DEM an Inverse Distance Weighting (IDW) (within the spatial analyst toolbox) method was applied (known as a deterministic, multivariate method; ArcGIS Help 2013). The IDW method assigns a value to an unknown target cell or pixel (in this project, this is the removed vegetation spaces) using the surrounding points and following the nearest neighbourhood function – a weighted average of the surrounding neighbourhood of points defined by a set radius (Figure 10). The tool also interpolates the entirety of the surface based on the correlation of points between one another, that is, points that are further away from a target point have less of a spatial relationship to the target point then those points close to the target point, and therefore a smooth surface of the weighted average of points is created across the landscape.

Spline and kriging were also attempted to compare results and determine the best interpolation method to use across the sites in this project. It was found that IDW method provided the best results for the evaluation of soil loss.
3.6. Model accuracy and image analysis

According to Roosevelt (2014) the accuracy of a model produced with Photoscan is established using the average pixel Root Mean Squared Error (RMSE), the pixel size (m), and the total RMSE for each of the x, y and z values. Spatial autocorrelation was conducted on the final RUSLE output to determine the likelihood of a given value being based on chance and was implemented to ensure the values were not generated randomly.

Following the method outlined by Uysal et al. (2015), the total elevation RMSE was deduced by using three forms of data. The first ($Z_1$) was collected from the visible GCPs on the completed model, the second ($Z_2$) from the respective GCPs collected by RTK in the field, and the total number of GCPs as the third ($n$). Using the equation from Uysal et al. (2015) (Eq. 1) in Microsoft Excel, the total vertical accuracy (RMSE) of the completed model could be determined.

**Eq. 1:**

\[
\text{Vertical Accuracy (RMSE)} = \sqrt{\frac{(Z_1 - Z_2)^2}{n}}
\]
Further, transects from each of the interpolated models compiled in Photoscan and ArcGIS were also compared, not only to ascertain the elevation errors between each of the models, but to also visualise the interpolation and vertical accuracy differences. Photoscan also provides an assessment of the overlap of images based on the number of intersecting images, which is useful when finding the source of present errors.

3.7. Limitations and other software tests
Other free, open source software is also available for this task, such as CloudCompare and QGIS. The software has a good reputation for classification and was therefore attempted when classifying the model. However the steep learning curves associated with the tools resulted lengthy implementation time and were hence relinquished of use.

3.8. Evaluation of sediment units and mounds
Each sediment mound containing archaeological deposits were assessed in terms of its elevation in relation to the Doring River to provide information about the formation of each of the sites. This was completed by assessing and comparing each sites elevation profiles collected from the final DEMs and RTK line transects to find coinciding (or not coinciding) elevations in the artefact bearing mounds across each of the sites. Determining how these elevations vary across each of the sites can provide information about river morphology and active landscape formation processes acting at the sites in periods of early human occupation.

To begin, the lowest elevation value recorded on the DEM for each of the sites was re-interpolated into 0 as a minimum value, and the lowest elevation value further subtracted from each elevation point across in the DPC using the Raster Calculator. This process allows for the elevation of the DEM to scale in relation to the river, now having an elevation of 0 m, and each of the sediment mounds and site elevation values ranging relative to the elevation from the lowest point. The values of the DEM were re-interpolated to fit the profiles from the RTK line transects, that is, the lowest point in the DEM was given a value relative to its position along the RTK transect line, as the base of the DEM’s did not reach the river base level of 0 m. Exaggerated models of each of the sites were also used in conjunction with these profiles for easier visual analysis of the sediment mounds.
3.9. Applying the Revised Universal Soil Loss Equation

To estimate the sensitivity of sediments to erosion and assess spatial displacement of artefacts in the study areas, the Revised Universal Soil Loss Equation (RUSLE) (Eq. 2) was applied using ArcGIS software, and following the procedure outlined by Howland et al. (2018).

\[ RUSLE(A) = R \times K \times LS \times C \times P \]

For the equation, several factors are calculated to assess the potential of soil erosion in an area where the rainfall erosivity (R) factor is a measure of local, yearly precipitation (MJ.mm)/(ha.h.year), the soil erodability factor (K) (t.h/(MJ.mm)) assesses the soil erosion potential, the length/slope (LS) (dimensionless) factor establishes the effects of hillslope and length; and cropping (C) (dimensionless) and conservation (P) (dimensionless) factors relating to any ongoing soil conservation practices and the how ground coverage and slope impact soil erosion. By multiplying these factors together, the average annual soil loss estimation per unit area (A) (t/ha.year) for each site can be evaluated. The sources of data for each of these factors are outlined below:

- Rainfall erosivity (R): Provided by Alex Mackay
- Soil erodibility (K): Soil analysis
- Slope and length (LS): Derived from the interpolated DEM
- Cropping and Conservation (C and P): Nil at each site (given a value of 1 as according to Howland et al. 2018)

Before applying the equation, each of the factors had specific variables which were necessary to determine before finding the final factor value, and this value being represented in ArcGIS Desktop and ArcGIS Pro as a series of raster layers to be combined into the RUSLE equation (Eq. 2). The methods for attaining values each of these factors and the variables are detailed below. By combining each of the factors using the raster calculator in ArcGIS, erosion (t/ha.y) across each of the sites and the sites sensitivity to erosion is estimated. The output was further reclassified into easily interpretable classes to better visually represent the data, following the proposed matrix of site integrity in attempt to illustrate areas with high and low sediment erosion risk and estimate the overall site integrity. Further, artefact migration patterns are assessed also using ArcGIS by a path of least cost analysis - combining water caused erosion with the waters path of least resistance down-slope, again following the methods by Howland et al. (2018), providing further information into the sensitivity and integrity of individual artefact deposits on the surface of the site.
3.9.1. Soil Erodibility (K) factor

The K factor was determined using the equation outlined by Howland et al. (2018) where estimated soil data properties provided from soil analysis (including particle size, percentage of organic matter, soil structure index, profile permeability factor, and clay percentage) are combined (Eq. 3) to determine the erosivity of the landscape. Part of the soil samples were firstly sieved to remove gravel (particle size > 2 mm) and components estimated using the mass spectrometer, after removal of carbonates with 10% HCl and removal of organic matter with 30% H$_2$O$_2$. From this, each sample was dissolved in 1 L of water for analysis by the Mastersizer. Other sub-samples of the sediment were further heated in a furnace for Loss of Ignition (LOI) analysis - at firstly at 550 °C for 4 hours to remove organics and then at 950 °C for 2 hours to remove inorganic carbon. Soil structure, permeability and texture were estimated with the assistance of Dr Brian Jones and Dr Chris Ames. As the soil components will vary across sites for this study, we will be using an approximation of values best suited for all sites estimated using the formula below (Eq. 3) provided in Howland et al. (2018).

Eq. 3. \[ K = (1.292) (2.1 \times 10^{-6} (Average \ Text{ Particle Size (mm})^{1.14}) \\
\quad (12 - \text{Organic matter (%))} + 0.035 (\text{Soil Structure} - 2) + 0.025 (\text{Soil Permeability} + 3) \]

The final K value was checked against the nomograph method provided by Goldman et al. (1986) (Figure 11). This method used the nomograph to firstly estimate the K value using the soil components and making further adjustments to this initial value based on soil properties including organic matter, rock content, soil structure, texture and permeability. To estimate the K value using the nomograph, the intersection point between the total amount of sand and the total amount of silt found in the sample was fist found, and a line parallel to the K value line followed to the right to estimate the K value. Adjustments were made accordingly to the soil texture at each site, organic matter and rock content within the sample set, and soil structure and permeability of the soils.
3.9.2. Length Slope (LS) Factor

To create the LS factor, a series of tools were implemented to create 3 datasets to be combined into the final LS equation using ArcGIS. To begin, a raster defining the slope of the area was created using the previously created DEM. Next, the flow length tool was applied to this slope raster to determine flow length across the site, providing the slope length factor. The final variable, the \( m \)-value (constant, exponential values of slope derived by combining slope steepness and slope gradient as according to Goldman et al. (1986) and Howland et al. (2018)) was derived using the slope layer, transforming it into degrees and reclassifying the layer based on the set of \( m \)-values provided by Goldman et al. (1986). Finally, each of these raster layers were combined in ArcGIS following Eq. 4 from Goldman et al. (1986) to produce the LS factor across each site as described by Howland et al. (2018). The variable \( s \) is slope in degrees, \( l \) represents the flow length and the exponent \( m \) is the \( m \) factor.

