

https://dspace.org/

The role of rock properties in stone tool production in the Middle Stone Age at Sibudu

Kempson, Helen

2016

http://hdl.handle.net/10539/21730

Kempson, Helen (2016) The role of rock properties in stone tool production in the Middle Stone Age at Sibudu, University of Witwatersrand, Johannesburg, <http://wiredspace.wits.ac.za/handle/10539/21730>

Downloaded from a DSpace repository. https://dspace.org/

THE ROLE OF ROCK PROPERTIES IN STONE TOOL PRODUCTION IN THE MIDDLE STONE AGE AT SIBUDU

Helen Kempson

A Thesis submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

Johannesburg, 2016

DECLARATION

I declare that this Thesis is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

_____

Helen Kempson

_____day of_____ 2016 in Johannesburg_____

ABSTRACT

This study is within the context of the Howiesons Poort Industry of the Middle Stone Age. This is a dynamic period of increasing behavioural and material complexity. In the lithic assembles, this can be seen in a strong bias towards the selection of high-quality fine-grained rocks. This has often been interpreted as evidence for long distance travel, reciprocal exchange, or even increased mobility.

This study aims to determine what influence the mechanical properties of rock types exerted on the Middle Stone Age assemblages at Sibudu. This requires a consideration of the distribution of rock types across the landscape surrounding Sibudu Cave. The study was limited to hornfels and dolerite as these rock types dominate the Sibudu assemblage, and quartz and quartzite that were sometimes used at the site are exceedingly difficult to collect in large enough sample sizes to conduct experiments. It was important to carry out tests on the mechanical properties of hornfels and dolerite and to characterise them. Hardness, roughness, elasticity and brittleness dictate the ease of knapping as well as the durability of flaked tools and these rock properties can be measured by the mechanical tests described here. To understand how these properties affect the assemblage in practice, dolerite and hornfels flakes were produced and used experimentally for cutting and scraping leather. The edge damage produced was compared. Finally, preliminary analysis was undertaken of square C4, layer PGS, which forms part of the oldest Howiesons Poort layer at Sibudu. The information and insights gained from the mechanical tests and experimental work were used to interpret the role of mechanical properties for the archaeological sample of PGS.

The results show that all rocks used at Sibudu are local, and do not support any models of long distance travel/trade, reciprocal exchange, or models of increased mobility. Dolerite and hornfels form the bulk of the assemblage at all times (except briefly in the post-Howiesons Poort), and there is a bias towards the selection of fine-grained rocks during the Howiesons Poort. Dolerite can be characterised as hard, tough, elastic, and rough, while hornfels is hard, brittle, and fine-grained. These properties affect knapping and the qualities of a tool's edge.

The properties of hornfels allow for knapping accuracy and predictability, and it is better suited to blade production and cutting. However, tool edges are not robust. Dolerite is not as easy to knap, but produces tools with a robust edge that are particularly suited to scraping. Each rock type appears to have fulfilled a different function at Sibudu.

Most rock studies geochemically source rocks, establish models of rock procurement or show trends in rock selection for artefact classes. Mechanical studies of rocks have typically formed part of heat treatment debates (Brown *et al 2009*; Domanski & Webb 1992, 1994; Webb & Domanski 2008). Through the combined approach of mechanical testing, experimental knapping and tool use, and lithic analysis, this research provides a context for possible rock procurement choices at a time in the past when many African sites reveal a changing pattern of rock selection.

In memory of my father

Gordon Kempson

1940-2014

ACKNOWLEDGEMENTS

A great number of people assisted me with this project. In particular Professor Grant Cawthorn of the School of Geosciences, who helped me with deciding which mechanical properties were pertinent to determining knapping and flaking characteristics. Professor Cawthorn also provided the rock identification for thin sections, and helped me to find a method for determining roughness by directly measuring grain size. He and Dr Bybee patiently identified rock samples, and helped with interpreting the results of XRF. Professor Koursaris, formerly of the School of Chemical and Metallurgical Engineering, assisted with choosing a method of determining hardness, and helped me with understanding the principles of fracture mechanics. I am grateful to Dr Van Der Merwe, also of the School of Chemical and Metallurgical Engineering, who helped me with, and conducted, the fracture toughness tests. Dr Halil Yilmaz, of the School of mining Engineering conducted the Uniaxial Compression Tests and also patiently helped me to interpret the results.

I am grateful to Thomas, the owner of Rosemary Hill, for permission to collect hornfels samples there, and to Vaughan Ross for assisting me with information and where best to collect samples. James Miles very kindly cut sections of rock for me with a water jet, and Russel Thompson further prepared these samples, and conducted Charpy and hardness tests. I am particularly grateful to him for his work, and also for giving me a much better insight into not just the results, but the context in which they were interpreted.

I am indebted to the Palaeontological Scientific Trust (PAST), as well as to Dr Lombard and the NRF, for financial support during the course of this study. I would also like to thank Kevin Miller for his patient assistance with technical support. Many thanks are also due to Wendy Voorvelt who provided the drawings. Dr Paloma de la Peña helped me greatly with advice and by listening to my various concerns. I would also like to thank Gillian Kempson for providing encouragement throughout. Lastly, and most of all, I would like to thank my supervisor, Professor Lyn Wadley, for her sustained patience and support.

CONTENTS

	Page
DECLARATION	ii
ABSTRACT	iii
DEDICATION	v
ACKNOWLEDGEMENTS	vi
LIST OF FIGURES	xi
LIST OF TABLES	xiii
CHAPTER 1	
INTRODUCTION	1
Sibudu lithic assemblages	1
Theoretical basis for this study	4
The research question	5
Aims of the research	7
Project layout	8
CHAPTER 2	
PUBLISHED PAPER	12
A review of rock studies for archaeologists, and an analysis of dolerite and hornfels from the Sibudu area, KwaZulu-Natal	

CHAPTER 3

BACKGROUND 35

Sibudu Rock Shelter 36

Rock exploitation and distribution 38

The significance of Sibudu 42

Establishing diachronic change at Sibudu 45

The Still Bay at Sibudu 45

The Howiesons Poort 47

The post-Howiesons Poort 49

The late-MSA 51

The final-MSA 51

The Howiesons Poort 56

The Howiesons Poort at Sibudu 62

Mechanical properties and their influence on knapping and tool edges for hornfels and dolerite 67

Dolerite and hornfels 67

Mechanical properties 70

Knapping qualities of rocks 75

Edge qualities of rocks 77

Summary 79

CHAPTER 4

METHODOLOGY 81

Chemical and mechanical properties 83

XRF 85

Rock identification 86

Hardness 87

Elasticity (elastic modulus) 88

Roughness 89
Fracture toughness 90
Production of dolerite and hornfels flakes and experimental cutting and scraping 92
Knapping 92
Photograph and recording 93
Experimental cutting and scraping 93
Analysis of Howiesons Poort material 96
Summary 97

CHAPTER 5

RESULTS 99
Chemical and mechanical properties 99
XRF 99
Hardness 101
Elasticity (elastic modulus) 102
Roughness 104
Fracture toughness 105
Experimental cutting and scraping 109
Dolerite 109
Chilled dolerite 111
Hornfels 115
Comparison of rock types 117
Analysis of Howiesons Poort Material 119
Tools 119
Cores 120
Blades and blade fragments 125
Summary of results 130

