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A STUDY OF SILCRETE RAW MATERIAL ACQUISITION IN THE HOWIESONS POORT AT KLASIES RIVER USING GIS CATCHMENT ANALYSIS TECHNIQUES

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720311

A dissertation submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science.

02 August 2019

DECLARATION BY THE CANDIDATE

I declare that this dissertation is my own, unaided work. It is being submitted for the degree of Master of Science, at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any university.



_____

(Signature of candidate)

____ 02___day of ___08___ _____2019_____at____Wits_____

ABSTRACT

Klasies River Main (KRM) site contains Middle Stone Age archaeological material from the Howiesons Poort (HP) techno-complex that demonstrates a marked expression of complexity. The complexity is also apparent in the lithic technology of the HP that is characterised by an increase of different types of silcrete raw material. Although changing mobility patterns have been related to the increase in silcrete in the HP at KRM, no studies have investigated this aspect in detail. Therefore, the mobility patterns involved in the procurement of silcrete has been investigated through GIS modelling methods. GIS Least Cost Path (LCP) algorithms have been used to model silcrete raw material acquisition in the HP at KRM, using the currently recorded sources of this material in the south Eastern Cape. The results demonstrate that GIS LCP algorithms produce differing output results. The Tripcevich Tobler Hiking Function (TTHF) and ArcGIS Default Built-in Cost (DBC) algorithms modelled paths that favoured flat terrain whereas the White Tobler Hiking Function algorithm modelled paths that favoured steep terrain. The two time-based algorithms models produced different travel time ranges. The TTHF algorithm produced travel time that are more comparable with Google maps and the White Tobler Hiking Function (WTHF) produced slightly larger travel times. The travel times of TTHF implied that HP groups at KRM followed a daily foraging strategy, while the WTHF travel times imply that the groups followed a logistical foraging strategy. The nearest silcrete source from KRM is located 28.3 kilometres from the site and can be reached in 4 hours according to the TTHF. The possibility of interaction between groups from KRM, Pinnacle Point (PP) and Nelson Bay Cave (NBC) was investigated by calculating LCP's from these sites to the silcrete sources. The results demonstrated that there was a high possibility of interaction between groups from the three sites, if they sourced silcretes in the Uitenhage and Grahamstown areas. Mapping procurement patterns of silcrete raw material and modelling predictive paths that the HP groups from KRM may have followed bring new perspectives regarding the complexity of human behaviour within this period and add to studies of silcrete raw material use in the South African Middle Stone Age.

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CHAPTER ONE : INTRODUCTION

South African archaeological research, particularly on the Middle Stone Age (MSA), is at the forefront of the modern human origins research as some of the earliest anatomically modern remains have been found in the region. Klasies River main site (KRM) is an archaeologically significant site in the southern Cape that has contributed to our understanding of the development of typically human forms of anatomy and behaviour (Wurz *et al.* 2016). The archaeological sequence at KRM encompasses a 21-meter-long archaeological deposit of stone and bone tools and other evidence that built up from recurrent visits by hunter gatherers between ca. 120 000-2 300 years ago (Wurz 2016). However, most of archaeological deposits at KRM belong to the MSA and formed between ca. 120 000 and 55 000 ka (Klein 1976; Wurz 2002).

KRM (34º6'29.17" S 24º23'24.50" E) is located along the Tsitsikamma coastline, roughly 110 km west of Port Elizabeth (*Fig. 1.1*) (Singer & Wymer 1982; Wurz 2016). The site is located in a densely vegetated area and is bordered by the Tsitsikamma mountain range. Table Mountain Group quartzitic sandstone dominates the KRM landscape. The site is located in a quartzite cliff and consists of three caves (caves 1, 2 and 1C) and two shelters (caves 1A and 1B).

KRM was first excavated by Singer and Wymer in 1967/8 (Singer & Wymer 1982). Singer & Wymer (1982) divided the MSA at KRM into five cultural stages, which are the MSA I, MSA II, HP, MSA III and MSA IV (listed from older to younger). The HP phase occurs in Cave 1A and Cave 2 where it was excavated in the Initial and Top cuttings. The HP in Cave 1A is recorded in layers 21-10, and in Cave 2, in layers 1-5 (Singer & Wymer 1982) (*Fig. 1.2*).

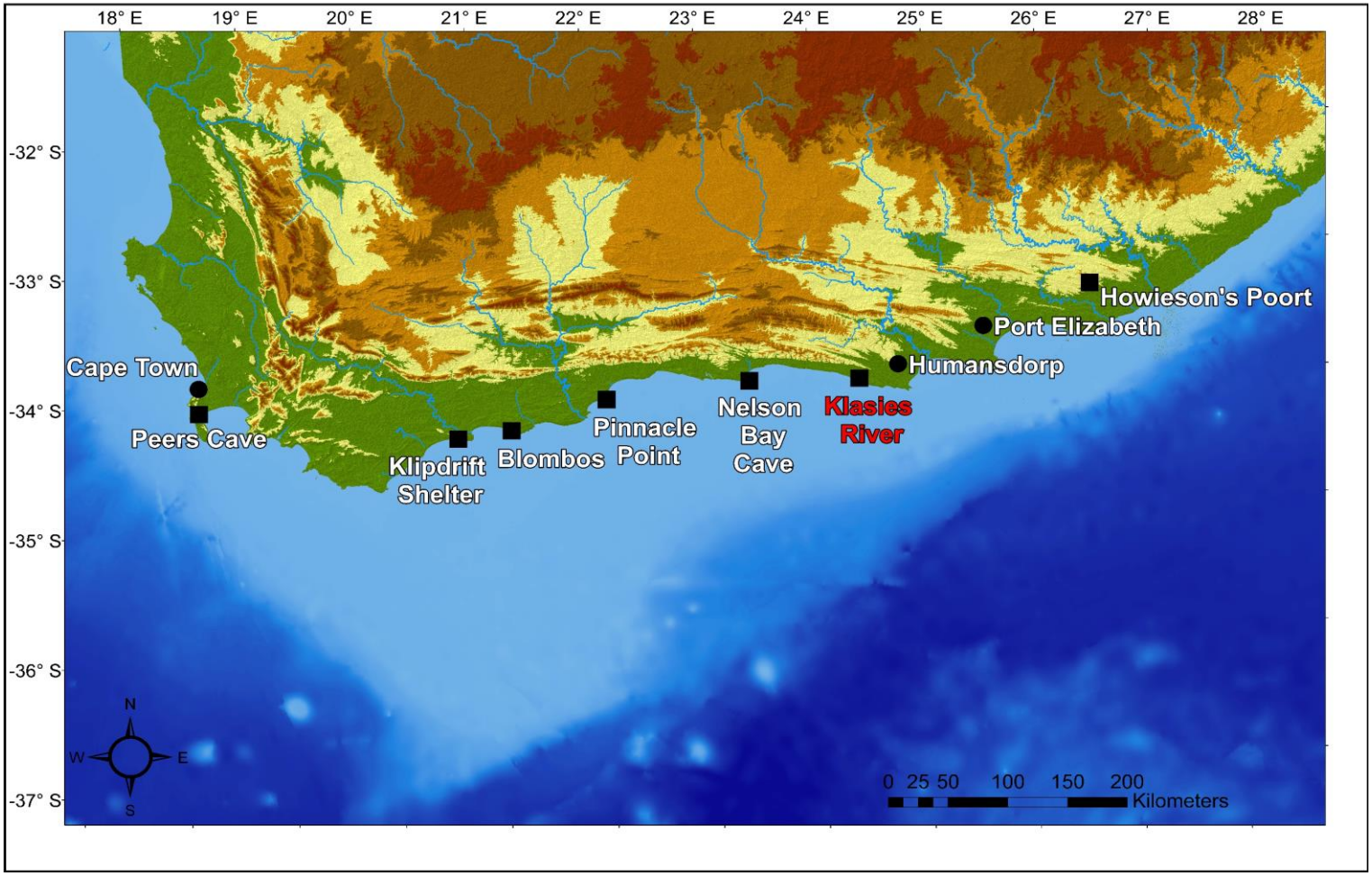

Figure 1.1: Map depicting Klasies River Main site in relation to other Howiesons Poort sites in the southern Cape. (Archaeological sites are symbolised by squares while cities/towns are symbolised by circles). (Sources: Bathymetric data from MGDS; DEM: USGS; river data: from DWA).

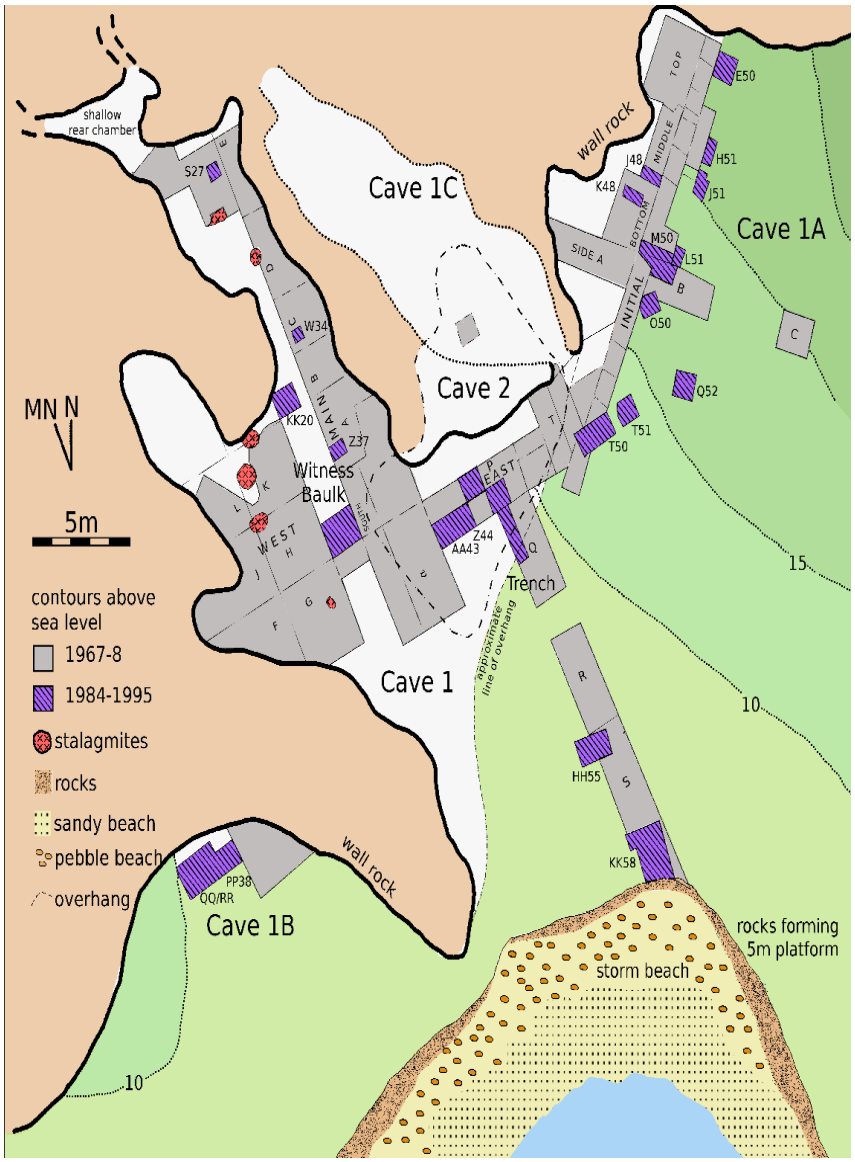

Figure 1.2: Plan of Klasies River Main showing the Singer & Wymer and Deacon excavations (Image from Wurz et al. 2018).

The Singer and Wymer excavations were followed by the Deacon excavations undertaken between 1984 and 1995. Deacon divided the stratigraphic sequence into a number of members and excavated the 1.8 m of HP material in the Upper member (Deacon & Geleijnse 1988). The Rock Fall member underlies the HP and is believed to have been a period of low occupation and the HP a period of higher occupation intensity (Deacon & Geleijnse 1988). The HP was excavated in three squares, J51, H51 and E50, off the Singer & Wymer initial cutting (Deacon & Geleijnse 1988). The HP layers excavated by Deacon are shown in Figure 1.3. Since 2015 the site is excavated by Wurz with a current focus on Cave 1. The HP

period at KRM is dated to between 65-55 ka (Wurz 2013; Wadley 2015) using a wide variety of techniques.

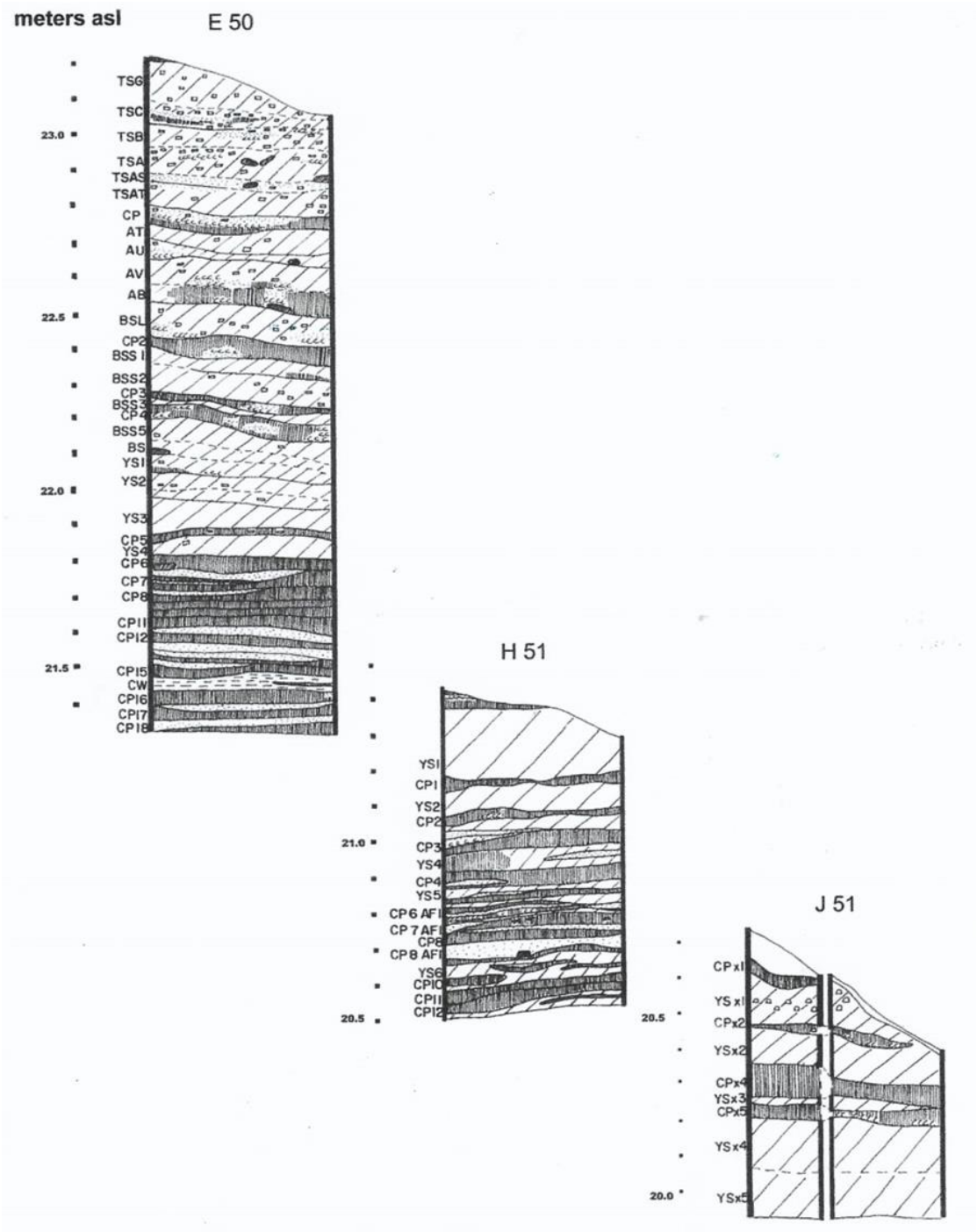

Figure 1.3: Stratigraphy of the HP and the MSA III layers Cave 1A of the Deacon excavation (Image from Villa et al. 2010).

The HP in South African archaeological sites is dated approximately from 64.8 ka to 59.5 ka (Jacobs *et al.* 2008), although, at Diepkloof Rock Shelter, much earlier dates, around 100 000 years ago, have been recorded (Porraz *et al.* 2013, see also Wadley 2015). This industry is characterised by a distinct lithic raw material utilisation, and the increased use of fine-grained raw materials like silcrete. The HP is a small blade industry, which is characterised by backed and irregularly notched artefacts, scrapers and unifacial and bifacial points (*Fig. 1.4*) (Wurz 2000; 2013). Studies have shown an increase in the use of silcrete raw material in sites such as Pinnacle Point (PP), Klipdrift Shelter (KDS), Nelson Bay Cave (NBC) and KRM (*Fig.1.1*; Wurz 1999; Minichillo 2006; Brown 2011; Reynard *et al.* 2016; Wilkins *et al.* 2017) PP and NBC are the two HP sites closest to KRM.



Figure 1.4: Howiesons Poort silcrete artefacts from Klasies River Main site.

Silcrete is defined as a sedimentary rock that formed as a result of silica accumulating within or near-surface geologic deposits and cementing pre-existing geology (Nash *et al.* 2013a; Will & Mackay 2017). The use of silcrete for the production of lithic tools has been linked to subsistence behaviour, complex behaviour, changes in mobility patterns and environmental change (Ambrose and Lorenz 1990; Wurz 1999; Minichillo 2006; McCall & Thomas 2010; Wilkins *et*

al. 2017; Mackay *et al.* 2018). This study focusses on possible mobility patterns of resource procurement (silcrete) of the groups that lived during the HP. Topographical and environmental factors that may have played a role in paths chosen for procurement are investigated.

Research problem statement

The increased occurrence of silcrete raw material in the HP techno-complex at KRM and its procurement patterns feature prominently in discussions on landscape use and mobility patterns, but to date there has been no detailed studies on the specific movement patterns and routes related to the silcrete sources.

Research questions

1. How do different GIS Least Cost Path (LCP) algorithms differ in modelling movement patterns in the southern Cape landscape?
2. To what extent do factors such as slope, vegetation and rivers impact on the LCPs to the silcrete outcrops?
3. Is there an overlap in the paths from PP, NBC and KRM to silcrete sources?
4. What is the travel time to procure silcrete raw material from KRM to the nearest silcrete outcrop sources and how does this fit within procurement strategies choices?

Aim and objectives

The aim of this research is to investigate possible routes HP people at KRM may have taken for silcrete raw material acquisition through GIS modelling. The following objectives are set:

1. Assess the effects vegetation and rivers on the LCPS when moving on the KRM landscape.
2. Evaluate the possible extent to which groups from PP, NBC and KRM interacted through comparing their possible procurement ranges.
3. Investigate the feasibility of using LCP methods to model travel times and pathways to silcrete outcrops in the Southern Cape landscape.

Rationale

The HP is one of the MSA phases that demonstrate a marked change in human behaviour due to its distinctive lithic technology. The HP techno-complex is characterised by the increased use of fine-grained raw material such as silcrete (Will & Mackay 2017). At KRM, more than 40% of the artefacts in the HP are made in silcrete (Wurz 1999). This increase has been linked to changes in the complexity of human behaviour (Wurz 2013), a response to changing climate which resulted in the expansion of group foraging ranges (Ambrose & Lorenz 1990) and increased costs of raw material acquisition (Minichillo 2006). The exact source of the silcretes from the HP levels at KRM is unknown (Thackeray 1992; Villa *et al.* 2010; Wurz 2013), complicating understanding of group foraging ranges and cost of raw material acquisition.

The distribution of silcrete raw material in the south Eastern Cape has been mapped by Roberts (2003), and Nash *et al*. (2013b) analysed the geochemistry of silcretes from selected southern Cape non-archaeological sites. To date, there has been no detailed investigation of the possible location of silcretes that occur within the KRM HP. However, understanding the sources of silcrete raw material at KRM is relevant as it may add to our understanding of mobility and procurement strategies. This is important in understanding the behavioural patterns of modern humans during Marine Isotope Stage (MIS) 4. This study focussed on modelling and predicting possible past routes to the documented silcrete sources using Geographical Information Systems (GIS), assuming that some of these sources were used by HP hunter gatherer groups. By mapping the paths taken from KRM to the silcrete raw material sources, a deeper understanding of the effort involved in obtaining silcrete in the HP at this site can be developed.

Organisation of the dissertation

This dissertation comprises of seven chapters, which include this introduction (Chapter one). The following chapter (Chapter two) discusses the geology of the southern Cape, the associated topography and the formation of silcrete in the area.

This is followed by a discussion of the HP with a focus on the lithic technology, palaeoenvironment and silcrete raw procurement strategies. In Chapter three, the background on the development of spatial archaeology and how GIS forms an important part of movement studies in archaeology are explored. Chapter four describes the methodology and data collected and how it was incorporated into the GIS study. The results of the dissertation are discussed in Chapter five. The results include the different algorithms used, maps depicting the Least Cost Paths (LCPs) modelled and the effects of environmental factors, vegetation and rivers, on the landscape. The discussion is in Chapter six and the conclusions of the project are presented in Chapter seven.

CHAPTER TWO : THE GEOLOGICAL CONTEXT OF KLASIES RIVER MAIN SITE, THE SOUTHERCAN CAPE AND THE HOWIESONS POORT.

This chapter provides the context for the study undertaken. It reviews the geology and geomorphological setting of the southern Cape and the landscape features associated with the specific study area. Secondly, the Howiesons Poort (HP) and its associated paleoenvironment are discussed with specific reference to Klasies River main site (KRM). Please note that the images used in this dissertation were taken by Mosweu (2018) unless stated otherwise.

2.1 Geology and geomorphological setting

2.1.1 Geology of the southern Cape

The southern Cape is characterised by a variable geology (*Fig. 2.1*). The oldest geological formations in the southern Cape include the Kaaimans, Gamtoos Groups and Malmesbury, which are related to the Pan African Orogeny (*Table 2.1*) (Greese *et al.* 2006; Maud 2008). The Pan African Orogeny was a chain of tectonic, magmatic and metamorphic events that led to the formation of Gondwanaland, a supercontinent, from ±870 - 550 million years ago (Ma) (Kroner & Stern 2004; Greese *et al.* 2006). The Cape Granite Suite was deposited in the Southern Cape during the Late Precambrian to Early Cambrian (Appendix 1) due to igneous activity during the formation of the Pan African Orogeny and it overlays the Malmesbury Group (Scheepers & Enoch 2006).

The southern Cape is dominated by the rocks of Cape Supergroup (Maud 2008), formed from the Early Ordovician (±500 Ma) to the Early Carboniferous (±330 Ma) (Thamm & Johnson 2006). The Cape Supergroup overlay the Cape Granite Suite rocks (Thamm & Johnson 2006), which are 3 000 m thick (Maud 2008). The Cape Supergroup is divided into three subgroups, the Table Mountain group (comprises of conglomerate, sandstone, siltstone, mudrock, diamictite), Bokkeveld Group (contains a fine- grained sandstone and mudrock units) and lastly the Witteberg Group (comprising of quartzitic sandstone and micaceous

mudrock) and each subgroup has various formations (Appendix 2) (Thamm & Johnson 2006). Table Mountain Group quartzitic sandstone occurs in the KRM landscape in association with slate, shale and Bokkeveld metashales (Butzer 1978; Marker & Holmes 2010). The Cape Fold Mountains, discussed in more detail in Section 2.1.2, is comprised of Cape Supergroup rocks.

The Cape Supergroup is overlain by the Karoo Supergroup which comprises of the Dwyka, Ecca, Beaufort and the Drakensburg subgroups (Thamm & Johnson 2006; Johnson *et al.* 2006). The Karoo Supergroup was deposited from the Late Carboniferous 310 Ma ago to the Middle Jurassic (Johnson *et al.* 2006) 180 Ma ago. The volcanic lava intrusion of the Drakensberg Group led to the end of the Karoo Supergroup (Maud 2008). Today the Karoo Supergroup rocks cover the northern portion of the Eastern Cape province, but they do not cover the area in close vicinity of KRM (Analysis of the Geology map of the Southern Cape from Council of Geoscience).

Table 2.1: Geological context of the southern Cape and associated geomorphic events (After Maud 2008; Marker & Holmes 2010).

Era	Age (in Ma)	Geological Epoch	Geological Group or Formation	Geomorphic Event
Cenozoic	0.01	Holocene	Bredasdorp & Algoa Group	
	1.8	Pleistocene		
	5	Pliocene		
	23	Miocene		200 m uplift
	34	Oligocene		200 m uplift
	56	Eocene		
	65	Palaeocene	Grahamstown Fm	Coastal Platform
Mesozoic	145	Cretaceous	Uitenhage Group	African Erosion Surface
	200	Jurassic	Karoo Supergroup	Gondwana rifting
	250	Triassic		Cape Orogeny
Palaeozoic	300	Permian		
	360	Carboniferous		
	416	Devonian	Cape Supergroup	
	444	Silurian		
	495	Ordovician		
	545	Cambrian	Cape Granite Suite	Igneous activity
	800	Late Precambrian	Malmesbury, Kaaimans Gamtoos Groups	Pan African Orogeny

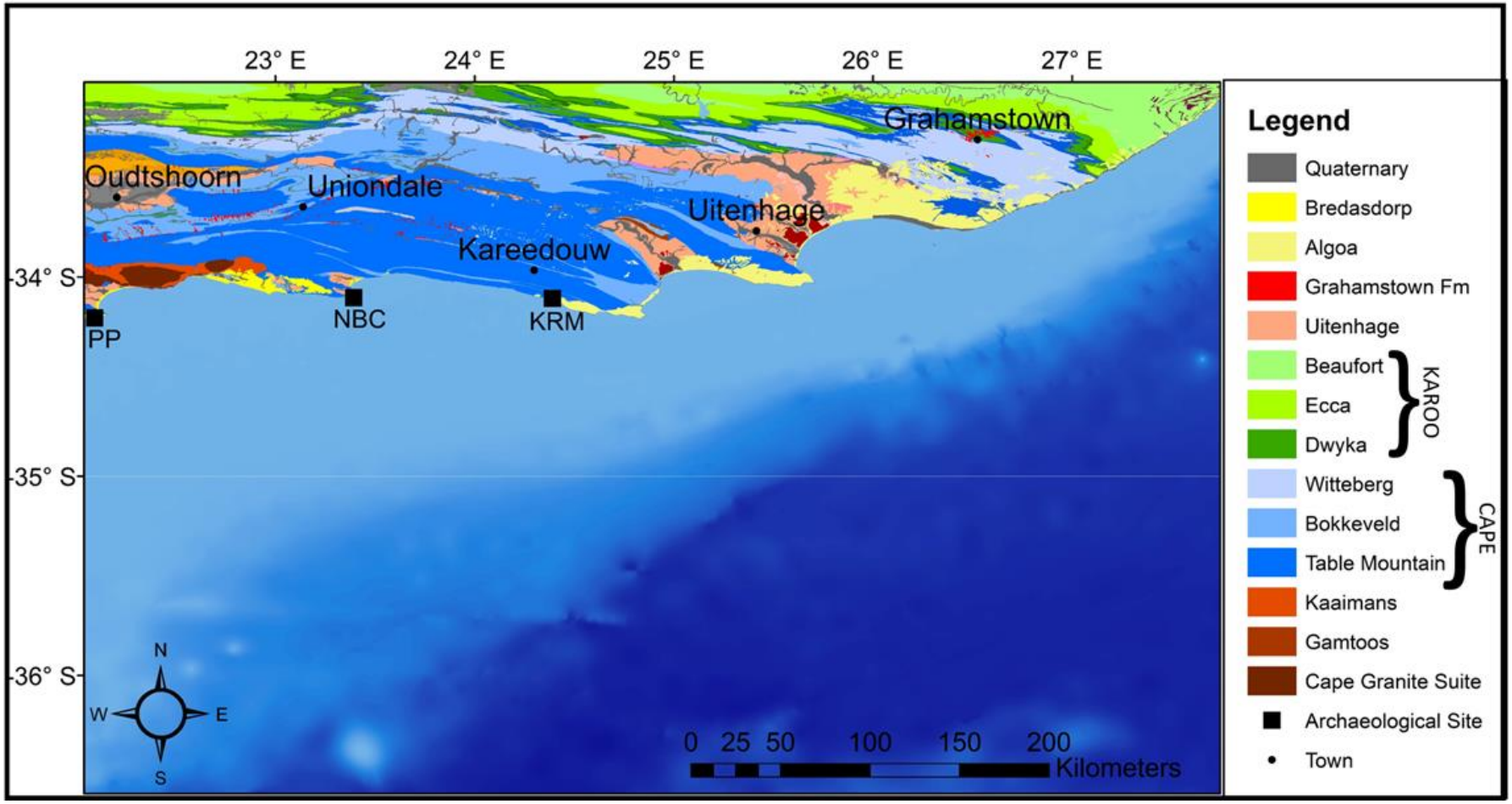

Figure 2.1: Geology of Klasies River and the surrounding, simplified to group and formation (fm) level. (Sources: geology: from the Council of Geoscience; bathymetry: from MGDS). The archaeological sites discussed in this study are Pinnacle Point (PP), Nelson Bay Cave (NBC) and Klasies River Main site (KRM).

The Uitenhage Group that overlies the Karoo supergroup was formed due to the reactivation of the Cape Fold Belt mountains between 145-130 Ma (Watkeys 2006). During the Cretaceous, many areas of Africa were weathered down to level horizons and these are known as the African erosion Surface. The moist and humid conditions during this period gave rise to the Grahamstown Formation (fm) consisting of silcretes (Roberts 2003; Maud 2008). The last geological event in the southern Cape happened during the Late Miocene and Pliocene when an uplift initiated an erosion cycle in the region giving rise to the formation of the Algoa and Bredasdorp groups (Maud 2008). More detail on the silcretes are provided in section 2.

2.1.2 The Cape Fold Belt mountains

The Cape Fold Belt (CFB) bounds the southern Cape coastal plain and is a prominent geomorphic feature of the southern Cape. At approximately 330 Ma, between the Late Permian and the Early Triassic ages, a subduction zone developed in the southern side of Gondwana (Maud 2008) (*Fig. 2.2*). The subduction caused surfaces to be compressed in the Cape region (Maud 2008), which gave rise to folding and uplift of the Cape Supergroup deposits in what is now referred to as the east-west trending of the CFB (Thamm & Johnson 2006; 2008). Subsequently, erosional processes produced extensive intermontane lowland valleys within the CFB (Maud 2008).

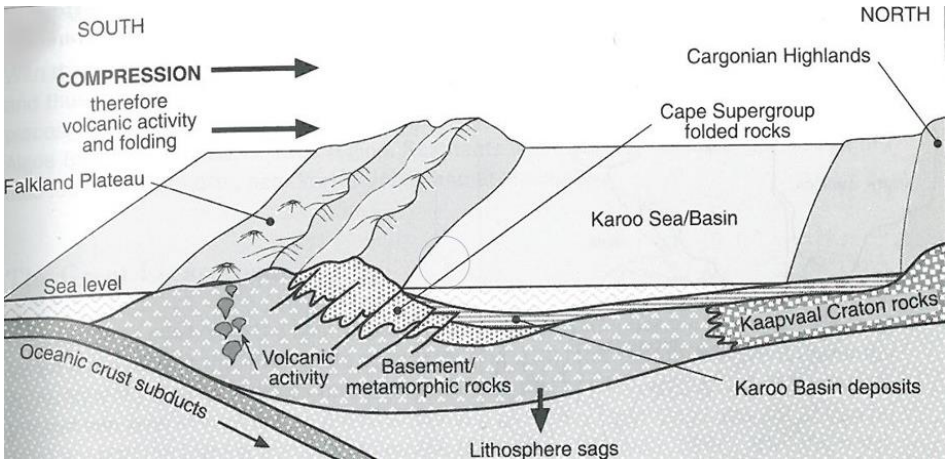

Figure 2.2: The subduction zone that developed in the southern part of Gondwana at approximately 330 Ma. Volcanic activity and folding occurred on the Falkland Plateau. The Cape Supergroup deposits were consequently compressed to form the CFB (Image by Maud 2008:7).

In the South and the Eastern Cape area, the CFB are characterised by a series of northwest and east-west to south trending folds (Newton *et al*. 2006). The CFB consists of two parallel mountain ranges. The Swartberg range forms the northern part (Geldenhuys 1997) and the Langeberg, Outenequia and the Tsitsikamma mountain ranges forms the southern part (*Fig. 2.3)* (Geldenhuys 1997; Newton *et al.* 2006). Furthermore, the Kouga mountain range occurs to the north of the Tsitsikamma mountains (Geldenhuys 1997).

The CFB mountain ranges are characterised by landscape features that link and separate them. The Kamanassie Mountain occurs between the Oudtshoorn and Uniondale areas and it links the Swartberg, Langeberge and the Outeniqua ranges (Geldenhuys 1997). The Langkloof valley, an important feature in this study, separates the Kouga and Tsitsikamma Mountain ranges from each other (Geldenhuys 1997). The Langeberge Mountains are bordered by the Swartberg in the south and the Outeniqua Mountains and Tsitsikamma Mountains in the east. The Tsitsikamma Mountains (*Fig. 2.4*) are the CFB Mountains that are closest to KRM. The Tsitsikamma Mountain ranges are 13 km wide (Wurz *et al.* 2018) and are associated with the Tsitsikamma, Klipdrift and Krom rivers (*Fig. 2.5*) to the east of the site and the Klasies and Groot river towards the west of KRM. The closest river to KRM is the Klasies river (*Fig. 2.6*), previously known as the 'Kaapsedrift Rivier' that occurs about 500 meters west from the site whereas the Tsitsikamma river that is about 5 km east from the site.