\[
LS = \left( \frac{65.41 \times s^2}{s^2 + 10,000} + \frac{4.56 \times s}{\sqrt{s^2 + 10,000}} + 0.065 \right) \left( \frac{l}{72.5} \right)^m
\]
3.9.3. Rainfall Erosivity (R) factor

The R factor (MJ mm ha\(^{-1}\) h\(^{-1}\) year\(^{-1}\)) was found using a 30yr average of total rainfall data across the Beidow and Doring River confluence (specifically from Hough Farm 1983-2014) produced and given access to by Dr Alex Mackay. As these values were derived off site a mean annual precipitation value was derived from this data set, and inputted into the following regression Eq. 5 (for areas with < 850 mm mean rainfall) outlined by Renard and Freimund 1994:

\[
R = 0.04830P^{1.610} \text{MJ mm ha}^{-1} \text{ h}^{-1} \text{ year}^{-1}
\]

Where P is the mean annual precipitation values, falling below 850 mm/yr. A raster layer with the constant value was created for the entirety of the site and using the raster calculator the regression equation was compiled, outputting the R factor layer in a raster format necessary for the execution of the RUSLE equation.

3.9.4. Cropping (C) and Conservation (P) factors

Each of these factors will be given values based on the outlined procedure by Howland et al. 2017. That is, these factors will both be given a representative value of 1 as there is no signs of conservation practises and the vegetation of the area as extremely sparse (fynbos vegetation; generally characterised by sparse succulent bushes and light, sporadic ground cover), therefore not affecting the soil erodibility via rain splash effects.

3.9.5. RUSLE

As each of the factors worked out in raster format, the compilation of the RUSLE equation was straightforward. Using the raster calculator, each of the factors were combined using Eq. 2 (Howland et al. 2018). Factors R, K, C and P were inputted into the equation as constant values as these values did not vary across the site due to lack of data. The LS factor was left as the raster layer to be multiplied by each of the constants (Eq.6). To create the final erosion risk map, the RUSLE layer was reclassified into 5 classes following the method of Howland et al. (2018) and Farhan et al. (2013) representing values 0-5, 5-15, 15-22, and 25-50 t/ha/yr.

\[
RUSLE = (225)(0.37)(LS)(1)(1)
\]
3.10. Site and lithic integrity

Each of the outputs from the proposed methods were assessed to estimate the extent of erosion experienced by an archaeological site, and the likelihood (potential) of the site to be destroyed by erosion. This provides an estimate of the sites archaeological integrity – the potential for displacement of artefact deposits and clusters at a site based on erosional processes acting on a site; and the degree to which these deposits have been impacted by these processes resulting in loss of archaeological information. To achieve this, an urgency matrix has been developed opposing the sensitivity of the landscape to potential erosion estimated with RUSLE against the potential for water caused displacement of the artefact deposits (Figure 12). That is, artefact deposits and clusters that are not dispersed or have migrated throughout the site show high integrity, containing high future preservation potential. Moreover, if these deposits are found to be in locations that are estimated to have high erosional sensitivity, the sites and deposits will be considered to have a high urgency to be studied. Alternatively, clusters that are well dispersed across the surface contain no future preservation potential - having lost their archaeological integrity (low integrity) - and therefore are not of immediate priority to be studied in the future.

Firstly a map illustrating the susceptibility of lithics to erosional processes was constructed using a cost path analysis (following Howland et al. 2018) providing an estimate on possible migration and deposition of artefacts across the landscape was compiled using the previously acquired artefact data and RUSLE values. To perform a cost path analysis, firstly a flow direction layer was created using the appropriate tool, followed by the creation of artefact cluster polygons in a shapefile format (identified as groups of lithics on the surface of the site using a lithic industry-based approach). These layers were further converted into a raster format for analysis. Using “Cost Path” tool, the rasterised cluster layer as the input raster layer, the DEM as the cost distance raster and the flow direction layer as the backlink raster (specifying the path type of ‘each zone’), the output of this function was then converted into a vector layer and buffered by 1m to account for natural variation in water flow across the landscape.

Next, each of the artefact points (identified by industry) were assigned values according to their respective K values - as determined by pixel vs. point - using the “extract values to points” tool. This data was further displayed (using the layer symbology) to illustrate the assigned values, rendering an output providing the each identified lithic’s susceptibility to erosion related disturbance.
Combining this data together, a static quadrant matrix model was created using Microsoft Excel to illustrate the susceptibility of lithic clusters to erosion. The data that was used included a cluster dispersal value – based on a nearest neighbour analysis for the lithics in each defined cluster polygon – and an average RUSLE value for each of these polygons. This data was displayed in an x y scattergram, where the x-axis ranges from high to low cluster dispersal rates (dispersal rates quantified as the observed mean distance from each artefact in m), and low to high average RUSLE values.

A clusters integrity was determined using the integrity matrix below (Figure 12), where, for example, artefacts with high cluster dispersal rate (highly dispersed) that present a lower RUSLE value will be showing low integrity – that is – the lithic cluster has more than likely lost its archaeological integrity and therefore has little information to provide. Conversely, when an artefact cluster illustrates a high cluster dispersal and have a high RUSLE value, the cluster is at high risk of being disturbed by erosional processes leading to loss of integrity and context. This is important if the artefact deposits are in-situ, and at the sites it is currently unknown as to whether all artefacts are dispositioned or in-situ.

The matrix bases its analysis of an industry-based approach, where only identified time-specific lithics were assessed to determine the rate of dispersal associated with each cluster or group of lithic’s. Each cluster of artefacts n the landscape was assigned to a polygon, even when including other industry types for accurate analysis of cluster dispersion. The matrix provides information about the clusters dispersion and average risk of erosion. It predicts how sensitive a possibly in-situ cluster is to erosion, and how likely it is to be affected by the processes. Low dispersal values mean a cluster is closely grouped together (and vice versa with high dispersal values).

![Figure 12. The developed and final static urgency matrix depicting how a cluster-based analysis will be conducted in terms of artefact integrity and susceptibility to erosion.](image-url)
Chapter 4. Results

4.1. Georectification and Classification Results
As KH1 was the first site assessed in this study, the site was subject to many trials and tests to determine the best workflow suited to the landscape, and that could be applied across each of the sites. Therefore, this section will detail these attempts and trials while assessing the reproducibility of the outlined workflows. During the time of model generation, Agisoft (parent company of PhotoScan) released an update of the software to version 1.5, changing its name to Metashape (all other components and workflows remain concurrent with Photoscan version 1.4.5).

Using Agisoft Photoscan (version 1.4.5) a flight altitude of 40 m at KH1 collected a total of 99 images (all used for model generation after visual and software-based image matching). For this site, 1 flight pass was necessary to acquire sufficient imagery for this analysis. A total of 7 drone GCPs (temporary) were placed across the surface of KH1 and a further 4 GCPs (permanent) were utilised for georectification. A total of 11 GCPs provided highly accurate results within image analysis and georectification (Figure 13). After georectification, the vegetation was removed from the DPC using unsupervised classification and further interpolation create a smooth surface.

A total of 83 images was used for the compilation of the DEM at DB8 for a flight altitude of 40 m. A total of 10 GCPs were included within the single flight path for georectification, with 7 of those being temporary markers and the remainder being permanent control points. The final DPC was compiled in high quality producing 52,490,046 points. The DPC and project was then moved into ArcGIS for classification and vegetation removal.