CHAPTER 6

DISCUSSION 132

Mechanical properties and XRF 132

Experimental flake production and use 137

A preliminary analysis of Howiesons Poort material 142

Interpreting the archaeological assemblage in terms of mechanical properties and experimental tool production and use 149

Blade production 149

Tools 150

Backed tools (segments) for hunting 151

Rock selection at Sibudu 154

CHAPTER 7

CONCLUSION 155

REFERENCES 161

APPENDIX 1 186

LIST OF FIGURES

		Page
Figure 1	Map of Southern Africa showing the location of Sibudu Cave (courtesy of Lyn Wadley)	37
Figure 2	Plan view of Sibudu Cave, showing the 21m^2 excavation. From Wadley & Jacobs 2006.	38
Figure 3	Photograph taken from Sibudu Cave (facing south) with a view of the uThongathi River and riverine forest at the base of the site.	39
Figure 4	Sibudu stratigraphy (courtesy of Lyn Wadley). The Howiesons Poort levels are shaded grey, and the layer included in this study, PGS, is shaded in dark grey.	40
Figure 5	Hornfels and coarse dolerite	69
Figure 6	Suede leather, 2 mm thick, used for cutting and scraping	94
Figure 7	Hardness values (Hv) of dolerite and hornfels samples	102
Figure 8	Average grain size in mm of hornfels and dolerite samples tested for roughness.	105
Figure 9	Fracture toughness of hornfels and dolerite samples	106
Figure 10	Use-wear images for experimentally used dolerite flakes	111
Figure 11	Use wear images for experimentally used chilled dolerite flakes.	113
Figure 12	Use-wear images for experimentally used chilled dolerite flakes	114
Figure 13	Use-wear images for experimentally used hornfels flakes	116

Figure 14	Proportion of rock type use, a) for the whole of the PGS lithic sample b), for PGS blades/blade fragments c), and for PGS flakes/fragments	121
Figure 15	Backed tools from Sibudu layer PGS	123
Figure 16	Cores from layer PGS	124
Figure 17	Complete unretouched blades from layer PGS	125
Figure 18	Blades, a) average ratio of length to width b) average thickness	127
Figure 19	Size distribution of complete blades for hornfels, dolerite and fine dolerite	128
Figure 20	Graph showing the distribution of blades and blade fragments by width in mm, for hornfels, dolerite and fine dolerite.	129

LIST OF TABLES

		Page
Table 1	Frequencies of debitage and formal tools by raw material. Formal tool numbers are in parenthesis. After Delagnes *et al.* 2006.	48
Table 2	Change through time at Sibudu in terms of technology, rock type selection and interpretations by various analysts.	52
Table 3	Howiesons Poort stratigraphic layers, dating using OSL (after Wadley 2008).	64
Table 4	Summary of non-quartzite raw material usage in Klasies River Cave 1A, D sample, after Wurz (2000).	64
Table 5	Summary of the geological and archaeological samples used for XRF analysis, hardness and roughness tests, and rock identification through the analysis of thin sections.	83
Table 6	Data for XRF samples.	85
Table 7	Provenance and dimensions of uniaxial compression tests used to establish elasticity.	89
Table 8	Samples prepared for fracture toughness test with notch cut into sample.	91
Table 9	Samples prepared for fracture toughness test with no notch cut into sample.	91
Table 10	Edge characteristics of experimental flakes before use	95
Table 11	XRF results of archaeological and geological samples	100
Table 12	Provenance of samples and their hardness values (Hv)	103
Table 13	Results of uniaxial compression strength tests (UCS), with E (Young's Modulus) and n (Poisson's ratio)	104

Table 14	Results of fracture toughness tests of dolerite and hornfels samples from various provenances.	107
Table 15	Results of fracture toughness tests on a single dolerite rock sample, and a single hornfels rock sample.	108
Table 16	Assemblage composition for layer PGS	123
Table 17	Description, rock type, length and width of tools from layer PGS	
Table 18	Description, rock type and maximum dimensions of cores from layer PGS	124
Table 19	Average length, width, Length/Width ratio and thickness for complete blades, and average width and thickness for blade fragments of hornfels, dolerite and fine dolerite.	126

CHAPTER 1

INTRODUCTION

Sibudu is a Middle Stone Age (MSA) site in KwaZulu-Natal, South Africa. It preserves an important sequence of well excavated sediments, currently dating from 77.3 ± 2.6 ka (Jacobs *et al.* 2008a) to 38.6 ± 1.9 ka (Jacobs *et al*. 2008b). Most layers are clearly stratified and well dated, which has made it possible for the site to contribute meaningfully towards broadening our understanding of the MSA. A vast and varied body of research has been published that has contributed to our knowledge of the past. This includes aspects of behaviour in the MSA, as well as providing insight into the cognitive capacity of the inhabitants of Sibudu.

In southern Africa, the Still Bay and Howiesons Poort are viewed as innovative, and demonstrate early cultural complexity (Henshilwood & Debreuil 2011). Sibudu is one of few sites that preserve a sequence of assemblages that include both the Still Bay and Howiesons Poort Industries. According to Henshilwood & Debreuil (2011) these sites, such as Sibudu, Pinnacle Point (Brown *et al.* 2012) and Diepkloof (Tribolo *et al.* 2013) have the potential to contribute to debates on symbolic material culture and the evolution of the human mind.

Sibudu lithic assemblages

This study is concerned with the extensive lithic component of the Sibudu excavations. At the base, the oldest assemblage predates the Still Bay, but has yet to be published. The presence of the Still Bay at Sibudu (Wadley 2007) established an extended range for the Industry, demonstrating that it occurs

outside of the Western Cape. This assemblage has been well described by Soriano *et al.* (Soriano *et al.* 2009, 2015), and has an OSL date of 70.5 ± 2.0 ka (Jacobs *et al.* 2008). It is almost exclusively oriented towards biface production and shows no preference for fine-grained rock selection.

This is immediately followed by a Howiesons Poort assemblage, with an OSL date of 61.7 ± 2.0 (Jacobs *et al.* 2008). This has been described in several studies, and conforms to a classic definition for the Howiesons Poort. This is evident in emphasis on blade production, dominance of backed tool types and selection for fine-grained rocks (Delagnes *et al.* 2006, Villa *et al.* 2005, Soriano *et al.* 2015, de la Peña 2015a, 2015b). There is however a clear intention to produce flakes as well as blades, seen in the presence of discoidal cores and Levallois flakes. Also rare, both at Sibudu and for the Howiesons Poort Industry, is the presence of prismatic blades and small quartz bifaces on quartz flake blanks (de la Peña 2015b).

This is followed by a hiatus of 10.4 ±1.4 ka and may reflect a period of non-occupation associated with an arid environment (Wadley & Jacobs 2006). The late MSA follows this at 49.7 ± 1.2 ka. It is described by Villa *et al.* (2005) as a mixed flake and blade assemblage and includes unifacial points, with no selection for fine-grained rocks. A hiatus again follows, with a period of 12.8 ± 1.4 ka of non-occupation, again possibly due to an arid environment (Wadley & Jacobs 2006). Lastly, the final MSA at Sibudu dates to 36.9 ± 1.2 ka (Jacobs & Wadley 2006). It is characterised by a trend towards blade production, the presence of bifacial tools, rare hollow based points, bifacial and unifacial points, scrapers, and rare bipolar cores (Wadley 2005).