The geology of the CFB is predominately of that of the Cape Supergroup (Maud 2008), as discussed above. The Table Mountain and Witteberg Groups form the west-east mountain ranges (Swartberg, Langeberge, Outeniqua, Tsitsikamma and Kouga) of the CFB (Maud 2008). The Bokkeveld Group forms part of the broad intermontane lowland valleys or coastal plain which run east-west in the south and Eastern Cape (Geldenhuys 1997; Maud 2008).

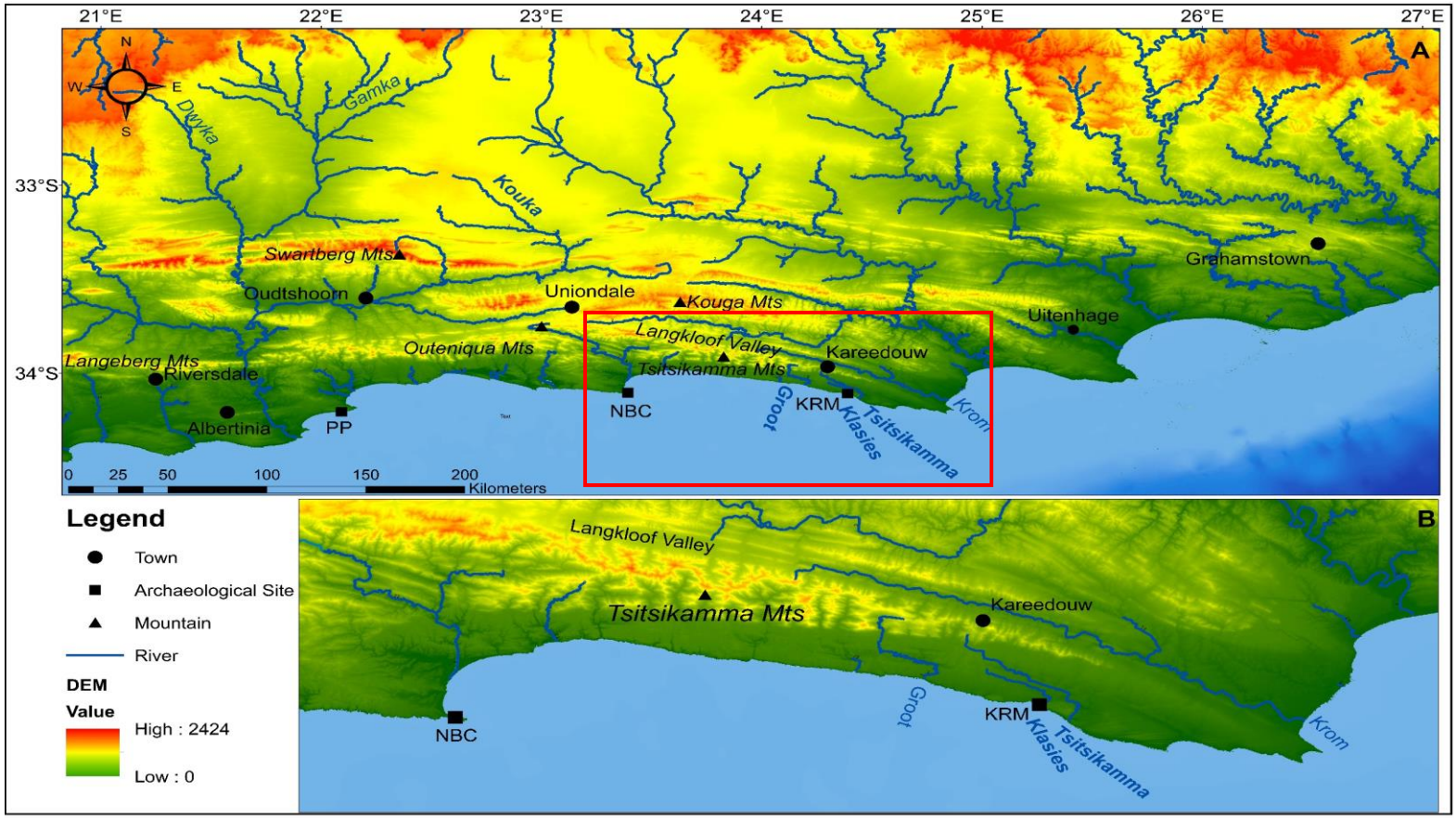

Figure 2.3: A) The location of the CFB mountain ranges in the South and Eastern Cape. DEM values are expressed in meters asl (above sea level). B) Enlarged section of the CFB in relation to KRM (Sources: bathymetric: MGDS; DEM: USGS; river from DWA).



Figure 2.4: The Tsitsikamma Mountain range in the background with the vegetation associated with the mountain in the forefront.



Figure 2.5: Image of Krom River flowing through the Tsitsikamma Mountain



Figure 2.6: Image of Klasies River flowing from the Tsitsikamma Mountain.

2.1.3 Coastal plain of the southern Cape

After the Gondwana break-up, during the hot humid conditions of the Cretaceous period (145- 66 Ma), the Great Escarpment was pushed into the interior by headward erosion (Dingle 1973; Marker & Holmes 2010). The incision of coastward flowing rivers caused further modification of the coastal plain (Maud 2008; Marker & Holmes 2010). Furthermore, an offshore marine-cut bench developed at the same time on resistant geological rocks (Maud 2008). This geomorphic event is known as the African Erosion Surface (Maud 2008; Marker & Holmes 2010), also referred to above in section 2.1.1. The African Erosion Surface processes also gave rise to the development of silcretes in the Grahamstown area, as will be discussed further below. The Agulhas- Fracture, a "linear tear-fault that extends offshore from the southern Cape coast along the southern margin of the Agulhas Bank" (Maud 2008:8), determined the current coastline structure of the southern Cape (Maud 2008). This was caused by the final split of Gondwana during the Late Cretaceous (±115-90 Ma) when the Falkland Plateau was disconnected from the Agulhas Bank (Watkeys 2006).

After ±100 Ma of erosion of the African Erosion Surface, the marginal regions were reduced to a coastal plain. The sediments that were eroded when the landscape was being reduced to a plain were deposited offshore during the Cretaceous age (Maud 2008). These sediments can be found in the Port Elizabeth

margins of what is called Kirkwood and Sundays River Formations of the Uitenhage geological group (Maud 2008). However, the coastal plain is best preserved in areas where resistant rocks of the Table Mountain Group Peninsula Formation occur, for instance, in the Heidelberg, Albertinia and Mossel Bay areas (Marker & Holmes 2010). The southern Cape coastal plain extends south to the Outeniqua mountain range in the west to Port Elizabeth in the west (Marker & Holmes 2010; Cawthra *et al.* 2014).

In the region where the KRM landscape is situated, the coastal plain is 13 km wide (Wurz *et al.* 2018). The coastal plain is topographically uneven and ends with steep cliffs that are 60 meters or more in height (Singer & Wymer 1982). As stated above, the geology, specifically around KRM, is characterised by Table Mountain Quartzite and Bokkeveld shales (Singer & Wymer 1982; Butzer & Helgren 1972). Butzer & Helgren (1972) describe the lithology as almost 100% quartzite, however, mentions that at close range the underlying Bokkeveld Series can be observed. Singer & Wymer (1982) further describe the coastal plain at KRM as associated with exposed and broken quartzitic sandstone located along the beach (Singer & Wymer 1982). Quartzites, including cobbles, are abundant along the KRM beach (*Fig. 2.7*).



Figure 2.7:Quartzitic cobble beach at Klasies River Main site (Yellow arrow).

2.1.4 Silcrete formation

Silcrete is defined as an extremely hard rock created through a process of near-surface silification (Roberts 2003). In general, silcretes are grey in colour; however red, brown and yellow shades of colour also occur (Roberts 2003). Silcretes do not have a uniform way of formation as they develop through different ways of weathering and environmental mechanisms (Ullyott *et al.* 1998; Roberts 2003; Runje 2016). Silcretes form through alkaline oxidising conditions, in either pedogenic and non-pedogenic environments, low and high pH conditions and detrital conditions (Summerfield 1983a, b; Ullyott *et al.* 1998; Roberts 2003; Nash *et al.* 2013a; Runje 2016). Due to different formation processes silcretes vary geographically and this is evidenced in differences in texture and geochemistry of the rocks (Roberts 2003; Nash *et al.* 2013a). Silcrete from outcrops found in the Eastern Cape area range from fine to coarse grained rocks and pebble type silcrete rocks also occur (Roberts 2003).

In his book "*The Geomorphology of the Eastern Cape*", Maud (2008) discusses the formation of silcretes from the perspective of the African Erosion Surface. According to Maud (2008), the warm and moist environmental conditions that characterised most of the Cretaceous age gave rise to the formation of silcrete during this period. Because of the warm and moist conditions, deep weathering of the rocks underlying the African Erosion Surface took place and this resulted in the dissolution of silica from bedrock that merged with the weathered mantle (Maud 2008). However, by the end of the Cretaceous age, the climate became dry and thus silica migrated to the upper portions of the soil profiles that overlaid the low portion of the landscape (Maud 2008). The dry conditions caused the silica to harden in the upper layers of the soil and as a result silcretes formed (Maud 2008).

In the south Eastern Cape area, silcrete fragments that formed due to the African Erosion Surface can be found along the coastal region (Maud 2008). Most of these silcrete overlie kaolinised and weathered rocks, for instance in the Grahamstown and Albertina areas (Maud 2008; Marker & Holmes 2010). Roberts (2003) emphasises that outcrop patterns of silcrete are variable. In his study of Western Cape silcretes around the Cape Town area, he observed that most of the silcrete

outcrops occur on top of the Cape Granite rocks (Roberts 2003:7). However, in the south and Eastern Cape areas, silcretes mainly occur on the Cape Supergroup rocks (Roberts 2003). For instance, the Bokkeveld Group, Witteberg Group quartzites and the Table Mountain Group Peninsula Formation quartzites have been reported to form host rocks for silcrete in the Eastern Cape area (Roberts 2003). Summerfield (1983b) found that silcretes in the Riversdale-Albertinia and Grahamstown are associated with calcrete and ferricrete.

Maud (2008) suggests that the silcretes that are found on the longitudinal intermountain valleys in the southern Cape are characterised by cemented pebble and rock debris. These rocks frequently form shoulders on the low mountain sides but are not overlain by deeply weathered rocks (Maud 2008). An example of these types of silcretes can be observed at the Kammanasie Mountains in Uniondale (Maud 2008). This underscores that silcrete formation varies geographically. Roberts (2003) found that in both the Western Cape and south Eastern Cape silcretes are found along modern drainages (Roberts 2003). Furthermore, Will and MacKay (2017) mention that silcrete in the CFB and the Grahamstown area are found as pebbles in rivers or on beaches.

Silcrete raw material provenance in the HP at KRM is regularly discussed in the literature (e.g. Ambrose & Lorenz 1990; Thackeray 1989; Wurz 1999; Minchillo 2006; Villa et al. 2010) but no studies have been undertaken to examine where the KRM silcrete raw material was collected. It is argued that it is possible to geochemically test silcrete to find out where it comes from. Nash *et al*. (2013a) geochemically tested the silcrete in the northern Kalahari Desert of Botswana and Namibia to match the sources of silcrete from this area and MSA silcrete artefacts from White Paintings Shelter. Nash *et al*. (2013b) further performed geochemical tests on silcretes found on the Cape coast, mainly from the Riversdale, Albertinia and the Grahamstown areas. Both studies showed geochemical differences in major and trace elements of the silcretes found in the respective areas. The geochemical differences in the Kalahari Desert samples were used to investigate silcrete raw material acquisition by MSA humans in Tsodilo Hills (Nash *et al*.

2013a). The study suggests that people walked distances of up to 220-295 km to obtain silcrete raw material (Nash *et al.* 2013a), a surprisingly long distance.

The silcretes from the Nash *et al.* (2013b) study of the Riversdale and Albertinia areas formed on the Bokkeveld Group lithology (Summerfield 1983b; Nash *et al*. 2013b) and the Grahamstown silcretes sample formed on the Dwyka group lithology (Nash *et al*. 2013b). The results show that the different bed rock types influence the geochemistry of the silcretes and that its geochemistry can be used to investigate the sources of raw material in the southern Cape's archaeological sites. Nash *et al.* (2013a; 2013b) studies provide a contribution that can help to understand the raw material selection by HP societies in future. Geochemical testing is important in raw material sourcing in archaeology, and ideally it needs to be incorporated with geospatial studies in order to create a database for further investigation. In this regard this dissertation focussed on GIS Least Cost Path (LCP) techniques to explore possible silcrete outcrops HP people at KRM may have used for stone tool making.

2.2 The Howiesons Poort (HP) techno-complex

The HP techno-complex is extensively studied in South African MSA archaeology. The HP is of great interest as the artefacts and cultural practices of this period are associated with innovativeness, argued to be indicators of cognitive complexity and symbolically modern human behavior (Wurz 1999, 2013; Henshilwood 2012; Wadley 2015). Examples of such artefacts include the use of ochre in producing compound adhesives for hafting lithic artefacts and engraved ostrich eggshell in the HP, and practices such as the utilization of bedding and burials also occur (Wurz 2018).

The stone stool artefacts found during the HP are characterised by geometric backed artefacts, blade and bladelets and bifacial points (Wurz 1999, 2013, 2016; Minichillo 2006; Villa *et al.* 2010; de la Pena 2015). This is evident in HP sites in the southern Cape such as Pinnacle Point (PP), Nelson Bay Cave (NBC), Klipdrift Cave (KDS) and KRM. During the HP, there was a marked microlithisation as the cores found for example at KRM show that they were knapped until they were

very reduced indicating a desire to maximise raw materials. This is especially the case for cores in silcrete (Wurz 2002). Wurz (2013) discuss evidence that suggest that the impact fractures and use wear on the backed artefacts may infer that these stone stools were used in different projectile weapons, including the bow and arrow, and also for cutting prey. The lithic artefacts inform on the thought process involved in the production process as it requires strategising, and also a particular technique and procedure need to be followed (Wurz *et al*. 2018).

The HP stone tools display a change in the production procedures and typology when compared to previous and subsequent periods (Minichillo 2006; Wurz 2016; Wilkins *et al.* 2017). In the HP, a marked increase use of fine-grained material, particularly silcrete in the southern Cape, occurs (Thackeray 1989; Wurz 1999, 2013, 2018; Minichillo 2006; Villa *et al*. 2010; McCall & Thomas 2012) in archaeological sites such as PP, NBC, KDS and KRM. At KRM, around 40% of the HP backed geometric artefacts are in silcrete (Wurz 1999). Furthermore, Brown (2011) has observed that silcrete artefacts at PP have been heat treated. Brown (2011) argues that heat treated silcrete produces more workable and improved flakable products than non-heated silcrete. It has also been shown at KDS that silcrete raw material was heated in the process of artefact production (Delagnes *et al.* 2016). There are different hypotheses that link the change in raw material selection and lithic technology in the HP, for example to symbolic behavior (Wurz 1999), but mainly to the change in the environment during this period (Ambrose and Lorenz 1990; McCall & Thomas 2010; Wilkins *et al*. 2017; Mackay *et al.* 2018).

2.2.1 Paleoenvironment and climate during the HP

The HP assemblages occur within Marine Isotope Stage (MIS) 4 which is dated to 74-58 ka at various archaeological sites in the southern Cape (Chase 2010; McCall & Thomas 2012; Carr *et al*. 2016). MIS 4 is considered a glacial period with fluctuations in climate (Bar Matthews et al. 2010; Ziegler *et al.* 2013), changes in the environment (McCall & Thomas 2012; Wilkins *et al*. 2017) and lowered sea levels (Compton 2011; Langejans *et al.* 2016). During MIS 4, the low sea level stands resulted in drastic landscape changes from MIS 5 conditions

(Fisher *et al.* 2010; Wilkins *et al.* 2017). The Southern Cape coastal plain expanded and this is believed to have influenced human behaviour in terms of the availability of resources and foraging practices, mobility and raw material acquisitions in the southern Cape (Wilkins *et al.* 2017: 28). Fisher *et al.* (2010) modelled how the Late Pleistocene sea levels would have fluctuated on the southern Cape coast. The models showed that the relative sea levels (RSL) of southern Cape sites were differently influenced due to the topography of the sea floor as discussed below.

At PP about 300 km west of KRM, the paleoscape model displays a regression of sea levels at 72 ka, the beginning of MIS 4 (Fisher *et al.* 2010: 1390), the distance averaged from 10.7 km to 20.7 km from the site (Wilkins *et al*. 2017). The RSL at Blombos Cave (BBC), 392 km west of KRM, have been modelled to be at 15.56 km at 72 ka (Fisher *et al*. 2010: *Table 2*). Fisher *et al*. (2010) did not model the sea levels at KRM in detail, but previously it has been estimated that the coast was 5 km away from the site during the HP that also occurred during MIS 4 (Langejans *et al.* 2012). However, new modelling from Dor (2017; Dor *et al.* in prep) shows that Blombos Cave would have been 44.26 km, PP 21.43 km and KRM 13.64 km from the coast at 65 ka. Due to the steep topography of the coastal floor the RSL at KRM remained closer to the coast than at PP and BBC during MIS 4. The low sea stands exposed new land for habitation and potentially changed the flora and fauna of the southern Cape region (Fisher *et al.* 2010). The distance to the coastline for outcrop acquisition would have required a change in foraging strategies as quartzite beach cobbles, for example would have been further away from the site.

There is some debate on whether the colder climate during MIS 4 was associated with wetter or drier and open or closed conditions. Some argue that MIS 4 in the southern Cape was characterised by drier conditions compared to the present, with more C4 grasses in the landscape, an indication of open environments (Bar-Matthews *et al.* 2010). Chase (2010) on the other hand argues that the conditions were wetter (Chase & Meadows 2007; Chase 2010; Ziegler *et al.* 2013) and associated with C3 grasses (Wilkins *et al.* 2017:3), perhaps indicating more closed

environments in general. At PP the first half of MIS 4 was characterised by instability of vegetation (Bar-Matthews *et al.* 2010; Wilkins *et al.* 2017). However, after 64 ka which is the HP period, "more C4 grasses covered the landscape on average" (Wilkins *et al.* 2017: 32). Faunal evidence from KDS Shelter suggest that during the first half of the HP, the environment was characterised by a mixed/closed landscape and the mid-later HP period was more of an open grassland environment (Reynard *et al.* 2016:361), confirming the results from PP.

Faunal and microfaunal evidence from KRM (Klein 1976: 82; Avery 1987:414) relating to the Singer & Wymer (1982) excavation, show that during the HP the environment was more open. However, a study of the macrofaunal evidence from the Deacon excavation (Deacon & Geleijnse 1988) show more subtle changes in the environment through time (Van Pletzen Vos & Wurz 2014). In Figure 2.8 the data from the Singer & Wymer excavation is compared to that from Deacon (Van Pletzen Vos & Wurz 2014). In the lower part of the HP, square J51 (see Chapter 1, *Fig. 1.2*), in the earliest part of the HP, the environment was more closed. During the middle period, represented by square H51, conditions became even more closed, whereas, in the upper section, represented by square E50, large medium to large grazers dominate. This indicates a more open and grassier environment (Van Pletzen Vos & Wurz 2014).

This supports the results from the faunal data at KDS which shows that the environment was dominated by large grazing bovids in the last part of HP period (Reynard *et al.* 2016), whereas during the earlier parts of the HP, environments in the HP were more closed. Therefore, when considering the faunal data from a finer resolution (e.g. when the layers are not lumped together) it is clear that the macrofauna reflect changing environments through the HP. The only relevant study for KRM indicates that, in the late Holocene increased summer rain may have occurred, perhaps leading to more closed environments (Zwane 2018). The current vegetation around KRM is mainly characterised by Fynbos, Afrotemperate forest, Albany thicket Biome and coastal vegetation (Quick *et al.* 2015; Van Wijk *et al.* 2017) (*Fig. 2.9*). The vegetation at KRM may have been closer to thicket

than fynbos during the periods, in the middle of the HP sequence, when silcrete occurred, as discussed in section 2.2.2, since the current vegetation is dominated by thicket (Van Wijk *et al.* 2017) and increasing rainfall may have caused denser vegetation (cf. Zwane 2018).

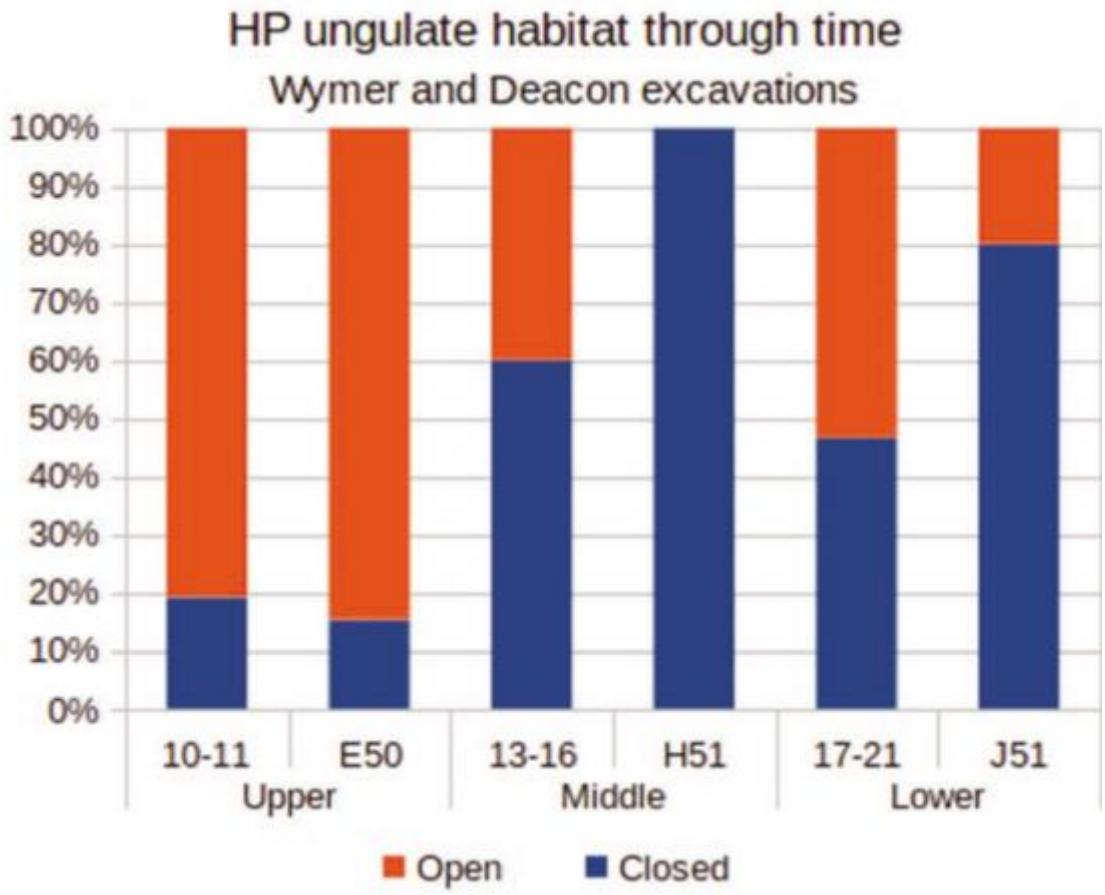

Figure 2.8: Howiesons Poort environments reflections from faunal data obtained from Singer & Wymer and Deacon excavations (Image by Van Pletzen & Wurz 2014).



Figure 2.9: The current vegetation in the vicinity of Klasies River Main site.

Molluscs from coastal sites are widely used as proxies for sea surface temperatures and related changes in the palaeoenvironment. During the HP at KRM, there was a change in prey choice of shellfish compared to the preceding MSA ll, due to changes in sea levels and environmental conditions (Langejans *et al.* 2012, 2016). In the HP assemblage there is evidence of a decrease of *Perna perna*, which indicates that the sea surface temperature was relatively colder, and the shore became sandier (Langejans *et al.* 2012) as this shell species prefers relatively warm temperatures and rocky shores. This notion is further supported by the increase of *Dinoplax gigas* and *Donax serra* in the HP, as they prefer sandy environments (Langejans *et al.* 2012). However, there was also an increase of the *Haliotis midae* which is a shellfish species that indicates both warm and cool sea surface temperatures (Langejans *et al.* 2012: *Table 1*). Langejans *et al.* (2016) argue that the change in shell species during the HP indicates that the sea surface temperatures were lower than before thus indicating a cooler phase.

The evidence from pollen obtained from hyena coprolites at Oyster Bay in the Eastern Cape, a site located ± 37 km from KRM, also infers that the environment was cooler during MIS 4 (Carrion *et al.* 2000). Similarly, the Vankersvlei pollen evidence from the Knysna area indicates that this period was characterised by cool environments (Quick *et al*. 2015). The change in the environment may have influenced the availability/accessibility and selection of lithic resources that becomes more silcrete rich in the middle HP layers at KRM (Wurz 1999). The change in environment has also been related to changes in the mobility of HP of societies and the procurement of silcrete raw material resources as further discussed below.

2.2.2 Silcrete raw material procurement during the HP

Silcrete was one of the important raw materials used for stone tools during the HP, particularly in the southern Cape region. At KRM and PP (Will & Mackay 2017), and at NBC (Wurz 1999) the use of silcrete increased during the HP. As mentioned above, the silcrete is usually fine-grained and it is considered 'exotic' and 'non-local' as it is thought not to be found in the near vicinity of the archaeological sites such as PP (Wilkins *et al.* 2017) and KRM (Singer & Wymer 1982; Wurz 2000; Minichillo 2006). The source of the silcrete at NBC in the HP has not received any recent attention in the literature. At PP the closest silcrete outcrops is 8.5 km away (Brown 2011; Wilkins *et al.* 2017: 12) and closest silcrete sources at KRM is thought to be 20 km away in the Langkloof valley (Thackeray 1989: 41). However, Villa *et al.* (2010) mentions that surveying in the Langkloof valley area produced chunks of coarse silcrete of low knapping quality (*Fig. 1.4, 1 and 5*) are in coarse silcrete seemingly similar to that sourced at Kareedouw). My preliminary survey of the region supports this (*Fig. 2.10*). It must be noted that what is considered "non-local" to one society may not be considered "non-local" to another, therefore, concepts such as close and far may be relative to societies and individuals. Furthermore, Brown *et al.* (2009) notes that the silcrete they found when surveying around the PP landscape looked different from the archaeological silcrete. However, through actualistic experiments they found that the silcrete from the landscape appeared to change

during heating and become similar to the archaeological silcrete after heat treatment. Therefore, heat treating the silcrete alters the silcrete and as a results it looks like the silcrete that is considered non-local thus what may be fine-grained non-local silcrete may be local silcrete that was heat treated (Brown *et al*. 2009). The same may be the case at KRM, but this needs further investigation. For the purpose of this study, however, it is assumed that the coarser silcretes observed in the Langkloof valley became part of the KRM HP assemblages in the past.



Figure 2.10: Silcrete outcrop found during preliminary study.

In the KRM HP sequence, the relative amounts of non-quartzitic raw material vary through time. As shown in figure 2.11, the amount of quartzite remains relatively similar and dominant all through the HP, whereas other raw materials such as silcrete and quartz change through time (Wurz, 2000; Wurz pers comm 2018). In the lower HP, in square J51, silcrete comprises 3.7 % of the raw material. In the middle layers, relating to square H51, silcrete use increases to 10.3 % in the middle 1 phase, and 23.1 % in the middle 2 phase. In the HP upper phase in square E50 silcrete comprises only 5% of the raw material, whereas the utilization of quartz increase.

Silcrete use at KRM thus increases during the middle layers. This is similar to PP, whereby around 60-64 ka there was a shift towards using non-quartzitic raw material (Brown 2011; Wilkins *et al.* 2017). At PP during the HP artefacts in silcrete showed more early stages of reduction, and changes in tool types (e.g. backed artefacts) and function (e.g. hunting) than those in other raw materials (Wilkins *et al.* 2017). Also, there was an increase of flaking efficiency during this period of all the raw materials (e.g. quartzite, quartz, chert and silcrete) (Wilkins *et al.* 2017), this may be due to foragers wanting stone tools that were smaller and efficient for hunting fauna available at the time. At NBC, as at KRM, most of the HP artefacts are in quartzite, with for example 82% of the backed artefacts from quartzite and 18% is made in silcrete and other raw materials (Volman 1981).

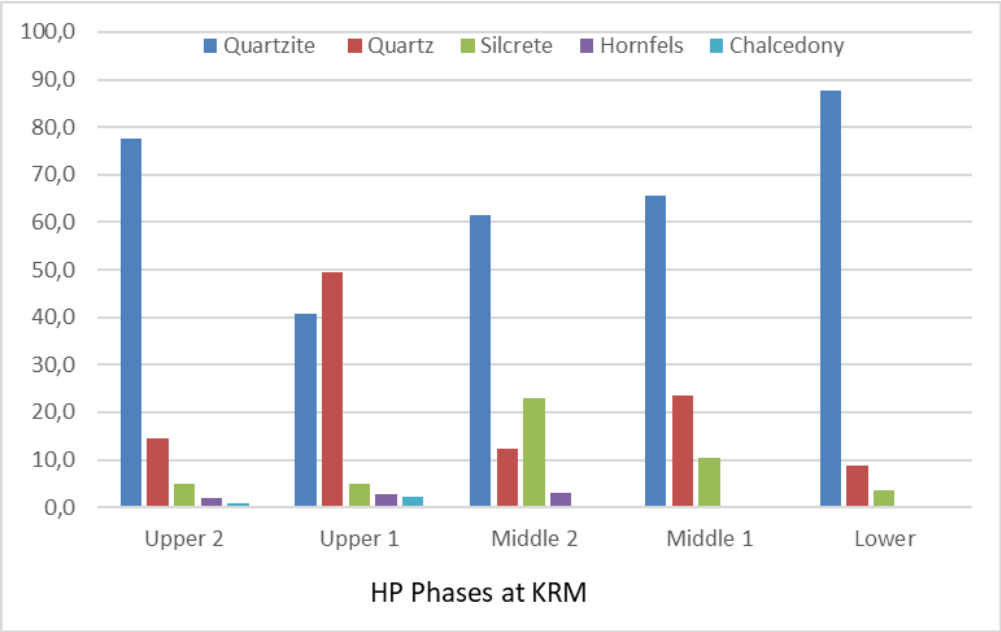

Figure 2.11: Bar chart (in %) of Howiesons Poort raw material at Klasies River Main (Data courtesy of Wurz).

The presence of silcrete stone stools in the HP archaeological sites is assumed to indicate long distance transport of raw material and therefore long foraging ranges (Ambrose & Lorenz 1990; McCall & Thomas; Wilkins *et al.* 2017: 33) and increasing costs in procuring the raw material (Minichillo 2006). Ambrose (2006) suggests a foraging range of > 40 km for hunter gatherers of the HP at KRM. He proposes that this period was likely to have been characterised by low primary productivity with scarce unpredictable resources due to more open environments thought to be related to 'deteriorating' environments (Ambrose & Lorenz 1990: 25). Therefore, the HP hunter gatherers would have been forced to travel long distances for resources and thus expand their foraging ranges, and as a result expand the cost of procuring resources. Long distances are sometimes often linked to the intensity of lithic reduction. It is assumed that the further away from a raw material the smaller a flake becomes (Wilkins *et al.* 2017). During the HP, it is also thought that the hunter gatherers had an intense increase in interactions between groups over long distances, which was characterised by exchange of information and resources (Ambrose 2006).

Minichillo (2006) challenged the validity of the Ambrose model for long-distance transport of exotic and non-local silcrete raw material in the HP. Minichillo (2006) used optimal foraging theory, which will be discussed further in Chapter 3, to explain the changes in lithic raw material utilization in the HP in relation to mobility. He argues that instead of seeing the utilization of silcrete raw material as a "by-product of increased foraging ranges", the HP groups may have increased their foraging time in order to procure silcrete from outcrops that are further from the site. Therefore, cost in this context was the time to procure the silcrete from the outcrops (Minichillo 2006). Furthermore, in order to ensure optimal diet when environments changed, the HP groups at KRM had a shift in technology (Minichillo 2006: 363).

Minichillo (2006) suggests that the sources of the silcrete raw material from KRM and NBC may have been local and that it may have been sourced as a secondary raw material from river channels as pebbles or beach cobbles. Singer and Wymer (1982), Thackeray (1989) and Wurz (2000; pers comm) also mention that the HP

silcrete stone tools from KRM may have originated from pebbles from river channels such as the Tsitsikamma river (Thackeray 1989). Minichillo (2006) furthermore suggests that there may have been sources from the offshore bedrock that was exposed during the lower sea stands. Therefore, there may be outcrops that may be presently submerged which may have been exposed when sea levels were low during MIS 4. Some authors, for example Deacon (1989) and Thackeray (1989) also suggest the silcrete used in the HP at KRM area were obtained from river channels that may be submerged offshore. It is currently not known which percentage of KRM and NBC HP silcrete is from outcrop sources. As opposed to river channels.

Based on field surveying of frequent visits over a four-year period, Brown (2011) remarks that the silcrete in the Mossel Bay area, close to the PP site, may have been acquired through secondary sources such as cobble beaches and through river drainages. For example, Oestmo (2017) interprets, from his own field surveying that the silcrete found at Dana Bay may have travelled from the Blinde River down to the Indian Ocean during MIS 4 and the waves may have then pushed the silcrete to Dana Bay (Oestmo 2017). However, he also points out that the silcrete cobbles may have been deposited at now submerged beaches (Oestmo 2017: 168). This is supported by the observation by Brown (2011), who found that in his second-year visit to Dana Bay the cobbles were covered by beach sand. Brown interprets this as that beach cobbles are unpredictable resources, and this could have been the case during MIS 4 (Brown 2011).