Classification of vegetation for KH1 was completed in using a total of 12 classes, and the classes were grouped to produce a mask to be applied to the DPC (39,562,927 points remaining). Both the “Unsupervised Classification With Cleanup” and the “Supervised Classification with Cleanup” were tested (post generalisation and smoothing). From this test, the “Unsupervised Classification With Cleanup” was found to provide the best results for classification and was applied across each of the sites. Using the IDW interpolation method, the final DEM was generated and the orthomosaic was also constructed (Figure 14). DB8 needed a total 12 classes to ensure all vegetation was included in the mask and extraction process. The final DEM was created in ArcGIS from the initial point cloud generated by Photoscan.
Figure 13: Locations of GCP’s used for georectification across KH1 (A) and DB8 (B). The Doring River is located to the north of KH1, whereas it can be observed to the east of DB8.
Figure 14: The final DEM of KH1 (A) shows the lower fluvial terrace to the north of the site, and the steepening scree slope to the southern extent. The small abandoned tributary can be observed to the western extent, where a few industry-based (time-specific) groups of artefacts are located north of this. DB8 (B) is distinctly different to KH1, where the active tributary is incising into sandstone bedding although artefact groups also occur on the northern extent of this site.
4.2. Image and DEM analysis

4.2.1. Analysis of GCPs and georectification

A previous study by myself found large discrepancies between RTK elevation data and model data. This study shows that when image data is essentially ignored in the model generation process, much more accurate results could be obtained when the DEMs were built on the manual input of elevations for the GCPs and georectified to these points (Table 5). When comparing the GCP differences across each of the sites (Table 5), it becomes apparent that KH1 has a much lower difference than DB8 suggesting there may have been an issue with georectification process when creating the DEM for DB8. When compared with the original elevation data, the georectified data showed a correction of 27.9 m at KH1 and 17.6 m at DB8 (Table 6) – a significant improvement. A table of each GCP and its RTK position, DEM position and average differences across all GCPs can be found in Appendix 1. The results show a very low RMSE values for KH1 (0.027) indicating that the models are accurate and within error for RTK values (Table 7a). DB8 presented a much higher RMSE value (3.63) suggesting a much higher error rate and therefore more discrepancies for the DEM (Table 7b). Global Moran I was also calculated to evaluate spatial autocorrelation and tested to ascertain the likelihood of the RUSLE values being random or not (Table 7c). Low values were found for KH1 proving the results were not generated randomly. This analysis for DB8 could not be conducted due to insufficient machine memory. Image overlap results can be found at Appendix 1 and illustrate substantial coverage of the site by the drone imagery which provided DPCs with high resolution. Varying RMSE results for each across the sites of the GCP’s observed in Figure 15 may be due to elevation differences across the sites, or inefficiency in manual placement when preparing the GCP data on the DEM, although the higher results found across DB8 possibly illustrate an issue with georectification.

Table 5: After georectification using the RTK collected GCP’s, elevations differences in meters are much less apparent across each of the sites.

<table>
<thead>
<tr>
<th></th>
<th>KH1 GCPs Differences</th>
<th></th>
<th>DB8 GCPs Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Z (Elevation) across RTK points</td>
<td>Average Z (Elevation) across DEM points</td>
<td>Average Difference (m)</td>
</tr>
<tr>
<td></td>
<td>180.265</td>
<td>180.245</td>
<td>0.0192</td>
</tr>
<tr>
<td></td>
<td>164.422</td>
<td>163.441</td>
<td>0.981</td>
</tr>
</tbody>
</table>
Table 6: Using the average difference in elevation from the previous Table 5 and the current average elevation difference measured from each of the GCPs on the current DEM, the georectification correction could be determined.

<table>
<thead>
<tr>
<th>KH1</th>
<th>Previous Average Difference in Elevation (m)</th>
<th>Current Average Difference in Elevation (m)</th>
<th>Correction (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>27.899</td>
<td>0.0192</td>
<td>27.872</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DB8</th>
<th>Previous Average Difference in Elevation (m)</th>
<th>Current Average Difference in Elevation (m)</th>
<th>Correction (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>18.618</td>
<td>0.981</td>
<td>17.637</td>
</tr>
</tbody>
</table>

Table 7: For KH1, Table (A) describes the Root Mean Squared Error (RMSE) and standard deviation from this error for each of the planes – Elevation (Z), Latitude (X) and Longitude (Y) and Table (B) outline these results for DB8. Table (C) outlines the results for the Global Marans’s I analysis using both an IDW method and Contiguity method to ensure accuracy.

<table>
<thead>
<tr>
<th>Table A: KH1 Results</th>
<th>RMSE</th>
<th>Standard Deviation (O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>0.027</td>
<td>0.0000047</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table B: DB8 Results</th>
<th>RMSE</th>
<th>Standard Deviation (O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>3.63</td>
<td>0.00097</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table C: KH1 Results</th>
<th>Global Moran's I Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inverse Distance method</td>
</tr>
<tr>
<td>Moran’s I</td>
<td>Z score</td>
</tr>
<tr>
<td>0.1244</td>
<td>41.46</td>
</tr>
<tr>
<td>Less than 1% chance of random choice</td>
<td></td>
</tr>
</tbody>
</table>

|                      | Contiguity method        |
| Moran’s I            | Z score                  | P value                  |
| 0.2665               | 2.536                    | 0.011                    |
| Less than 5% chance of random choice |
Figure 15: The root error is displayed in Figure (A) for KH1 as blue columns for each of the GCP’s. This value has the potential to waver, and can be observed doing so, across the site possible due to the elevation fluctuations. The standard deviation – depicted as the orange line – can be seen to waver across the site, however, stays relatively low. Figure (B) depicts the results for DB8 where there is a much higher RMSE rate for 4 out of 11 of the GCP’s and lower standard deviation rates can be observed.
4.2.2. Transect Profiles for KH1

Profiles for each of the transect lines were also constructed (Figure 16 and 17). At KH1 the elevation of the river was found to be 168 m.a.s.l. and artefact deposits on along each of the transects had an elevation of between 186 - 176 m (Figure 17). Converting relative altitude to ‘meters above the Doring River’ (mADR), the elevation of the artefact bearing deposit was found to be between 8 and 18 mADR. Across each of the transects, the scree slope (SS) begins ~20 - 30 mADR on the southern end of the site. Modern aeolian sediments (~9 - 20 mADR) overlying an ancient alluvial terrace (< 9 mADR) can be observed throughout the mid-section of the site and profiles, beginning on the northern side of the tributary.

Figure 16: The position of each of the transect lines used to create the profiles below. Transect line 1 corresponds to line (A) and transect line 2 is depicted as profile (B). Artefact deposits occurred throughout the middle of the site between 8 and 18 mADR.
Figure 17: Transects taken from the left side of the site across the tributary and the sediment mounds. Each of these transects depict the identified termite mound towards the middle of the site.

Transect 1 (A) shows the artefact deposit located past the abandoned tributary, whereas in Transect 2 (B) the deposit of artefacts is located throughout the middle of this transect, from close to the scree slope to the beginning of the alluvial terrace.

4.2.3. Transect profiles for DB8

Each of the transects outlined in Figure 18 shows a number of terrace features deposited by flooding events (transect profiles in Figures 19 through 20). The Doring River occurs at an elevation of 152 m. The base of the tributary which cuts through the site can be observed at ~155 - 157 m (3 – 5 mADR). Terrace 1 (T1) is occurs at ~5 mADR and is overlain by Terrace 2 (T2) (5 - 9 mADR). Terrace 3 (T3) (9 – 11 mADR) is topped by a large deposit termed Terrace 4 (T4) (~15 - 17 mADR) – the youngest sediment deposit at the site. Each of these deposits are weathered and eroded, and rill features throughout the site are also illustrated on these transects. Artefact deposits were found between 161 – 172 m, or 9 – 20 mADR.
Figure 18: Each of the transect lines below are numbered 1 through to 4. The Doring River was situated at 152 m elevation and the artefact deposits range between 9 – 20 mADR across the site.