These assemblages are discussed in more detail in Chapter 3, but are presented here to show clear diachronic change in both technology and rock selection at Sibudu. This thesis does not attempt to explain the reasons for technological change through time. It does, however, seek to explain some of the choices behind changes in rock type use as established above. Sibudu is not a coastal site where rock availability may be affected by changing sea-levels, such as at Klasies River (Minichillo 2006). Therefore it is assumed that the availability of rock resources would have remained relatively constant for the duration of occupations at Sibudu. Also, all rock types used at Sibudu are local and occur within 20km of the site. Changes in patterns of rock selection must therefore have been motivated by choice. The distribution of rocks and the local geology of the vicinity are discussed in Chapter 2 and Chapter 3.

Establishing diachronic change in technology and rock procurement underlies this study as it is this pattern of changing rock selection that provides the context for the questions asked about rock types. Why did toolmakers prefer fine-grained rocks in some instances, and not in others? Consequently, I will characterise a range of mechanical properties of the dominant rock types used, dolerite and hornfels, to illustrate the properties that toolmakers were choosing when they selected either dolerite or hornfels. Mechanical testing will establish a theoretical basis to explain rock selection. However, to see how these rocks behave in practice I will produce and use flakes to cut and scrape leather. This will provide further insight into the usefulness and behaviour of each rock type.

Finally, I will perform a preliminary analysis of the dolerite and hornfels component of a small selection of Howiesons Poort (layer PGS, square C4) material. The Howiesons Poort is well described in the literature and will provide a good sample that can be compared with data from other well excavated and well dated sites such as Klasies River (Wurz 2002) and Rose Cottage (Soriano *et al.* 2007). I will provide an interpretation of this material in light of the mechanical

properties previously established. I will then provide some comparison of this assemblage with data published for the Howiesons Poort.

Theoretical basis for this study

This research will follow the framework of the chaîne opératoire theory. It considers the creation of the assemblages from rock procurement, through to considerations of tool discard due for instance to tool failure. These dynamic lithic assemblages are the end result of the conscious choices that early knappers made. While the form of these tools was probably largely dictated by function, rock selection is a more flexible behaviour, and rock choices were influenced by a variety of considerations. The distribution of rock resources on the landscape and their degree of scarcity or abundance reflect early people's partiality or aversion to carry rocks for some distance, or to spend time searching out desirable but relatively scarce resources. Binford's (1978) model of embedded procurement, based on observation of hunter-gather Nunamiut, suggests that the cost of rock procurement may be low, as rock is collected as part of basic subsistence schedules. Gould (1978) however noted that Australian aboriginals of the Western Desert often planned trips to quarries when they were known to lie within a day's walk of the base camp.

Fracture mechanics and the mechanical properties of rock play a critical role in the way in which rocks break, during the intentional knapping of rocks, as well as during the use of a tool (Braun *et al.* 2009; Cole 2002; Cotterell & Kamminga 1987, 1992; Delgado-Raack *et al.* 2009; Domanski & Webb 1992; Inizan 1999; Jones 1979; Lawn & Marshall 1979; McPherron *et al.* 2014; Webb & Domanski 2008; Yonekura *et al* 2008.). This will be discussed in more detail in Chapter 2. However, the choice of rock selection occurs in conjunction with their grasp of the effects of the mechanical properties of selected rocks, where toolmakers

selected rocks for grain size and knapping qualities (Webb & Domanski 2007), or for hardness (Braun *et al.* 2009; Yonekura *et al.* 2008).

These specific mechanical properties dictate the relative ease of tool production as well as suitability of a tool to its intended function. In context, the rocks themselves have the potential to help archaeologists answer questions about behaviour and the conscious choices that people made in the past, from their selection of rocks through to the production and subsequent discard of artefacts. This can be seen in toolmakers preferentially selecting rock types for tool types. For instance, in Australia, Webb & Domanski (2008) found that fine-grained silcrete is often used for blade-based implements, while medium-grained silcrete, with poor flaking properties, is often used for flake manufacture. Raw material selection in Oldowan contexts have been used to assess cognitive abilities and the ability to adapt to environmental change (Goldman-Neuman & Hovers 2009).

The research question

As discussed above, the large body of work produced by researchers on the Sibudu lithic assemblages makes it possible to see clear change through time in rock selection and technology at Sibudu (Cochrane 2006; Conard *et al.* 2013; de la Peña 2015b; Delagnes *et al.* 2006; Soriano *et al.* 2009, 2015; Villa *et al.* 2005; Wadley 2005).

As Garvey (2015) points out, the costs of procuring suitable materials often overwhelmingly exceeds the cost of tool manufacture. Importantly though, the collection and use of inferior material often produces a higher rate of failed manufacturing attempts (Garvey 2015). This trade-off between procuring high

quality rocks from more distant sources is significant because it points to the priority given to tool manufacture, or more likely, the priority given to a certain type of tool manufacture. This can be seen in studies that show the preferential use of high quality rocks for a specific tool type, where rock resources are not equitably distributed in the landscape, such as at Klasies River and Nelson Bay Cave (Henshilwood & Dubreuil 2011). This increased procurement cost is frequently driven by the need to match suitable rocks to specific tool types.

However, the selection of rocks can also provide information regarding aspects of past behaviour and decision making that need not correlate with the production of tools or their function, such as issues of style or for purposes of reciprocal exchange. As such no aspects of style or symbolic function will form part of this study. All rocks types represented in the Sibudu assemblages occur within 20km of the site. Therefore, no 'exotic' materials have been discovered at Sibudu and there is no need to interpret rock selection in terms of behaviours such as long distance trade or reciprocal exchange (Deacon 1995).

The purpose of this thesis is to establish the role that mechanical properties may have played in the production of the archaeological assemblage at Sibudu, and for this reason a sample assemblage from Sibudu will be analysed. While current research does take raw material types into account, very little research has been conducted to investigate the advantages and limitations inherent in these rock types. Research has been done on stone used in the construction of ancient buildings, such as the limestone quarries in Burgenland and Styria in Austria (Bednarik *et al.* 2014), and the basalt rock hewn churches of Lalibela (Asrat & Ayallew 2011) in Northern Ethiopia. However, these studies are of limited value for lithic analysis of artefacts because the tests conducted have different emphasis, for example on rock porosity, or focus on rocks not usually knapped, such as limestone.

Archaeologists have investigated mechanical properties of rocks purely for purposes of lithic analysis, (Braun *et al.* 2009; Cole 2002; Delgado-Raack *et al.* 2009; Webb & Domanski 2008; Yonekura *et al.* 2008), but these are relatively few considering the range of rock types used in the past, and the variability within rock types themselves. Also, some rock types have been studied as part of the heat treatment debate and centre on Silcrete, which is absent from Sibudu. Here rocks are characterised before and after heat treatment (Brown *et al.* 2009; Domanski & Webb 1992,1994). Excepting for work on the heat treatment of rocks, such as the work of Brown *et al.*, there is no research known to me that seeks to characterise rock properties and relate these to the effect they have on rock selection and the resultant site assemblages in Southern Africa.