On the other hand, from analysing the lithic stone tools at PP, Wilkins *et al.* (2017: 32) found that during the MIS 4 silcrete from outcrops rather than silcrete pebbles were used. This is reflected by the outcrop silcrete cortex on the artefacts. It is considered that the pebbles would have been located beyond what is considered a daily foraging range of a forager. Brown (2011) arrived at a similar conclusion through cortex analysis. Nevertheless, to test an alternative scenario, Brown (2011), constructed a model using the Fisher *et al.* (2010) sea level curve in order to model a scenario where silcrete outcrops existed in the now submerged sea in Mossel Bay. The model indicates that the increase in silcrete corresponds to

the change in distance to the sea. He observed that silcrete percentage was high when the coastline was further away from the site. However, when the coastline was close to the site, silcrete was low. This indicates that the assumption that silcrete may be found in the presently submerged sea levels may be accurate. Nevertheless, it is also possible that the foragers at the PP site may have chosen to use outcrop silcrete instead of pebbles.

There is also a hypothesis that the environment may have influenced residential mobility patterns at PP. The hypothesis states that occupation periods at the site were longer during the HP, and, consequently, that residential mobility was lower (Wilkins *et al*. 2017: 33; see also Mackay *et al*. 2018). This is seen as evidence of "place provisioning" (Wilkins *et al.* 2017; Mackay *et al.* 2018). Wilkins *et al.* (2017) suggest that silcrete was transported from silcrete outcrops across the landscape to ensure that the residential site was always stocked with silcrete raw material (Wilkins *et al.* 2017). During the HP, some sites have higher densities of artefacts, suggesting the longer use of residential sites and increased population density (Mackay *et al.* 2018). Furthermore, evidence from KDS, also located on the southern Cape coast, suggests that during the HP the occupation intensity during some periods of the HP was high (Reynard *et al.* 2016). These inferences are in contrast to Ambrose and Lorenz (1990) and Ambrose (2006) that link their model of the HP raw material use to high residential mobility and low population density.

2.3 Summary

The HP is considered a period that marks a change in cognitive complexity in humans in southern African archeological sites. This is for example shown by the change in stone tool technology used at the time. The use of silcrete raw material during the HP has been linked to the change in the complexity of the groups that lived at KRM. Furthermore, it is believed that the change in environment may have played a role in this change. It is acknowledged that the current knowledge on the distribution of silcrete sources in this landscape during HP times is not detailed and that precise information is not available for vegetation during this time period. As such, whilst this study presents a number of limitations for modeling movement patterns using GIS LCP, it can be adjusted as new

knowledge on these aspects becomes available. This dissertation used GIS to investigate how environmental factors such as vegetation and river channels can impact paths chosen in acquiring outcrop silcrete raw material. GIS is considered an effective tool to model different scenarios to answer archaeological questions as multiple layers of data can be put in a GIS (Wheatley and Gillings 2002). GIS use in archaeological studies will be discussed in more detail in the following chapter.

CHAPTER THREE : SPATIAL ANALYSIS AND ARCHAEOLOGICAL APPLICATION OF GIS IN THE CONTEXT OF LANDSCAPE ARCHAEOLOGY

This chapter begins by reviewing Geographical Information System (GIS) and its uses in archaeological studies. It briefly outlines the development of the study of space, the various phases of archaeological research and the importance of movement studies in archaeology. Next, Optimal Foraging Theory (OFT) is explored as it has been used as a theoretical framework to study movement and raw material acquisition in archaeology. Lastly, GIS based methods used in archaeological movement studies are discussed.

3.1 Archaeology and GIS

GIS is a computer system that is used to store, retrieve, analyse and display real world spatial data (Burrough 1986). GIS is used in a variety of disciplines such as geography, engineering and environmental science. GIS gives archaeologists the opportunity to integrate, analyse and explore a variety of data (Wheatley & Gillings 2002). It has the ability to generate layers of information from existing data and thus in turn the data can be modelled and analysed. Multiple layers of information can be incorporated and different scenarios that may have influenced human behaviour can be modelled (Wheatley & Gillings 2002; Hu 2011). GIS can be used as a tool to visualise archaeological data and the distribution of material in relation to environmental variables (Fitzjohn 2007; Goodchild 2011). It also provides the opportunity to store information in databases and to test for statistically-significant patterning (Kauviutzis 2009).

Before the introduction of GIS in archaeology, spatial patterns were mapped on paper by plotting the locations of finds. Highly detailed, accurate maps and recording of spatial finds are first mentioned in an archaeological context dating back to the 18th century (Wheatley & Gillings 2002). Mapping of material culture and patterns of past people was always an important aspect of archaeological research and studies in order to infer past human behaviour (Wheatley & Gillings 2002). Through time archaeologists developed new ways of studying past people and the relationship between the space and environment they lived in through the use of spatial technologies (Wheatley & Gillings 2002). In recent decades the use

of GIS in archaeology has increased due to its beneficial application in incorporating different ideas of space. As discussed below, the ideas of what constitutes a landscape and space have been debated through the years and thus many philosophies of what space is have emerged (Wheatley & Gillings 2002; Hu 2011).

The early 20th century archaeology was dominated by what is known as the culture history approach (Trigger 2006; Wheatley & Gillings 2002), characterised by tying human cultural change to diffusion. Diffusion is the assumption that cultural traits were borrowed/transmitted from elements of other cultures and that cultural elements spread out from a core (Wheatley & Gillings 2002; Johnson 2010). During this period material culture was mainly plotted on simple hand maps visualising a sequence indicating the diffusion of ideas in space that showed a significant change in cultures (Johnson 2010). The culture history approach was critiqued by processual archaeologists such as David Clarke and Colin Renfew who argued that this approach was mainly a description and/or a narration of cultural groups, material culture and events and did not provide explanations and understanding of culture (Krieger 2006; Johnson 2010).

The dissatisfaction with cultural history brought about a new movement within archaeology in the 1960s and 1970s. This was a time when the concept of the influence of landscape on human behaviour and culture grew and archaeologists turned to other disciplines such as geography for ideas on spatial analysis (Trigger 2006). As a result, a new school of thought termed the New archaeology or Processual archaeology emerged. The basic premise for processual archaeology was that cultural and behavioural change are results of ecological and economic adaptation (Wheatley & Gillings 2002; Trigger 2006; Johnson 2010; Renfrew & Bahn 2016). Processualists believed that changes in the environment could result in technological innovation (Trigger 2006). A South African example is the hypothesis that the shift in technology during the HP was due to the change in environments (Minichillo 2006; Wilkins *et al.* 2017).

Furthermore, processual archaeology provided the opportunity to shift to a dynamic scientific approach that focused on culture processes to understand past

people and their relationship to the environment (Krieger 2006). Processual archaeologists like Clarke (1968) argued that archaeologists should focus on quantitative and scientific methods when interpreting archaeological data; thus, positivism was central to processual archaeology (Trigger 2006; Johnson 2010). With the positivist approach, data are used to test hypotheses about societies and the world (Clarke 1968; Johnson 2010) and logical thought is applied when investigating cultural change in the hopes to produce law-like statements (Connolly & Lake 2006), in other words universal generalisations can be made (Trigger 2006; Johnson 2010). In this perspective, conclusions would remain the same regardless of the period, the region or culture being studied (Trigger 2006). Processual archaeologists saw landscape as a neutral, quantifiable, static and a universal concept (Trigger 2006; Kavoutzis 2009) where humans were predictable beings that generally behaved in the same manner (Johnson 2010).

Within the processual archaeology school of thought, the cognitive archaeology body of thought emerged in the 1980s (Johnson 2010). Cognitive archaeology was mainly pioneered by Colin Renfew in the book *Towards an Archaeology of Mind* in 1982. According to Renfew (1982) as cited by Trigger (2006), scientific methods need to be applied to study the thought behind an artefact. The goal of cognitive archaeology was to 'develop a secure methodology by which we can hope to learn how the minds of the ancient communities in question worked and the manner in which that working shaped their actions' (Renfrew 2005: 41). However, this proves to be difficult, as we cannot model the thoughts of past people. In recent years, cognitive archaeologists have shifted to examine the evolution of symbolic behaviour and the cognitive abilities of past people, for instance, the complexity of applying *chaînes opératoires* in the manufacturing of stone tools instead of trying to determine what past people actually thought (Wurz 1999; Lourdeau *et al.* 2014).

The type of analysis that emerged during the processual archaeology phase pushed archaeologists to pay attention to concepts of paleoenvironment, creating methods that can be tested and providing room for debates within the discipline that changed the shape of archaeology. However, in the 1980s and 1990s, some

archaeologists mainly in Europe and America were not satisfied with the shortcomings of processual archaeology which led to processual archaeology to be questioned and challenged (Wheatley & Gillings 2002; Trigger 2006) through postprocessual archaeology. Postprocessualists argued that landscape is a complex concept that is experienced, qualitative, temporal and active (Ingold 1993; Knapp & Ashmore 1999; Van Hove 2004). They argued that scientific thought cannot explain human behaviour as it doesn't consider the perspective of the people that are being studied (Connolly & Lake 2006). We also cannot see people's thought scientifically, especially people that have passed for thousands of years (Johnson 2010). They stated that people's experiences with their landscape can be subjective and subject to different interpretations because people experience and view landscape differently (Fitzjohn 2007; Johnson 2010).

Also, postprocessual archaeologists argue that economic and ecological approaches to studying human behaviour are not sufficient (Trigger 2006). These approaches do not account for the influences of culture on decisions people make (Trigger 1989; Connolly & Lake 2006). Accordingly, postprocessual archaeologists have criticised processual archaeology for being environmentally deterministic (Wheatley & Gillings 2002; Connolly & Lake 2006; Van Leusen 1999) as it does not account for social and cultural variables. As a result, postprocessual archaeologists have placed emphasis on meaning and symbolism in human behaviour (Knapp & Ashmore 1999; Connolly & Lake 2006). However, it is argued that this may pose a danger in focussing on one side of human behaviour and thus replacing environmental determinism with social and cultural determinism (Connolly & Lake 2006). Recent scholars of landscape archaeology have thus argued for studies to investigate the complex relationship between humans and landscape by looking at the holistic influences on landscape (Van Hove 2004; Trigger 2006; Hu 2011).

Ingold (1993) states that landscape is a space known to people who live in a particular area. Through people's experiences, day-to-day activities and the paths they take, people construct and shape space (Wheatley & Gillings 2002). People may have different ways of thinking in groups and even individually as

experiences are different (Conolly & Lake 2006; Fitzjohn 2007). Therefore, landscape is not absolute and straightforward. To study the relationship of past people with their landscape one has to look beyond the economic and politics of landscape, it should include the complex relationship between humans and landscape by looking at the environmental and cultural influences on landscape (Ingold 1993; Knapp & Ashmore 1999; Hu 2011). In recent years, archaeologists recognise that cultural change and changes in material culture can be caused by different factors. Some changes can be due to environmental changes, spatial and temporal changes, availability of resources, religion and ethnic differences (Trigger 2006). Therefore, archaeologists, especially in America, recognise that processual and postprocessual archaeology complements each other as both can be used to study different aspects of archaeological data (Trigger 2006). Hence, archaeological projects dedicate time and teams in researching different aspects of cultural change. In this way, a holistic research can be achieved, and technology such as GIS have made it possible for different aspects to be tested. In recent years, scholars have argued that GIS tools may provide a holistic way of representing past people experiences with landscape (Connolly & Lake 2006).

3.2 Movement Studies in Archaeology

Studying past people's movement is considered an important aspect of archaeological research as movement is a representation of a universal mechanism through which humans order their landscape (Llobera *et al.* 2011: 843). In this context, *order* refers to sequences that are created and that link locations in a landscape (Ingold 1993; 2000). Through these sequences, individuals can understand their landscape and social rules are created and passed on (Llobera *et al*. 2011). Analysis of past movement gives archaeologists the opportunity to reveal significant information of past people as movement through a landscape was an important part of past people's life as experiences were created (Howey 2011).

There are various aspects that can affect how people move in a landscape (Bell *et al.* 2002; Verhagen *et al.* 2019), e.g., political boundaries, social divisions, topography and cultural restrictions. Humans create territories in the areas they

live in and thus political boundaries are formed into these areas. As a result, political boundaries might be a movement barrier and may have influenced people to choose other routes to obtain resources. Furthermore, some areas may be taboo to walk in (Wheatley & Gillings 2002; Howey 2007; Anderson 2012; Frakes et al. 2008), as there might be burials or a sacred place whereby some people may be not allowed to move or come close to therefore this might be a constraint in movement when foraging (Howey 2007). However, these factors do not leave any evidence on the archaeological record. As a result, as mentioned above, political and social factors are difficult to model in a GIS (Bell *et al.* 2002; Herzog 2013).

Consequently, topographic factors such as slope, vegetation and river networks are the most commonly used as parameters for the modelling of movement in a GIS (Anderson 2012). These parameters influence the decisions and experiences people make about the landscape. For instance, the presence and absence of resources such as water may dictate the course of movement people take as it is believed that humans would likely travel alongside watercourses (Anderson 2012) so that they can always have access to drinking water. Additionally, in dense vegetation, walking speed may be different to the walking speed in lighter vegetation (Frakes *et al.* 2008). Therefore, humans may choose to take routes that have light vegetation. Also walking is easier in low-lying areas than in steep, rugged terrain; as a result, it is assumed people would choose routes that are associated with easier walking (Rademaker 2012). However, people's view of steepness and effort depends on the landscape they live in and how valuable a certain resource is to them (Browne & Wilson 2013).

It is assumed that an individual will optimise the time and energy taken to arrive at a destination at a shortest time and with the least possible effort (Frakes et al. 2008; Rogers *et al.* 2015). However, humans do not always choose to behave optimally or as a person may expect (Bird & O'Connell 2006; Anderson 2009; Diwan & Doumit 2017). Therefore, computer modelled past routes may not be a definite representation of actual routes used by past people (Anderson 2012). In some cases, whether movement is difficult or not, humans still travel considerable distances (Howey 2007) since there are other factors that may hinder movement in

certain areas. For instance, some groups believe that it is taboo to walk in certain places i.e. graveyards (Wheatley and Gillings 2002; Howey 2007; Anderson 2012; Frakes *et al.* 2008). On the other hand, the ranking of resources may play a bigger part in foraging than time (Smith *et al.* 1983).

3.3 Optimal Foraging Theory

Optimal foraging theory (OFT) is a cost and benefit method that was first used in the 1960s to study animal behaviour in environmental ecology studies (Smith *et al.* 1983; Bousman 1993; MacDonell 1995; Arroyo 2009). It was later borrowed by anthropology and archaeology during the time when ecological and economic research developed in processual archaeology (Trigger 2006). OFT has recently been used to study territoriality, resource time allocation and human foraging behaviour (Macdonell 1995; Nel 2012). OFT is a subset of Behavioural Ecology (BE) models. One of the main principles of BE is that foragers will always choose to maximise the net energy return per unit of time (Smith *et al.* 1983; Bird and O'Connell 2006; Taliaferro *et al*. 2010; Codding & Bird 2015). OFT models are used to study human behaviour in a specified set of conditions (Bird & O'Connell 2006).

A number of different models use OFT to investigate human behaviour, including the diet breadth also known as prey choice, the patch choice and the central place models. The diet breadth model assumes that foragers choose resources in terms of a ranking system (Smith *et al.* 1983; Codding & Bird 2015). Bird & O'Connell (2006) describe the Diet Breadth model in terms of search and handling costs. Search is the time spent searching for resources and handling costs are the activities performed after a resource is encountered, captured, preparation and the consumption of the resource (Bousman 1993). In terms of lithic studies, handling means the manufacturing and transportation of stone tools (Bousman 1993; Oestmo 2017). The model assumes that if a forager wants to maximise the foraging productivity, the post foraging activity of a particular resource must return an output that is equal to or greater than the overall foraging energy return (Bird & O'Connell 2006).

Furthermore, the range of optimal resource choices contracts and widens due to the accessibility of high-ranked species (Smith *et al.* 1983; Bousman 1993). Resources are added to and dropped from the diet in terms of ranking order; low ranked resources are added to the diet when the handling and search costs of high ranked species are too high (Smith *et al.* 1983; Codding & Bird 2015). When new resources are added to the diet the time spent in searching for resources decreases as the chance to encounter resources is high, though the handling costs increases (Bousman 1993). Resources that are highly ranked will always be selected, even if they are scarce, if the energy return from searching and handling them is higher than the energy return for low ranked species (O'Connell & Hawkes 1981; Smith *et al.*1983; Codding & Bird 2015).

The patch choice model assumes that resources are found in heterogenous environments known as patches (Smith et al 1983; Bousman 1993). It predicts greater annual movement to areas that are characterised by high resources (Codding & Bird 2015; Byrd *et al.* 2016) and resources that are available year-round (Byrd *et al*. 2016). It is assumed that foragers will always harvest in patches that produce a greater energy return for the time travelling, searching and handling resources (O'Connell & Hawkes 1981). Decision making in terms of which patches to forage is influenced by the availability of highly ranked resources (O'Connell & Hawkes 1981; Uthmeir *et al.* 2008). For instance, time spent in a patch will increase if the exploitation of that patch returns high energy rates (Bouman 1993). When the return rates of a patch decreases, the forager will move to another patch that will return high energy rates. However, if the resources that are favoured are distributed differently in type and quantity across patches foragers will optimise the time spent in each patch.

The central place model assumes that foragers will always go back to the central place which is the place of origin (residence) after acquisition (Byrd et al. 2016). Thus, Byrd *et al.* (2016) argues that it is important to model the extent of the landscape where people forage because it helps archaeologists to understand the factors that influence decisions of foraging. The model assumes that foragers aim to maximise their foraging efforts in that they will choose the optimal solutions to

acquisition strategies (Byrd *et al.* 2016). In this case, travel time is an important factor when foraging (Byrd *et al.* 2016). Minichillo (2006) remarks that HP people at KRM may have increased time to procure silcrete raw material thus time was an important factor in their procurement decision. In other foraging groups, time may not always be an important factor. Taliaferro *et al.* (2010) observed that to procure obsidian lithic raw material in the Mimbres Valley, Mexico, it would require a higher cost and it would have taken a week to get to the closest obsidian raw material thus the people at this site would have practiced logistical foraging. Additionally, it would have required physical costs in terms of labour and material supplies to collect and transport back to the site. Thus, they concluded that time might not have been a deciding factor in procuring obsidian in the area.

Some scholars believe that a change in climate and/or environment forces a change in foraging strategies (e.g., Minichillo 2006). Foragers may need to find new ways to accomplish their goals in harvesting more resources (Minichillo 2006), leading to intensification. Intensification occurs when foragers harvest more prey than usual by adding lower ranked resources to their diet (Smith *et al.* 2014; Minichillo 2006; Codding & Bird 2015) when costs for optimal high ranked resources increase (Smith *et al.* 2014). In other instances, foragers may increase the costs of procuring raw materials for tools or in designing tools to ease the capture of prey (Minichillo 2006), This is what is referred to as technological intensification (2006). This study incorporates environmental factors in order to assess the possibility of these factors impacting procurement strategies.

3.4 Catchment analysis techniques in archaeology

Site catchment analysis (SCA) is a technique used to investigate the relationship between the occupants of an archaeological site and their environment (Vita-Finzi & Higgs 1970; Becker *et al.* 2017). SCA draws from economic geography and OFT principles and it was developed before the use of computers in archaeology. The main idea of SCA comes from the central place model, in that humans always move from and back to an origin point when foraging for resources in an environment (Hamilton & Watt 1970; Wheatley & Gillings 2002). Thus, the further away resources are from the origin point, the greater the cost of exploiting

them (Wheatley & Gillings 2002). Therefore, areas that are nearby are important to the forager's economy (Kvamme 1999; Surface-Evans 2012).

SCA is considered to have theoretical weaknesses, in particular it is considered to be unrealistic (Kvamme 1999) as at worse it assumes that site catchments are circular (Vita-Finzi & Higgs 1970) and at best, that a landscape is uniform (Kvamme 1999; Surface-Evans 2012). Furthermore, SCA does not take into account the effects of natural landscape, such as slopes on movement (Kvamme 1999; Wheatley and Gillings 2002; Surface-Evans 2012). In reality, site catchments have irregular shapes and they vary in sizes (Kvamme 1999; Anderson 2012). SCA does not take account that factors such as slope, dense vegetation or taboos may limit people from getting to some parts of the circular areas, on the other hand areas that are outside the circular slope may be more accessible due to flat terrain or no taboos associated with the area (Wheatley & Gillings 2002). However, in more recent uses of SCA using GIS, attempts have been made to correct some these limitations as described below.

In a GIS, SCA is used to answer questions of past peoples cost of transport during foraging (White & Surface-Evans 2012), by generating a territory of an area based on the cost distance from the origin point to the destination instead of a geometric distance (Wheatley & Gillings 2002; Surface-Evans 2012). Two paths that are the same linear distance may have different costs. For instance, one path may have flat terrain thus may require less energy and time when and the second path may be characterised by steep slopes and clustered vegetation which may require more energy and time to get to the same destination (Wheatley & Gillings 2002). Therefore, in a GIS, the Least Cost Paths (LCP) tool is a catchment analysis technique used to model past routes people may have taken and incorporating factors that may be a hinder to movement of people.

3.4.1 Least cost paths

A least cost path (LCP) "is a route that minimizes the total cost of moving between two locations on an accumulated cost source" (Conolly & Lake 2006: 294). LCPs have been used in archaeology to model, reconstruct and/or predict

past routes (Whitley & Hicks 2001; Connolly & Lake 2006; Howey 2007; Anderson 2012; Herzog 2013; Güimil-Fariña & Parcero-Oubiña 2015; White 2015). LCP analysis follows the OFT theory that people optimise the costs of the routes they take (Herzog 2013; Güimil-Fariña & Parcero-Oubiña 2015). The energy that is spent on obtaining resources must be outweighed by the output of the procurement (Uthmeir *et al*. 2008). Therefore, the optimal path is the route that is characterised by minimum costs between the starting point and the destination (Howey 2007).

LCPs mainly use landscape data that may affect route choices, such as slope, hydrology and vegetation (Herzog 2013). There are two methods that are used to model least cost paths; isotropic and anisotropic. Isotropic cost models calculate the cost of movement across a landscape, however, do not take in consideration direction of movement (Wheatley & Gillings 2002; Connoly & Lake 2006; Llobera *et al.* 2011; Herzog 2013 & 2014), therefore, the cost of travelling to and from a destination is identical (Diwan & Doumit 2017). Isotropic cost modelling is often applied to model vegetation and water features as the cost of these factors is uniform regardless of the direction a person is travelling (Conolly and Lake 2006; Schild 2016). For instance, grasslands offer the same resistance whether a person is taking an eastern or western route. Anisotropic cost models take into account how direction has an impact on cost (Wheatley & Gillings 2002; Llobera *et al.* 2011; Herzog 2013, 2014) and the magnitude of walking in the landscape (Connoly & Lake 2006). For instance, the cost is high when walking up a slope, whereas in flat areas the velocity will be equivalent to the average human walking speed (Frakes et al. 2008) which is 5.047 km/h (Becker *et al.* 2017). For that reason, anisotropic cost models are derived mainly from slope surfaces (Wheatley & Gillings 2002). However, it is important to include other factors such as vegetation and water networks in order to account for other factors that affect movement (Howey 2007).

There are criticisms of the LCP approach to modelling movement. Some studies criticise the LCP for producing only one optimal route to travel in a landscape to a destination (Howey 2011; Howey & Burg 2017). Howey & Burg (2017) suggest

that circuit-based modelling be used in studies of movement as this approach provides multiple paths that may be optimal instead of one optimal route. People may have used more than one route to get to a destination as they may not have chosen the shorter path but may have had alternative paths to take. There are matrices that can hinder accessibility and cause isolation (e.g. increase of sea levels) in a landscape. Circuit-based modelling has also had its own limitations, namely the tendency to "overemphasise the relationship between multiple pathways and resistance values" (Howey 2011: 2533). The circuit-based model has the disadvantage of understating the possibility that past societies may have had only one travel route to a destination (Howey 2011). Therefore, the one optimum path LCP approach has the advantage of identifying real life scenarios where people had only one optimum route they used and therefore predominantly important to them (Howey 2011).

As LCPs mainly use environmental factors to model past routes, the same criticism given to processual archaeology for being environmentally deterministic has been given to the use of LCPs. Cultural and social variables are difficult to model as they are hardly found in the archaeological record (Bell *et al*. 2002; Herzog 2013). However, with the arguments for a more holistic archaeology, archaeologists introduced methods such as visibility and intervisibility modelling to model cultural and social variables in a GIS. Visibility modelling is used to model areas that can be seen by a forager from a certain point in a landscape in order to model people's attraction to certain landscapes. This method is mostly used in settlement studies to model the relationship between humans and the choice of settling in a site (Tilley 1994; Wheatley & Gillings 2002).

Howey (2011) thus suggests that archaeologists should combine LCP and circuit-based modelling to critically analyse and to fully understand the experience of human movement. Furthermore, Herzog (2013) argues that researchers should not stop with the analysis once they generate the optimal routes. Herzog (2013) suggests that the results of the LCP model should be further investigated by comparing them to archaeological known routes in the landscape to assess the reliability of the LCP model. For example, Bell *et al.* (2002) use LCP to predict

and reconstruct the original route of past roads in Italy by using noticeable remains of the road networks that are preserved. Additionally, Güimil-Fariña & Parcero-Oubiña (2015) used LCP to model ancient Roman roads in order to understand why the present roads are where they are. Güimil-Fariña & Parcero-Oubiña (2015) compared their LCP model to the present-day routes and the LCP model supported the suggestion that the present roads formalised the ancient roads used in the past. For areas that have no trace of past routes the distribution of archaeological features or finds can be analysed and be compared to the LCP model (Herzog 2013). In the case study done by Herzog (2013) of past routes Wipperfürth, Germany, the LCPs that were modelled were to some extent aligning with some paths of the old main roads in the study area. So, LCP is not perfect however it gives an idea of where the route might have been.

3.4.2 Mathematical basis of LCPs

GIS archaeological studies use an array of methods used to model ancient paths. Popular models are mainly 1) walking speeds and travel time models and 2) energy based and travel time models. Both methods are used to calculate the cost of moving in a landscape between an origin and a destination in units of time (Connoly & Lake 2006). In ArcGIS, there is a default built- cost function method that is straight forward and easy to use. However, this method is isotropic, and the output result is measured in only distance. Thus, Tobler's Hiking Function is most popular in archaeological studies as it allows for researchers to calculate costs in terms of time.

Tobler's Hiking Function was derived by Tobler (1993), which was expanded from Imhof's (1950) experimental investigation of Swiss soldiers' walking speeds. Tobler's (1993) original equation (1), is an exponential equation that calculates human walking speed for provided slope values (White 2015; Becker *et al.* 2017). For each slope degree walked in a landscape, Tobler (1993) calculated the velocity of an individual. This equation predicts a maximum speed of 6 km/h at a slope degree of 3 downslope (Tobler 1993; Kondo & Seino 2010).

$$V = 6e (-3.5 * abs (s + 0.05))$$

Where;

V = walking velocity (Km/Hour)

e = base of natural logarithms

s = slope (degrees)

Equation 1

Tobler's original equation has been criticised by Herzog (2013) for not being based on scientific experiments, stating that the equation is a rule of thumb (Herzog 2013). Nevertheless, the equation is widely used in LCP archaeological studies (e.g. Taliaferrp *et al.* 2010; White & Surface-Evans 2012; White & Barber 2012; Rogers *et al.* 2015; Güimil-Fariña & Parcero-Oubiña 2015; Byrd *et al.* 2016). White (2015) argues that the equation is misunderstood. He states that the problem with the equation arises in the conversion of the degree of slope to travel time of crossing a raster cell (White 2015; Schild 2016) when people use the percent slope instead of the degree slope (Schild 2016). Thus, when the equation is used incorrectly, the function returns an output of zero walking speeds (White 2015). Due to the misapplication of the original equation, recent studies have modified the equation (Tripcevich 2009; White 2015).

Tripcevich (2009) derived a modified equation of Tobler's Hiking Function. Instead of calculating walking speeds, Tripcevich (2009) used Tobler's (1993) original equation to develop a vertical factor table (Table 3.1) that calculates travelled times. This was achieved by dividing the speed obtained in a certain slope degree by one hour and the distance travelled (Tripcevich 2009; Standley 2014). The Tripcevich (2009) equation provides an opportunity to create an anisotropic LCP model. In 2015, White (2015) also adjusted Tobler's Hiking Function by adjusting Tobler's equation. As with Tripcevich (2009), White (2015)

adjusted Tobler's Hiking Function to calculate the time a person travels over a given distance instead of calculating walking speed of an individual (White 2015).

Table 3.1: Summarised Tripcevich (2009) Vertical Factor table with the associated speed obtained per slope degree (Standley 2014: 54).

Slope (degrees)	Tobler's Vertical Factor	Speed (Km/hr)
-90	-1.000000	-0.001
-80	-1.000000	-0.001
-70	2.099410	0.000
-50	0.009065	0.110
-30	0.001055	0.947
-10	0.000259	3.856
-5	0.000190	5.262
-4	0.000179	5.596
-3	0.000168	5.950
-2	0.000176	5.692
-1	0.000187	5.354
0	0.000199	5.037
5	0.000270	3.708
10	0.000368	2.717
30	0.001498	0.668
50	0.012863	0.078
70	2.979204	0.000
80	-1.000000	-0.001
90	-1.000000	-0.001

Several studies have also assessed ways to incorporate energy consumption of an individual when walking on a terrain (e.g., Rademarker 2012, Byrd *et al*. 2016), as some studies have stated energy is a better indicator of cost than time (e.g. Kondo & Seino 2010). They used Pandolf *et al's*. (1977) energy consumption equation (2), which calculates an individual's metabolic rate. These studies

incorporated Tobler's Hiking Function in their studies in order to investigate the relationship between metabolic rates of an individual and travel times. Due to time constraints energy-based models were not implemented.

$$M = 1.5\ W + 2.0\ (W+L)\ (L/W)^{2} + n\ (W+L)\ (1.5\ V^{2} + 0.35\ VG)$$

Where:

M = metabolic rate (watts)

W = travellers' weight (Kg)

L = Load (Kg)

V = walking velocity (metres per second)

G = slope (%)

n = terrain coefficient

Equation 2

The use of GIS has made it easier for archaeologists to model different aspects of a forager. Several scholars have used the above methods to assess which method works in their given landscape (Surface-Evans 2012; Becker *et al.* 2017; Diwan & Doumit 2017). However, the methods have not been used on the Southern African landscape. Therefore, in order to investigate the difference of modelling movement patterns using different LCP methods the Southern Cape landscape, this study utilised the ArcGIS default cost function, and the Tripcevich (2009) and White (2015) methods to model LCPs in KRM landscape.

3.5 Summary

The LCP model used in this dissertation is based on concepts of optimal foraging theory (OFT). The incorporation of OFT provides understanding on how movement is organised in a landscape and the decision people make when foraging (Byrd *et al.* 2016). The procurement and use of lithic raw material are influenced by choices foragers make and their behavior (Browne & Wilson 2013).

Therefore, if time was optimised and the procurement of silcrete sources was not affected by social or cultural factors the procurement of silcrete raw material may have been encompassed by the least costly source (Taliaferro *et al.* 2010).

The use of GIS to model archaeological data has increased through the past decade due to its ability to incorporate multiple layers of data which is beneficial to archaeologists as different factors may affect a foragers day to day decisions. However, in South Africa, with the exception of Sadr (2017) GIS has not been utilised in LCPs studies, especially procurement of silcrete. Thus, the feasibility of LCPs methods in South African movement patterns is investigated in this dissertation. LCPs have been criticised for being environmentally deterministic, nevertheless, as a basis study this dissertation explored the effects of environmental factors on movement patterns in the KRM landscape. Furthermore, LCPs are critiqued for only producing one optimal route. This has been addressed by modelling several possible routes that HP groups may have travelled through to procure silcrete raw material.

CHAPTER FOUR : MATERIALS AND METHODS

This chapter discusses the materials acquired and methods employed to investigate the travel time to different silcrete outcrops found in the study area and methods employed in creating a Least Cost Path (LCP) model to examine the routes the Howiesons Poort (HP) people may have taken to acquire silcrete raw material at KRM. In order to create the models, different datasets are needed thus data acquisition and the pre-processing procedures are discussed below. The last section discusses the methodology employed to create the LCP models and the travel times. The models were generated using both the ArcGIS 10.3 and 10.5 software.

4.1 Study area

The study area includes the area of the southern Cape, from Oudtshoorn (33°35'S 22°12'E) in the west to Grahamstown (33°18'S 26°31'E) in the east (*Fig. 4.1*). Roberts (2003) indicate several outcrops of silcrete relatively close to KRM that may relate to the HP silcrete artefacts. These, together with the geology maps from Council of Geoscience, were used to map silcrete outcrops in the vicinity of KRM. The distribution of silcrete outcrops is uneven in the study area as it is abundant in the western part of the study area and it can also be found in large quantities in the Grahamstown area (*Fig. 4.1*). Nash *et al.* (2013b) also report silcrete from Kareedouw and Grahamstown areas. In the study area, silcrete is mainly found in primary outcrops. The hypothesis that secondary silcrete may have been transported through river channels near the archaeological sites (e.g., Minichillo 2006) could not be verified in this study.

KRM is relatively close to the two nearest archaeological sites with HP deposits, Nelson Bay Cave (NBC) and Pinnacle Point (PP). Data from these sites are used for the comparison of the models produced to investigate whether inhabitants of KRM, NBC and PP could have interacted with each other. Figure 4.1 represents the topographic area of focus as well as the area in which silcrete outcrops are found.