Figure 19: Longitudinal profiles (in relation to the Doring River) illustrating the rise in elevation as the sediment mound increases in size. Transect line 1 (A) is taken from the northern side of the site and Transect line 2 (B) from the southern side of the site. This sediment mounds may be displaying several ancient terraces (separated by dotted lines) possibly deposited by separate flooding events.
Figure 20: Vertical profiles depicting tributary separating the site. Artefacts deposits are at similar elevations. Transect line 1 (A) begins at the scree slope on the northern extent of the site and Transect line 2 (B) started from the southern edge of the site. Although the transects are only 75 meters apart the artefact deposits are at similar elevations.
4.3. KH1 RUSLE and Artefact Integrity Results

4.3.1. RUSLE evaluation

Rainfall erosivity (R)

Rainfall values collected over a 30-year period were yearly averages used to determine the average rainfall for the region, resulting in a total of 190 mm/yr. Detailed results of the data can be found in Appendix 1. The data utilised consisted of monthly and yearly totals and was applied into ArcGIS for the RUSLE equation (Figure 21) by creating a new layer containing the calculated value. The R factor was calculated following the regression model (Eq. 7 below) from Renard and Freimund 1994, where \( P = 190 \text{ mm/yr} \), resulting in a final value of 225.29 MJ.mm.ha\(^{-1}\).h\(^{-1}\).yr\(^{-1}\).

\[
R = 0.0483(190^{1.610}) = 225.29 \text{ MJ.mm.ha}^{-1}.\text{h}^{-1}.\text{yr}^{-1}
\]

**Figure 21**: The equation input into the Raster Calculator to find the R factor in a raster format. Specific operators are to be used for the output to be successful i.e. the use of the operator ** specifies an exponent.

Slope length (LS) factor

Derived from the interpolated DEM, the LS factor was found using Eq.4, which combines flow length, slope in degrees and the exponential m-value in the Raster Calculator (Figure 22). The LS values for this site ranged between 0.07 and 573.3, illustrating a long flow distance along moderate slopes throughout the middle of the site where the scree slope and study site converge. Providing interesting results which support the theory of little erosion on sediment mounds, the LS factor identified the path of water based on the steepness of the landscape. From Figure 23 below, the sediment mounds containing in-situ artefacts can be observed placed northward of the flow of water as it is channelled around them, possibly resulting in less erosion and loss of integrity. It can be also observed that lower LS values occur along the compacted road and reduced further when approached the Doring River at the north of the map (Figure 23).

**Figure 22**: The input of the LS factor equation into the raster calculator in ArcGIS.
Figure 23: LS factor output for KH1, provide an accurate output following the overland flow’s path of least resistance.

Soil erodibility (K) factor
For this site, a total of 3 samples were kindly donated for soil analysis. The samples soil structure was estimated as fine granular. Silt was found to be the main soil component (41.6 %) for the site (Figure 24), although as the samples were not taken from the surface this cannot be determinate of actual surface components however can still provide a valuable contribution to the final equation. Coarse sand comprised 38.3 % of the samples, fine sand 17.1 % and minimal clay (2.9 %) with the average particle size for the samples being 119.1 µm. There was negligible gravel content, and the samples contained 2.05 organic matter with the permeability of compact soil (Table 8). Detailed results of the sample analysis and LOI evaluation can be found in Appendix 2. The final K value used for the RUSLE equation was determined to be 0.37. The final K factor found using Eq. 8 blow was estimated at 0.37.

Eq. 8. \[ K = (1.292)(2.1 \times 10^{-6}(119^{1.14}))(12 - 2.05) + 0.035(6 - 2) + 0.025(3 + 3) \]

Following the method from Goldman et al. (1986), the K value was firstly determined using the percentage of sand and percentage of silt providing an initial value of 0.16. Adjustment 1 considered the texture of the soil being loam or finer, creating an adjusted silt (48.8 %) and
sand (48.3 %) value, further refining the K value (0.43). Adjustment 2 accounts for organic matter percentage and rock content where the nomograph assumes rock content of a soil to be 0-15 % (sample average rock content estimated at 3.57 %), and organic matter content of 2 % (sample average organic matter content found at 2.05 %), and therefore no adjustment was necessary for KH1. A third alteration to the K value was made for the soil structure being fine granular, producing a new K value of 0.37, and a final adjustment for the soil permeability yielding a final K value of 0.40 (Table 9). This value may differ slightly to the K factor above, although was found to not influence the final RUSLE output.

Table 8: Soil properties estimated for the samples taken from the soil profile at KH1. Mean particle size of 119.1 µm promotes a finer grained sediment deposit, where coarser grained sediments, albeit fine, are deposited in the area. This creates a lower K value suggesting the soil can be easily eroded.

<table>
<thead>
<tr>
<th>Site</th>
<th>Particle component</th>
<th>Size (mm)</th>
<th>Fraction of content (%)</th>
<th>Mean Particle Size (µm)</th>
<th>Organic matter (&gt;)2mm (%)</th>
<th>Soil Structure</th>
<th>Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klein Hoek 1 (KH1)</td>
<td>Sand</td>
<td>2.0 - 0.1</td>
<td>38.3</td>
<td>119.1</td>
<td>2.05</td>
<td>Very fine &amp; granular</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>VF sand</td>
<td>0.1 - 0.05</td>
<td>17.1</td>
<td></td>
<td></td>
<td>Fine granular</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Silt</td>
<td>0.05-0.002</td>
<td>41.7</td>
<td></td>
<td></td>
<td>Moderate - Coarse grain</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Clay</td>
<td>&lt; 0.002</td>
<td>2.9</td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
</tr>
</tbody>
</table>

Figure 24: Average sediment components for sediment samples taken at KH1. Although not taken from the surface, the samples can provide information about soil properties. Here, silty sediment is predominant in the soil profile which is expected for the valley mouth where higher flow velocities would slow depositing finer grained sediment.
Table 9: The evaluation of the K value based on the method outlined by Goldman et al. 1986. Each K value was adjusted based on sediment components, organic matter, structure and permeability to achieve the final K value for the site.

<table>
<thead>
<tr>
<th>KH1</th>
<th>Estimated K</th>
<th>Particle %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sand 38.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F sand 17.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Silt 41.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clay 2.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VF sand adjustment 0.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adjusted Sand 48.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adjusted Silt 48.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clay 2.9</td>
</tr>
</tbody>
</table>

Cropping and Conservation (C and P) factors

As these factors were nill at each site and therefore given a value of 1 as outlined Howland et al. (2018), values of vegetation cover for the site were given a 0 or 1 value in ArcGIS using a raster format. This method was adhered to across all sites providing the same output.

RUSLE final output

All the factors for the RUSLE equation were computed into raster layers on the basis that each layer would be able to be combined into Eq. 2 using the Raster Calculator and following the proposed method by Howland et al 2018. Although this may have been the initial proposed method for estimating factors across the sites (e.g. vegetation values), when it came to combine all layers, binary layers and single value layers were not compatible with the RUSLE equation in the Raster Calculator. As a result, Eq. 2 (proposed by Howland et al. 2018) was adhered to in the following format (Figure 25) to generate the RUSLE map; where R = 225.289, K = 0.37 for KH1, and the LS layer was able to be included and C and P values were given 1.

Figure 25: The representation of the RUSLE equation for the site KH1 in the Raster Calculator.
The results of the final output are illustrated in Figure 26 below. The final RUSLE values show a result attributable mostly to the LS factor. That is, much of the erosion is concentrated along the paths of moderate slope and long flow lengths. The path of least resistance for this flow can be observed to feed around the more cemented sediment, or termite mounds, possibly as a result of this biological sediment compaction. However, the artefact deposits along the surface of the slope show a much more curious effect of this erosion, where some such as the pH deposits (light green) can be considered as splaying downslope amid heavy erosion, and others for instance the Still Bay deposit (red) gathered in what may be an erosive palimpsest or are only slightly eroding from an in-situ position and have recently been exposed. These deposits can also be assumed to have been positioned at varying elevations in this site, where the pH deposit seems to occur at a much higher elevation than that of the Still Bay deposit, and again from the Robberg industry deposit can be observed to be eroding from a higher elevation and depositing behind a sediment mound.
Figure 26: The final RUSLE output for KHI illustrates each industry-based group of lithics which have moved throughout the site as a result of erosional processes. Here, rates of erosion would be deemed as erosional risk – where higher rates of erosion would lead to a greater erosional risk and therefore possible displacement of surface archaeology.
4.3.2. *KH1 Artefact dispersal patterns*