The hypothesis of the study is that the toolmakers responsible for producing the Sibudu assemblages were aware that different rocks would behave differently during knapping and tool use, even if they did not understand the various mechanical properties attributed to these rocks. Subsequently toolmakers mindfully selected rocks because of these characteristics, and despite differences in rock distribution across the landscape.

Aims of the research

To answer research questions, I propose the following aims:

1) To characterise the mechanical properties of both dolerite and hornfels (the two dominant rock types used), using the following tests;

   a. Vickers hardness

   b. Impact toughness

   c. Elasticity

d. Surface roughness

e. XRF

2) To produce hornfels and dolerite flakes and use these to carry out a cutting and scraping experiment to assess how these rocks, with their known mechanical properties, respond to use.

3) To conduct a preliminary analysis of blades in a Howiesons Poort assemblage from Sibudu. These data will be explained in terms of the mechanical properties and use wear knowledge gained in in terms of 1) and 2) above. I will also provide some comparison of this material with published data from other Howiesons Poort sites.

Project layout

Chapter 1 - Introduction

This chapter introduces the Sibudu rock shelter and the lithic assemblages which range from the pre-Still Bay at the base of the current excavations, to the final MSA at the top. While it is necessary to provide context for the research question, these assemblages will be discussed in more detail in Chapter 3.

This chapter then introduces the research question, and lists the aims necessary to answer this question. Finally it provides a summary of the content and framework of each chapter in this thesis.

Chapter 2 – Published research paper

This paper uses literature to discuss the types of information that archaeologically recovered stone can provide. It introduces a wide range of tests that may be applied to lithic materials and the contexts in which they might be used. It then presents and discusses the results of a few mechanical tests on geological samples of rock recovered from the Sibudu area. The results are then briefly discussed in relation to Sibudu's archaeological lithic assemblages.

Chapter 3 – Background

This chapter provides contextual information on the location of Sibudu and rock distribution in the area. It then discusses the Sibudu assemblages in more detail, and establishes diachronic changes in rock selection and technology. Because a small lithic sample from Sibudu's Howiesons Poort will be used as a case study, the chapter continues to provide contextual information regarding the Howiesons Poort, and more specifically the Howiesons Poort at Sibudu.

Following this, the chapter discusses relevant mechanical properties and their influence during knapping and tool use. To do so, a discussion of fracture mechanics is included. Finally, it introduces the two rock types, dolerite and hornfels, chosen for study.

Chapter 4 - Methodology

For the purposes of this study, tests will be carried out on both geological and archaeological material. The archaeological materials used in these tests were recovered from Sibudu during excavations at the site, but were collected out of context during site cleaning and maintenance. An AMAFA permit (#0008/09)

was issued allowing them to be destroyed for analysis. This chapter presents the methods used to measure selected mechanical properties. Sample provenance and the method of sample preparation are also provided.

Where possible the properties that will be investigated include the accurate identification of rock type by thin section (Alberti & Cardillo 2015), a hardness test (Rollason 1970), an evaluation of grain size (Sibley & Gregg 1987), as well as a determination of fracture toughness (Cole 2002). A range of rock types is represented at Sibudu, including sandstone, dolerite, hornfels, quartzite and quartz (Cochrane 2006, Wadley & Jacobs 2006), but tests will be conducted only on dolerite and hornfels as they dominate the Sibudu assemblage.

To relate this data to the archaeology of the site I will conduct experimental cutting and scraping activities to assess edge wear by rock type and replicated activities. This section discusses production of the flakes used, the photography of flakes, and recording of flake dimensions. This section also describes the manner in which tools were used, and the variables that were held constant as far as possible during tool use, such as contact angle and contact pressure.

Finally, I present the structure used to analyse a sample of blades from the PGS (Pinkish Grey Sand) layer within the Howiesons Poort Industry (64.7± 1.9 ka to 61.7 ± 1.5 ka) at Sibudu. I also present the definition of types used to create a typological breakdown of the sample assemblage. This analysis is limited to blades to produce a sample that can simply and readily be compared to other sites, and several studies have characterised Howiesons Poort blades.

Chapter 5 – Results

The results of the mechanical tests will be presented. This will be followed by the results of the analysis of the experimental production and use of flakes. The results of the analysis of Howiesons Poort material will follow. Finally, a summary of results will be presented. No interpretation is provided in this chapter.

Chapter 6 – Discussion

This chapter will provide a discussion and interpretation of the results of mechanical properties of the rock types, the effect of these properties on knapping, and tool use. This will be followed by a discussion and interpretation of the results of the experimental production and use of flakes, particularly in terms of expected rock type behaviour. Finally, I will discuss the preliminary analysis of Howiesons Poort blades from Sibudu. I will consider this assemblage within the context of parts one and two of this chapter, namely mechanical properties, and the experimental produce and use of flakes. I will then compare some preliminary aspects of the sample assemblage to data published for the Howiesons Poort of other sites, such as Klasies River (Wurz 2000) and Rose Cottage (Soriano *et al*. 2007), and I shall suggest how rock availability and selection in the past may have influenced the appearance of the Sibudu collection.

Chapter 7 – Conclusion

This chapter will summarise the results of the project and how these meet the aims of the research and answer the research question. It will also provide a summary of the limitations of this research and comment on possible future research potential.

CHAPTER 2

PUBLISHED PAPER

Wadley, L. & Kempson, H. 2011. A review of rock studies for archaeologists, and an analysis of dolerite and hornfels from the Sibudu area, Kwa-Zulu Natal**.** *Southern African Humanities **23**: 87-101*

The following paper was published in the Southern African Journal of Humanities by Professor Lyn Wadley and myself. It covers the following fifteen pages of this thesis, or pages 14-34. It presents a review of the information that rocks from archaeological sites can provide. It covers a substantial range or methods available for testing rock chemistry and rock properties. It also discusses the importance of understanding rock distribution across the landscape, the differing mechanical properties of rock, and how these criteria affect rock selection in archaeological assemblages.

As a case study, methods used to characterise rock types present in the Sibudu assemblages, and limited results are presented as only geological samples are included and no archaeological material is discussed in this chapter. A full description of methods and results will be discussed in later chapters.

Professor Lyn Wadley wrote much of the paper. She also produced Fig 1, Fig 2, as well as Table 4. Professor Wadley also produced much of the context and examples throughout the paper, as well as much of the text, including the petrographic study of rocks and text regarding. Some of the text, such as concluding remarks and the use of rocks at Sibudu, was written by both authors.

In addition, I provided the methodology and results for the mechanical properties reported here. In the process, I provided Tables 1-3 and Figures 3-5. I also wrote most of the section on mechanical studies of rocks. Further, I researched and wrote the section regarding methods for the geochemical studies of rocks and Professor Wadley added many of the examples for their use. Professor Wadley's contribution and editing made the paper publishable.