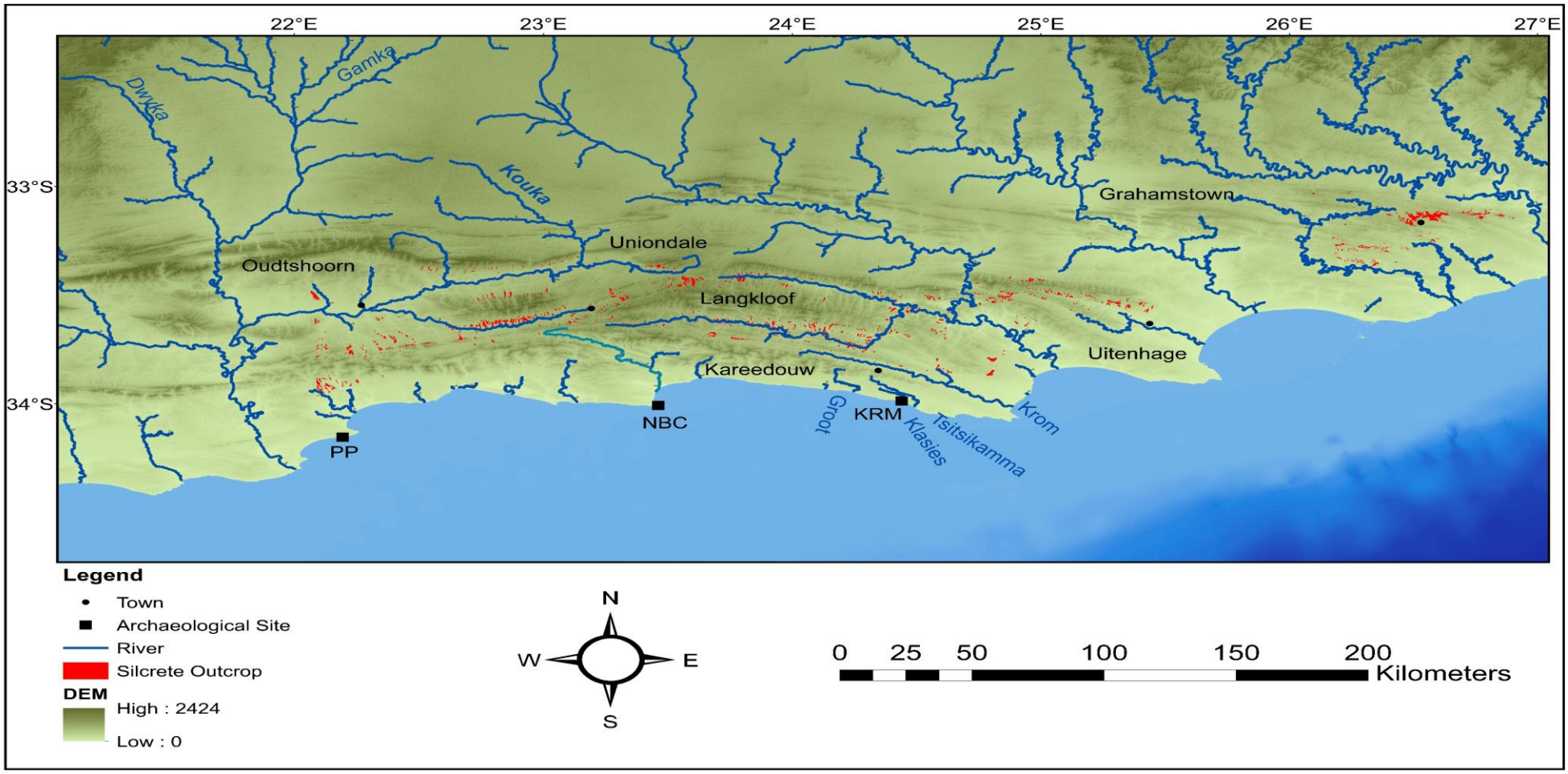

Figure 4.1: Map depicting the topography and silcrete found in the study area, including archaeological sites and towns. (Source: bathymetric from MGDS; DEM from USGS; river data from DWA; the silcrete geological data obtained from Council of Geosciences and the Roberts (2003).

4.2 Data acquisition and pre-processing

There are different factors that affect movement in a landscape. Topography, waterbodies (streams and rivers), vegetation and geology (in this study silcrete outcrops) data were used to calculate the LCP model. Bathymetric data was used in the map for display purposes. Table 4.1 below lists the geographical data sets that were used in this study and summarises the information of each data set.

Table 4.1: Summary of datasets used.

Data	**Dataset/Description**	**Source**	**Scale/ Resolution**	**Format**	**Date**
Topographic data	ASTER GDEM	The United States Geological Survey (USGS)	1 arc-second/ 30 m	Raster	2011
River data	Flow accumulation and direction of the river network	HydroSHEDS	15 arc-second/ 500 m	Raster	2006
Vegetation data	South African Biomes	South African National Biodiversity Institute (SANBI)	1:250 000	Vector	2012
Geology data	Geology of South Africa	Council of Geo-Science (CGS)	1:250 000	Vector	2006
Bathymetry	Bathymetry used as a base map to show the coastal platform	Marine Geoscience Data System (MGDS)	50 m	Raster	2017
Silcrete data	Silcrete outcrops of the Eastern Cape	Roberts' manuscript (2003)	25 km	Scanned paper map, georeferenced and digitised by author	2003

4.2.1 The DEM

A total of thirty Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM V2) 1×1 degree tiles were acquired from the USGS website. The DEM tiles are provided at a 1 arc-second spatial resolution. Both the ASTER GDEM and the SRTM sensors give problems in flat terrain as little SRTM radar signal is reflected back to space, and ASTER stereoscopy gets delayed as there are a lack of surface patterns in flat smooth terrain (Biagetti *et al*. 2017). Also, both data sets have spatial and elevation errors in landscapes that are characterised by steep and rugged terrain. However, the ASTER GDEM V2 has been corrected for voids and demonstrates an accuracy of 0.20 on average (Schild 2016). The ASTER DEM has an advantage in the KRM area as it is suitable for showing low lying elevations that are surrounded by the rugged terrain of the KRM landscape.

The ASTER GDEM tiles were mosaicked. The GDEM was projected to WGS_1984 with a Universal Transverse Mercator (UTM) zone 35S and the datum set to WGS 1984. All maps used in this study were projected to this spatial reference. Furthermore, the DEM was resized using the 'clip' geoprocessing tool to fit the size of the study area.

4.2.2 Silcrete data

Roberts (2003) conducted an extensive survey of silcrete raw material sources in the Cape area. The study was published as a monograph titled *Age, genesis and significance of silcrete of Southern African coastal belt silcretes* in 2003. Roberts (2003) identified mapped silcrete outcrop sources in the southern Cape area. It is important to note that the map includes only the inland silcrete outcrops and it does not include the secondary and submerged sources (Will & Mackay 2017). The Eastern Cape map from his publication was used for this dissertation. The silcrete map was scanned at a 600-dpi resolution and georeferenced using the longitude and latitude ticks provided on the scanned image. The map was then compared with Google maps to see whether they align, and the maps aligned completely. Therefore, the silcrete map was accepted to be used for this study.

The map was subsequently digitised by creating a new single feature class in ArcMap. The digitised map was analysed and compared to the geology map from the Council of Geoscience (CGS) that contains silcrete of the study area. Through visual inspection, it was realised that the digitised silcrete map had some missing outcrops in the area near Grahamstown and the CGS map had missing outcrops in Kareedouw and Uitenhage areas. In the south-east the silcrete region outcrops of the digitised and the CGS were overlapping. The CGS and digitised map were merged to create a more accurate silcrete map that was used for this study.

4.2.3 Slope

The most common cost function used in modelling LCPs is slope. In this dissertation, slope is used as a main cost components in order to investigate the most suitable LCP algorithm for the KRM study area. Other cost component such as vegetation and hydrology were used as constraints in order to examine whether environmental factors affect the travel times and LCPs of moving in the landscape. The ASTER GDEM was used to create a computer-generated degree slope raster by using the 'Slope' tool under Spatial Analyst in ArcMap. In ArcMap, slope is calculated by calculating "the maximum value rate of change in value from that cell to its neighbours" (ESRI 2016).

4.2.4 Vegetation

The importance of an evolving paleoenvironment is recognised. The environmental conditions of the present day were different from the HP environment (cf. Wheatley & Gillings 2002), the geographical distribution of the biomes may have also changed (Byrd *et al.* 2016) since the HP. However, South African studies have not thoroughly researched the palaeo-vegetation of the HP, therefore there is no certainty of the particular vegetation of the time. As a result, this study used present day biome types to create a cost surface to test the behaviour of the algorithms used.

The biomes used in this study were downloaded from the South African National Biodiversity Institute (SANBI). The shape files were imported as vector data into ArcMap and were converted to raster data using 'polygon to raster' in the

conversion tools. As the biome map was of the whole of South Africa, the raster map was clipped to cover the study area. Due to the lack of studies on South African biomes' speed coefficient, speed coefficients for vegetation developed by Frakes *et al.* (2008) and White and Barber (2012) (*Table 4.2*) were used to reclassify the biome map into biome speed coefficients for different biome types.

Furthermore, the USA has different vegetation types from that of South Africa; consequently, speed coefficients for other vegetation types that are found in South Africa but not found in the USA were estimated to an extent that they consist of similar characteristics to the vegetation type that are found in the USA. The biomes were reclassified to walking speed coefficient using 'raster calculator' (*Table 4.2*).

The vegetation map contained a category for water bodies. Algorithms in ArcGIS allow landscapes that have barriers to be specified to be a 'no-go' zone (Wheatley and Gillings 2002). For example, lakes can be considered a complete barrier by assigning 'restricted' to lake features, as one cannot move on lakes unless one has boats or other means of water transport (Frakes et al. 2008). Lakes were, consequently, given the NoData value so that ArcGIS can recognise it as being 'restricted' (White 2015).

For areas that are easy to walk through, such as Grassland, the speed coefficient was highest (0.80) as the speed increases when walking is easy. Forests were given the lowest speed (0.30) as it is difficult to walk through a forest and as a result a person's speed would decrease.

Table 4.2: Speed coefficient for differing biomes that are found in the area of interest (Adapted from Becker *et al*. 2017).

Biome names	**Speed coefficient**
Forests	0.30
Azonal Vegetation	0.50
Savanna	0.75
Albany Thicket Biome	0.55
Grassland	0.80
Nama-Karoo	0.70
Succulent Karoo	0.70
Fynbos	0.65
Water bodies	Restricted

4.2.5 Rivers

The rivers in the area during the HP were mostly likely always full because the area was and still is an all year rainfall zone. Since river networks affect the speed of human walking (Becker *et al*. 2017), speed coefficient for river networks were created. To create river networks for this study, flow accumulation and direction data were downloaded from HydroSHEDS. The HydroSHEDS data originates from topographic data of the Shuttle Radar Topography Mission (SRTM). The downloaded data is at 15-arc second resolution and it is made available as already been cleaned with ArcMap Algorithms such as void-filling (Lehner *et al*. 2006). The flow directions dataset outlines the direction a river flows from each cell to the steepest down slope (Lehner *et al.* 2006). On the other hand, the flow accumulation dataset outlines the quantity of water of an upstream area draining into each cell (Lehner *et al.* 2006).

The flow direction and flow accumulation dataset were clipped to cover the study area. Furthermore, in order to classify the river network with the Strahler order, a 'stream order' was calculated with the Hydrology tool. As with the biome raster, the output raster was reclassified by using 'raster calculator'. The speed coefficients for the river networks followed the permeability values developed by Theobald *et al*. (2010) and followed by Becker *et al.* (2017). The speed

coefficients were given assuming that people were willing to cross different river networks as rivers are characterised by gentle slopes and ArcGIS might regard waterbodies as good areas for walking (Güimil-Fariña & Parcero-Oubiña 2015). Therefore, different river networks were given different speed coefficients (Table 4.3). The larger the river network the less the speed (Table 4.3), thus as tributaries are smaller, they were assigned a higher walking speed coefficient whereas rivers were assigned a lower walking speed coefficient.

*Table 4.3: Speed coefficient of differing river networks found in the area of interest (*Adapted from Becker *et al.* 2017*).*

Stream Order	**Speed coefficient**
Tributaries (1st Order)	0.80
Small streams (2nd Order)	0.65
Large streams (3rd Order)	0.20
Rivers (> 3rd Order)	0.02

4.2.6 *Departure and destination points*

KRM was specified as the point of departure in the main model. PP and NBC were also used as points of departure for the models that were used to compare data of the three sites. The silcrete raw material outcrops were used as destination points in this study. The silcrete outcrops were in different polygon sizes therefore the 'feature to point' function was used to convert the silcrete outcrops into centroid point shapefiles. This was done to break down the larger outcrop formations into smaller areas in order to examine whether the silcrete outcrops can be reached in different directions. Some of the outcrop formations were large which would ultimately hinder ArcGIS to generate paths from other directions. Therefore, the cost of travel would be limited to a few outcrops in the study area. This produced 994 destination points.

4.3. Modelling the LCPs

Model Builder, an ArcGIS tool that is used to process a spatial model and includes tools used, inputs and outputs (ESRI 2016) was used to build the LCP models. Each model was broken down into two parts: the creation of an accumulative cost distance raster and the calculation of LCPs. The cost distance raster defines the cost value for each cell in the raster initiating from the point of interest. The cost grows as the distance from the source location increases, thus each cell in the resulting raster represents the cost of travel back to the source location (ESRI 2016). The Cost Path tool was then used to calculate LCPs from the cost surface and the cost back rasters created in the previous step.

4.3.1 Generating the accumulative cost surface/ cost distance

In movement studies, distance is mainly characterised by time or effort. The cost distance calculates the cost of moving away from or towards a point in a cell to a destination point in another cell using the "cost distance" tool (Connoly & Lake 2006; White & Barber 2012; Rogers *et al.* 2015). The further away a forager travels from the origin point, the higher the cost (Kvamme 1999; Becker *et al.* 2017). The resulting cost distance raster represents the cost of travel in units from the origin point to each raster cell (Whitley & Hicks 2003; Rogers *et al.* 2015). The calculation considers the maximum cost a forager might have taken, taking into consideration factors such as slope, land cover and hydrology as these factors influence which area was exploited by past people (Connoly & Lake 2006).

In site catchment studies, the cost distance raster is mainly used to demarcate the territory of the site (Connoly & Lake 2006). It is believed that hunter-gatherers walked a maximum of two hours per day to acquire their resources (Vita-Finzi & Higgs 1970). Nonetheless, some researchers (e.g., Utheimer *et al*. 2007) use 3 hours as the maximum time. In the model of Byrd *et al.* (2016), the minimum travel was set to four hours as it assumed a maximum of eight hours per day for a forager to walk. They chose it as it allows a forager to walk from the site to the destination and go back to the site at the end of the day (Byrd *et al.* 2016). This

dissertation followed Byrd *et al.* (2016) travel times of four hours for a forager as the maximum range to procure silcrete raw material.

To generate a cost distance model, the origin and cost surface raster are required (*Fig. 4.6*). The origin feature contained the location of Klasies River main site. The 'cost distance tool' produced an accumulated cost surface raster and the output backlink raster. When the accumulated cost surface is generated, a backlink raster is derived (ESRI 2016).

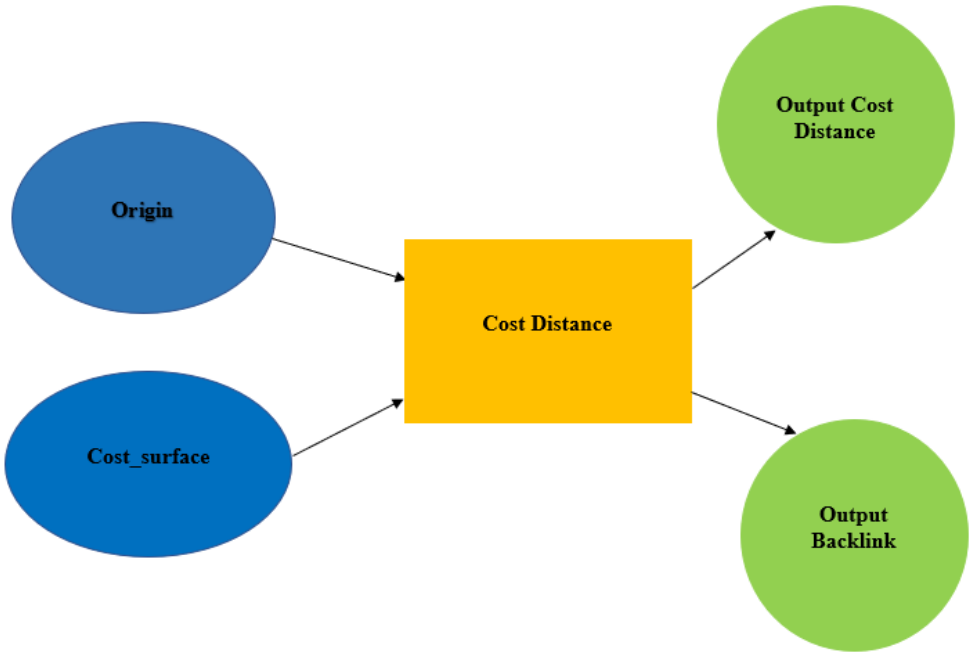

Figure 4.2: The Cost Distance model, blue ovals indicate the inputs and the green indicate the output.

4.3.2 Generating the LCP

The accumulative cost surface and backlink rasters from the previous algorithm (cost distance) are used to run a least-cost path. It mainly records the short efficient paths from the origin to the closest destination cell that was defined when the accumulative cost raster was calculated (ESRI 2016). Therefore, the resultant raster shows the least-cost path in terms of the cost identified.

After the accumulated cost surface raster was created, the LCP was generated. The 'Cost Path' tool was executed to create the LCPs. Three input rasters were

required to perform this function (*Fig. 4.7*). They were the destination, accumulated cost surface and backlink rasters. The cost path tool creates the LCP output, which shows potential routes people may have taken to different silcrete outcrops. The LCPs were converted to vectors using 'Raster to Polyline' to visualise them properly (*Fig. 4.7*).

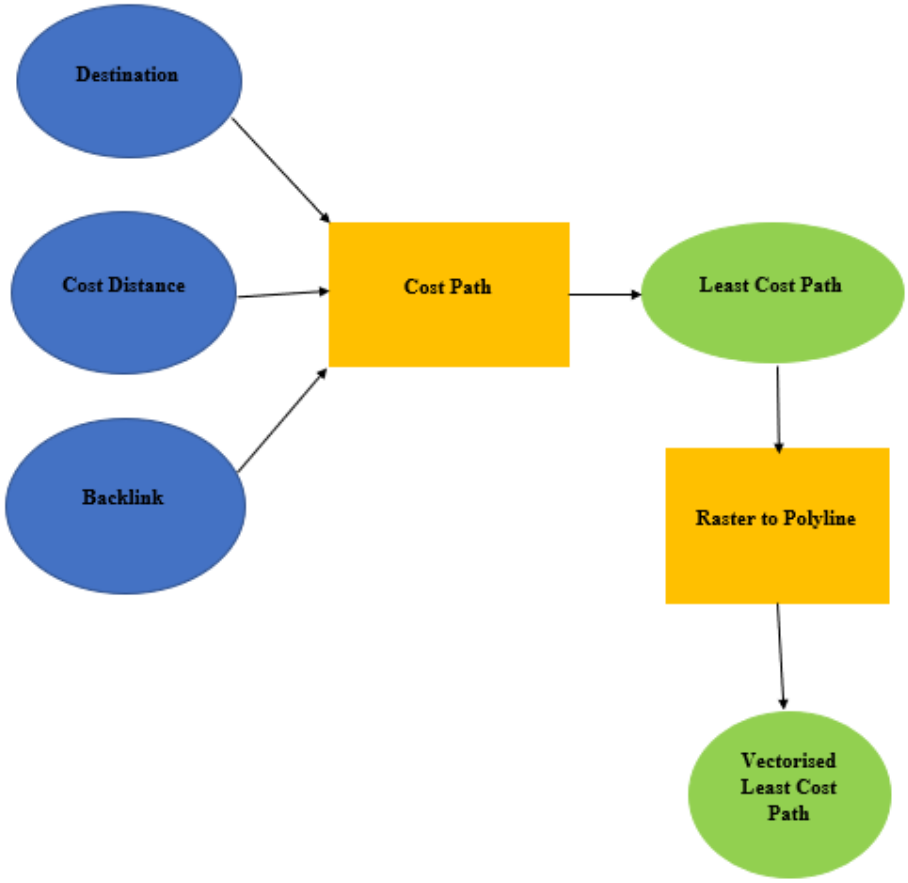

Figure 4.3: The Cost Path model.

4.3.3 Algorithms used for the creation of the cumulative cost surfaces

Archaeological studies have assumed that slope is the primary factor influencing movement in a landscape (Rademaker 2012; Surface-Evans 2012; Schild 2017). Therefore, three slope-based algorithms were utilised to test the feasibility of LCP algorithms model cost surfaces and travel times in the KRM landscape (three anisotropic and one isotropic).

These were the default built-in ArcGIS cost function (DBC), Tripcevich (2009) adjusted Tobler Hiking Function (TTHF) and White's (2015) modified Tobler Hiking Function (WTHF). The two (TTHF and WTHF) models that calculate time instead of distance were used to investigate the nearest silcrete source in terms of time from KRM.

Below is a brief description of algorithms used.

1. DBC - The DBC is a simple isotropic algorithm that calculates the cost of moving in a landscape. The methodology by Diwan and Doumat (2017), was followed to generate costs and LCPs in terms of distance in units of meters. A slope raster was reclassified according to the weight values showed in table 4.4. The weighted slope values were reclassified into ten categories representing a range of slope values using the "reclassify" tool. The accumulated cost surface and cost backlink (Direction raster) rasters were then created by running the cost distance tool using the reclassified slope. Thereafter, LCPs were created by running the cost path tool using the accumulated cost surface and backlink raster. The output result is a new raster layer showing the paths from the origin point (KRM) to the destination (silcrete outcrops). The paths were converted to a polyline.

Table 4.4: Reclassified slope classes.

Degree slope	**Cost Value**
80-90	10
70-80	9
60-70	8
60-50	7
40-50	6
30-40	5
20-30	4
10-20	3
5-10	2
0-5	1

2. TTHF - Due to the limitations of the original Tobler (1993) equation (see section 3.4.2), Tripcevich adjusted Tobler's original equation to be used in a GIS environment (Equation 3).

TIME (HOURS) TO CROSS 1 METER or the reciprocal of Meters per Hour =0.000166666*(EXP(3.5*(ABS(TAN(RADIANS(slope_deg))+0.05))))

Equation 3

The generation of LCPs using the TTHF is performed using the path distance tool instead of a cost distance. These tools are similar, as they perform the same function in that they both calculate the cost of moving away from or towards a point in a cell to a destination point. The difference is that the path distance tool also calculates the actual surface distance that is travelled for the horizontal and vertical factors influencing the cost of moving from the ongoing to the destination (ESRI 2016). Thus, Tripcevich's (2009) vertical relative table (see Table 3.1) can be applied to convert slope angles to time when the path distance is processed.

As this method was designed in ArcGIS 10.1, it does not work in some other versions of ArcGIS software, for example, it does not work in the ArcGIS version 10.3. Therefore, for this dissertation it was processed in ArcGIS 10.5. To generate the travel times and the LCPs, a cost surface is required. The ASTER DEM was used as cost surface raster and the Tripcevich reciprocal table was used as a vertical factor table. The resulting output of an accumulated cost surface is the travel time of moving in a landscape and a backlink raster. Both the rasters were used to generate LCP's using the cost path tool. These paths were converted to polylines.

3. WTHF - White (2015) observed that past publications in LCP archaeological studies encountered errors when creating LCPs. As a result, he modified Tobler's Hiking Function by proposing that the output model to produce an estimate of travel time over a given distance instead of an estimate of walking speed (White 2015). He came up with the following equation:

(Dem Resolution/ 1000) / (6 * Exp (-3.5 * Abs (Tan ((“Slope_Raster” * 3.14159)/180) + .05)))

Equation 4

In his “*The basics of least cost analysis for archaeological applications*” paper, White (2015) gives a detailed workflow on how to generate the LCPs in ArcGIS. The first step is to generate a slope raster using the Slope tool. Next, a cost surface is generated using the modified equation (2) above, using “raster calculator”. The procedure to generate LCPs is similar to Tripcevich’s procedure. The difference is that in White’s (2015) workflow, a cost distance is used and in the Tripcevich’s steps a cost path tool is used.

4.3.4 Factors affecting movement

Different factors affect how an individual move across a landscape. Thus, a cost surface raster representing the costs (slope, vegetation, waterbodies) related with moving across a landscape was created. A cost surface calculates the difficulty of moving between cells in a raster grid (Llobbera *et al.* 2011; White & Barber 2012). Factors that affect movement are incorporated in the calculations to represent costs that are factored by natural landscape.

To create the cost surface raster that included slope, vegetation and hydrology, the created maps needed to be combined. With the DBC model, vegetation and hydrology were reclassified and weighted in the weighted overlay tool. The biomes were reclassified in a process similar to slope reclassification, with the exception that the cost value of the biomes represent the estimated level of difficulty when walking in a landscape. Table 4.4 represents the reclassified cost of considered for this dissertation. For the hydrology, weights were given according to the estimated level of difficulty of crossing waterbodies. Thus, rivers that have a stream order of greater than three were reclassified to be restricted (Table 4.6) assuming that they are too large to be crossed.

Table 4.5: Biomes cost value reclassification.

Biome names	**Cost Values**
Forests	7
Azonal Vegetation	5
Savanna	2
Albany Thicket Biome	5
Grassland	1
Nama-Karoo	3
Succulent Karoo	3
Fynbos	4
Water bodies	Restricted

Table 4.6: Hydrology cost value reclassification.

Stream Order	**Cost Values**
Tributaries (1st Order)	6
Small streams (2nd Order)	8
Large streams (3rd Order)	9
Rivers (> 3rd Order)	Restricted

With the TTHF and WTHF, vegetation and hydrology were reclassified according to the speed coefficients outline in section 4.4 and 4.5 above. In order to merge the three rasters, for the WTHF, the Becker *et al.* (2017) methodology was followed. The time derived slope rasters were divided by the river walking speed raster, and the resultant output raster was then divided by the biome walking speed raster to create a cost surface raster. For the TTHF method, only the vegetation and rivers were merged, and the resultant cost surface raster was in put to the path distance tool as a cost surface and was used conjunction with the DEM and vertical table.

4.3.5 Validation

Herzog (2013) argues that due to the limitations of GIS software and the resolution of DEMs, LCP models need to be validated. The LCP models need to be tested through comparing the models with the archaeological and historical

data (Herzog 2013). However, no standard validation methods exists (Schild 2016). As mentioned in Chapter 3, in LCP studies Roman road current formal roads are used to test LCPs. However, we do not know which paths people followed during the HP and KRM is located in an area with very few current existing paths or roads. For this dissertation, similar methods employed by Rademarker (2012) and Schild (2016) were used to validate the primary models. They mainly introduced a slight difference in their respective models to verify and assess paths that might not have performed as expected.

The validation test was performed in two ways, firstly by introducing an error on the models by extracting 20 silcrete outcrops from the original silcrete outcrops and adjusting the origin point of KRM by moving it 250 m north and easterly from the original location and analyzing the resultant LCPs. Secondly, the travel times were verified by of comparing the travel times of the models produced in this dissertation and Google maps travel times.

4.3.6 Other archaeological sites

With PP, NBC and KRM all situated on the coast and not far from each other, a model was created to investigate the possibility of the interaction of HP from these three sites. The algorithm that provided the most realistic results for the KRM LCPs was used to run a model for other archaeological sites. This method was used to assess the possibility of which these people may have interacted. Furthermore, an "Equal to Frequency" tool was used to determine the KRM paths that intersect with PP and PP respectively, where a frequency of either 0 or 1 is given, where 0 equals to 0 % interaction and 1 equal to a 100 % possibility of interaction. The raster was further converted to polylines for better visualisation.

4.3.7 The nearest silcrete outcrop

To investigate where the nearest silcrete outcrop is located, the travel times of 1, 2 and 3 days were calculated from their respective locations to the nearest silcrete outcrops. As stated above, 1 day daily foraging refers to 4 hours maximum of walking to reach a destination and having time to go back to the site thus overall it is 8 hours a day travel time. 2 days foraging refers to 8 hours maximum to reach a

destination and 3 days refers to 12 hours to reach a destination. Then, distances were calculated by extracting the distances from the DBC cost distance. This distance were determined by calculating the maximum speed of walking in a landscape for an individual which is 6 km/hr (Tobler 1993) by the maximum travel time to walk for resources which is 4 hours in this study.

4.4 Summary

Different data sets were used to investigate silcrete procurement in KRM. In order to explore which time-based LCPs is best suited to the southern African landscape context different isotropic and anisotropic algorithms were tested. Environmental data were then incorporated to assess whether these factors affect the LCPs and travel times in the KRM landscape. All the algorithms were validated using standard methodologies. A frequency calculation was run to determine the possibility of interaction between KRM, NBC and PP. This was done to explore the extent of which the groups from the three sites may have had the opportunity to interact with each other. The ArcGIS measure tool was used to determine the nearest silcrete source from the three archaeological sites. The results from above mentioned methods are presented in the next Chapter.

CHAPTER FIVE : RESULTS

This chapter discusses the results obtained in this study. Sections 5.1-5.3 present the LCPs from Klasies River main site (KRM) to various silcrete sources. Section 5.1 details the modelled Least Cost Paths (LCP) using the three different time-based cost algorithms and the travel times calculated, 5.2 describes LCPs and travel time models incorporating the environmental factors. The validation analysis is discussed in section 5.3. Furthermore, section 5.4 describes the LCPs and frequency of possible interaction models of KRM, Pinnacle Point (PP) and Nelson Bay Cave (NBC). Lastly, in section 5.5, the results of the nearest silcrete outcrop from the three sites are discussed. For purposes of clarity of the maps, the silcrete outcrops were not included in the maps depicting the LCPs. The destination of the LCPs are the silcrete outcrops as indicated in chapter 4.

5.1 The modelled LCPs from different cost surface algorithms

To investigate movement patterns of the HP communities in the KRM landscape, this study used three slope-based LCPs. The algorithms used for the definition of cost surfaces are the ArcGIS Default Built-in Cost (DBC), Tripcevich Tobler Hiking Function (TTHF), and White Tobler Hiking Function (WTHF) described in chapter 4. Nine hundred and ninety-four (994) paths were generated from one origin, KRM, to the respective silcrete outcrops points (destinations).

Algorithm DBC (*Fig. 5.1a*) and TTHF (*Fig. 5.1b*) functioned similarly over the landscape as they travelled similar routes in similar directions. To reach the silcrete outcrops in the Grahamstown area, in the east, the LCPs travelled through the route of low elevation of 0-400 and in a north-easterly direction and continued in that direction until reaching the destination. This is similar in the Uitenhage area, as the paths followed low elevation of 0-400 m and 400-800 m and travelled in a north-east direction.

In the Kareedouw and Langkloof valley area, the paths take a northern direction to reach the silcrete outcrops. Whereas in the Uniondale and Oudtshoorn areas, the paths take a south-west direction to reach the silcrete outcrops, following the topography of low elevations. To the silcrete outcrops located in the Langkloof

valley, south Uniondale and north of Oudtshoorn, the LCPs of DBC and TTHF travelled through the Langkloof valley going around the mountain instead of climbing through the mountain. However, to reach the silcrete outcrops located to the north of both Langkloof valley and of Uniondale, the paths climb through the mountainous areas with an elevation of 1200-1600 m. A major trend with the DBC and TTHF method-based LCPs is that with the silcrete outcrops that are located in valleys, the paths go around the high elevated areas and take the routes through the valleys to reach the silcrete outcrops.

In contrast to the DBC and TTHF algorithms, the pathways modelled by using the WTHF algorithm (*Fig 5.1.c*), travel through a terrain of high elevations. This can be seen in the Grahamstown, Uitenhage, and Oudtshoorn, Langkloof valley and Uniondale areas. The LCPs from KRM to the Grahamstown silcrete outcrops travels north in going through high elevated terrain, and the path branches out to the respective silcrete outcrops before it reaches the outcrops in the Grahamstown. The LCPs travelling to silcrete outcrops to the north of Uniondale and Langkloof valley areas, the paths climbed through the mountainous terrain similar to the DBC and TTHF algorithms. The paths to the silcrete outcrops in the Kareedouw area travel on the flat areas with the WTHF algorithm.

Even though the paths of DBC and TTHF follow the same directions to the silcrete outcrops, the paths do not entirely overlap each other (*Fig. 5.2*). The paths that go through Uitenhage to Grahamstown and those to the north of Langkloof valley and Uniondale, follow the same direction and go through similar areas; however, there is a gap between the paths. Furthermore, the paths modelled by the WTHF algorithm do not overlap the DBC and the TTHF algorithms.