The results of the cost path analysis are shown below (Figure 27). They illustrate the path of least resistance water takes down slope. From the results, it is possible to discern that pH artefacts are being displaced in a north easterly direction around sediment mounds on the site, instead of in a north westerly direction as firstly assumed from the RUSLE factor analysis results. This suggests that the distribution of these artefact deposits is a function of erosivity (slope and flow) rather than *in-situ* placement. The Robberg deposit can be observed to be eroding in a northerly direction, but not attributable to any lagging deposits moving downslope from the southern end of the site. This can be interpreted as these deposits are eroding entirely from this elevation of site and may well be layered sequentially in the underlying strata as such. There is also no connection between the upper Robberg lithics and the lithics found to the west as there is no directive flow to move them into this position directly from the deposit. The Still Bay deposit shows a similar effect, where the main aggregation is not connected by flow to the deposit just west, and therefore must be eroding from the underlying strata. It may well be the case in excavation, that the Robberg deposit sits above the Still Bay deposit in the strata, hence the mixing observed between these two industries.
Figure 27: Artefact dispersal patterns can be observed to be a result of overland flow across the surface of the site from clusters of artifacts (numbered 1-8). The slope of the site directing this overland flow promoting the notion that lithics are dispersed (e.g. the pHPI deposit) or clustered – such as the Still Bay Deposit and the Robberg deposit - according to the erosion of the landscape.
Figure 28 illustrates lithics that were given an erosion risk value to find the potential risk of erosion caused transportation. We can see that some of the highly dispersed lithics are found in highly erosive parts of the site, whereas others are not. From Figure 27, the Robberg deposit can be observed to be moving in a northerly direction, whereas from Figure 28 below, it can be observed that the main deposit (on a termite mound) shows smaller RUSLE values than artefacts directly surrounding them. As this sediment mound is more than likely a termite mound, it can be observed the more cemented part of the mound with artefacts is less erosive than the immediate site around the mound and therefore lithics are less susceptible to displacement, whereas lithics along the edges of the mounds are highly susceptible to erosion and displacement displaying higher RUSLE values.

Figure 28: As each artefact was given a value according the erosion risk value underlying it, each of the lithics with a higher erodibility values can be predicted to have more of a chance of being displaced (if not already); or possibly not prone to erosion caused movement with lower erodibility values.
4.3.3. Artefact deposit integrity and susceptibility to erosion

Using a cluster-based analysis with a nearest neighbour approach, each artefact within a defined area was tested against an average RUSLE value for that cluster to determine the artefacts susceptibility to erosion, or cluster integrity. A number of clusters were identified for KH1 (8 in total) and are defined in Figure 29. Clusters were determined by having numerous artefacts within a small range of each other and shows similar industries. It is important to note that artefact clusters are comprised of splayed industry based lithics, or very clustered artefacts (Figure 29). Each of these clusters were assessed for a dispersal value (using a nearest neighbour approach) and given a RUSLE value attributable to its current position and further placed on the integrity matrix below (Figure 30). This creates a risk of disturbance, providing an artefact clusters susceptibility to erosion and displacement.

The result of this analysis illustrates clusters with highly dispersed artefacts that have lower RUSLE values are of low risk to further displacement; whereas clusters with a high grouping value and a high RUSLE value are at high risk of disturbance. Using the integrity matrix in Figure 30 it can be seen that few clusters are in the lowest to low risk categories (blue to green) and most clusters sit within the medium risk range (orange). Particular clusters within the lower range such as cluster 4 and 6 are displaying high dispersal values and higher RUSLE values, and therefore have already been displaced and removed from original archaeological context. Cluster 8 (Still Bay cluster) is in the high-risk region (red) – showing that this tight time specific cluster (which can possibly be in-situ) has the potential to be eroded from its current positions and displaced across the landscape resulting in loss of archaeological context. However, cluster 5 (Robberg cluster) is showing a low dispersal value with a low RUSLE value - a medium potential of being affected by an increase in erosional influences. Cluster 3 can be observed to already be splayed down the slope and being within a highly erosional zone of the site (see Figure 24) will continue to be displaced. Clusters 6 and 4 show medium to high RUSLE values and higher cluster dispersion rates, illustrating the already displaced nature of these clusters.
Figure 29: A total of 8 clusters of artefacts were identified at KH1, each displaying varying ranges of integrity and dispersal. Some clusters were created based on industry, and others based on having other artefacts close by.

Figure 30: The integrity matrix was composed using a static matrix model where cluster dispersal and risk of erosion were combined for each cluster to ascertain its susceptibility to erosion. The matrix allows for very low risk of erosional based displacement (light blue) to very high risk (black). Artefacts with a high cluster dispersal value and high RUSLE values would be placed in the high-risk region, whereas those with lower dispersal values and lower erosional values would therefore be less prone to erosion-based displacement.
4.4. DB8 RUSLE and Artefact Integrity Results

4.4.1 RUSLE evaluation

Rainfall erosivity (R), cropping and conservation (C and P) factors

For this site, the R value remained the same as estimated for KH1. The pre-created raster layer was added to the map during processing, containing the correct value in raster format for the RUSLE calculation. C and P factors were given a value as 1 as with KH1 and according to Howland et al. (2018).

Slope length (LS) factor

As opposed to KH1, the result of the LS factor computation for DB8 presented dissimilar values across the site (Figure 31). This may have been a result from slope being the main function of deriving the output. The following output was generated, where it can be observed that the LS values are very low, ranging from between 0 to 28.59, whereas we would expect to see much higher values across this terrain as high slopes and cliffs border the north-eastern edge of the site with steep inclinations flanking the deeply incised tributary; including the sharp face at the south of the site. In comparison to the previous site, the LS factor at DB8 appears to have been dominated by slope and the m factor, as opposed to flow length at KH1. Although, this result may be attributable to shorter more moderate slopes across this site, where moderate LS values were attained for steeper inclinations.

Figure 31: The LS factor output for DB8. Note the sharp inclination at the middle of the site along the outer bend of the meander and leftover points from classification of vegetation having been interpolated to the west of the site.
**Soil erodibility (K) factor**

Average sediment components for DB8 were estimated from 15 samples with the soils having a main component of sand 67% (comprising coarse sand 54.9%; and fine sand 18.6%) 26.9% silt, 5.5% clay with no gravel content (Figure 32). The average organic matter content is found to be 1.02%. Average particle size of the sample set was determined to be 148.9 µm with a fine granular soil structure and permeability of compact soil (Table 10) (refer to Appendix 2 for detailed results). Following the method described by Howland et al. 2018, and Renard et al. 1997 inputting this data into the K factor equation (Eq. 9) below estimated the K factor at 0.37.

**Eq. 9.** \( K = (1.292)(2.1 \times 10^{-6}(149^{1.14}) (12 - 1.02) + 0.035(6 - 2) + 0.025(3 + 3)) \)

The result of the K factor equation provides a reasonable value, where coarse-grained sediments often produce a lower value (K = 0.05 – 0.2), sediments containing high silt content or having a silty loam texture will increase the K value (as silt is highly erosive; K = 0.25 to 0.4). At this site, sediments present as sandy with no rock content, however an increase in the K value will better represent erosive soils in this area as organic matter content is low and silt content is high. An adjustment (each made to the resultant K value) of +0.05 was made for organic matter (equal 1 %) as well as -0.06 for soil structure being fine granular and +0.03 for permeability of medium to coarse pores. Checking against the nomograph method outlined by Goldman et al. (1986), the K value obtained was determined to be reasonably accurate for this site (K value estimated with this method at 0.32) (Table 11).