CHAPTER 3

BACKGROUND

Chapter 2 provides some of the context for this study, but is limited in nature as no archaeological material was presented, and consequently the archaeological context is missing. This chapter provides further context for Sibudu, and the significance of the site within MSA research. This chapter then provides a discussion of the lithic assemblages from the Still Bay to the final MSA. In doing so it describes changes in technology and rock procurement strategies over time. Establishing that differences existed in the way that rocks were used in the past, and determining what these changes were, is the first step in explaining possible reasons behind the changing pattern of rock use.

This project therefore first establishes that change through time in both technology and rock selections have taken place at Sibudu. Why change the ways things have been done before? If changes in rock selection are not forced due to changes in rock accessibility, and if they are not merely serendipitous, then what reasons could be suggested for this change? A vast body of work has previously been produced on the technology and typology of the Sibudu collection. This project has a different focus. It will provide an answer based on differences in rock properties, and how different rock types might be better suited to changes in knapping, or reduction strategies, and changes in tool requirements. Sibudu is therefore an eminently suitable site for this study.

As the Howiesons Poort was chosen as a case study within which to interpret results of the mechanical properties as well as the experimental production and use of flakes, the Industry is presented in more detail here. This chapter also discusses fracture mechanics, and the effect of rock properties on both the knapping qualities and the edge wear qualities of rocks. Lastly it introduces the two rock types featured in this study, hornfels and dolerite.

Sibudu Rock Shelter

The Sibudu rock shelter is located approximately 40 km north of Durban and 15 km inland of the Indian Ocean (FIG. 1) (Wadley & Jacobs 2006). It is situated upon a steeply sloping ledge within a sandstone and shale cliff that geologically is within the Mariannhill Formation of the Natal Group (FIG. 2 & FIG. 3) (Clarke *et al*. 2007). The rock shelter is 55m long and 18m wide (Wadley & Jacobs 2006), and was formed by downcutting of the uThongathi River which currently flows past the base of the cliff between 10-25m below the shelter (Cochrane 2006).

The stratigraphic sequence is long and complex (FIG.4). The oldest date at present is 77.3± 2.6ka (Jacobs *et al.* 2008a) though excavations have continued below the layer with this date. The youngest date for the MSA sequence is 38.6 ± 1.9ka (Jacobs *et al.* 2008b). These late layers are overlain by Iron Age occupations, with no Later Stone Age (LSA) represented at the site. In total 21m^2 have been excavated to a variable depth. The deepest parts of the excavation predate the Still Bay Industry and are more than 3m deep (Wadley 2005).

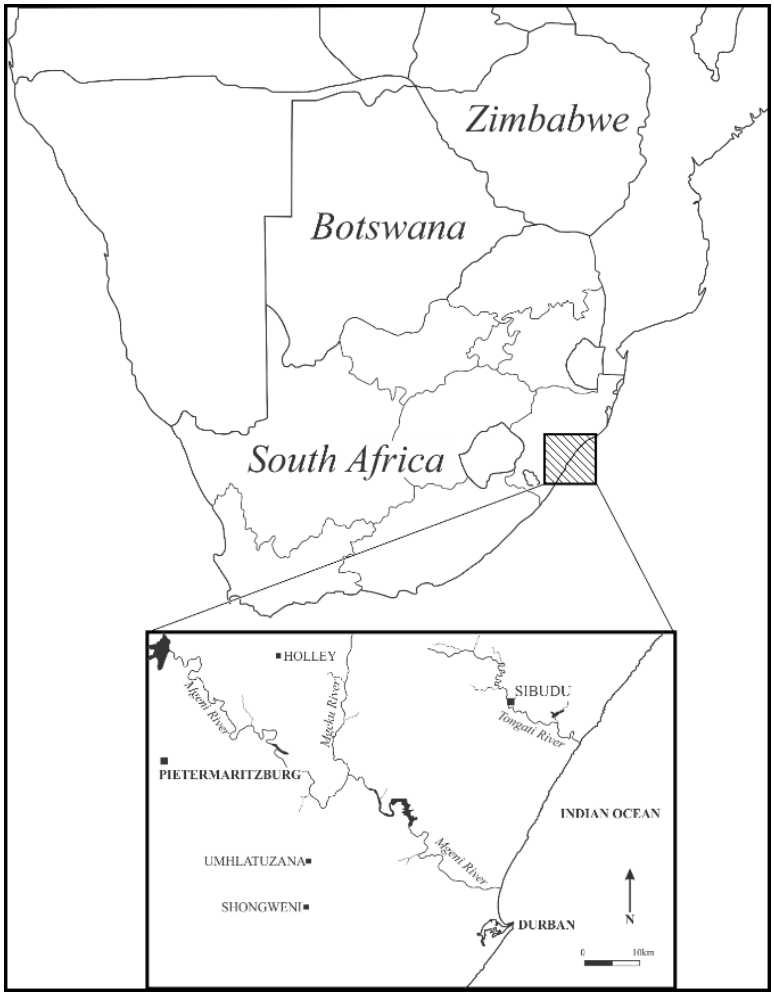


FIG. 1. Map of Southern Africa showing the location of Sibudu Cave on the Tongati (also spelled uThongathi) River. Courtesy of Lyn Wadley.

The site was excavated by Wadley from 1998 to 2011 and from then on by Conard. The site has been excavated following the natural stratigraphy, which is clear. However, where natural layers exceed 10cm in thickness, they are arbitrarily divided into spits within the layers (Wadley & Jacobs 2006). An analysis of the sediments (Pickering 2002) shows that they are poorly sorted and largely anthropologically derived, and many hearths and ash lenses are clear in stratigraphy (Wadley 2005). The MSA cultural sequence includes pre-Still Bay, Still Bay, Howiesons Poort, post-Howiesons Poort, late MSA and final MSA layers (Wadley & Jacobs 2006) and these will be briefly discussed later.

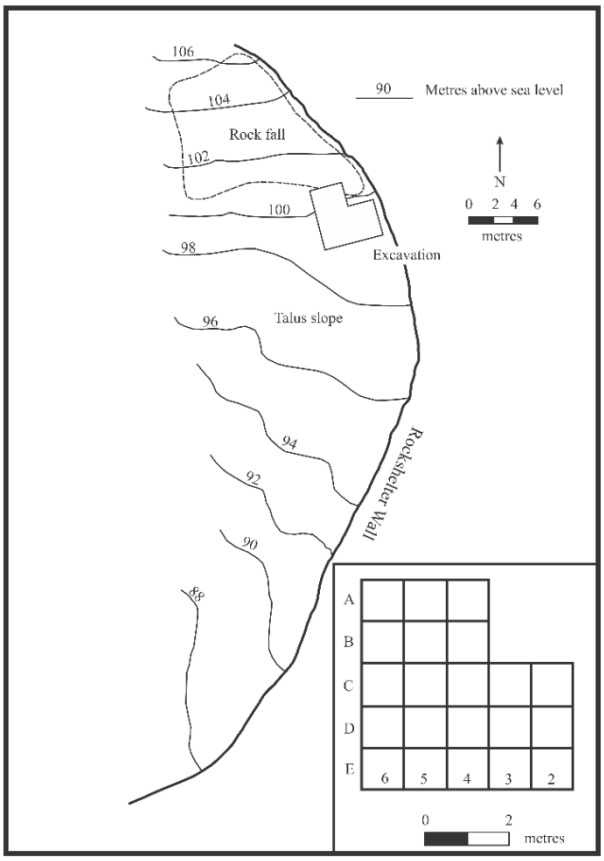


FIG. 2. Plan view of Sibudu Cave, showing the 21m^2 excavation. From Wadley & Jacobs 2006.