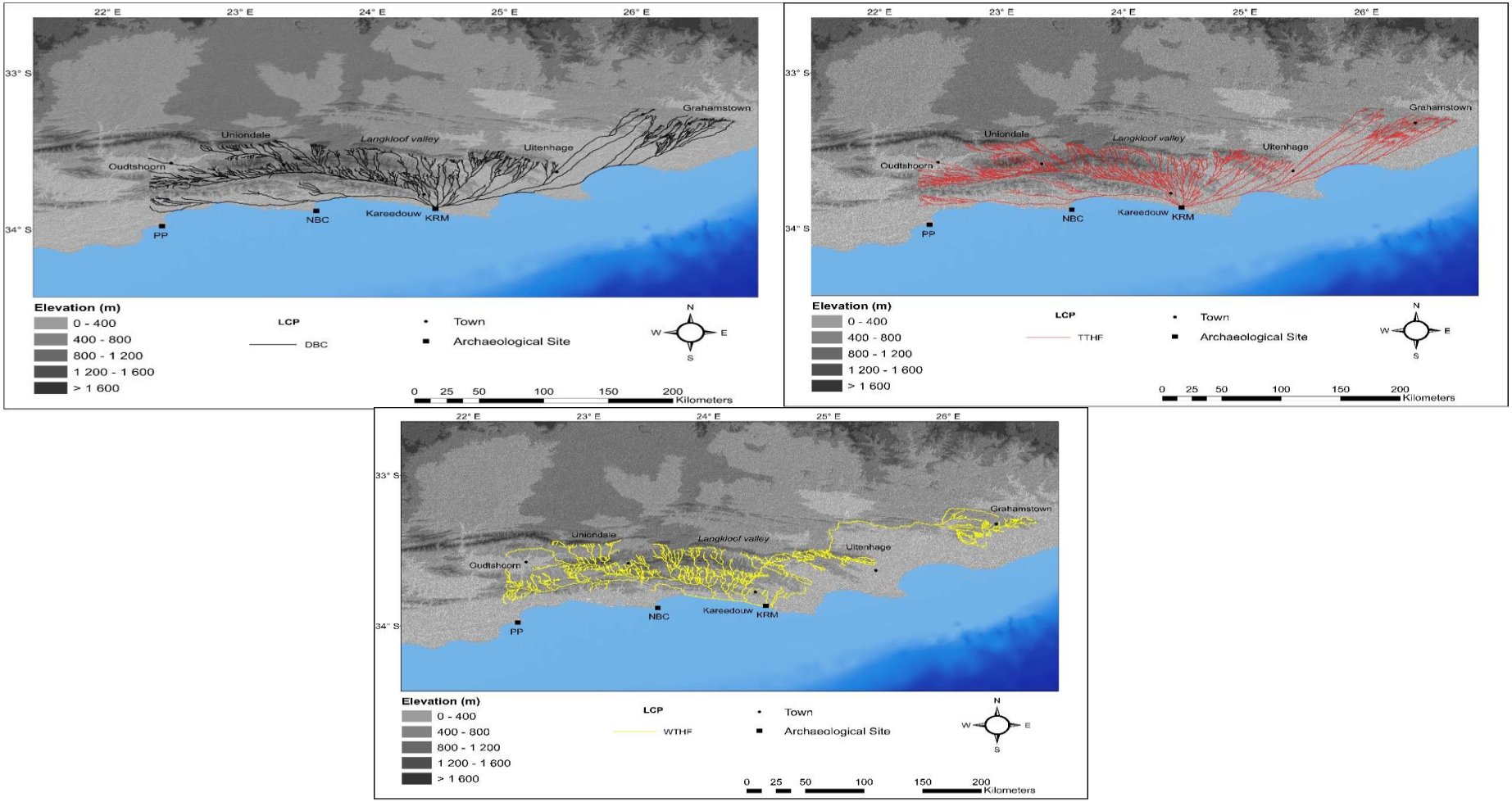

Figure 5.1: The LCP results of the a) DBC, b) TTHF and c) WTHF.

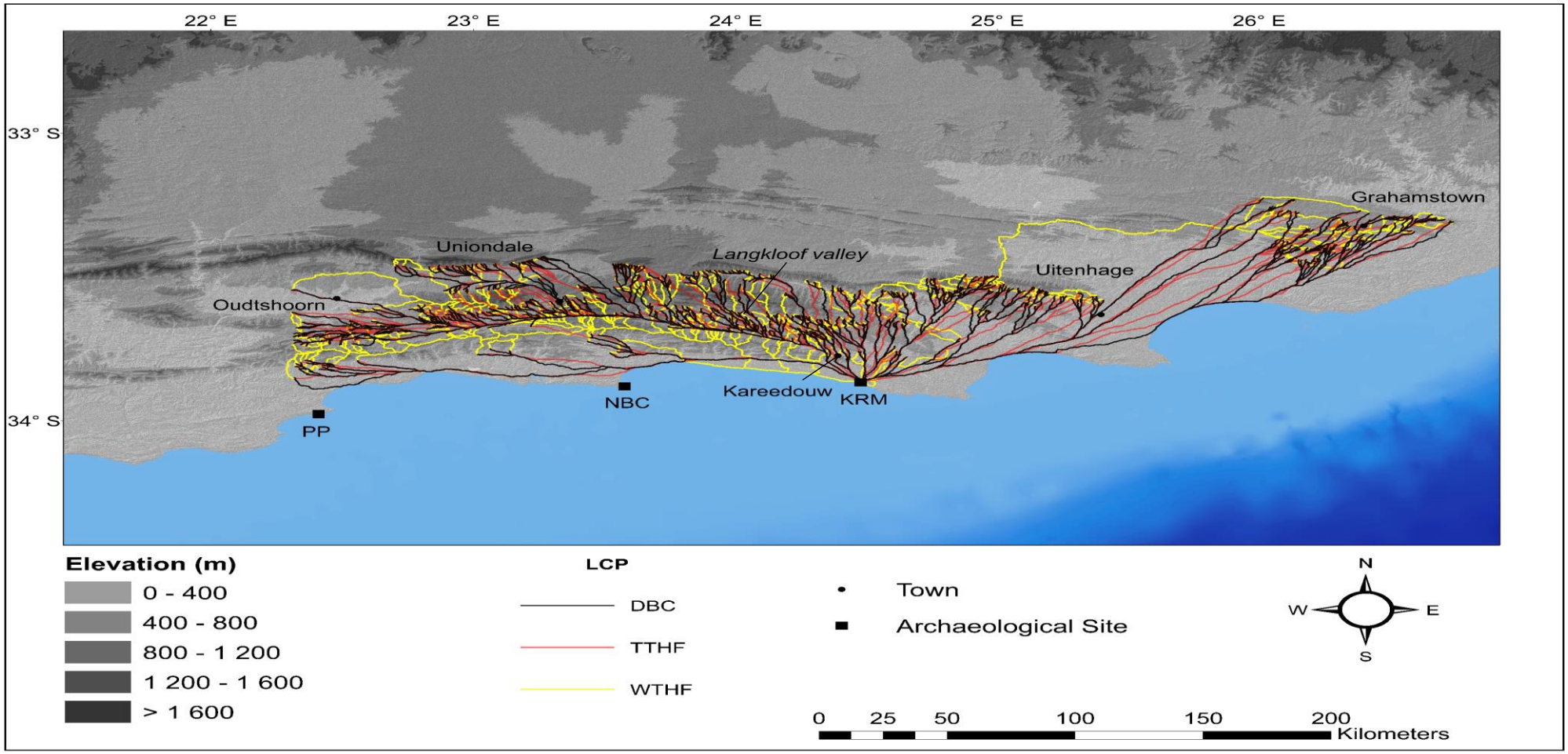

Figure 5.2: Map depicting the results of the DBC, TTHF and WTHF algorithms from Klasies River Main.

5.1.1 The travel times of the time-based models (Slope)

The further away a person travels from the departure point, the higher the cost of travelling in a landscape. Cost in this study was used to calculate the time taken to reach destinations. It must be noted that the DBC algorithm is isotropic (see chapter 3) and is based on distance instead of time. Therefore, this section includes results from the two algorithms that are based on time.

Figures 5.3 and 5.4 show 4-hour isochrones. An isochrone map displays the time it takes to reach a particular location in the landscape from the departure point (ESRI 2018). The results of the isochrone models show that the different algorithms return different travel times to reach a certain location in the landscape (*Table 5.1*). The resulting isochrones map plays an essential role because it shows that the travel times are affected by the topography of the area such as flat and hilly terrains, as the travel times are smaller in flat terrain and increase in hilly terrain (Becker *et al.* 2017).

Small area sizes characterise the isochrones of the TTHF algorithm. The isochrones are affected by the topography as the shape of the isochrones are more irregular as the topography changes; however, the influence of topography on the results is very low (*Fig. 5.3*). The TTHF algorithm predicts a travel time of 4-8 hours to the closest silcrete outcrops in Kareedouw at a distance of 28.3 km. The silcretes in the Grahamstown, Oudtshoorn and Uniondale areas are located in travelling time areas from KRM greater than 24 hours.

The isochrones of the WTHF algorithm vary considerably from the isochrones of TTHF. The isochrones of the WTHF algorithm are affected by the topography of the area more than the TTHF algorithm (*Fig. 5.4*). For instance, on the 8-hour isochrone, the shape of the isochrone is affected by the mountain as it increases towards the north-west, covering the mountain. The same pattern can be observed with all the isochrones of other travel times. With regards to the travel times with the WTHF algorithm, the travel time calculated to the Grahamstown is similar to that of TTHF (*Table 5.1*). The nearest silcrete outcrops in terms of time for the

WTHF algorithm are located in the Langkloof valley and Kareedouw area with a travel time of 8-12 hours.

Table 5.1: A summary of the travel times in hours of silcrete raw material acquisition at KRM (Nearest indicates the nearest silcrete outcrop from KRM and further indicates the furthest silcrete outcrop in the area from KRM, the distances obtained from the DBC algorithm cost distance).

Towns/Valley	**Distance (km)**	**TTHF travel times (h)**	**WTHF travel times (h)**
Kareedouw	28.3	4-8	8-12
Langkloof Valley	86.3	8-12 (nearest) 16-20 (further)	8-12 (nearest) 16-20 (further)
Uitenhage	136.5	20-24 (nearest) >24 (further)	12-16 (nearest) 16-20 (further)
Uniondale	176.0	> 24	12-16 (nearest) 20-24 (further)
Oudtshoorn	276.8	> 24	12-16 (nearest) >24 (further)
Grahamstown	291.7	>24	>24

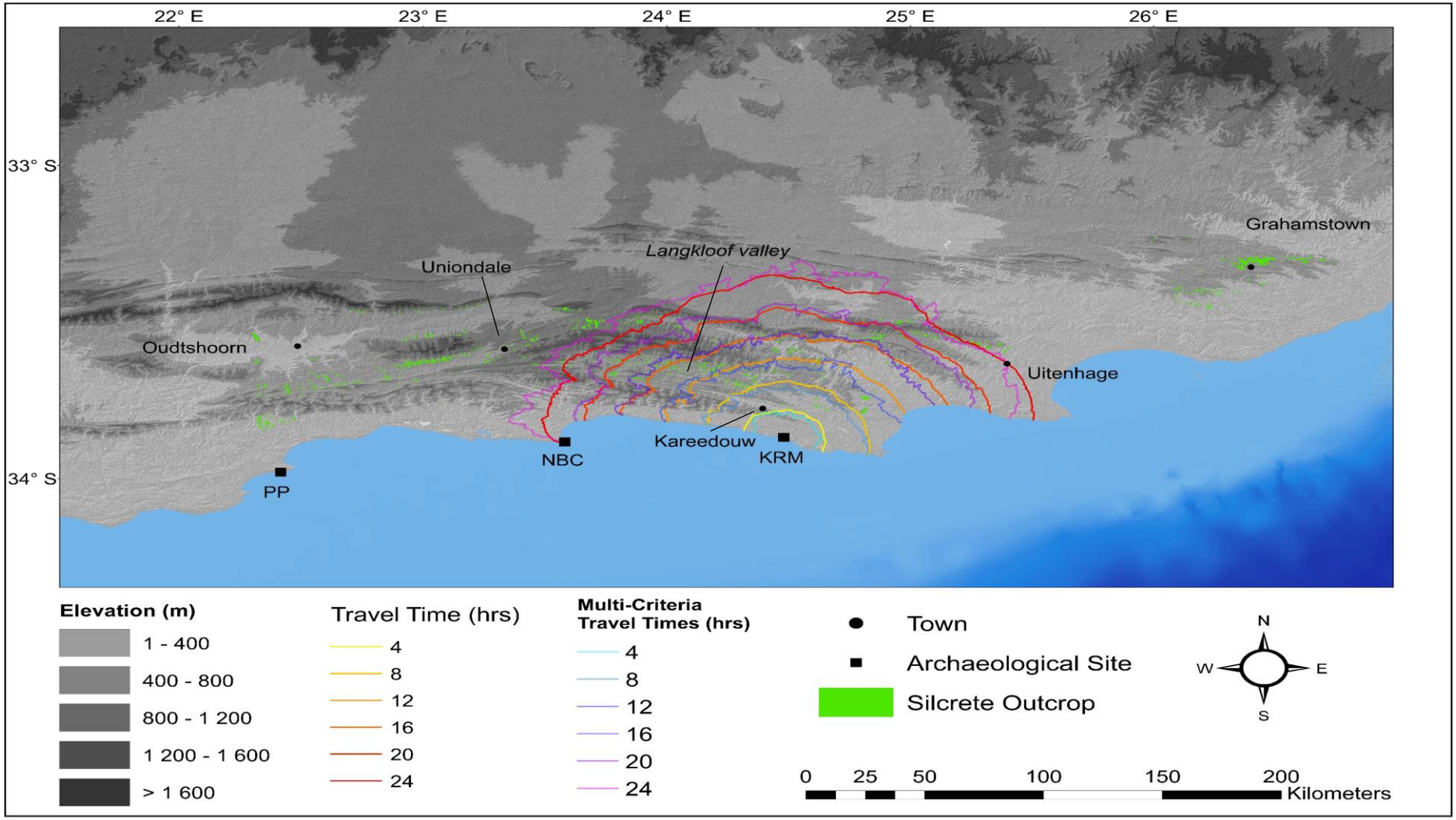

Figure 5.3: TTHF travel times of 4-hour intervals.

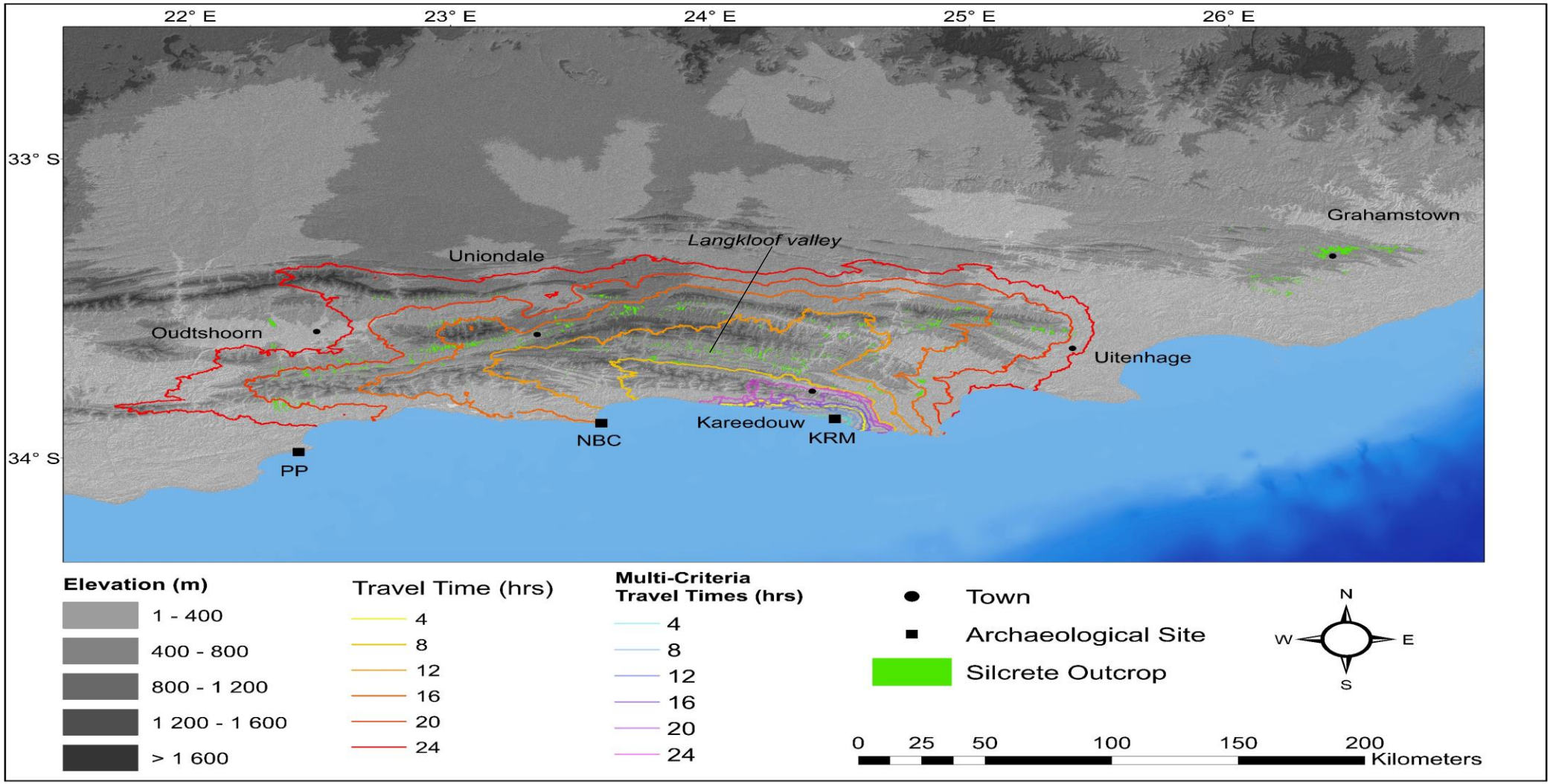

Figure 5.4: WTHF travel times of 4-hour intervals.

5.2 LCPs of incorporated environmental factors (Multi-criteria)

LCP and travel time models incorporating environmental factors were created in order to examine the effects these factors have on the paths modelled for HP groups movement and the time needed for reaching the destinations. From the map of figure 5.5, it is evident that the paths of DBC slope and DBC multi-criteria follow the same directions to reach the silcrete outcrop. However, the paths do not entirely overlap each other even though the same directions are taken. On the LCPs going to the Grahamstown area, the slope paths take a south-east direction whereas the multi-criteria paths take an east and northeast direction. The high overlap mainly occurs before the paths reach the destination which can be observed with the LCPs of the combination of red (multi-criteria) and yellow (slope) turn into an orange colour. The DBC multi-criteria LCPs climbs the through rivers in the landscape (*Fig. 5. 8*). This is interesting as the rivers were given a high cost, excluding the 3rd order streams as they were given a NoData value. Also, the LCPs pass through forests whereas it would be expected that forests were avoided as they have higher costs than other biome areas. This is similar to the TTHF multi-criteria algorithm LCPs as they also pass through forests (*Fig 5.9*).

The LCPs of the TTHF multi-criteria implementation of the algorithm travelled different directions to the destinations (*Fig. 5.6*). For instance, in the Grahamstown area the TTHF slope LCPs travel in a south-east direction whereas the TTHF multi-criteria LCPs travel in a north direction. The overlap between the LCPs is very low. However, both the TTHF slope and TTHF multi-criteria travel through valleys and low elevated areas. Furthermore, the TTHF multi-criteria algorithm follows the exact pathways of the rivers and overlapping the hydrology in the area from the origin point to the destination. This is not realistic as people cannot travel through rivers from their departure to their destination by foot.

The WTHF multi-criteria and WTHF slope have a high overlap seen with the orange colour of the LCPs (*Fig. 5.7*). Both travel in the same direction and through high elevated areas. The exception is with the LCP from KRM to the outcrops north of NBC, where the WTHF slope travels in flat terrain and the multi-criteria travels in high elevated areas. The WTHF multi-criteria algorithm LCPs avoided the hydrology in the landscape. The rivers were crossed only when it was unavoidable. In contrast to the

DBC multi-criteria and TTHF multi-criteria algorithm LCPs, the WTHF multi-criteria algorithms avoid the forest area.

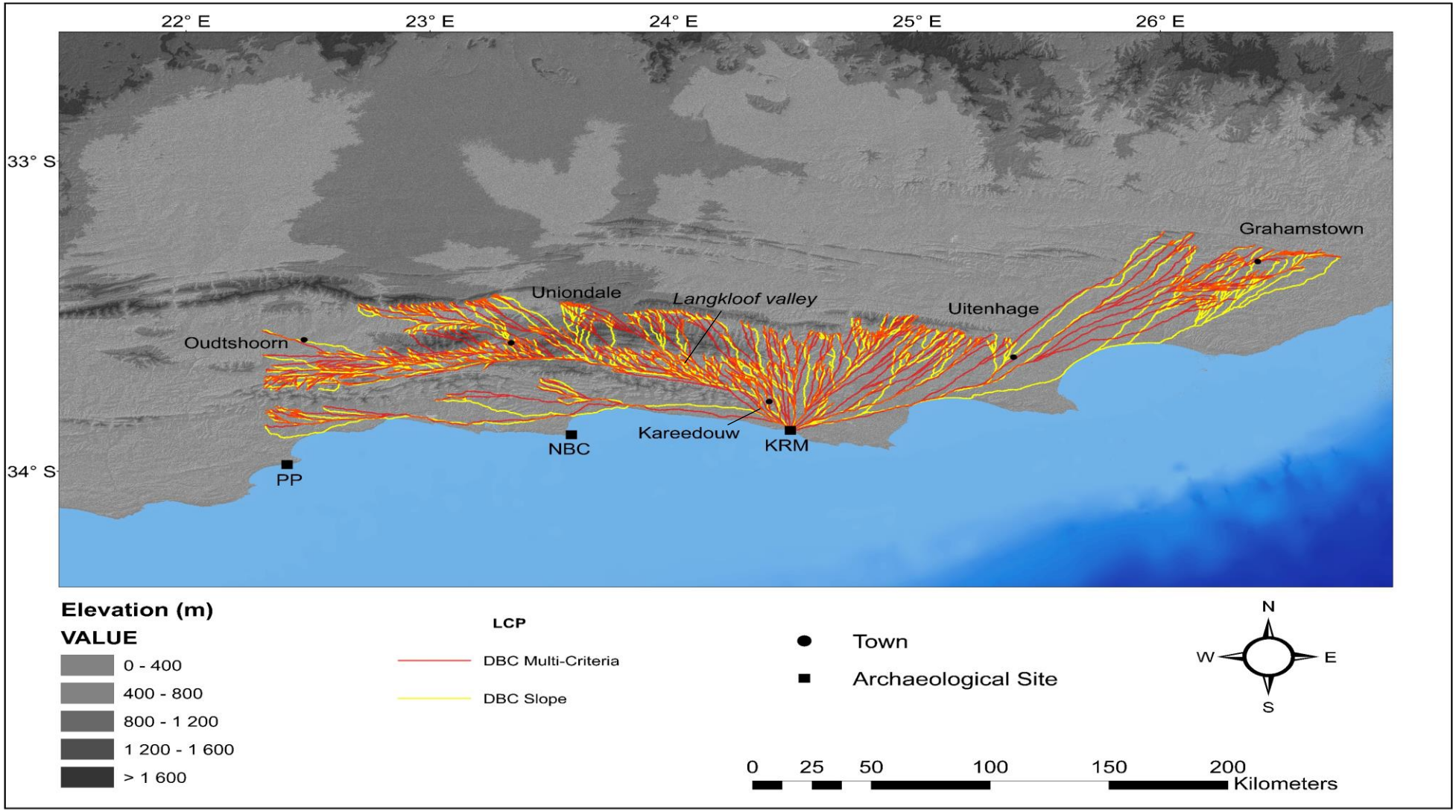

Figure 5.5: Overlain LCPs of DBC multi-criteria and DBC slope.

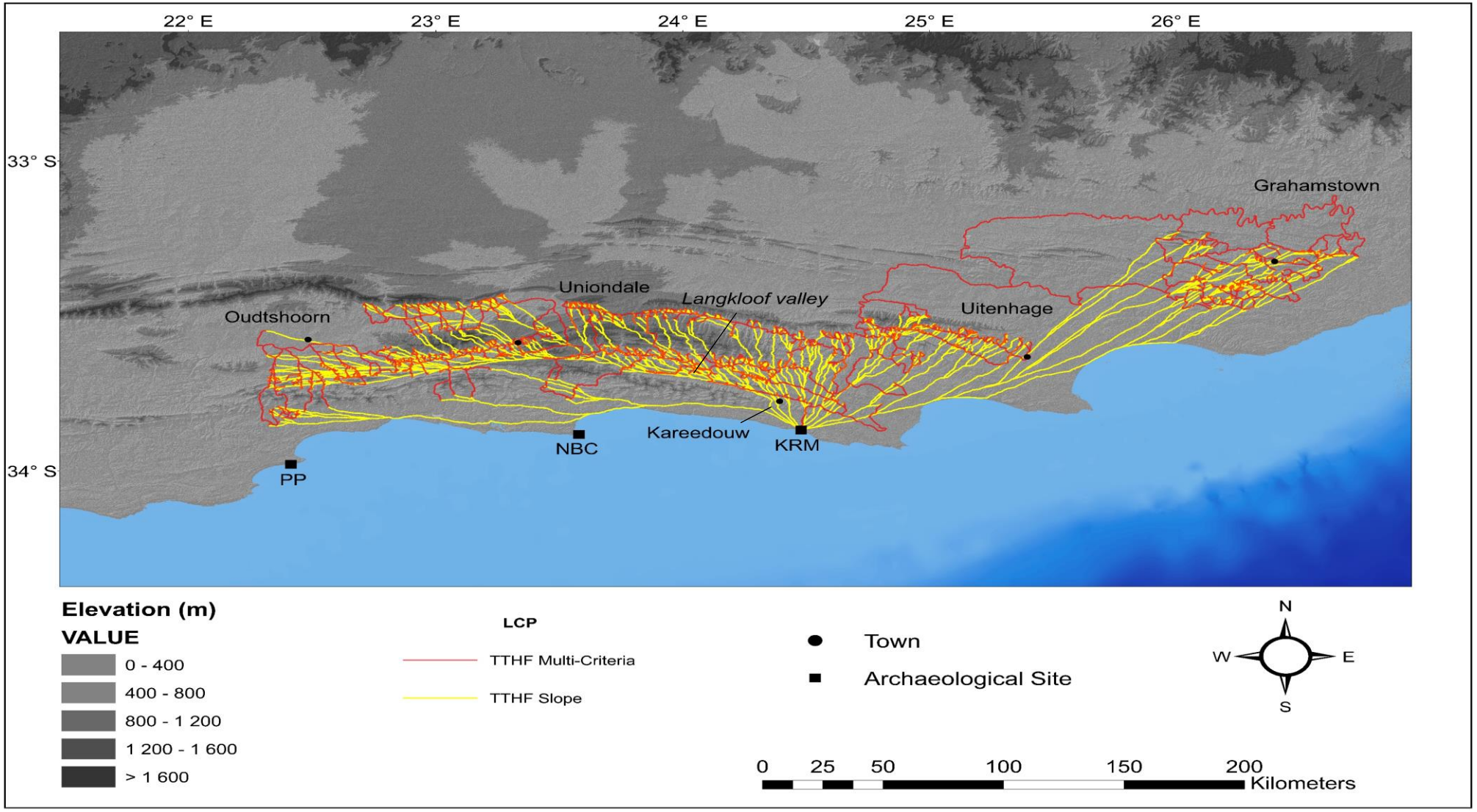

Figure 5.6: Overlain LCPs of TTHF multi-criteria and TTHF slope.

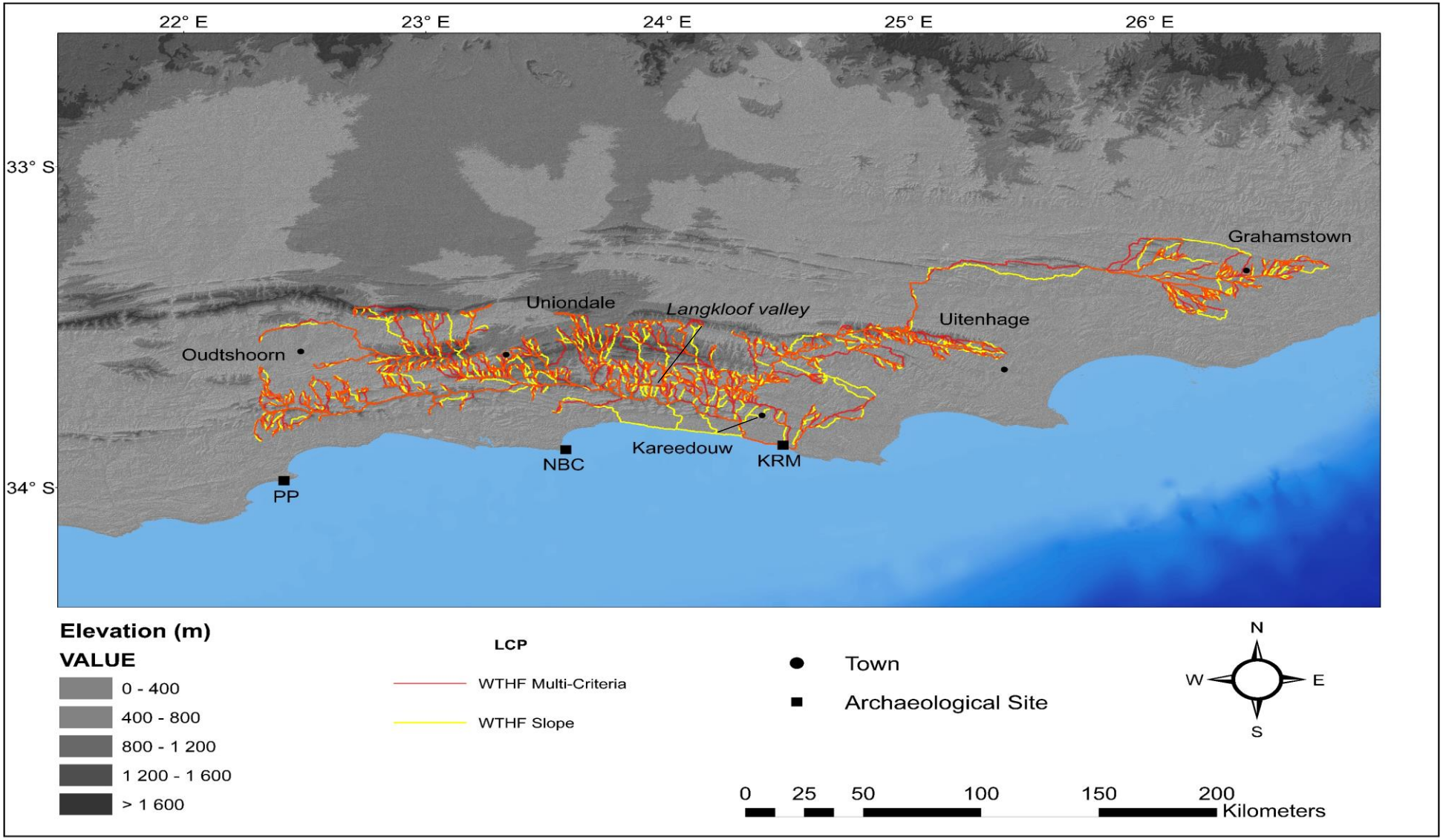

Figure 5.7 Overlain LCPs of WTHF criteria and WTHF slope.

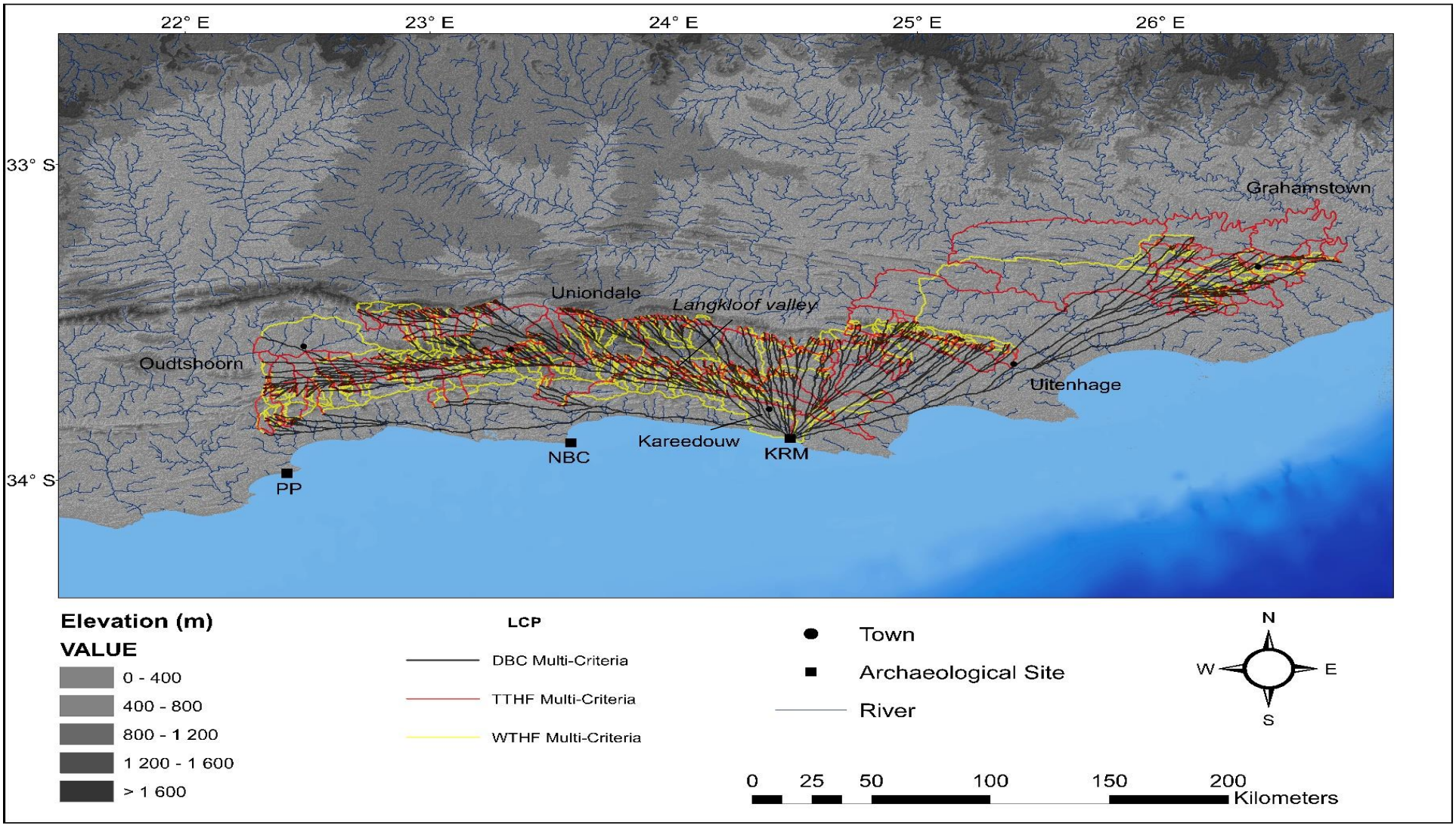

Figure 5.8: Map depicting the behaviour of multi-criteria LCPs on rivers.