**Table 10: Soil properties from 15 soil profile samples acquired at DB8. A mean sediment size of 148.9 µm was achieved**

<table>
<thead>
<tr>
<th>Site</th>
<th>Particle component</th>
<th>Size (mm)</th>
<th>Fraction of content (%)</th>
<th>Mean Particle Size (µm)</th>
<th>Organic matter (%)</th>
<th>Rock content (&gt;2mm) (%)</th>
<th>Soil Structure</th>
<th>Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dorinbos 8 (DB8)</td>
<td>Sand</td>
<td>2 - 1</td>
<td>54.9</td>
<td>148.9</td>
<td>1.02</td>
<td>0</td>
<td>Very fine &amp; granular</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>VF sand</td>
<td>0.1 - 0.05</td>
<td>18.6</td>
<td></td>
<td></td>
<td></td>
<td>Fine granular</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Silt</td>
<td>0.05-0.002</td>
<td>23.8</td>
<td></td>
<td></td>
<td></td>
<td>Moderate - Coarse grain</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Clay</td>
<td>&lt; 0.002</td>
<td>2.7</td>
<td></td>
<td></td>
<td></td>
<td>Compact soil / pH &gt; 9.0</td>
<td>Y</td>
</tr>
</tbody>
</table>
Table 1: The estimate K value using the adjustment method outlined by Goldman et al. (1986). This method produced a slightly higher final K value than that found by the Renard et al (1997) method, although was determined to be within a reasonable range of deviation and therefore was not sued for the final RUSLE evaluation.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Estimated K Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>0.22</td>
</tr>
<tr>
<td>F sand</td>
<td>0.22</td>
</tr>
<tr>
<td>Silt</td>
<td>0.30</td>
</tr>
<tr>
<td>Clay</td>
<td>0.29</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component Percentage</th>
<th>Average Sediment Components for DB8</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.7%</td>
<td>Clay</td>
</tr>
<tr>
<td>23.8%</td>
<td>Silt</td>
</tr>
<tr>
<td>18.6%</td>
<td>VF sand</td>
</tr>
<tr>
<td>54.9%</td>
<td>Sand</td>
</tr>
</tbody>
</table>

Figure 32: Sediment components for DB8 illustrate a high sand content with a moderate silty content. Very fine sands are also present at this site suggesting an ebb or decline in flow rates during higher flow periods.

Table 11: The estimate K value using the adjustment method outlined by Goldman et al. (1986). This method produced a slightly higher final K value than that found by the Renard et al (1997) method, although was determined to be within a reasonable range of deviation and therefore was not sued for the final RUSLE evaluation.
**RUSLE final output**

The results of the final output can are illustrated below (Figure 33). Presumably due to the LS factor being primarily a function of slope rather than overland flow, the final RUSLE output for this site was not sufficient and did not accurately represent (or detail at all) soil erosion across the landscape at this site. However, a variety of explanations can describe the results.

The result may be showing a response to shorter and less considerable slopes and flow paths. At DB8, site-based watersheds such as the smaller rills leading into the tributary, have much shorter flow paths, and therefore overland flow is directed more slowly down gentler inclinations (as opposed to steeper slopes observed at KH1). Higher RUSLE values can be observed at the outer bend of the tight meander, and along the straight of the tributary towards the mouth of the tributary. However, the result only partially accounts for erosional hollows and other features observed across the site (Figure 34). The site can be perceived to be acting differently to that of KH1 – possibly due to the steep inclines at KH1 and more moderate slopes (although a larger range in slope) at DB8. This suggests the erosional conditions experienced at each site vary due to the changing surface geomorphology and size of watershed catchments at each of the sites. Stabilisation of the site also may have been achieved at DB8, where the majority of the erosion occurred during the time of downcutting. Once the tributary reached its current bedrock base, most overland flow is systematically diverted into the tributary leading to less erosion across the entirety of the site. This theory suggests the likelihood of mass erosion occurring at DB8 during times of regular precipitation would be low, whereas higher rates of erosion could occur during higher downfalls (not necessarily periods of sustained rain rather sudden heavy downpours). Figure 34, image A, depicts a large erosional feature (circled in red) to the east of the site that may be presumed to be highly erosional, although the RUSLE output only depicts a low amount of soil loss to be occurring in this area. Similar features are depicted in image C. Image B illustrates deep incisions or rills that can be assumed to be due to large amounts of erosion, whereas the RUSLE output depicts a small range of soil loss to be occurring in this area. These present-day erosional features could also have been caused by more modern downpours rather than erosion over a substantial period of time.
Figure 33: The final RUSLE output for DB8 may not be accurately depicting erosional values possible due to shorter slope lengths. However, these erosional features can be observed on the DEM including lobe effects to the west of the site.
Figure 34: Compared with the high resolution orthomosaic, modern erosional features such as aeolian blow outs (A and C) and fluvial rills (B) can be observed across the site. However, fluvial features are not accurately represented by the soil loss output (right).
Chapter 5. Discussion

The results are synthesised below and assessed in context of the thesis objectives. The thesis aimed to evaluate two open-air archaeological sites in South Africa. The sites have varying terrain that allows or an evaluation of the effectiveness of the RUSLE equation across complex landscapes. The sites were also observably prone to erosion that is likely causing exposure and displacement of surface artefacts. Moreover, the sites contain clusters of time-specific artefacts that have the potential to be displaced across the site given highly erosive conditions and site degradation. The evaluation of these archaeological sites was completed using a combination of high resolution DEMs compiled from low altitude UAV imagery and RTK GNSS survey data, as well as lithic survey data.

5.1. Georectification, classification and image analysis of DEMs

The accuracy of the DEMs was controlled through the combination of GNSS RTK field collected GCP’s. The final RMSE for KH1, being within reasonable limits and error, suggests that by following the proposed methods the final outputs are accurate. However, the accuracy of these results was not duplicated at DB8, implying a georectification or coordinate system error. Georectification saw the point clouds tied to the ground as the models produced earlier were set above ground level. This can happen for a variety of reasons – such as machine error and operations in a non-optimal environment (hot conditions or coordinate system differences). Classification can and would be enhanced if a combination of technologies were used. For example, smaller LiDAR devices can be attached to these smaller drones via USB allowing vegetation-free elevation data to be collected from the air.

Photoscan, although ambitious, has provided a series of sub-standard processing tools for classification and model analysis. These tools did not provide an optimal output, even whilst combining each of the available methods together. Also, this procedure was quite time consuming. This method of DPC classification was determined to be unsatisfactory and was not attempted at other sites. ArcGIS provided a software suite much more suited to this task and was therefore employed instead of Photoscan for DPC classification. As this software provided an array of classification options, several tools were tested to determine the most accurate output. From these results, it was identified that the “Unsupervised Classification With Cleanup” method provided the most accurate results with the ground surface model providing a highly detailed output using this method. It was, therefore, deemed the most appropriate method of classification for the remainder of this study.
5.2. Landscape and formation processes

The Doring River was observed to be a low sinuosity, bedrock-controlled river with anastomosing features throughout the region (indicated from the meandering river planform viewed on satellite imagery – Figure 35). Studies previously conducted in the region suggest the Doring River is a first order system and varies in behaviour from a straight to anabranching with a dendritic pattern (Boelhouwers et al. 1999; Eckardt and Quick 2015). Fixed topology and bedrock constrain the river, and where there are larger flood plain areas and levee reaches such as that near KH1, sediments can be deposited in bars (sometimes bank attached) creating the braided effect. The river can erode vertically with downcutting in areas where vegetation cover is abundant (although not always the case), however shows lateral migration and undercutting where vegetation cover is minimal (i.e. at KH1). Other constraints on this migration can include bedrock structure (such as dipping) and bedrock outcrops. Eckardt and Quick (2015) explains that morphologically, the Tanqua-Doring system while topographically influenced, is also affected by sand, gravel and boulder bedding – including isolated boulder bars and pool and riffle systems. Overland flow is increased in areas with convex slopes with shorter hillslope lengths creating larger flows with higher velocity, which can contribute to deposition of fine sediments (e.g. clays and silts) in levee reaches and on bars in the system as flow velocity slows during periodic flooding events (Anderson & Anderson 2010). Boelhouwers et al. (1999) suggested that deposition of poorly sorted debris fans throughout the Doring River region are also a result of these sporadic flooding events.

**Figure 35:** The Doring river traverses between mountainous terrain proving the topographical constraints previously mentioned. The meandering system can be observed as well as topographical constrains. DB8 (green star) and KH1 (yellow star) occur approximately 9.3 km apart.
At KH1, the Doring River channels pass along the northern extent of the site was situated on a bed of fluvial mixed sands and large boulders which are also present along the southern flank of the river as an elongate lateral bar, although this has not been tested (best to test with a long drill hole). Sands are predominantly located towards the southern flank of the river and undercutting of sediment and bedrock were observed along the northern edge of the river, however, was not modelled – although indicating a continuing northerly migration of the river bend at this site. In this context, KH1 could be represent a bank attached bar (Figure 36).