Rock exploitation and distribution

The local geology of the Sibudu area was discussed and illustrated in Chapter 2, and for the most part is not repeated here. However, two natural features are important for describing Sibudu's rock collection and they are discussed here. These include the uThongathi River, and the dolerite dyke near the site.

The rock types used at Sibudu are dolerite, hornfels, quartz, quartzite, some sandstone, and very rare instances of crypto-crystalline silicates (Cochrane 2006). Rock selection is discussed in general terms here to avoid repetition. It is discussed in more detail later in the section 'Establishing diachronic change at Sibudu'.



FIG. 3. Photograph taken from Sibudu Cave (facing south) with a view of the uThongathi River and riverine forest at the base of the site.

The dolerites found in the study area originate from intrusive Jurassic volcanism, and most occur as sills, though a dolerite intrusion close to Sibudu is a true dyke (Clarke *et al*. 2007). Dolerite sills in the area include the Mhlasini sill, which is a prominent, fine-grained sill that outcrops extensively in the inland region (Clarke *et al*. 2007). The dolerite dyke mentioned earlier occurs within 200 m of the shelter and it seems likely to have been the source of some of the tabular dolerite pieces.

Dolerite it the most commonly used rock at Sibudu. While dolerite is readily available in large pieces in the vicinity of the Sibudu rock shelter, fine-grained, or chilled dolerites are rare. Chilled dolerite forms at the margin of a dolerite intrusion and therefore cools quickly to form a narrow band of fine-grained rock. It is therefore not only rare, but also tends to occur in small pieces.

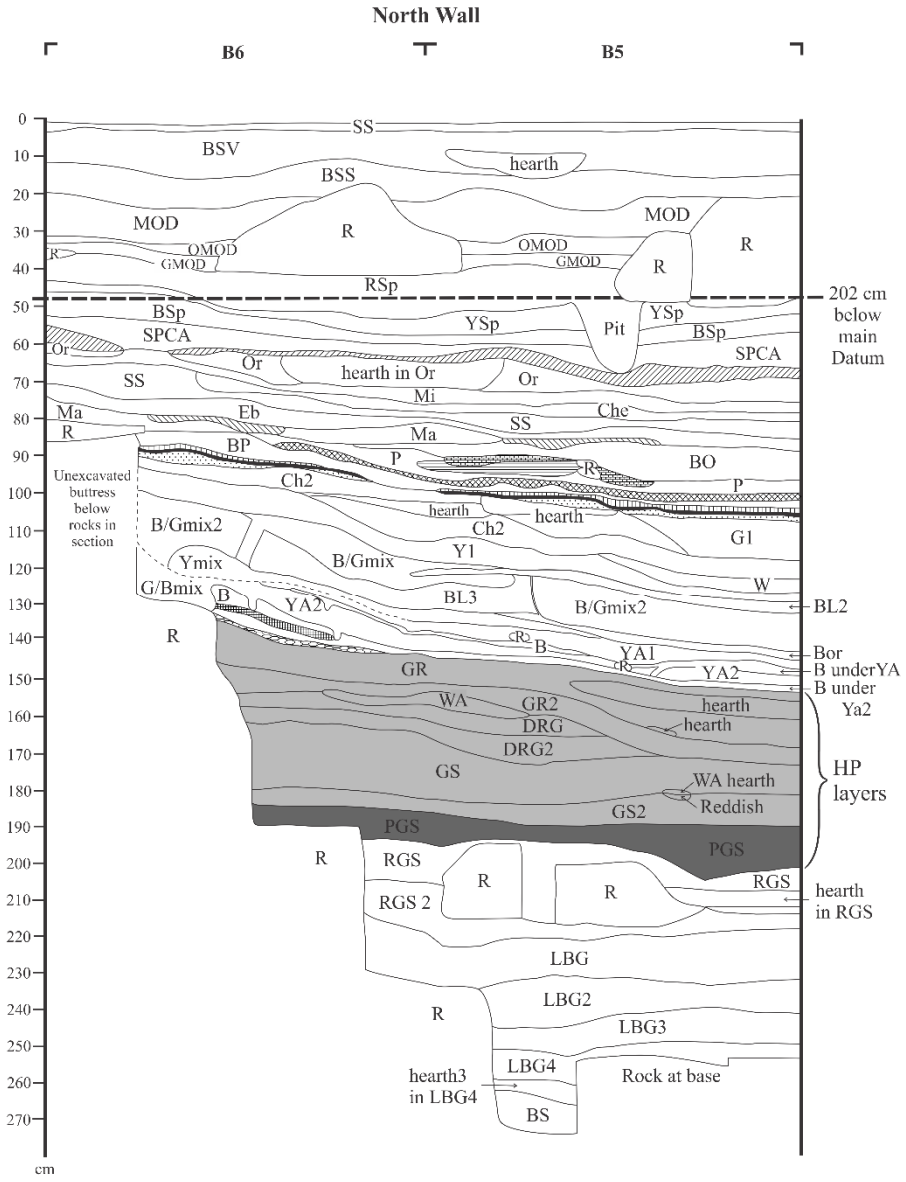


FIG 4. Sibudu stratigraphy (courtesy of Lyn Wadley). The Howiesons Poort levels are shaded grey, and the layer included in this study, PGS, is shaded in dark grey.

Sources of hornfels are more difficult to locate, but it is possible that outcrops near the site are now covered with sand (Wadley 2005). One source of hornfels occurs in the Verulam area on the Black Mhlasini River, within 15 km of Sibudu (Cochrane 2006). This hornfels occurs as thin slabs a few centimetres thick at most, and it is often not very well metamorphosed. Small water-worn pebbles of hornfels occur on the nearby coastline, but would have been too small for use.

Quartz and quartzite were also knapped though most often to a far lesser degree, and extremely rare examples of cryptocrystalline silicate knapping products occur. The uThongathi River below the site was a nearby source of dolerite, providing a nearby source of material ranging from cobbles to boulders. Some quartzite cobbles, and small quartz pebbles can also be found here. Quartz, in particular larger pieces, is absent from the river and is quite rare in the landscape, but occurs in exposed river terraces. Small quartz and cryptocrystalline silicate nodules occur in small pebble conglomerates that can on rare occasions be seen in the uThongathi River. The rounded cortex of cobbles and/or pebbles remaining on some Sibudu cores shows that rounded shapes such as cobbles were also selected, very likely from the uThongathi River.

Sandstone and dolerite of varying quality dominate the immediate area surrounding Sibudu. The sandstone derived from the cave walls has occasionally been flaked (Wadley & Jacobs 2006) but better quality of sandstone was usually procured, almost undoubtedly from elsewhere in the cliff within which Sibudu occurs.