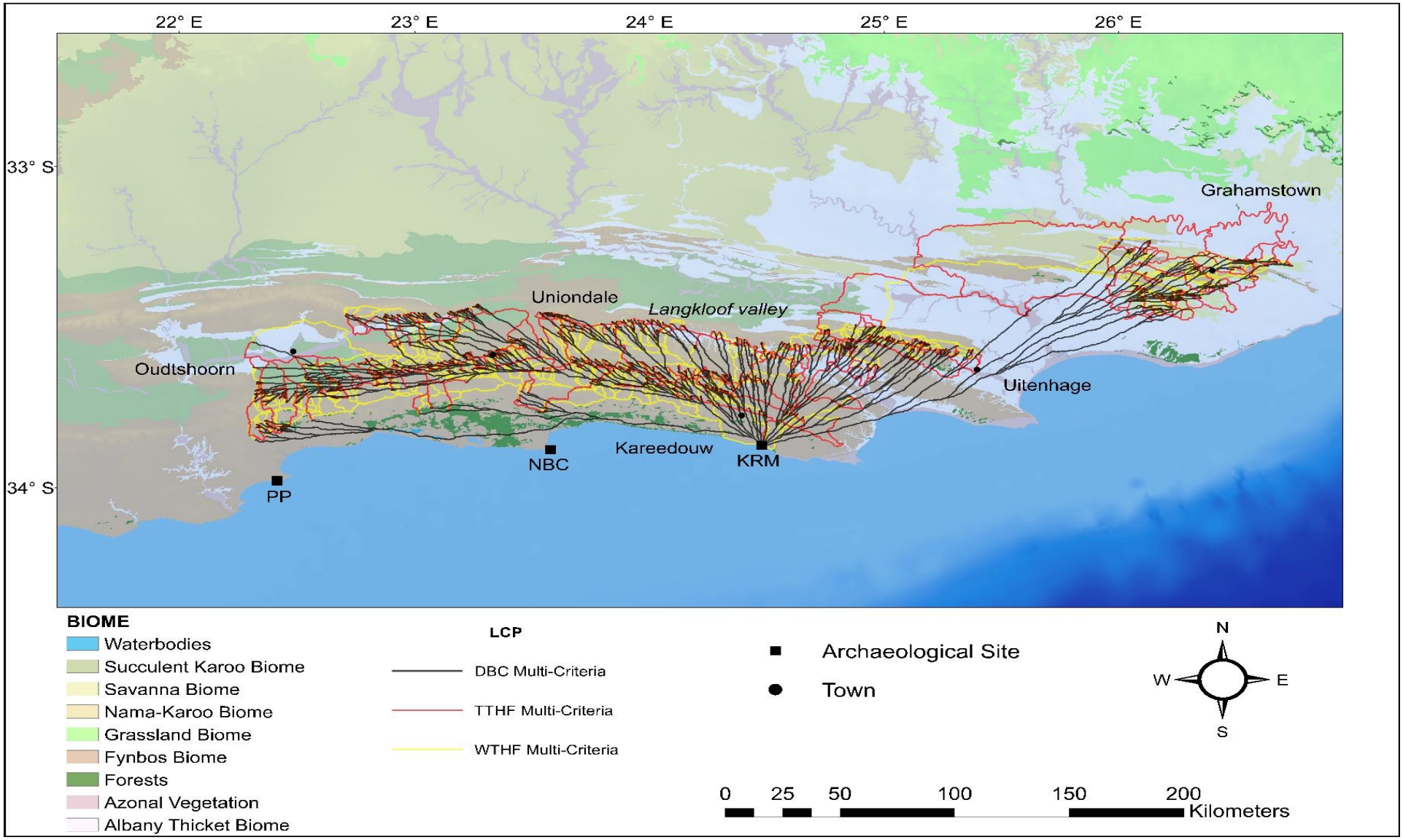

Figure 5.9: Map depicting the behaviour of multi-criteria LCPs on vegetation/biome.

5.2.1 Travel times of the multi-criteria and slope models

When environmental factors are taken into consideration, the travel times of the TTHF algorithm are the same and increase and decrease on different parts of the landscape. The 16-hour isochrones demonstrate that the area that can be reached in 16 hours with slope only will take longer when environmental factors are considered (*Fig. 5.10*), however, in the same isochrone some areas are reached at the same amount of time and some areas can be reached faster than when slope only is used. This pattern can be observed with other isochrones in the model.

The WTHF algorithm considerably increases the travel times when environmental factors are considered. For instance, the 4-hour slope isochrone overlaps with the 16-hour multi-criteria isochrone; with the 8-hour slope isochrone overlapping with the of the 24-hour multi-criteria isochrone. Therefore, the model shows that it would take 2 times longer when environmental factors are considered to reach a destination (*Fig. 5.11*).

The multi-criteria models are influenced by the speed coefficients discussed in chapter 4. Therefore, the amount of travel time to reach a certain point is influenced by both the topography and the speed coefficient determined for biome (*Table 4.2*) and hydrology (*Table 4.3*) in the landscape (Becker *et al.* 2017). Furthermore, the shape of the isochrones shows the influence of the environmental factors in the landscape, they represent the effect of the biomes and hydrology in the landscape. For example, in an area where there is grassland the travel time will be less than in an area where there is a forest.

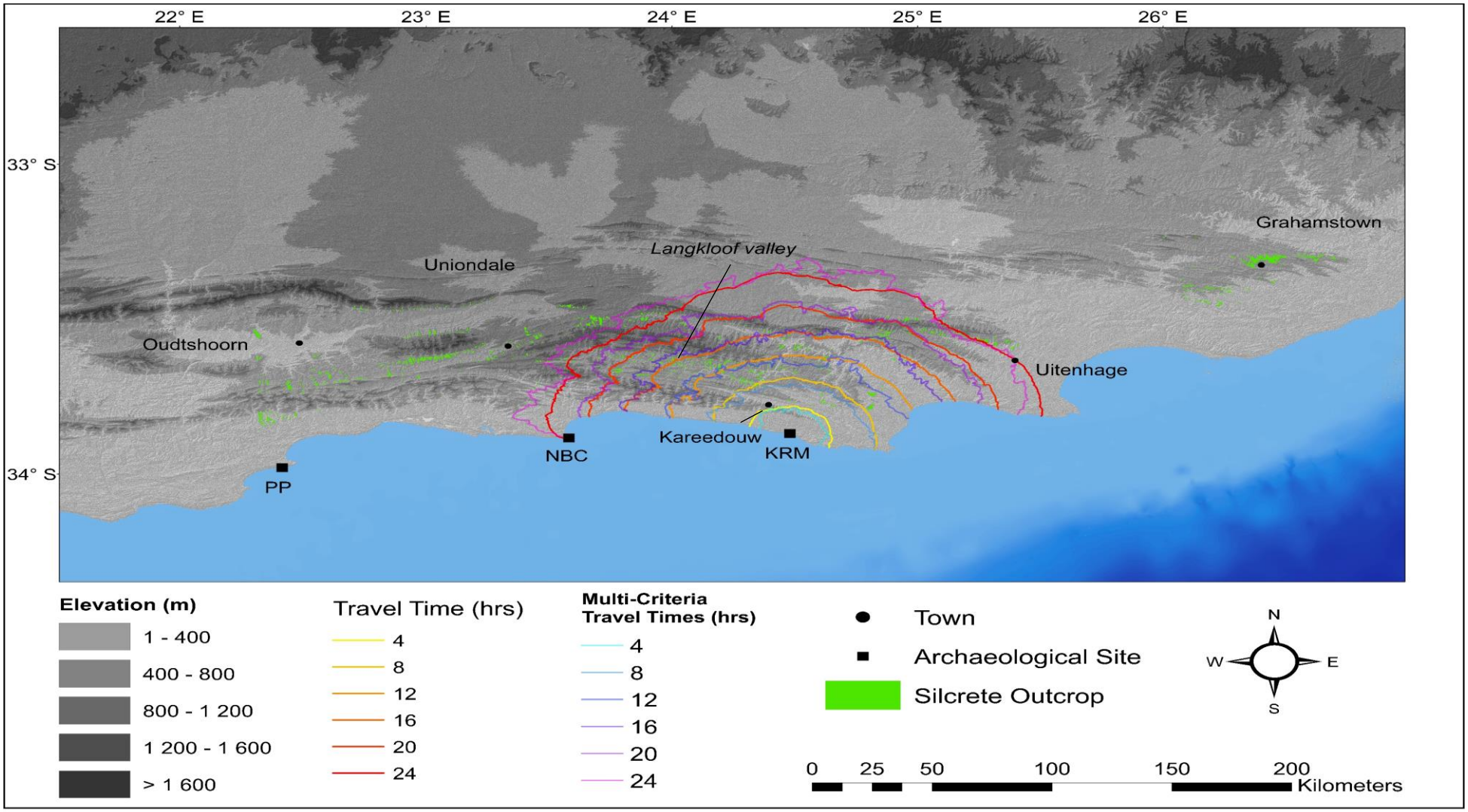

Figure 5.10:Overlain travel times of the TTHF multi-criteria and slope model.

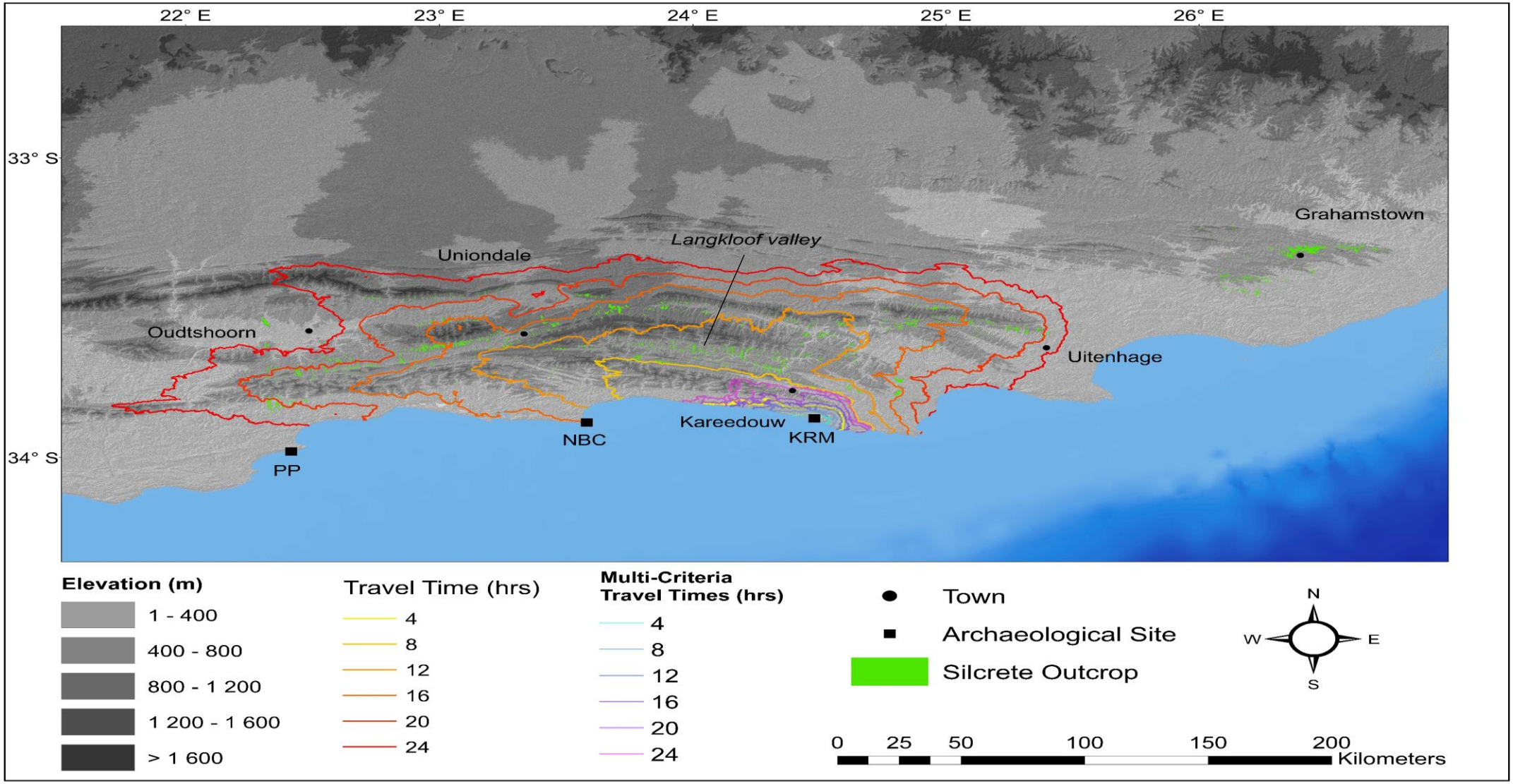

Figure 5.11: Overlain travel times of the WTHF multi-criteria and slope model.

5.3 Validation

As stated above, three algorithms were run in a GIS to model movement patterns in the KRM landscape. The models were further validated. The validation test was performed in two ways, firstly by introducing an error on the models by extracting 20 silcrete outcrops from the original silcrete outcrops and adjusting the origin point of KRM by moving it 250 m north and easterly from the original location and analyzing the resultant LCPs. Secondly, the travel times were verified by using a combination of comparing the travel times of the models produced in this study and Google maps walking travel times. In general, Google maps calculates travel times using different factors and data sources (Amirian *et al.* 2016). In the case of human walking, Google maps estimates the travel time by calculating the average walking speed of an individual, and the distance of the route from departure to the destination (Amirian *et al.* 2016).

In terms of the LCPs produced by introducing an error, all the algorithms behaved the same regardless of the error introduced (*Fig 5.12*). The DBC and TTHF algorithms travelled the route of low elevations and travelled through valleys to reach the destination, similarly to the original models. For instance, on the paths travelling through Langkloof valley to the respective silcrete outcrops, the DBC and TTHF algorithms behaved similarly. Furthermore, the LCPs of DBC and TTHF algorithms travelled the same directions to reach the silcrete outcrops. The LCP's created with the WTHF algorithm also travelled similar routes than the original models when an error was introduced. They also indicated the route of high elevated areas to reach the destinations. For example, as shown for the path to Grahamstown, it followed an elevated area instead of the flat terrain.

In terms of the travel times, only the algorithms that returned cost in terms of time were compared to Google maps travel times. The analysis of Google maps travel times to the different silcrete outcrop areas showed that the TTHF algorithm produced more realistic travel times than the WTHF and BTHF algorithms (*Table 5.2*).

The TTHF algorithms shows that silcrete outcrops in Kareedouw can be reached in 4-8 hours. This is comparable to estimated travel times of Google Maps which shows that Kareedouw can be reached in 6 hours when walking. This is realistic as Kareedouw is located 28.3 km away from KRM and the average walking speed of a human is 5. 047 km per hour (Tobler 1993; Becker *et al.* 2017). Therefore, Kareedouw can be reached in under 8 hours. The WTHF algorithm provides the result of 8-12 hours which is slightly higher than the TTHF algorithm. This is possible if the walking speed is less than 5.047 km per hour; however, this study assumes the 5.047 km per hour average.

From Google Maps, Uitenhage can be reached in approximately 25 hours, and Langkloof valley can be reached in 23 hours. The travel times obtained from the TTHF algorithm indicate a more accurate travel time, at 20-24 and 25 hours away, which are comparable to Google Maps travel time. For the Langkloof valley silcrete outcrops, the TTHF algorithm indicates that it can be reached in 8-12 and 16-20 hours. This is less than the Google Maps travel time but is more comparable as the furthest outcrops are 20 hours away with the TTHF algorithm, whereas with the WTHF algorithm the silcrete outcrops in this area are only are located 8-12 hours away.

Furthermore, the TTHF algorithm travel times to reach Uniondale silcrete outcrops are more realistic as it is greater than 24 hours and therefore it is closer to 31 hours of Google Maps than the travel times of 16-20 hours obtained from the WTHF algorithm. In general, the TTFH algorithm provided travel times that are more comparable with Google maps travel times than the WTHF algorithm.

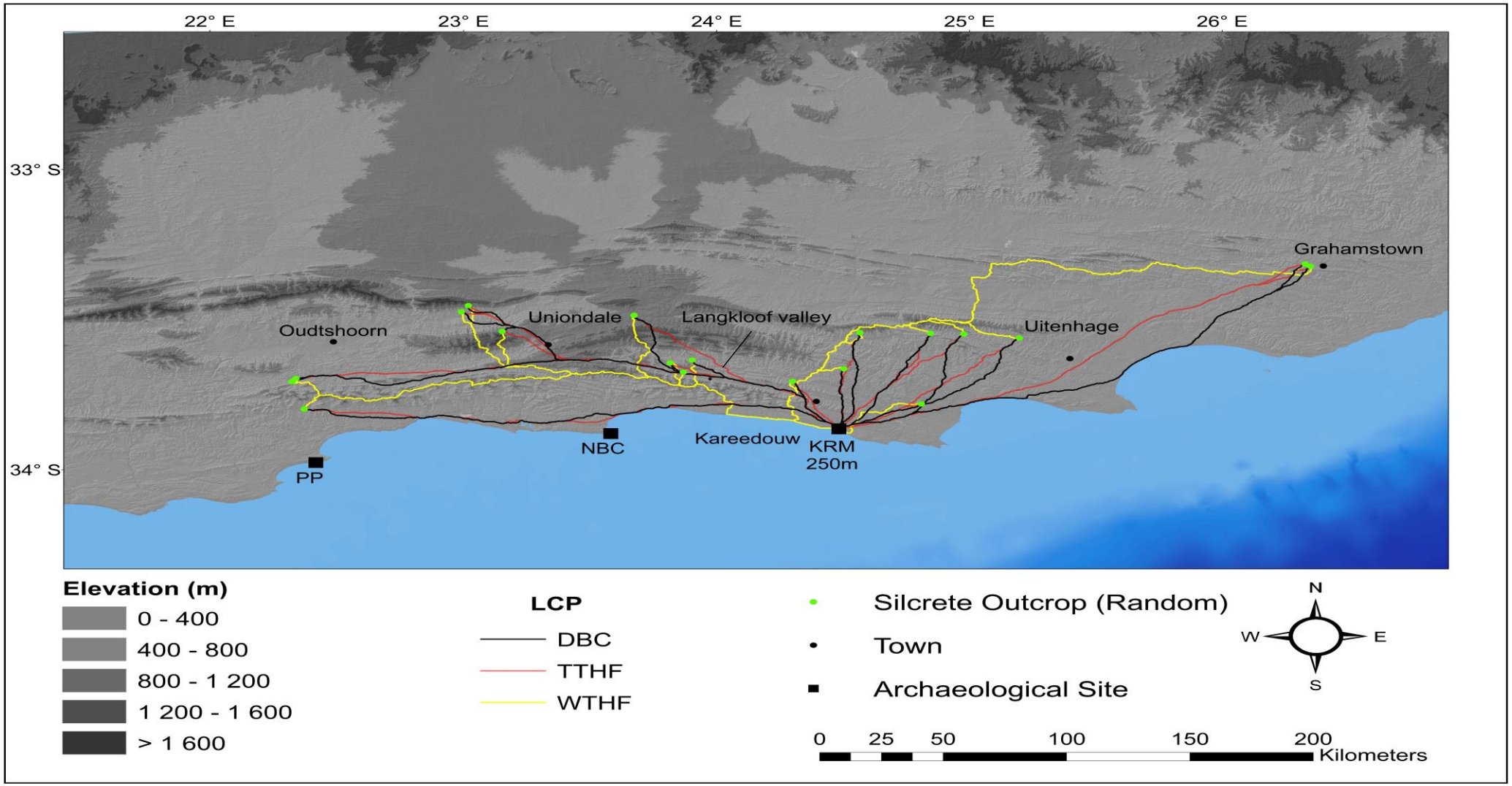

Figure 5.12: Map depicting results of the validated LCPs.

Table 5.2: A comparison of Google maps travel times and travel times obtained from models produced in this study using different algorithms.

Towns/Valley	**Google Map travel times (h)**	**TTHF travel times (h)**	**WTHF travel times (h)**
Kareedouw	6	4-8	12-16
Langkloof Valley	23	8-12 (nearest) 16-20 (further)	8-12
Uitenhage	25	20-24 (nearest) 25 (further)	16-20
Uniondale	31	30	16-20
Oudtshoorn	50	49	16-20 (nearest) 20-24 (further)
Grahamstown	53	50	48

5.4 LCPs and possible frequency of interaction between KRM, PP and NBC

After the validation, the TTHF algorithm was chosen to run the LCPs for NBC and PP and further run a frequency calculation. The WTHF overexaggerating of the travel times made it less reliable therefore, a more conservative algorithm was chosen. The LCPs of KRM and PP mainly overlap with each other in Grahamstown, Uitenhage and Langkloof valley. With the LCPs that travel to the Grahamstown area, the KRM LCPs come from a south direction whereas the PP LCPs come mostly come from a north direction, but they overlap before reaching the destination (*Fig. 5.13*). Therefore, there is a high chance of interaction

between groups traveling on these paths to the silcrete outcrops located in the south of Grahamstown as there is no possibility of interaction in the outcrops in the north. This is similar to the other areas where the LCPs come from different directions with a slight overlapping. The frequency model (*Fig. 5.14*) demonstrates that there is a high frequency of possible interaction between people travelling on overlapping paths between the KRM and PP in the Uitenhage and Grahamstown areas. There is less opportunity for possible interaction between groups the LCPs travelling to Kareedouw, Langkloof valley and Uniondale.

KRM and NBC LCPs travel through almost similar routes to the silcrete outcrops. On the paths to the silcrete outcrops in Grahamstown area, the routes overlap each other except for one path that diverges for 200 meters and then aligns with the paths again until it reaches the outcrop (*Fig. 5.15*). There is a high possibility for interaction in the Uitenhage and Grahamstown areas (*Fig. 5.16).* The possibility of interaction is low in the Uniondale and Oudtshoorn areas, with some patches where interaction is possible in the Langkloof valley and Karedouw area.

The LCPs of PP and NBC travel in different directions. The paths between the two sites overlap in the Uitenhage, Langkloof valley and Grahamstown areas (*Fig. 5.17*). The possible interaction of groups traveling between PP and NBC is high towards the outcrops to Langkloof valley, Uitenhage and Grahamstown (*Fig. 5. 18).* Overall, there is a higher possibility of interaction between groups traveling between KRM and NBC than KRM and PP. Furthermore, there is a higher possibility of groups interacting that travel between NBC and PP. There is a higher possibility of interaction between groups traveling between the three sites in the eastern part of the landscape towards Uitenhage and Grahamstown (*Fig. 5.19).*

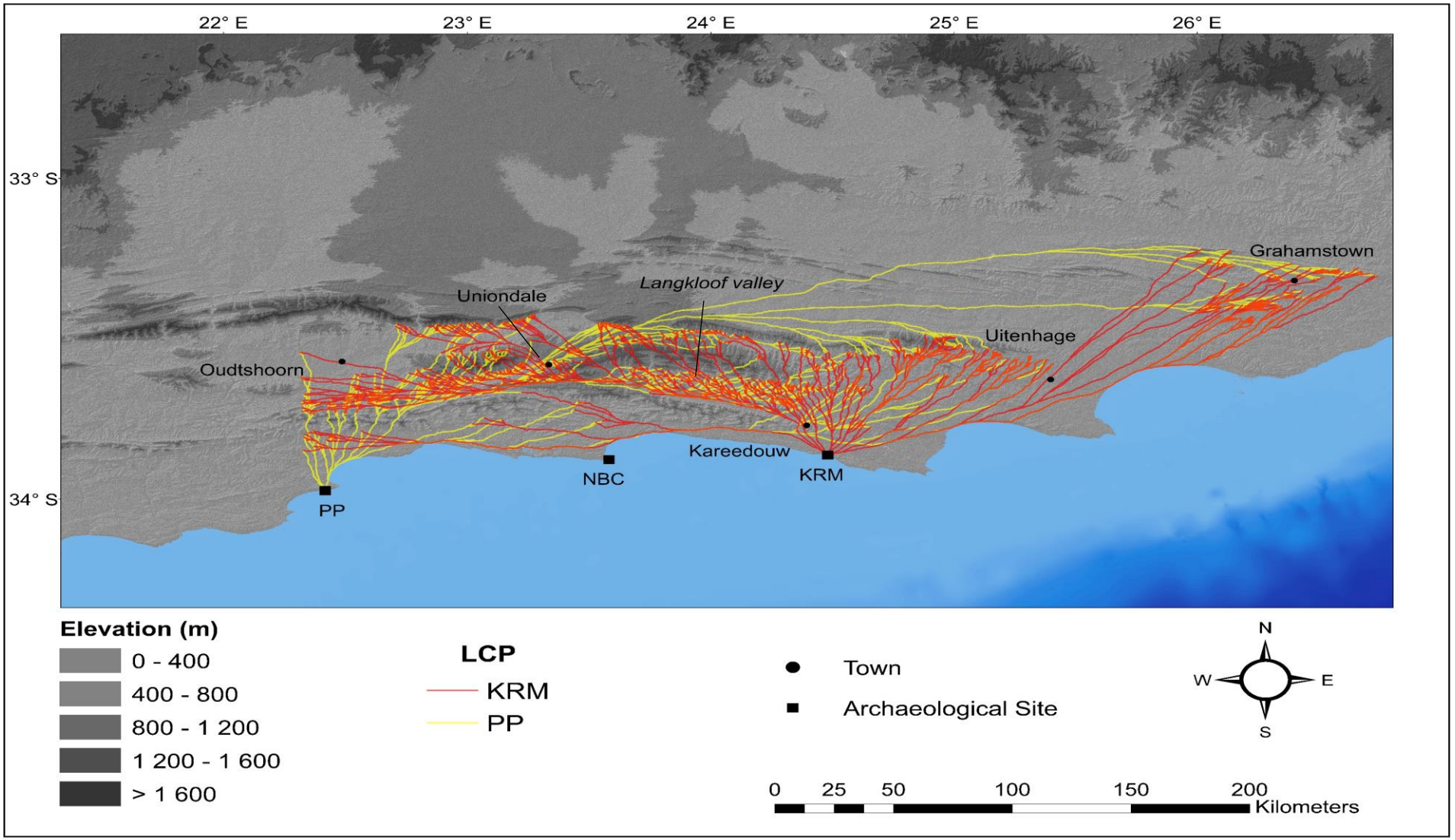

Figure 5.13: Map depicting the overlain LCPs of Klasies River Main and Pinnacle Point.

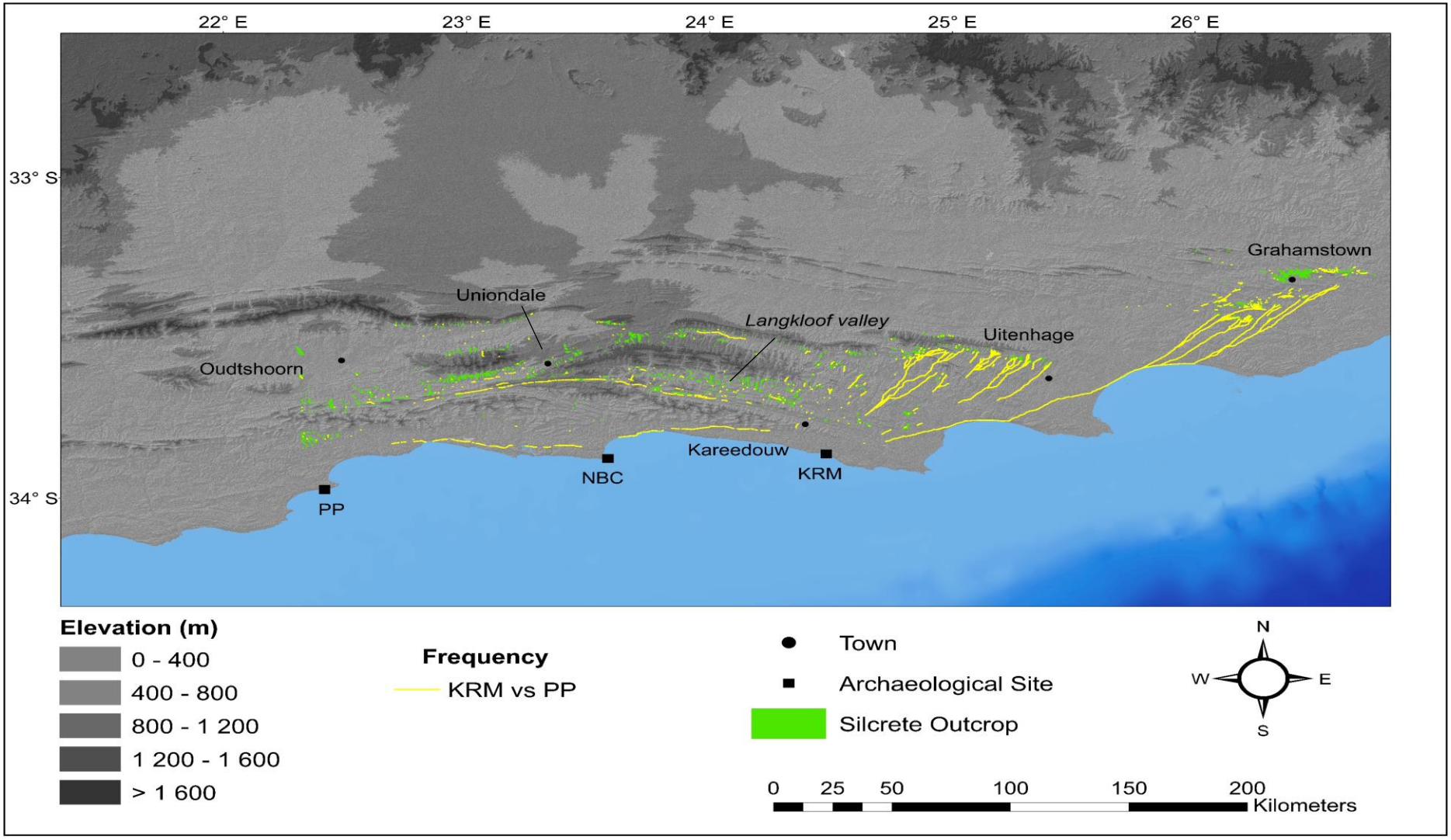

Figure 5.14: Map depicting the possible frequency of interaction on the shared paths (see orange path in Fig 5.13) between Klasies River and Pinnacle Point.

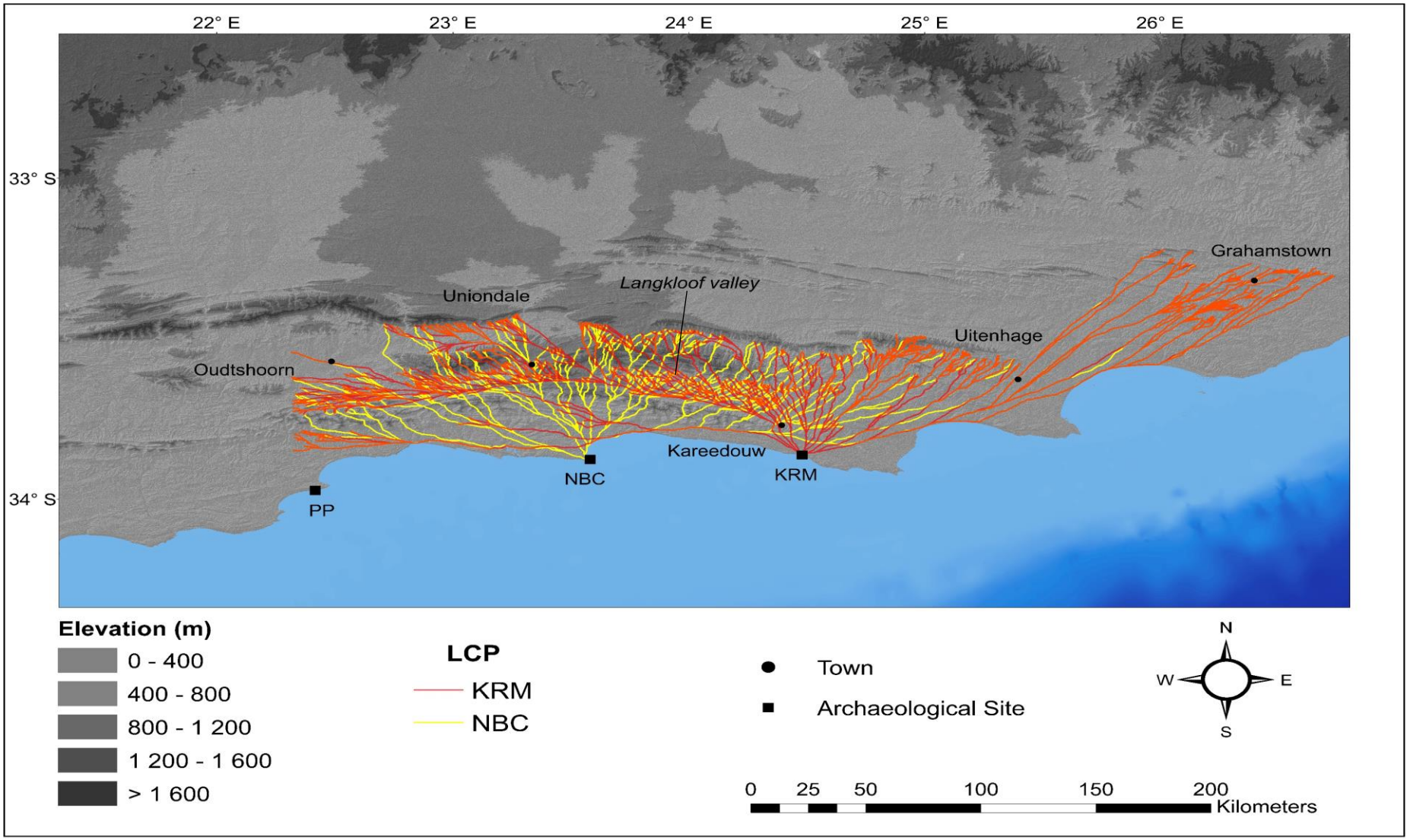

Figure 5.15: Map depicting the overlain LCPs of Klasies River Main and Nelson Bay Cave.