The southern extent of the KH1 is flanked by a cliff face and a talus and scree slope transporting high amounts of detritus downslope. The small abandoned tributary may be a deep-rooted rill and would still be active during periods of high precipitation and overland flow. A terrace located at the boundary between modern sediments and alluvial sediments may have been deposited during higher flows or even flooding events. The modern sediments atop this ancient terrace seem to have been deposited and reworked uphill by aeolian processes forming small coppice dunes around the sparse vegetation, and/or eroded down-slope by both wind and water. This can occur during drought periods or times of little precipitation, where dry sediments are easily transported by winds leading to accumulation on the fluvial bars and sediment deposits. These sands potentially bury the intact archaeological assemblages on the surface of fluvial deposits and can further re-preserve the archaeological palimpsests – a process which can take place numerous times. Reworking uphill can explain the south-east facing dune observed - seemingly deposited by the preferential, strong westerly winds experienced in the region. *Heuweltjies* (termite mounds) cementing sediment and lithics in mounds across the site provide more stability within the sediment, and thus remain *in-situ*. A depression in one of the mounds (there are two on the site) tends to encompass a number of lithics which have been identified as Robberg Industry.
DB8 presented a different landscape to KH1, although with similar sediments and boundaries. A Holocene terrace could be observed along the edge of the tributary that provides a high sediment load into the tributary during periods of high flow and precipitation. Erosion on the steeper slopes along the tributary was also observed. This may be due to the weak consolidation of the sediments here and the presence of high bioturbation by aardvark’s – larger burrowing mammals. During high flow periods, a rapid decrease in flow velocity could be recognised towards the mouth of the tributary (where it meets with the Doring River) by means of sediment deposition. However, at other times, the Doring River may be at or over bankfull level, creating a backflow effect into the tributary where sediments are further deposited where flow velocity is at its lowest. The backflow effect could also be a result of the river rising before the tributary receives as much water creating a higher base level.

It is possible, that before the tributary was established these backwater deposits filled the gully where DB8 resides. Once the base level to the current position in the tributary, aided again by precipitation and erosion, down-cutting into these terraces continued until it reached bedrock (where it currently stands) creating the distinctive two-sided site. As the terraces may have been created from finer sediments, deposited rapidly and are rather modern, the tributary formed easily following the path of least resistance. Deposition of each of the sediment units (terrace) may have occurred during periodic flooding events. When compared to the 30-year precipitation record, these high precipitation events contributing to large flooding events are
not present although one major flooding event of mass scale has been logged in the record provided by Dr Alex Mackay (Appendix 1).

A younger sand sheet was observed to be overlaying the underlying sediment body at DB8. Fine sediments (~200 µm) are present at the site and being the easiest to move by aeolian processes are more likely responsible for the younger sand sheet. A high sand content at DB8 may be showing a continual upward migration of very fine sand from the river towards higher slopes. Smaller peaks in the sediment size analysis data may be illustrating older overbank deposits as at KH1, consistent with the high flooding hypothesis of sediment deposition at DB8.

5.3. RUSLE evaluation: Predicted soil loss

Both of the sites provided varying results when following the same methods. That is, the final soil loss output for KH1 illustrated results which may be relatively accurate however DB8 did not accurately represent an estimation of soil loss at all. It was found the KH1 output was more dependent on the variable LS factor, whereas the DB8 output seemed to rely more on the K factor – a sitewide constant value – and to some degree the slope variable. This, it was assumed, may have been to due more weighting being given to overland flow direction at KH1, whereas more weighting may have been given slope or soil properties at DB8 during the computation resulting in the poor output.

The discrepancy between the results may also be an effect of the nature of the RUSLE equation, usually only yielding reliable soil loss estimates across flat agricultural land where it is mainly applied. The RUSLE equation has also been tested in complex terrain where it is found that the products do not provide accurate outputs. It can also be assumed this was performed across each cell, or pixel, where the weight given to each cell within the operation may be having an effect, where the resolution of the grid is too small (2.5 cm per pixel). Increasing the grid size to, for example 1 m or even 10 m, could also assist with producing more accurate soil loss results, providing the output is dependent on scale.

For the results of the analysis of DB8 to be improved, instead of using soil samples acquired from trenches and pits to deduce one K factor value, it may be more useful to determine top soil properties and map these within ArcGIS (for example: consolidated to un-consolidated or fine sands to coarse sands), and further collect soil samples across the surface of the site where these soil areas are present. Finding a K factor value for each of these areas (i.e. having a varying K value based on surface soil properties) and additionally evaluating the soil loss
potential for each of these areas would possibly deliver more accurate results. This method could also be applied at KH1 delivering a more precise analysis.

Much of the erosion at KH1 site is presumably a direct result of vegetation clearing on the eastern side of the fence line. Higher erosivity values are concentrated around sharp inclinations and follow the path of overland flow concentration. The results of the LS factor illustrate high flows on moderate slopes flowing around the more consolidated sediment mounds and, therefore, patterns of soil loss values suggest potential erosion occurs around cemented pocketed sediments. This may be due to the soil properties encountered at and around the mounds creating higher erosion where sediments are less consolidated i.e. following the path of least resistance downslope. This can create a downcutting effect which can erode lithics from their positions that, in some instances, may still be in-situ. Clusters of lithics can be observed bordering medium to high erosion risk values, whereas dispersed material is spread across higher values.

Soils for analysis were taken from OSL sample off-cute and kindly donated for this study. However, as these samples are usually collected from an excavation pit, the samples do not accurately represent surface sediments across the surface of the sites. Nonetheless, as the samples were the only available samples for analysis, they were used to determine the K factor. As a result, the final K factor value may not be as accurate as possible.

5.4. Artefact integrity: Risk of erosional disturbance

The potential erodibility of lithics can be estimated using the pre-determined RUSLE values, providing a measure of how susceptible the artefact is to displacement in the landscape. It is possible that highly dispersed material at KH1, such as pH type lithics, have been displaced as a result of erosion and therefore it is likely they will be further transported downslope – where high flow coupled with higher slope creates areas of intensified erosivity causing displacement across the landscape. As erosion at this site is a driver of artefact migration throughout the landscape, clustered material (possibly in-situ) has the potential to be eroded from its current position. The results of the integrity matrix analysis illustrated already dispersed artefacts, and artefacts at high risk of disturbance due to erosion. Illustrating how highly dispersed material can be linked to high erosion rates (and vice versa), these outcomes can explain why time-specific artefacts are currently positioned and further where some artefact clusters have the potential to be further displaced - based on the risk of erosion. For KH1, clusters of artefacts can be observed to border medium to high RUSLE values, and the
integrity assessment informs how susceptible these artefacts are to transportation throughout the landscape as a result of erosional processes. As some of the present artefact clusters may be in-situ, further displacement can and will result in loss of context and loss of archaeological information.

Deposition and dispersal patterns of artefacts can be examined when analysed with slope and overland flow, and KH1 illustrates how there can be flow accumulation in areas with lower RUSLE value and areas of lower slope. Overland flow may also accumulate behind areas of higher elevation such as the sediment mounds, directing the flow in a different direction. This is an expected result of the erosion risk analysis combined with overland flow analysis and can provide information about the lithic movement patterns observed and expected across the surface of the site, including: giving reason to the positions of the artefacts within the clusters observed in Figure 29; and how these patterns of deposition perceived in the artefacts occurred.

5.5. Comparing artefact and sediment mounds at KH1 and DB8

When comparing formation process between each of the sites, it has been previously noted that each of the sites formed by differing processes. At KH1, the height of the Doring River sat at 168 m, whereas at DB8 the height of the Doring River was found to be 152 m, a range between the sites of 16 m. Changes in elevation may be a result of the westerly flow direction of the river, where DB8 is located downstream from KH1. However, this change in elevation could be a result of varying depositional processes acting at each of the sites.