Most of the rock used at Sibudu seems easy to procure (Cochrane 2006), and while there is no archaeological definition for local rocks, all materials were available within 20km of the site, which we consider local (Wadley & Kempson

2011). All materials can therefore be considered locally available. However, it cannot be ignored that dolerite is immediately available and required no distance to travel. Hornfels would have required significantly more time and energy to collect, even as part of embedded practices. Quartz would similarly have involved increased distance to transport, but because of its rarity would probably also have been collected as it was encountered. The uThongathi River does provide a nearby source of small pieces, however, purposeful collection of quartz from this source would have been time intensive as pieces are rare.

The significance of Sibudu

Sibudu has contributed enormously to our knowledge of the MSA. This has been possible because of the complex stratigraphy that can clearly be seen in most of the deposit, combined with a fine chronological record at the site (Wadley & Jacobs 2006). The stratigraphy is well preserved, and some layers preserve occupation floors (Goldberg *et al*. 2009); the post-Howiesons Poort in particular preserves occupation floors marked by discrete hearths. Where these hearths have hard, cemented surfaces, they are sometimes associated with ochre processing (Wadley 2010c).

The Sibudu sediments have also preserved residues on some stone tools, highlighting aspects of past behaviour. Lombard's (2008) study of the distribution of residues and use-traces on fifty-three Howiesons Poort segments suggest that most segments were probably hafted, most likely as inserts for hunting weapons. Lombard further suggests that changes are evident in both hafting materials and hafting configuration practises over time. Subsequent research that includes a study of impact fractures, residues and morphology implies that some segments may have been used as arrowheads (Lombard 2011).

Residue analysis (Lombard 2006, 2007) had shown the close relation between the distribution of ochre and plant gum on hafted stone tools, strongly suggesting that ground ochre was mixed into adhesives. Compound adhesives were used at Sibudu by 70ka, and used to haft similarly shaped stone segments (Wadley 2010c). The complexity involved in managing the variables necessary to produce the glue, and the processes involved in hafting the segments required the ability to multi-task, and advanced mental abilities (Wadley 2010c).

In recent research a residue adhering to a 49ka flake from Sibudu has been interpreted at paint (Villa *et al*. 2015). The residue consists of powdered ochre mixed with bovid milk and was neither an adhesive nor used for preparing animal hides. The mixture may have been applied to the skin, either for skin protection or as paint, or may have been applied to surfaces such as stone (Villa *et al.* 2015).

The preservation of floral remains at Sibudu has made it possible to track changing environments for the later MSA. Charcoal analysis (Allott 2006), reveals the presence of an evergreen forest, bordered by a warm, woodland savanna habitat for the Howiesons Poort. By ~58ka, though evergreen forest is present, there is a shift towards a drier environment. This is supported by data from carbonized seeds, nuts and the stones of fruits (Sievers 2006), where there is some indication of a shift from evergreen forest to deciduous woodland. Floral preservation has also revealed more familiar behaviours in the construction of bedding (Goldberg *et* al. 2009, Wadley *et al*. 2011), primarily using sedges, and possibly pest control, though the burning of bedding. The original construction of bedding at Sibudu occurs at approximately 77ka, where aromatic leaves were used to repel insects. Burning of the bedding material as part of site maintenance began at approximately 73ka. However, by approximately 58ka, this cycle of bedding construction followed by burning is intensified. This probably reflects population

fluctuations, and the proposed rapid population growth that followed a suggested bottleneck at 60ka (Wadley *et al*. 2011).

Sibudu is one of few sites that preserve fauna from the Howiesons Poort and post-Howiesons Poort transition (Clark & Plug 2008). For the period 65-58ka there is a clear change in the representation of animals. Those preferring a closed, or forested environment occur early on, whereas those preferring a predominantly open environment are more common immediately following the Howiesons Poort at about 58ka. This suggests that the evergreen forest enclosing the site was more extensive during the Howiesons Poort. The change in subsistence can be seen in the shifting focus from hunting small bovids, small mammals and suids in the Howiesons Poort towards seeking out large and very large bovids and equids, requiring a change in hunting strategies (Clark & Plug 2008).

Some research has recognized instances of enhanced working memory and complex cognition (Wadley 2010b; Wadley 2011, Wynn 2009). This can be seen in the inferred early use of snares and traps (Wadley 2010b) as a remote method of hunting. This behaviour has been proposed for the Howiesons Poort, and perhaps for the Still Bay Industry. The use of snares and traps is suggested by the high frequency representation of animals that prefer a forested habitat and that are susceptible to being caught in traps and snares. A high taxonomic diversity is typical of the use of remote capture as this form of hunting is not selective.

Small quantities of marine shell were recovered and interpreted as a raw material rather than a food source (Plug 2006). Possible shell beads of *Afrolittorina* shells occur in the Still Bay at Sibudu (d'Errico *et al*. 2008). Where undisputed beads occur, they convey some aspect of symbolism. The earliest well dated appearance

of beads in South Africa occurs in the Still Bay at Blombos Cave dated to c. 75ka (Henshilwood *et al*. 2004; d'Errico *et al.* 2005).

A proliferation of bone tool types occurs at Sibudu (Backwell *et al.* 2008; d'Errico *et al.* 2012), falling into broad typological classes, including pins, notched pieces, smoothers, *pièces esquillées*, pressure flakers, a possible projectile point, awls, and wedges. Sibudu bone tools show more variability in terms of morphology and function than contemporary sites, and *pièces esquillées* and smoothers are so far particular to Sibudu. Of the tool types present, bone pressure flakers are formerly only known from the Upper Palaeolithic, and d'Errico *et al.* (2012) argue that these occur 30ka earlier in the Howiesons Poort at Sibudu. These differences across sites in time, in variety, and in their early presence are seen to represent a local tradition as they are different or absent from contemporaneous southern African sites.

Establishing diachronic change at Sibudu

Looking at the assemblages and rock selection at Sibudu, there is both technological change as well as rock selection change throughout the sequence as is established in the text below (Table 2) (FIG. 4).

The Still Bay

The earliest assemblages have been termed pre-Still Bay, and have not yet been published. However, the Still Bay (70.5 ±.2.0 ka Jacobs *et al.* 2008a) has been well described in two studies by Soriano *et al.* (Soriano *et al.* 2009; Soriano *et al.* 2015) (Table 2).

The Still Bay has been seen as a cultural marker, with the carefully prepared points representing the 'uppermost level of technical skill', and associated with strong raw material selection (Henshilwood & Dubreuil 2011). Increasing social and material complexity is also attributed to this period.

For the Still Bay levels RGS and RGS2, lithic production was almost completely oriented towards bifacial tool production. The assemblage is overwhelmingly dominated by shaping by-products, which number 2169 out of an assemblage total of 2363. Of these, 63.7% are dolerite, 27.2% are hornfels, 4.1% are quartzite, 2.2% are sandstone, 1.7% are quartz and less than 1% are indeterminate or other (Soriano *et al.* 2015). The authors have been able to distinguish three types or shaping flakes, belonging to initial flaking, advanced flaking, and final shaping. Pressure flaking was not identified within any of these flaking types, even though pressure flaking has been suggested for the final stages of shaping at Blombos. The remaining flakes (n=4) and elongated flakes / blades (n=41) are short, of variable shape, and have large platforms. Only four cores were recovered and these are undiagnostic or broken.