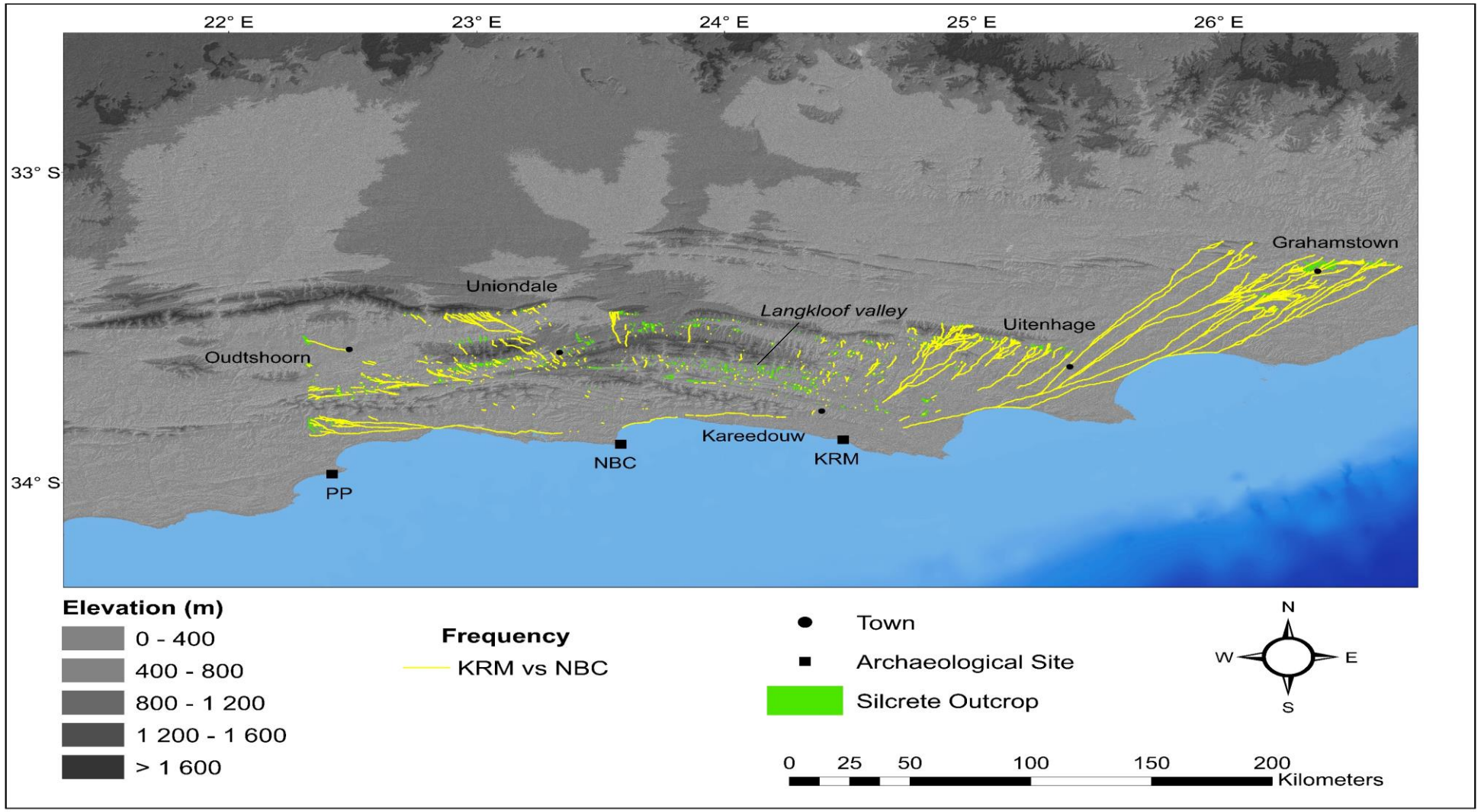

Figure 5.16: Map depicting the frequency of possible interaction between Klasies River and Nelson Bay Cave.

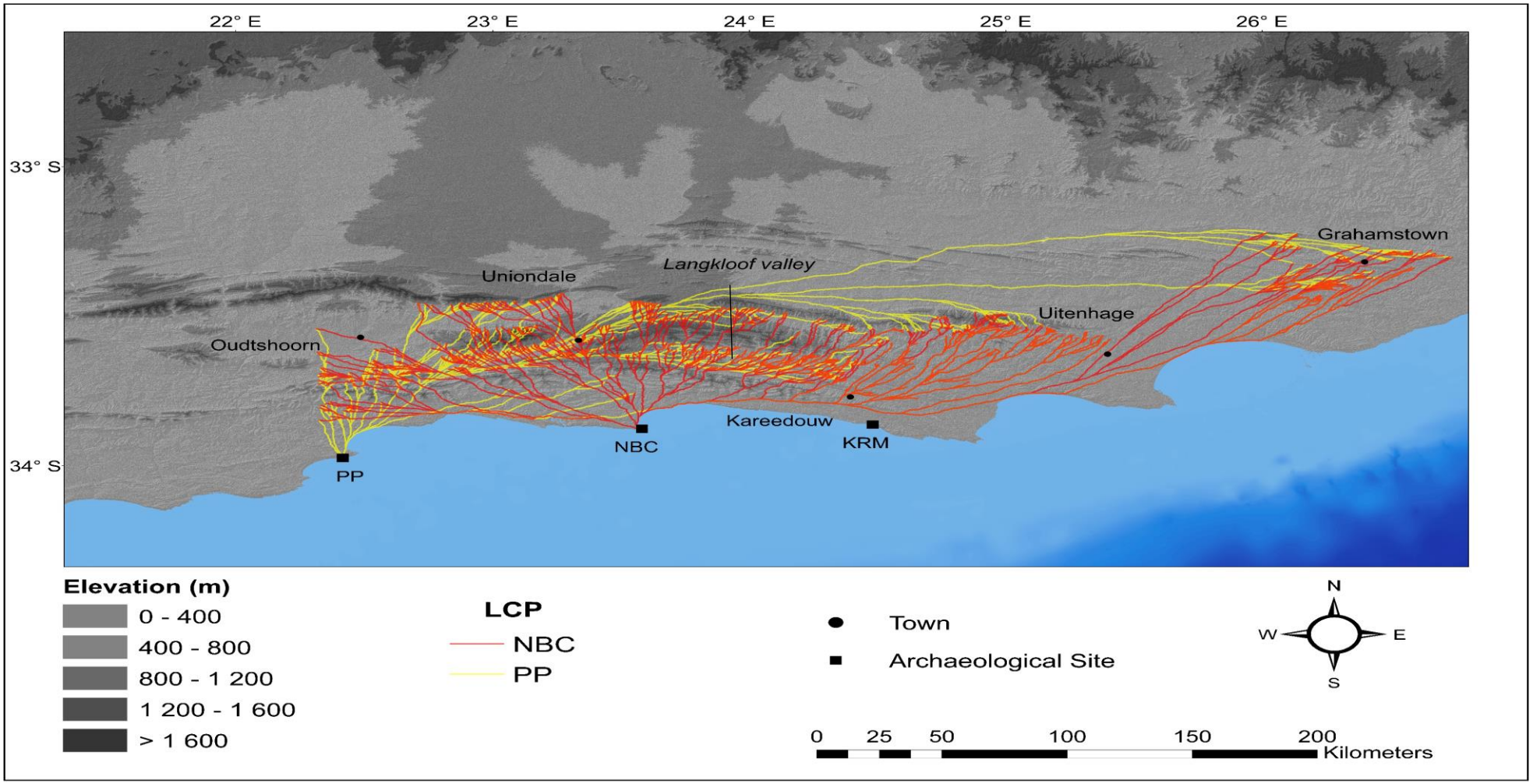

Figure 5.17: Map depicting the overlain LCPs of Nelson Bay Cave and Pinnacle Point.

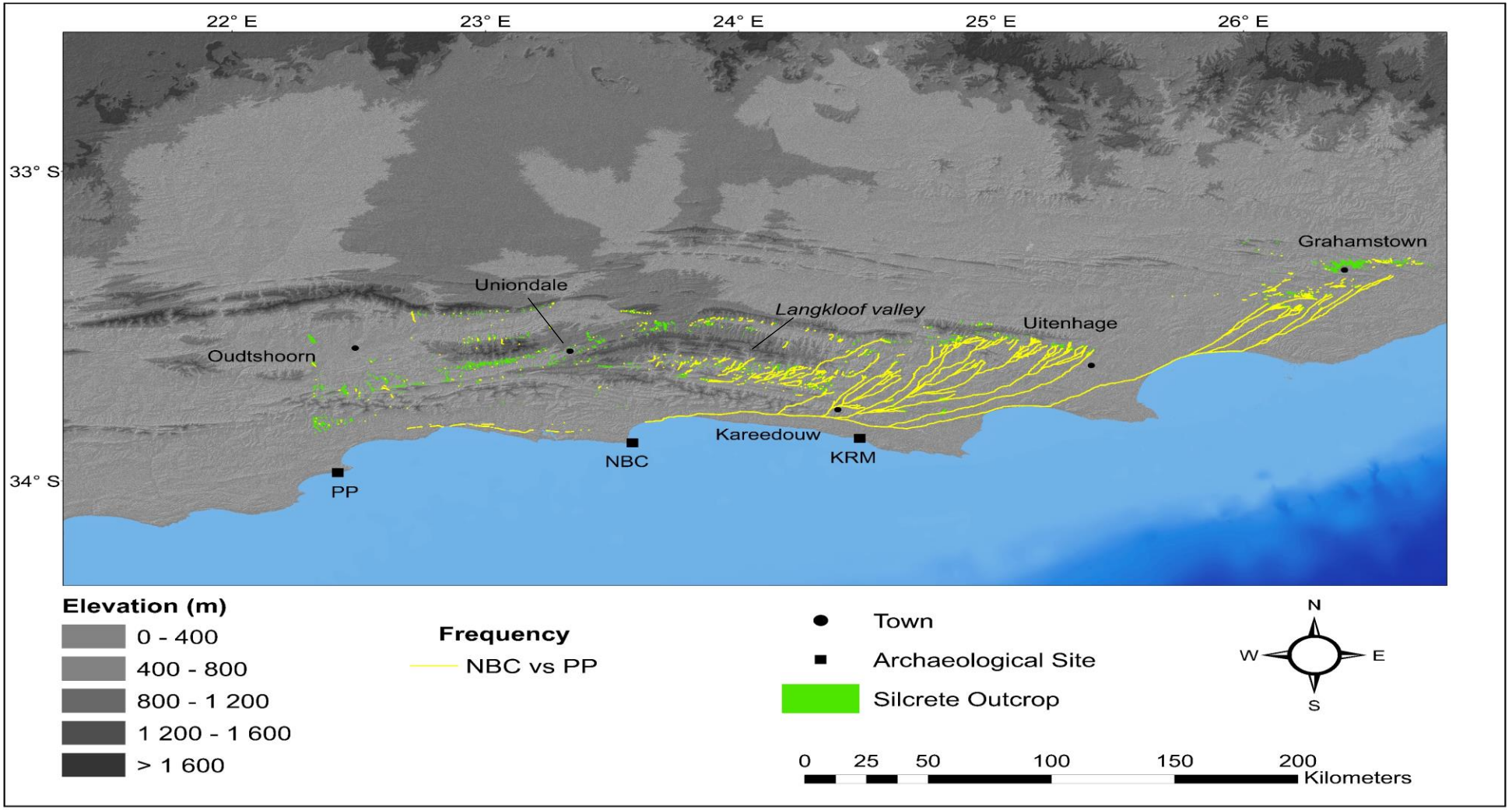

Figure 5.18: Map depicting the frequency of possible interaction between Pinnacle Point and Nelson Bay Cave.

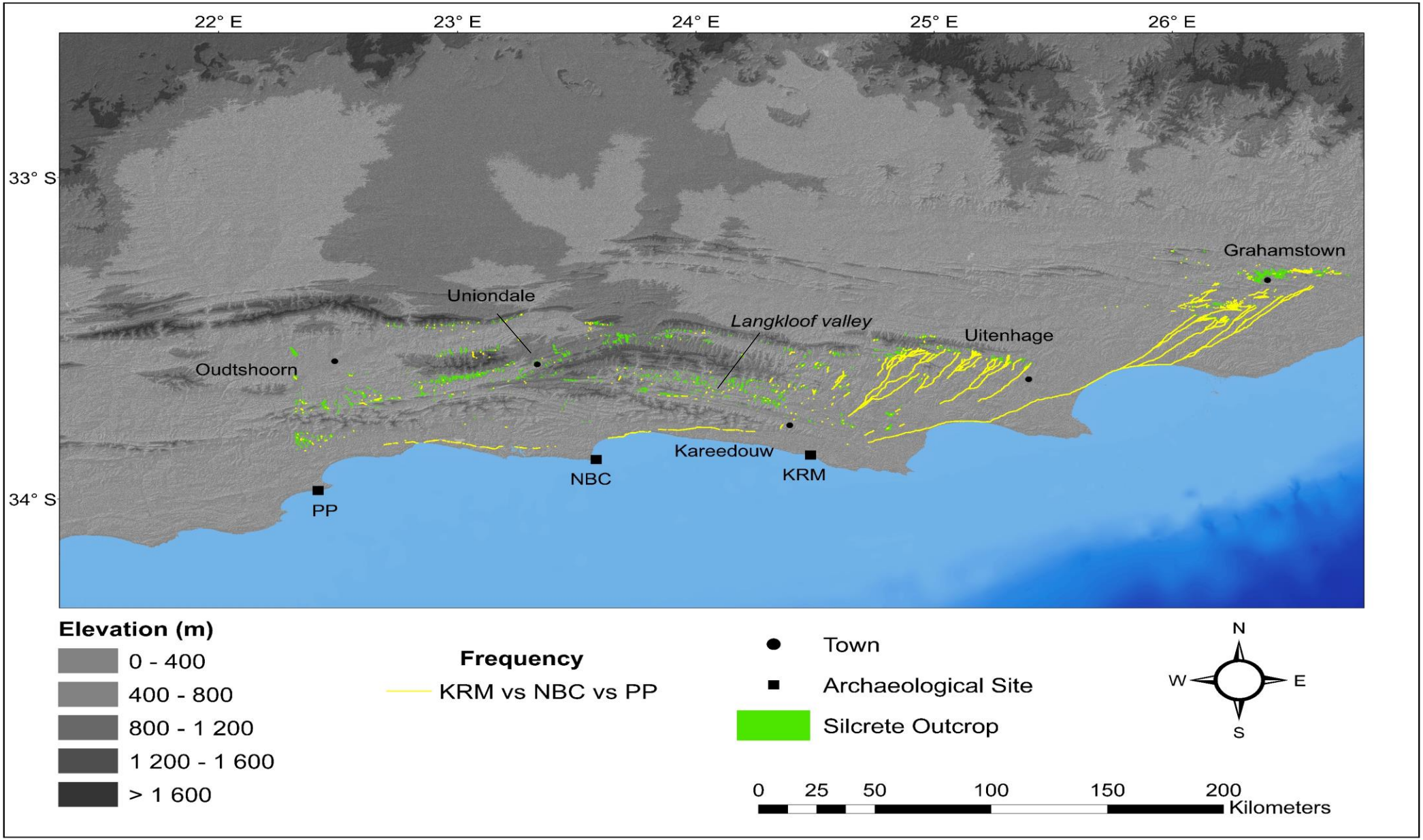

Figure 5.19: Map depicting the frequency of possible interaction between Klasies River, Pinnacle Point and Nelson Bay Cave.

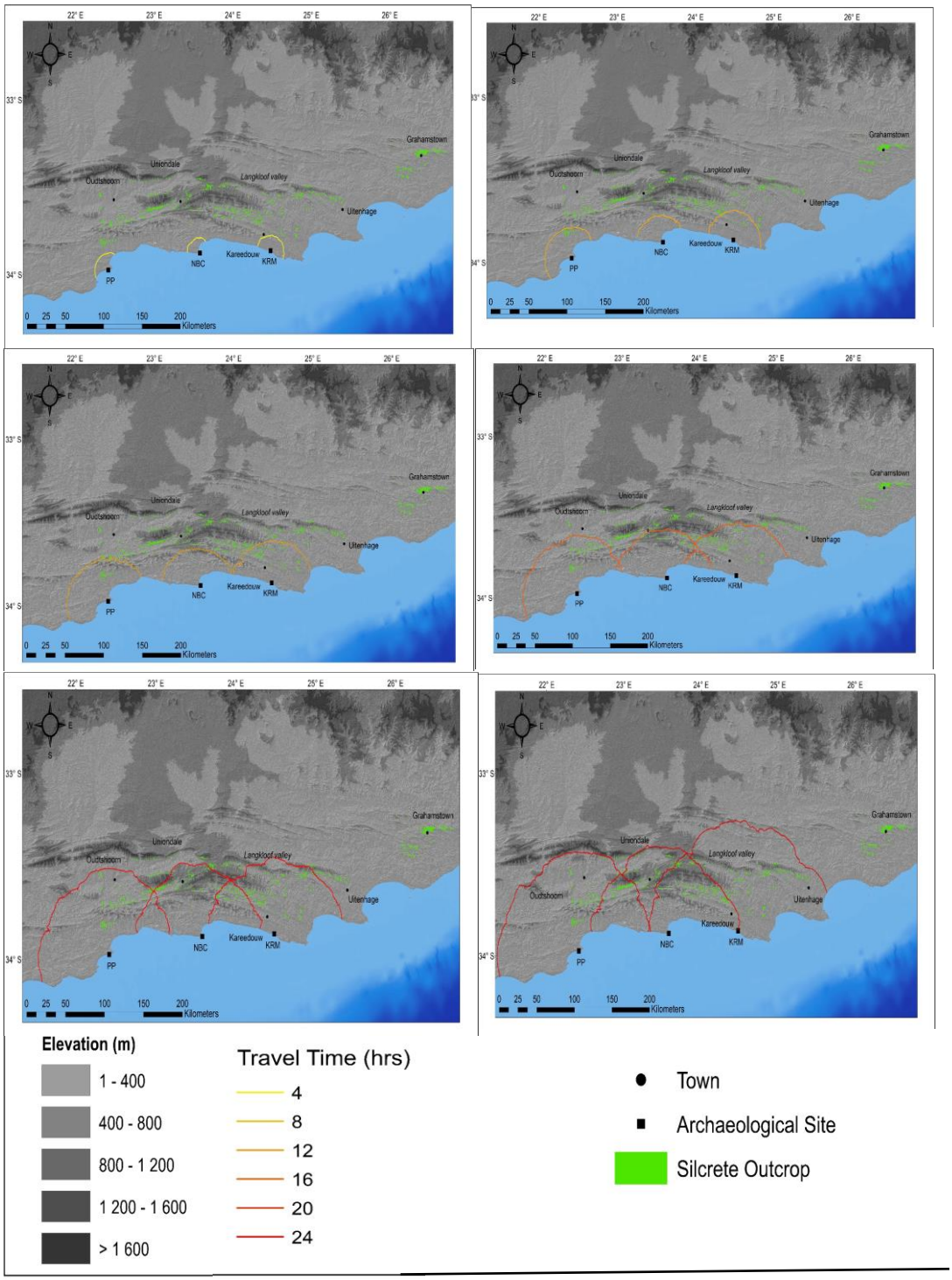

Figure 5.20: Map depicting the travel times of Klasies River Main, Nelson Bay Cave and Pinnacle Point.

From the travel times, it is most likely that HP groups from KRM and NBC would have interacted as overlap of travel times of the two sites occurs at 16, 20- and 24-hour (*Fig. 5.20*). The travel times of NBC and PP overlap at similar travel times as of those of KRM and NBC. On the other hand, no overlap of travel times occurs between KRM and PP. However, at the 24 hours travel time, the travel times of KRM and NBC contact at the margins but do not overlap.

5.5 Calculation of the nearest silcrete outcrop from KRM, NBC and PP

The nearest silcrete outcrops from the three different archaeological sites were calculated to identify which silcrete outcrops are within the 1, 2- and 3-day foraging range spectrum (4, 8- and 12-hours isochrones respectively).

At KRM, there are 17 silcrete outcrops located in the 4-8 hours travel times (*Table 5.3*) and 69 silcrete outcrops in the 8-12 hours travel times (*Table 5.4*). PP contains 20 silcrete outcrops 4-8 hours travel time *(Table 5.5*) and 12 silcrete outcrops at the 8-12 hours travel time (*Table 5.6*). NBC is characterised by the lowest number of silcrete outcrops, with 2 outcrops in the 4-8 travel times (*Table 5.7*) and 4 outcrops 8-12 hours travel time (*Table 5.8*).

Two silcrete outcrops can be reached at the 4 hours at KRM, the outcrops are located at the margin of the 4-hour isochrone (*Fig. 5.21*). Therefore, they can be reached in 1-day foraging range. Both PP and NBC do not have silcrete outcrops that can be reached in a 1-day foraging range.

The nearest silcrete outcrop from KRM is located around the Kareedouw area at silcrete outcrop 52, and it is 28.3 km away, which can be reached in 4 hours (*Fig. 5.21*). The silcrete outcrop is located in a low elevated area. The nearest silcrete outcrop from PP is 34.8 km away, 5 hours away from the site. The silcrete is also located in a low elevated area (*Fig. 5.22*). From NBC, the nearest silcrete outcrop is located in a low elevated area, 20 km away from the site, which can be reached in the travel time of 5 hours (*Fig. 5.23*).

Table 5.3: 4-8-hour travel time ranges from KRM.

Silcrete outcrop	Distance (km)	TTHF algorithm (hrs)
52	28.3	4
53	28.7	4
25	33.3	5
50	31.5	5
51	30.4	5
56	33.8	5
57	34.3	5
58	34.2	5
24	37.6	6
54	39.0	6
55	35.5	6
27	46.5	7
19	50.9	7
19	49.3	7
20	49.1	7
23	50.5	7
26	46.8	7

Table 5.4: 8-12 hours travel time ranges from KRM.

Silcrete outcrop	Distance (km)	TTHF algorithm (hrs)
6	57.2	8
7	56.2	8
9	58.4	8
13	58.9	8
14	57.1	8
15	56.5	8
16	56.4	8
17	53.7	8
21	52.6	8
22	54.8	8
30	57.1	8
59	48.6	8
77	56.4	8
228	52.1	8
2	61.2	9
3	64.3	9
4	62.4	9
5	60.6	9
10	62.1	9
11	61.6	9
12	60.3	9
28	52.3	9

29	55.1	9
40	58.2	9
41	57.3	9
42	60.8	9
43	62.6	9
60	56.8	9
71	62.1	9
72	63.9	9
75	58.3	9
76	58.1	9
85	58.1	9
86	59.1	9
229	58.6	9
246	63.9	9
247	65.6	9
248	64.5	9
249	64.4	9
1	69.5	10
31	67.2	10
34	65.7	10
35	66.7	10
38	69.8	10
39	65.2	10
44	68.2	10
45	70.4	10
47	65.3	10
48	68.3	10
49	71.4	10
61	62.9	10
73	65.0	10
87	63.7	10
89	67.6	10
90	64.7	10
91	67.2	10
92	67.6	10
93	67.7	10
94	69.8	10
244	61.4	10
245	67.1	10
250	68.0	10
251	70.9	10
272	72.0	10
36	72.0	11
62	64.8	11
88	72.0	11
755	68.8	11

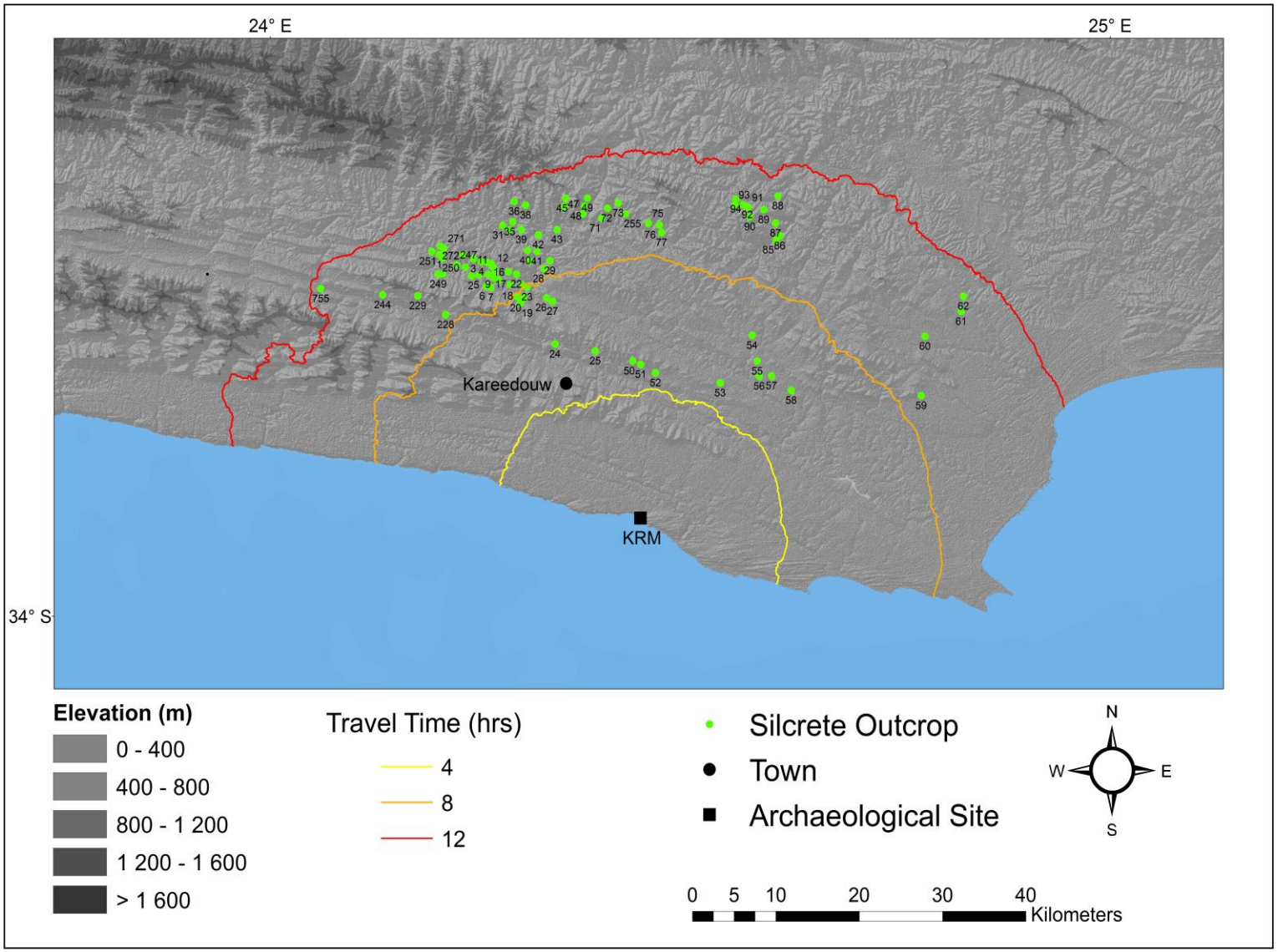

Figure 5.21: Map depicting travel times and correspond silcrete outcrops from Klasies River Main.

Table 5.5: 4-12 hours travel time ranges from PP.

Silcrete outcrop	Distance (km)	TTHF algorithm (hrs)
454	34.8	5
500	35.2	5
363	39.4	6
747	38.4	6
787	40.1	6
922	41.8	6
938	37.8	6
362	40.8	7
385	41.8	7
389	40.9	7
390	46.0	7
570	47.3	7
785	42.0	7
786	42.4	7
921	42.7	7
925	46.4	7
926	47.7	7
569	47.3	8
920	40.5	8

Table 5.6: 8-12 hours travel time ranges from PP.

Silcrete outcrop	Distance (km)	TTHF algorithm (hrs)
750	50.6	8
474	70.8	11
475	69.0	11
476	69.9	11
507	71.3	11
751	69.8	11
752	71.5	11
837	70.2	11
838	70.5	11
840	71.9	11
951	71.3	11
575	71.7	12

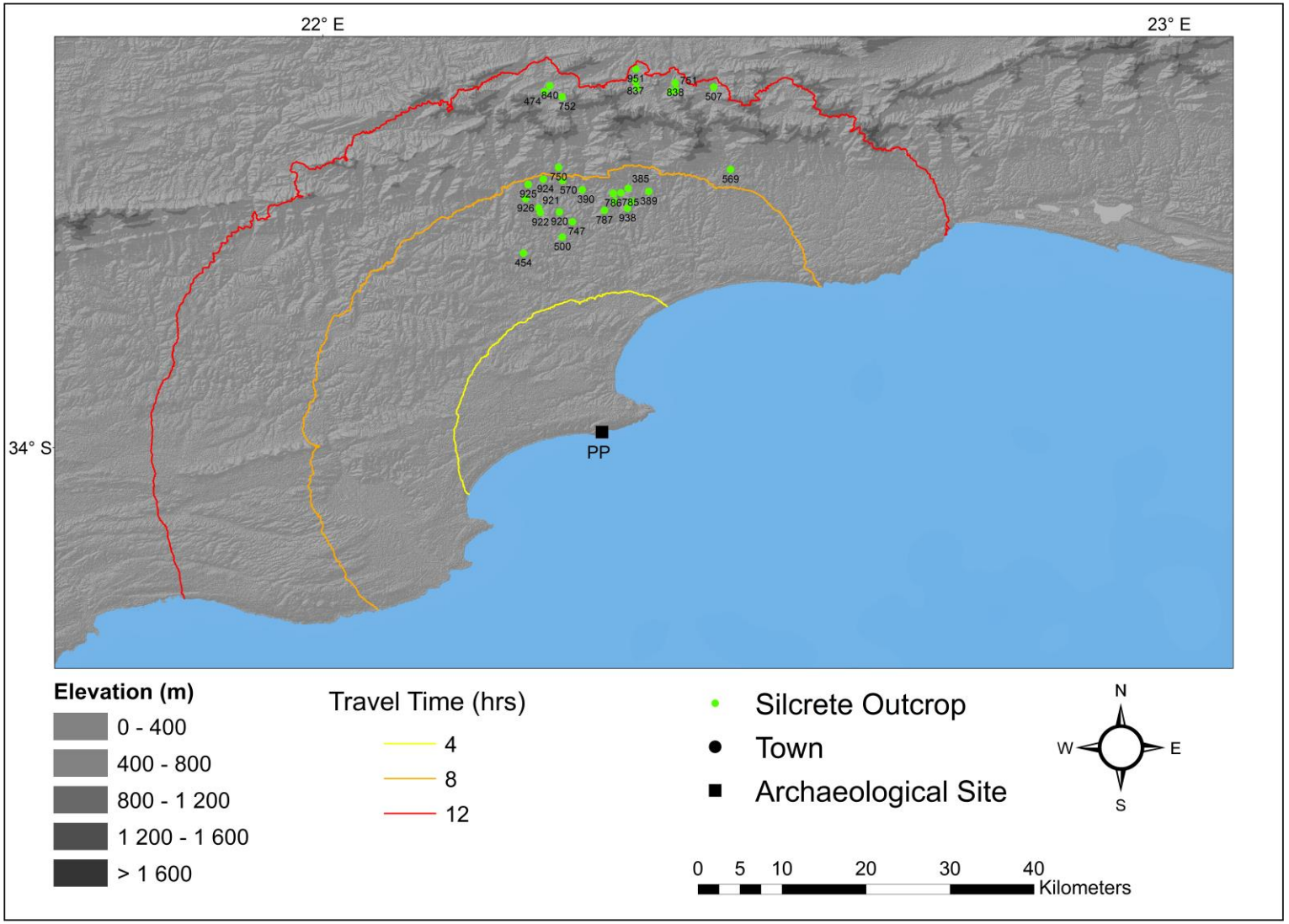

Figure 5.22: Map depicting travel times and corresponding silcrete outcrops from Pinnacle Point.