KH1 is found at the beginning of a wider flood-plain like channel that constricts around 7 km downstream before reaching DB8. This can produce slower flows at KH1 where finer sediments are deposited, and higher velocity flows at DB8 where larger grained sediments are found. Each of the sites have distinct sediment mounds which were determined to not be at the same or similar elevations above the river, even when accounting for the site elevation differences mentioned above. The boundary between the alluvial terrace and modern sediment deposit of 177 m at KH1 could not be identified at DB8 (terraces between 157 m and 169 m), suggesting sediments at each of the sites were deposited at differing times. This can also provide evidence for the slack water sediment deposition hypothesis discussed earlier.

Using the entire artefact collection (Figure 5 and 6), the range of artefacts elevation in relation to the Doring River was established to assess the potential of similar site formation processes in relation to the main river channel at each of the sites. At KH1, artefact deposits range between 8 - 18 mADR, whereas artefacts at DB8 presented a range of 9 – 20 mADR vertically.
(respectively of the longitudinal and vertical transects). Artefact deposits occurring in clusters
across each of the sites, particularly the Robberg and pHp industries were also assessed to see
if each industry cluster had overlapping elevations. Each of the artefact deposits were found be
to at similar elevations across each of the sites, with KH1 deposits having a relative elevation
of 8 – 18 mADR and DB8 deposits at 9 – 20 mADR. Although sediment deposits are at varying
relative elevations and thus may have been deposited at different times, the relative elevation of
like-age artefacts, including the Robberg (12 – 18 ka) and pHp (40 ka) deposits (Table 2),
suggests the sites were occupied during the same time. It is possible to say these sites were
occupied at a similar time based on parallel artefact ages, although are showing variable
depositional histories.

5.6. Limitations
The nature of the project allowed for numerous limitations to arise, however these were
documented to produce a more streamlined approach and method of analysis. As processing
times can be lengthy, many differing methods of analysing were tested to ascertain the least
time-consuming method.

There is much discussion surrounding the use of 3D modeling with UAV’s, however there is
little consensus on the most efficient and appropriate method to be used when modelling. As
there are also many limitations surrounding 3D modelling, such as incorrect image acquisition
and machine GPS offset, one way of overcoming a few of these issues is to combine the data
with another form of data, such as that collected by an RTK, which can offer further validation
of both data forms.

Photoscan provided an ambitious array of tools for creating classified point clouds and DEMs,
however these tools have not yet been optimised and thus did not accurately or sufficiently
classify the vegetation at KH1. After several different software were tested in attempts to
sufficiently classify the vegetation in the orthomosaic including CloudCompare and QGIS, it
was determined that working within ArcGIS Pro was more appropriate for classification as the
software could processed upwards of 45 million points, whereas ArcGIS Desktop could only
process around 2 million. A way of mitigating this process would be to attach a LiDAR device
to the aircraft to effectively classify a point cloud using accurate vegetation data.

Machine specs were also a limitation in the context of processing time and memory. Large
memory utilisation of complex computations would mean fewer large operations would
succeed due to ‘out of memory’ issues on machine. In these cases, it is not necessary to upgrade
the machine, rather split the project into sections for processing and merging these sections back together. However, at times this could not be completed, and it was necessary to leave a machine running overnight to complete the operation.

The soil loss equation has also been proven to not provide thoroughly accurate results in complex terrain, and as a result it suggested to be applied to flat land – where it is mainly used in agricultural context. Other issues with the application of RUSLE include resolution and weightings given to each factor during the computation – for example the final output for DB8.
Chapter 6. Conclusion

By combining RTK and DEM data, the results of this project can be compiled with further assessments of the sites to provide a more accurate evaluation of soil loss over a period of years, which may further continue to provide information about lithic migration patterns in the landscape and their possible in-situ placement.

Future recommendations for further study at these sites would include:

- Collecting similar data each to repetitively conduct the erosional risk analysis.
- Assessing surface geomorphology in more detail – such as taking samples of each defined surface sediment.
- Using drill holes to examine beneath the surface sediments; or conducting larger GIS studies of regional hydrological watersheds and river system behaviour could provide more information about formation processes and possible depositional events.
- Sediment origins and landscape formation processes would be better defined if placed in context of sediment ages, for example, those collected by OSL.
- Artefact movement patterns may be better understood if there was a possibility to combine other artefact morphological data, such as weight and size data, with the risk of erosion.

The results can illustrate destructive processes acting at each of the sites and provide information about the ages of the sediment bodies and the processes which formed them. Further, artefact transportation and preservation rates may be inferred, including the age of sediments body in which they eroded form. This can shed light on human movements and lithic type dispersal across groups of ancient humans and time periods. It can also inform future decisions about the management of archaeological research on these sites – and specifically the need for analysis of clusters like the KH1 Still Bay deposit before erosional processes destroy it. Information about the formation of sites including relationships between sediment elevations and lithics and inferences between sediments and time-specific artefacts can be further made for insights into mechanisms behind ancient human behaviour.
References


Appendix 1

Table 1: The flight parameters employed for the initial stage of image acquisition.

<table>
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<tr>
<th>Altitude</th>
<th>Speed</th>
<th>Shooting Angle</th>
<th>Overlap Ratio</th>
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<td></td>
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<td><em>Side: 40%</em></td>
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Figure 1: This flowchart outlines the standard model generation procedure from the image acquisition stage to the final output. Processes are defined at stages where tools in the software are implemented; sub-processes are to be implemented when chunks are being used; and steps denote manual tasks, such as breaking the initial image set into an array of chunks, or merging these chunks to compile the final model.
Table 2: After multiple tests, these parameters were found to be the most appropriate for model generation across many landscapes, including the complex landscapes encountered in this study.

<table>
<thead>
<tr>
<th>Align Images</th>
<th>Optimise Cameras</th>
<th>Build Dense Cloud</th>
<th>Build Mesh</th>
<th>Build Orthomosaic</th>
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<tbody>
<tr>
<td>Each image in each chunk to be aligned to each other based on the software.</td>
<td>Fitting all the fit variables to the image set.</td>
<td>Generating a point cloud from the images based from SfM algorithms.</td>
<td>Compiling the dense point cloud into an interactive 3D model of the site.</td>
<td>Compiling a high resolution stitch of imagery</td>
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<td><strong>Quality:</strong> High</td>
<td><strong>Surface type:</strong> Default (Arbitrary)</td>
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<td><strong>Source Data:</strong> Default (Sparse cloud)</td>
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| **Generic pre-selection:** Checked | **Face Count:** Default (Medium) | **Interpolation:** Default (Enabled) | **Point classes:** Default (All) | Use default parameters, or select preferred coordinate system, as with hole filling and colour correction. Select the setup boundaries box and press ‘Estimate Boundaries’.

Figure 2: Image overlap for Kh1 and DB8. KH1 shows good image overlap as with DB8 – although lower overlap ranges at the edges of the site could create error and less dense point clouds when generating models.
## Appendix 2

### Table 1: GCP results for KH1

<table>
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<th>Label</th>
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<th>RTK Longitude</th>
<th>RTK Elevation (m)</th>
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KH1 GCP’s
Figure 1: Yearly Rainfall averages for the Doring-Biedouw Confluence (A). Monthly data is provided in (B). Data access provided by Dr Alex Mackay 2018.
**Figure 2:** KH1 comprehensive soil analysis results for finding the K factor - grain size analysis results for 3 samples.
**Table 2:** Particle component and size analysis for KH1.

<table>
<thead>
<tr>
<th></th>
<th>Clay</th>
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<th>Very fine sand</th>
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**Table 3:** Comprehensive results of LOI analysis for KH1 samples.

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Figure 3: DB8 comprehensive soil analysis results for finding the K factor - grain size analysis results for 15 samples.
Laser size analysis for DB8-7 - Average

Laser size analysis for DB8-8 - Average

Laser size analysis for DB8-9 - Average
Laser size analysis for DB8-10 - Average

Laser size analysis for DB8-11 - Average

Laser size analysis for DB8-12 - Average
Table 4: DB8 particle component and size analysis.

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<th>Clay</th>
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Table 3: Comprehensive results of LOI analysis for DB8 samples.

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