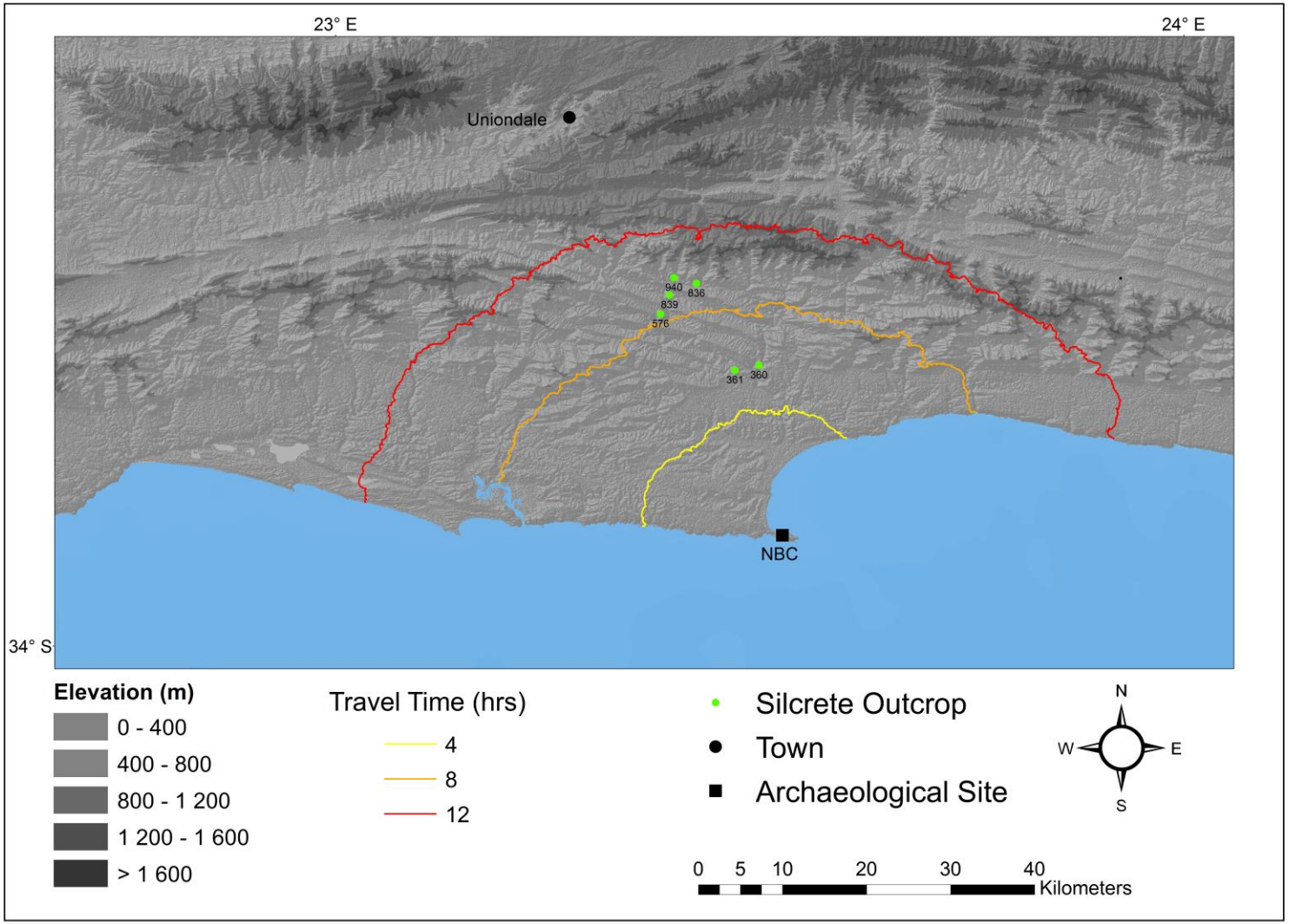

Figure 5.23: Map depicting travel times and corresponding silcrete outcrops from Nelson Bay Cave.

Table 5.7: 4-8 hours travel time ranges from NBC.

Silcrete Outcrop	Distance (km)	TTHF algorithm (hrs)
360	31.5	5
361	34.6	5

Table 5.8: 8-12 hours travel time ranges from NBC.

Silcrete outcrop	Distance (km)	TTHF algorithm (hrs)
576	54.2	8
836	57.5	8
839	59.6	9
940	62.1	11

5.6 Summary

Three algorithms were used to calculate LCPs and travel times from the KMR site to silcrete outcrops in the southern Cape landscape. The algorithms produced different results for LCPs and travel times. Adding constraints such as environmental factors affects the behaviour of the models and produces different LCPs than when slope only is utilised. The closest silcrete source to KRM is 28.3 km away, and it would take 4 hours to reach it, using the TTHF algorithm. KRM has the closest outcrop silcrete source, followed by NBC and PP. The assessment of the frequency of overlaps of KRM, NBC and PP LCPs to silcrete sources show that there is a possibility that HP groups from the three sites may have interacted with each other.

CHAPTER SIX : DISCUSSION

This dissertation used three GIS algorithms to investigate a range of Least Cost Path (LCP) methods to model pathways and travel times in the south Eastern Cape landscape. It aimed at utilising the algorithms to predict the possible paths that the inhabitants of Klasies River Main (KRM) site during the Howiesons Poort (HP) may have used to procure silcrete raw material. The algorithms utilised were further elaborated upon by adding environmental factors to the calculations in order to assess the effects of these factors on the LCPs. There are suggestions that there could have been interaction and/or network exchange between HP groups from different sites (e.g. Ambrose & Lorenz 1990; Wilkins et al. 2017) and therefore the probability of overlap of paths, and possible interaction between groups from KRM, Pinnacle Point (PP) and Nelson Bay Cave (NBC) was modelled. These aspects are discussed in this chapter in relation to the objectives set for this dissertation.

6.1 Least Cost Path methods modelling pathways and travel times in silcrete procurement at KRM

The modelled LCPs demonstrated that different algorithms used produce different patterns. The different patterns include the type of terrain chosen by the paths and the direction that the paths take. For instance, the LCPs produced from the Tripcevich Tobler Hiking Function (TTHF) and the ArcGIS Default Built-in Cost (DBC) favoured valleys and flat areas. Interestingly, both these algorithms produced paths that travelled in the same directions. On the other hand, the White Tobler Hiking Function (WTHF) produced LCPs that favoured steep terrains and they took opposite directions from the DBC and TTHF algorithms.

Diwan & Doumit (2017) recorded varying patterns for their study on reconstructing a past road that connected Berytus to Heliopolis during the Roman Period by using different algorithms. They also observed that the analysis that used the Built-in algorithm seemed to have produced an LCP that preferred flat areas and avoided steep slopes. The Tobler Hiking Function using the Path Distance tool (TTHF in this study) and the Tobler Hiking Function modified by White (WTHF in this study) produced LCPs that preferred steep terrains (Diwan

& Doumit 2017). They remarked that the Roman authority at the time preferred routes that used less energy thus it is interesting that their route is similar to the one that would have most likely reduced costs according to the modelled paths of the DBC and TTHF algorithms (Diwan & Doumit 2017). Surface-Evans (2012) had similar remarks in that the DBC algorithm produced a model preferred flat terrain and this fit with the archaeological data. In contrast, Rademaker (2012) observed that the DBC algorithm overexaggerated the results of his model and saw that the Tobler Hiking Functions produced better results. Thus, LCP algorithms produce different results.

The preference for flat areas fits with the assumption that people are most likely to choose routes that are associated with easier walking (Rademaker 2012). The cost of moving in flat terrain is less because less energy is used. Therefore it is most likely that people would prefer routes that are characterised by flat terrain as it optimises the effort taken to arrive at a destination (Frakes et al. 2008; Rogers *et al.* 2015). However, human beings do not behave as expected all the time (Bird & O'Connell 2006; Anderson 2009; Diwan & Doumit 2017). There are some cases whereby people will travel in difficult terrain as it would likely take less time to travel through mountains than going around.

Moreover, cultural factors may play a role hindering movement in certain areas thus people might choose to walk less favourable terrain (Howey 2007). Therefore, it is realistic to model patterns whereby LCPs travel on routes that are characterised by terrain of both low and high elevations as humans may choose to walk on either topography. In this regard, it is possible that the HP groups at KRM may have travelled through flat areas in order to spend less effort when foraging for silcrete outcrops. However, if cultural factors such as taboos in walking in certain areas would be considered, then it is possible that they would have climbed through mountains to reach silcrete outcrops.

The difference with the resultant models may be due to the way the algorithms were derived, and the software used. Multiple scholars have mentioned that results may differ based on the software package used and how the software employs the algorithms (e.g., Herzog 2014, 2016; Kondo *et al.* 2008). Different

ArcGIS tools and software were used to run the algorithms as the TTHF algorithm uses the Path Distance tool and ArcGIS 10.5 and the other algorithms use the Cost Distance tool. The TTHF was also tested in ArcGIS 10.1 to check if it would return any results, which it did. However, it did not return sensible results when it was run on ArcGIS 10.3 as it returned spider-shaped cost distance patterns. The cause of this result was further investigated on the ESRI community website and several scholars pointed out that they came across the same predicament and they could only solve it when a different ArcGIS software was used. ArcGIS Pro was found by them to be the most suitable software. The University of the Witwatersrand does not have access to ArcGIS Pro and therefore, the algorithm could not be tested on this software in this study.

Surface-Evans (2012) emphasises that the different results from different algorithms demonstrate that there is not a "one size fits all" algorithm for LPC analysis, as different factors influence which algorithm is most practical. These include the type of algorithm used, the size of the study area, the nature of topography and the culture that is being studied (Surface-Evans 2012). Therefore, in the KRM landscape when modelling LCPs and travel times in terms of the slope, it was observed that the TTHF algorithm seemed to be performing better. Moreover, based on the validity assessment carried out, the TTHF algorithm is more comparable with the Google maps travel times. The majority of the calculations were then calculated with the TTHF algorithm.

6.1.1 The effect on optimal routes and travel times when incorporating environmental factors

The Howiesons Poort (HP) period was characterised by fluctuating environments (Wilkins *et al.* 2017). At KRM, as discussed in Chapter 2, the fauna indicate that the beginning of the HP was characterised by relatively closed environments. Thereafter, during the middle period the increasingly environment became more closed environments. It is during these periods that silcrete occur most frequently. The last part of the HP indicated a more open and grassier environment (Van Pletzen Vos & Wurz 2014). Scholars (Ambrose & Lorenz 1990; Minichillo 2006; Wilkins *et al*. 2017; Mackay *et al*. 2018) assume that foraging strategies changed

when the environments changed. The denser vegetation at the beginning and middle of the HP period may have required groups to devise different foraging strategies in these periods than when the environment was open during the later HP at KRM, perhaps linking to changing lithic raw material acquisition strategies

The incorporation of environmental factors in the LCP model demonstrated that the change in environment may have had an effect on movement patterns of HP groups at KRM. For instance, the change in the direction indicated in the TTHF algorithm supports the conclusion that a change in the environment could have resulted in a change in foraging strategies (Minichillo 2006). However, a closer analysis of the LCPs of the TTHF multi-criteria shows that the paths meander following the exact pathways of the hydrology and also overlap the hydrology in the area. In reality this is unrealistic as people cannot walk on water from their origin to the destination. This is only logical when boats are used (Frakes et al. 2008). Also, the time period of focus in this study evidences that people at the time did not use boats to travel and therefore the paths are not realistic for HP foragers. Surface-Evans (2012) observed a similar error where the models provided access to the hydrology in the landscape.

It is more realistic if the paths cross through the rivers instead of going through them similar the TTHF algorithm. HP groups from KRM might have been able to cross small tributaries but it would have been impossible to cross large rivers. It is expected that in certain areas in the landscape some paths would cross the small rivers as speed coefficients and weights (for the DBC algorithm) were provided to produce a model that prevented individuals to walk on and/or cross large rivers. However, the DBC and WTHF algorithms do cross the rivers. If one takes into account that summer rainfall might have increased when the vegetation was dense (Zwane 2018), or winter rain fall might have increased during the HP (Chase 2010), the rivers would have been fuller at times. Thus, it would have been extremely hard to cross the rivers, making these models less likely to be true. Will & Mackay (2017) investigated silcrete procurement in southern Cape archaeological sites, including KRM, and did not find much evidence that supports the notion that changes in climate change, sea levels or the environment

affected the use of silcrete. However, they did not incorporate the faunal data that indicate change in the environment at KRM during the HP. This important issue needs further investigation.

Given that the dominant biome at KRM is fynbos, it would be expected that HP groups at KRM would have avoided travelling through the forest when they procured silcrete raw material, considering that the forest has a higher cost to cross than other biome areas. The HP groups may have rather travelled through the fynbos rich area than through the forest areas. In reality people would most likely travel in lighter vegetation than in dense vegetation (Frakes et al. 2008). However, the LCPs of the TTHF multi-criteria algorithm pass through the forest regardless, consequently not regarding the forest as increasing the cost of travel. This may be due to the fact that the forest area in landscape is located in a flat terrain, therefore the TTHF algorithm may regard the variable 'steep' as more costly than traveling through the forest. If the HP groups regarded walking on steep slopes as more costly then it is more likely that the people would have rather walked through forests areas than climbing mountains. Climbing mountains takes more energy especially if you have to walk and search for resources, thus it would make sense for a forager to save the energy to search for silcrete outcrops than deplete it by walking over mountainous areas.

No major changes were observed when the environmental factors were incorporated it is likely that environmental factors may have affected foraging strategies of the KRM HP groups thus their movement patterns may have stayed the same. The DBC multi-criteria and WTHF multi-criteria travel in the same directions and topography when only slope is considered. Furthermore, the travel times of the TTHF multi-criteria and TTHF slope showed varying patterns of travel times, however, the difference of arriving at a destination was not high. By investigating silcrete procurement in the southern Cape archaeological sites, including KRM, Will & Mackay (2017) did not find much evidence that supports the notions that changes in climate change, sea levels or the environment affected the use of silcrete. Therefore, the environment may have not affected movement patterns of the HP groups at KRM.

6.2 Silcrete foraging ranges of HP groups at KRM

KRM is located in an area that has an extensive of silcrete outcrops that can be reached in 1 day, 2 day and three days. A number of silcrete outcrops are located within 4 hours walking distance, which is within the maximum foraging range for one day. This is based on the assumption that hunter-gatherers walk a maximum of 8 hours a day (Byrd *et al.* 2016). (Byrd *et al.* 2016) states that 4 hours gives a reasonable time to walk to the silcrete outcrops and walk back to the site. In this regard, it is likely that the KRM HP groups some obtained their silcrete raw material in the Kareedouw area as this would provide an opportunity to collect silcrete and then come back to the site in a day. This would further provide an opportunity for inhabitants of the site to stay longer at the site.

The 4-hour maximum travel time produces an opportunity to forage for silcrete raw materials and possibly add other activities to the day such as manufacturing stone tools. In subsistence behaviour, it is assumed that foragers maximise the effort put into getting the food by putting more energy into its further processing (Smith *et al.* 1983; Bird and O'Connell 2006; Codding & Bird 2015). The 4-hour maximum travel time correlates with the hypothesis that was derived for PP, that residential mobility was low during the HP, resulting in occupation periods being longer at the site (Wilkins *et al*. 2017). Silcrete raw material may have been transported from the nearest outcrop to and from to the residential site and other activities may have been performed at the site.

In the same vein, foragers may have wanted to maximise the productivity of the silcrete, and therefore used more complex processing methods, such as heat treatment and more extensive reduction sequences. Silcrete raw materials produce better stone tools when they are heat treated as it produces a workable product and improves flaking (Brown 2011). Therefore, silcrete may have ranked higher during the HP. Even though quartzite was an abundant raw material in the HP assemblage its availability probably changed due to changing lower sea levels as the beaches at the time might have been covered with sand (Langejans *et al.* 2012). Furthermore, silcrete outcrops are abundant across the south Eastern Cape landscape and are found in heterogeneous environments. The sea level change

may have been pushed the HP groups at KRM to diversify their raw material choices by adding silcrete.

Given that the silcrete outcrops in the landscape are located near river channels. It is probable that silcrete outcrops may have travelled through river channels to the nearest river to the site i.e. the Klasies River and/or the Tsitsikamma River. Deacon (1989), Thackeray (1989) and Minichillo (2006) suggest the silcrete used in the HP at KRM area may have been obtained from river channels that may be submerged offshore. It is currently not known where the silcrete at KRM are from, thus there is a possibility that people from the site may have used the pebbles from rivers instead of the silcrete outcrops.

The majority of the silcrete outcrops in the landscape are found in the 2- and 3-day foraging ranges from the site. These silcretes could have been reachable using similar or different paths modelled but the likelihood of the HP groups travelling to procure at these silcrete outcrops is unlikely. If the people sourced at these silcrete outcrops, it is likely that they may have planned their trips and travelled to the outcrops using logistical foraging. Taliaferro *et al.* (2010) observed that procuring obsidian lithic raw material in the Mimbres Valley, Mexico, may have taken a week thus the people at this site would have practiced logistical foraging. Additionally, they suggest that it would have required physical costs in terms of labour and material supplies to collect and transport back to the site, this this may apply to the HP groups at KRM. If a person travels for more than a day, additional supplies may be needed to carry out the foraging.

6.3 The possibility of interaction between PP, NBC and KRM HP groups

This study also analysed silcrete availability for the three different sites and the possibility of interaction by the people from these sites. The scenario of the possibility of interaction between the three sites is based on the assumption that each site represented a distinct group of people and sites were inhabited simultaneously. The nearest silcrete outcrop from KRM is located 28.3 km away in the Kareedouw area, within the minimum travel time of 4-hours. This is different to Thackeray's (1989) hypothesis that the nearest silcrete outcrop from

KRM would be 20 km away in the Langkloof valley. However, according to this study the Langkloof valley is located 68.3 km away. The differences of distance from KRM to the Langkloof valley may be due to the fact that this study used anisotropic algorithms that calculate time distances by calculating landscape data that affect route choices, such as slope, hydrology and vegetation (Herzog 2013).

The time travel to reach the sources at Kareedouw can be reached in a day therefore, the sources for the coarser grained silcretes are mostly likely local than what is considered in studies that describe it as non-local and exotic (Singer & Wymer 1982; Ambrose & Lorenz 1990). However, this may still be true for other types of silcrete, not investigated in this study. The foraging range of >40 km suggested by Ambrose (2006), would only apply when HP groups obtained their sources in the silcrete outcrops beyond the Kareedouw area.

The nearest silcrete outcrop from NBC is located 31.5 km away from the site, reachable in a reasonable time of 5 hours according to the TTHF algorithm, although still beyond the 4 hours daily limit used as a standard foraging range in this study. The situation at PP is similar, in that the nearest silcrete outcrop is located beyond the maximum travel time, as it can be reached in 5 hours, 34.8 km away from the site. This is different from Brown (2011) who noted that the nearest outcrop source at PP is located 8.5 km away. It is important to note that Brown located the silcrete after surveying the Mossel Bay area, a town close to PP. Even though the nearest sources PP and NBC are located beyond maximum travel time for this study, the sources foraged in both these silcrete outcrops are accessible in a day. Therefore, the silcrete outcrops form these sites may be considered local and non-exotic in some cases. Here too, the type of silcrete occurring at the site needs to be correlated to the different silcrete outcrops.

If the three groups consistently selected the closest outcrops, they might not have met in the context of silcrete sourcing. They may have met if they secured silcrete in further areas. As demonstrated in the overlaid travel time ranges, NBC and KRM travel time ranges overlap only at the 12-hour travel times. In the KRM vicinity, there is an abundance of silcrete outcrops in this time range therefore, it is possible that the NBC groups may have travelled to source silcrete close to

KRM. Considering that the overall silcrete outcrops at NBC are scarce, it is also possible that NBC groups may have travelled in the vicinity of PP to procure silcrete outcrops as the PP and NBC travel times overlap at 20-24 hours travel time ranges. The frequency models indicate that there is a higher possibility of interaction between KRM and NBC groups than between KRM and PP, and a higher possibility of NBC and PP groups meeting.

If it can be shown that certain outcrops had silcrete that had particular favourable knapping qualities, it may be that HP groups could have met at such outcrops. Currently, there is no data to further investigate this hypothesis, but it could be further investigated by comparative lithic technological and raw material sourcing studies. There is a need for detailed studies of southern cape HP sites that correlate specific layers, dated to the same time period, with specific types of silcrete. Furthermore, the results from this study may be used hand in hand with geochemical data to understand mobility patterns in the southern Cape area further. This study contributes to research on silcrete raw material acquisition in the south Eastern Cape, as both geochemical and geospatial work is important in understanding raw material acquisition and human behavior (ten Bruggencate *et al.* 2017). At PP, Brown (2011) and Oestmo (2017) looked at the effects of the knapping quality of silcrete raw material when it is heat treated, and this should be also explored at KRM.

If the HP groups went to silcrete outcrops in areas farther away, such as Grahamstown, then it means that the trips for procurement were planned. Thus, the groups may have applied a logistical procurement strategy. McCall and Thomas (2012) argued that the increase of silcrete raw material during the HP was due to people travelling long distances for hunting. It is possible that the HP groups at KRM used a logistical strategy to procure silcrete raw material. However, perhaps the people went to procure silcrete raw material and at the same time made time for other tasks such as hunting and then coming back to the site (Taliaferro *et al*. 2010)

Will and Mackay (2017) state that perhaps during the HP, there were certain periods whereby people preferred to transport silcrete raw material to the

residential area to make stone tools. In that regard, they suggest that HP backed artefacts would have functioned as tools during logistical trips from the site (Will & Mackay 2017). This notion applies to foraging strategies that may have been employed at KRM as well as silcrete backed artefacts are common in some of the HP assemblage. If silcrete was highly ranked people would have travelled to areas beyond the suggested foraging range to obtain it, thus it is possible that people would have travelled as far as Grahamstown to procure silcrete from outcrops.

The idea of procuring silcrete raw material in the Grahamstown area would maximise the chances of interaction between KRM and HP groups from PP and NBC. The greatest overlap between KRM and the HP groups from PP occurs in Grahamstown and Uitenhage areas, and the greatest overlap between KRM and NBC also occurring in Grahamstown as well as Uitenhage in the east. Thus, it is most likely that that the HP groups from KRM would have interacted at silcrete outcrops located furthest away from the site. There is thus a high possibility of interaction between the three HP groups in the Uitenhage and Grahamstown area. This may be due to the fact that NBC and KRM are in closer proximity to each other than PP and KRM; therefore, it is most likely that the groups from NBC and KRM may have interacted with each other. The overlaps occur in the maximum travel times as it would take up to 50 hours to reach the silcrete outcrops to Grahamstown for groups from KRM; 104 hours for PP groups and 80 hours for NBC groups. It is interesting in this regard that KRM and NBC both combine substantial quartzite use with that of silcrete.

Silcrete use during the HP is linked by Wurz (1999) to symbolic behavior as a way of expression due to its unique qualities. As the three sites are characterised by an increase of silcrete raw material used during the HP, especially for the production of backed geometric artefacts (Wurz 1999; Minicihillo 2006; Wilkins *et al.* 2017), interaction between the groups from the three sites would have supported an exchange of ideas of manufacturing silcrete stone tools, perhaps influencing the production of similar kinds of stone tools.

6.4 Summary

This study has undertaken LCP modelling following methods and procedures such as those used by Taliaferro *et al.* 2010; White & Surface-Evans 2012; White & Barber 2012; White 2015; Rogers *et al.* 2015; Güimil-Fariña &Parcero-Oubiña 2015; Byrd *et al.* 2016; Becker *et al.* 2017. These studies included topography and environmental factors, a convention that I followed. In my study it was demonstrated that they influence LCPs and the travel times to reach the silcrete outcrops. Even though silcrete raw material can be accessed in close proximity to all three archaeological sites discussed in this study, there is a possibility that they may have procured silcrete from distant areas. This would increase the chances of interaction between the groups traveling between the three sites. This might have been a factor in exchanging knowledge of manufacturing silcrete stone tools.

CHAPTER SEVEN : CONCLUSION

Much of the existing body of movement research in South African archaeological is based on stone tool analysis and geochemically matching archaeological material to the raw material in the landscape. This research provides a different approach to exploring past movement and foraging which has been explored extensively in European archaeological studies but not in South Africa. GIS in landscape analysis is valuable in archaeological studies as it provides an opportunity to model different scenarios and gain insight into past human behavior and the relationship between humans and their landscape.

The use of different Least Cost Path (LCP) algorithms demonstrated that results may differ depending on the algorithm used. The Tripcevich Tobler Hiking Function (TTHF) and ArcGIS Default Built-in Cost (DBC) algorithms modelled paths that went through flat terrain whereas the WTHF algorithm modelled paths that travelled through steep terrain. The two time-based algorithms models produced different travel time ranges as the TTHF algorithm produced travel time that are more comparable with Google maps and the White Tobler Hiking Function (WTHF) produced slightly larger travel times.

Incorporating environmental factors into the algorithms affected the paths modelled. However, impact was not major on the DBC and WTHF algorithms. The TTHF algorithm was impacted negatively as the resultant paths meandered through the river network in the landscape.

The Klasies River Main (KRM) site landscape is characterised by an abundance of silcrete outcrops. The nearest silcrete outcrop from the site is located in Kareedouw, 28.3 km away and can be reached in 4 hours. Therefore, there is a possibility that that the Howieson's Poort (HP) group at KRM may have used a daily foraging. On the other hand, there is a possibility that the HP groups at KRM may have procured silcrete at areas further from the site such as Uitenhage and Grahamstown which in turn would have increased the chance of interacting with HP groups from PP and NBC, as indicated by the overlapping paths.

Limitations

Software malfunctions were encountered during the course of this study. The aim was to utilise ArcGIS 10.3 to run the algorithms however other versions had to be explored to run the TTHF model (discussed in Chapter 4). Other ArcGIS GIS users encountered the same problem when using the TTHF algorithm on ArcGIS 10.3 Other GIS software such as GRASS GIS could be used to investigate the feasibility of LCP algorithms as White (2015) stated that his modified algorithms might be run on other GIS software also. Thus, a comparison of the results from the two types of software using a common dataset would provide a robust method to use for future LCP studies. The Tripcevich Tobler Hiking Function (TTHF) demonstrated that it is better suited to model slope-based models in terms of time using ArcGIS 10.3 and 10.5.

It is important to note that vegetation is not constant due to natural and anthropogenic reasons and this should be taken into account when conducting GIS analysis (Wheatley & Gillings 2002). However, due to the lack of this data at present, this dissertation used data on the present vegetation. The three sites in the southern Cape, KRM, KDS and PP investigated here, are in the process of reconstruction paleoenvironments of the Howiesons Poort. However, only some faunal and sea level data are available. There is thus a need for finer grained models to reconstruct vegetation, perhaps through GIS. For this fine-grained environmental proxy are needed.

The Roberts (2003) silcrete outcrop map utilised in this study was included the south Eastern cape and not the whole of the southern Cape. As such, the silcrete outcrops by the Pinnacle Point area may not be complete. Furthermore, the silcrete outcrops that were presently submerged but could have been available to the HP groups are not available for this study. The HP groups may have had used those silcrete outcrops instead of the inland silcrete outcrops utilized in this study.

A major limitation is that it is not possible to know whether groups interacted on the LCP's, but this study is only a first step in trying to create hypotheses on silcrete raw material acquisition in the HP. It is important to keep in mind that this

is a theoretical study and testing possibility of interaction between the three the HP south Eastern Cape groups. These groups may have interacted for different reasons that had nothing to do with silcrete procurement.

Recommendations

This study employed time algorithms to model as a cost of travelling as the main objective was to investigate whether LCP algorithms can be utilised in a south Eastern Cape landscape. Future studies should incorporate travel time and energy algorithms (see Rademaker 2012) in order to model the cost of travelling in a landscape as it might provide more insight into silcrete procurement strategies at KRM. Furthermore, a comparison of travel time and energy-based algorithms would help in determining the most realistic paths the HP groups could have travelled. Also, it would be interesting to use travel time and energy-based models to model faunal foraging to examine the footprint of KRM HP groups. Energy based algorithms may allow an estimate of return rates on foraging times (Surface-Evans 2012).

It was observed through analysis that the topography and the environment were factors affecting the movement patterns of HP people. Other scholars (Bell *et al.* 2002; Wheatley & Gillings 2002; Howey 2007; Anderson 2012; Frakes et al. 2008) have suggested that social, political and cultural factors affect movement in a landscape. However, it is complicated to model these factors in GIS. Methods such as viewshed analysis may be used to model cultural and social factors (Wheatley & Gillings 2002). Thus, a future study could use this algorithm to investigate these factors in the KRM landscape.

Even though there appears to be an abundance of silcrete in the southern Cape landscape, the HP groups may have been interested in a specific type of silcrete in a specific area, a topic that needs further research. There are silcrete outcrops that are relatively close to each of the three sites. If time was an important consideration in the HP, groups might have procured silcrete at the closest silcrete sources. However, if future studies show that particular silcretes, for example from sources at Grahamstown and Uitenhage, were preferred through particular

time periods, it is possible that groups may have interacted in these areas. Future studies should incorporate the relationship between the silcretes found in KRM, PP and NBC, and the silcretes found in the landscape through chemical fingerprinting, a priority for future research (Nash *et al.* 2013b). Furthermore, until a closer description of the HP silcretes is known, this study remains hypothetical. The results produced in this work show that these outcrops are the most likely places that may have been exploited if the HP groups preferred outcrop silcrete during certain time periods. Future work may utilise these predictions and investigate further by geochemically testing the archaeological material and the silcrete outcrops.

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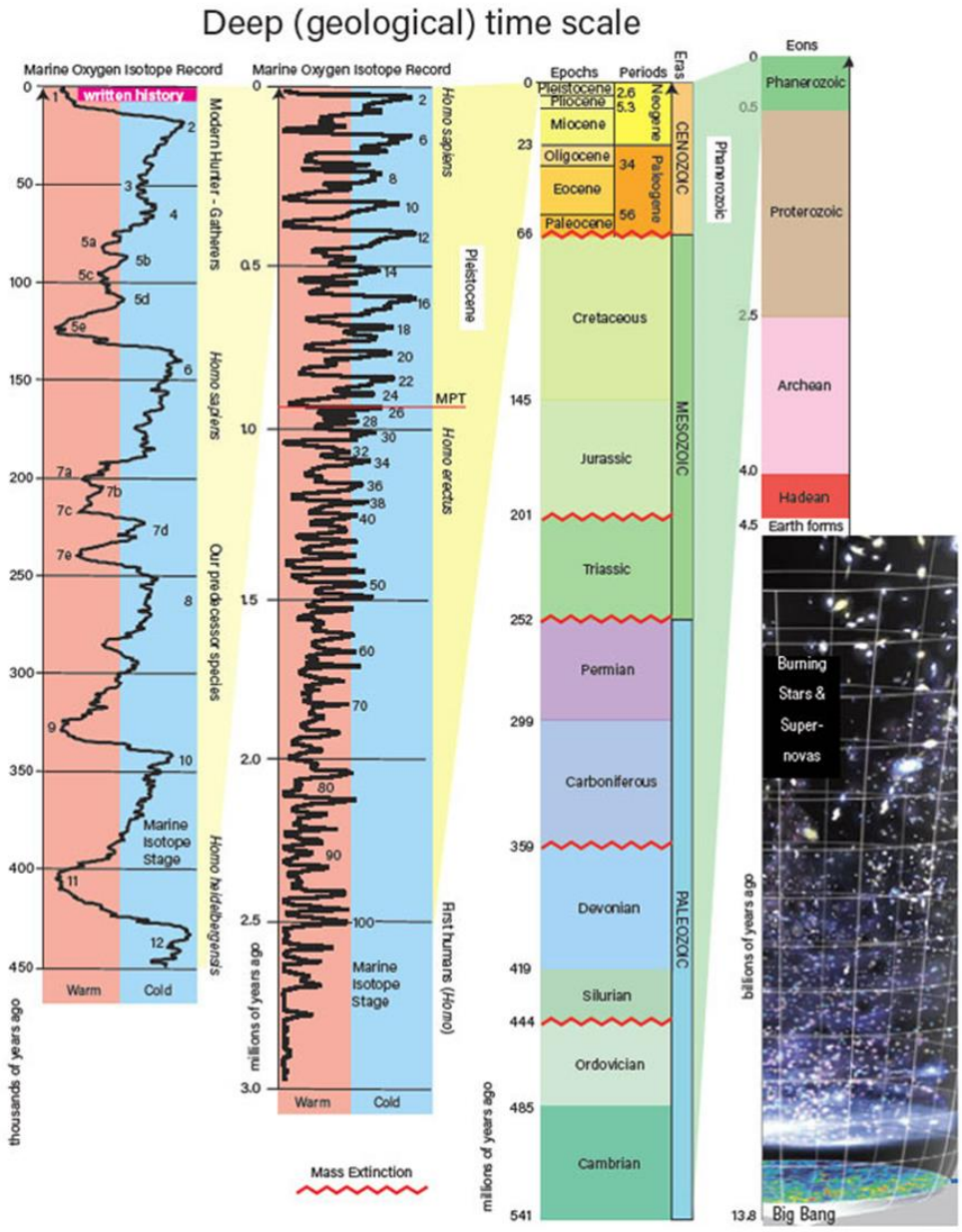
APPENDICES

Appendix 1



The Earths geological timescale (Image by Compton 2016).

Appendix 2

Dominant geology in the Eastern Cape and their dominant rock type (After Council of Geological Science data 2006).

Supergroup	Group	Formation (Fm)	Dominant rock or material type
		Grahamstown Fm	Silcrete
	Uitenhage	Sundays River Fm	Marine mudstone, siltstone
		Kirkwood Fm	Fluvial sandstone, mudstone
		Enon Fm	Conglomerate
	Drakensburg		Basalt, dolerite
Karoo	Stormberg	Clarens Fm	Sandstone, siltstone, mudstone
		Elliot Fm	
		Molteno Fm	
	Beaufort	Katberg Fm	
		Burgersdorp	
		Koonap Fm	
		Middleton Fm	
		Balfour Fm	
	Ecca	Waterford Fm	Sandstone, siltstone, shale, mudstone
		Tieberg Fm	Shale, claystone, mudstone, siltstone
		Colliham Fm	Shale, siltstone, mudstone, tuff
		Whitehall Fm	Shale, tuff
		Prince Albert Fm	Shale
	Dwyka		Diamictite
Cape	Witterberg	Waaipoort Fm	Shale, mudstone, siltstone
		Floriskraal Fm	Sandstone, siltstone, sandy shale
		Kweekvlei Fm	Shale, siltstone
		Witpoort Fm	Sandstone
		Swartuggens Fm	Silstonem mudstone, sandstone
		Blikberg Fm	Sandstone

Cape		Wagen Drft Fm	Siltstone, sandy shale, mudstone,
	Bokkeveld	Karoopoort Fm	Siltstone, sandy, shale
		Osberg Fm	Sandstone
		Klipbokkop Fm	Siltstone, mudstone, sandstone
		Wuppertal Fm	Siltstone, siltstone, shale
		Waboomberg Fm	Siltstone, shale, mudstone, sandstone
		Boplaas Fm	Sandstone
		Tra-Tra Fm	Shale, mudstone, siltstone, sandstone
		Hex River Fm	Sandstone
		Voorstehoek Fm	Mudstone, shale, siltstone
		Gamka Fm	Sandstone, siltstone
		Gydo Fm	Shale, mudstone, siltstone
	Table Mountain	Rietvlei Fm	Sandstone, siltstone, shale
		Skurweberg Fm	Sandstone
		Goudini Fm	Sandstone, siltsone, shale
		Cederberg Fm	Shale
		Pakuis Fm	Diamictite, sandstone
		Peninsula Fm	Sandstone
		Graafwater Fm	Sandstone, siltstone, shale
		Piekenierskloop Fm	Sandstone,conglomerate