At Sibudu tools on flakes occur, including unifacial points (n=68). The bifacial pieces (n=77) are almost exclusively foliate points (all but three, which were indeterminate types). Of these 49.4% are dolerite, 27.3% are hornfels, 22.1 are quartzite, and 1.3% are quartz. Many of these are fragments, in particular distal fragments. These points are variable, with maximum widths recorded of between 14mm-40mm. These points typically have broad bases with perfectly pointed, or slightly rounded tips. In some cases, either one of both edges of the tip are concave. These points often show reworking / resharpening.

These tools from Sibudu were produced using direct hard hammer percussion which was followed by thinning and retouch using a soft hammer (Soriano *et al*. 2015). In particular, ochre nodules were used as both abraders and as soft stone hammers for shaping flakes (Soriano *et al.* 2009). Shaping initially begins with internal percussion and during final shaping and resharpening it moves to marginal percussion. The low number of shaping flakes in quartzite and sandstone suggests that initial shaping was off-site, and preforms, not cores, were brought to site. For this industry dolerite and hornfels dominate though dolerite is favoured for tools. Hornfels bifacial tools were more frequently retouched, suggesting that dolerite edges are more hard-wearing and had a longer use-life. The authors (Soriano *et al.* 2015) suggest that the structure of these points implies a cutting function, and that these would have been hafted as spears and as knives.

The Howiesons Poort

The production of near-microlithic backed implements, and hafting in composite tools, has been considered a modern behaviour by many researchers (Deacon & Wurz 1996; Henshilwood & Dubreuil 2011; Wurz 1999). This period is also seen as a pene-contemporaneous cultural marker where it occurs. However, the timing and nature of the Howiesons Poort is also being questioned (Porraz *et al.* 2013a, Tribolo *et al.* 2013). The Howiesons Poort at Diepkloof has been dated to 105 ± 10 ka for the Early Howiesons Poort and 55.4 ± 2.0 ka for the post-Howiesons Poort (Tribolo *et al.* 2009, 2013*).* This is very different from most Howiesons Poort sites, which seem to occur within OIS4. This also suggests a much longer sequence for the Howiesons Poort, which also shows significant variation through time (Porraz *et al.* 2013a).

There is a distinct change in the Howiesons Poort towards the production of blades and backed tools (Table 2). Delagnes *et al*. (2006) suggest that the emphasis in selection for fine-grained rocks is linked to backed tool production.

The selection for fine-grained rocks (quartz and hornfels), diminishes in the upper layers, where the use of quartz crystal is almost absent and dolerite use increases (Table 1). The diversity in form of backed tools is the same for quartz, dolerite and hornfels. The backed tools include segments, partially backed pieces, trapeze-like forms, and obliquely truncated pieces.

Table 1. Frequencies of debitage and formal tools by raw material. Formal tool numbers are in parenthesis. After Delagnes *et al.* 2006. GR is the youngest layer.

Layer	Crystal quartz	Milky quartz	Hornfels	Dolerite	Indeterminate	Total
GR	8 (0)	45 (1)	153 (1)	426 (7)	22 (0)	654 (19)
GR2	17 (0)	44 (2)	176 (20)	422 (14)	13 (3)	671 (39)
GS	44 (8)	53 (1)	177 (18)	274 (5)	18 (3)	565 (35)
GS2	0 (0)	2 (2)	37 (15)	42 (4)	1 (1)	82 (22)

In a separate study, Soriano *et al*. (2015) found that 95% to 99% of backed tools are made on blades, revealing the importance of blade production in this industry. Blade production is stiffness controlled, where the flake being detached resists bending, and the crack extend down in the direction of the impact (see the section on knapping qualities of rocks) (Cotterell & Kamminga 1987, 1992). This property was observed by Soriano *et al.* (2015), when they noted that dolerite blades frequently had lipped platforms because the fracture has a bending initiation.

Studies of quartz pieces (de la Peña & Wadley 2014a, 2014b; de la Peña 2015a, 2015b) found that quartz was used differently to dolerite and hornfels throughout the Howiesons Poort. In particular, quartz was reduced through reduction of freehand prismatic cores. Quartz was highly valued and freehand quartz cores were subsequently recycled as bipolar cores.

A new core type for the Howiesons Poort at Sibudu is represented by rare, large prismatic blade cores. Blades were also produced on Howiesons Poort type cores (Villa *et al.* 2010) and cores on flakes (de la Peña & Wadley 2014a). A trend towards deliberate flake production of dolerite and hornfels flakes is evident in the presence of discoidal cores, while Levallois reduction is inferred from the presence of Levallois flakes, which occur only in dolerite.

de la Peña (2015a, 2015b) has described how quartz flakes were used to produce small bifacial tools, while quartz blades were used to produce backed tools.

The post-Howiesons Poort

Wadley consistently called the 58 ka occupations at Sibudu the post-Howiesons Poort (Wadley & Jacobs 2006). However Conard devised a new set of nomenclature when he began excavations in the eastern part of the excavation grid. The Sibudan (Conard *et al.* 2012), or post-Howiesons Poort assemblage (~58ka Cochrane 2006; Jacobs *et al.* 2008a; Jacobs *et al.* 2008b; Wadley and Jacobs 2006), initially involved a distinct increase in quartz, though selection by knappers soon reverted back to a preference for dolerite and hornfels (Table 2). While there is an abundance of dolerite close to Sibudu, Cochrane (2006) found that, for some Sibudu occupations, retouched flakes are almost three times more likely to be made of hornfels than unretouched flakes. Unretouched flakes, which may have been relatively expediently produced and used, are mostly (80%) made from dolerite (Cochrane 2006). While blades (length $\geq$26 mm) are often made of dolerite, bladelets (length <26 mm) are more usually made of hornfels. Possible explanations offered for these observations include the probable need to conserve hornfels, the small size of available hornfels nodules, or the knapping requirements of bladelet production (Cochrane 2006). Cochrane (2006) found

that a high proportion of split flakes occurred on dolerite, supporting his view that the toughness of dolerite promoted manufacturing errors due to the necessary force of the striking blow. Conard *et al*. (2012) recognize a range of unifacial reduction strategies and four distinctive tool types typical of the assemblage, including naturally backed tools, *biseaux* cleaver like), Tongati points and Ndwedwe points.

Tongati points are common in the material studied by Conard and colleagues. They typically have a short triangular functional end. The end, or tip is usually created through retouch, either symmetrical or asymmetrical, on both working edges of the point. Tongati points have a roughly trapezoidal base either through retouch or blank selection. Modification of the base precedes the production of the tip (transformative part) of the tool. This suggests hafting of the points. Ndwedwe tools were made using long, thick flakes and blades as blanks. Distinctive, strong, lateral retouch usually runs the entire length of both sides of the tool.

Naturally backed tools are made on large flakes. The blunt back is usually natural, but is occasionally retouched. The natural back is sometimes cortical, or may be the result of a split flake, or occasionally the flake has removed the edge of a core. Biseaux are tools that are structurally similar to a cleaver and are quite rare in the assemblage. These typically have an unmodified working edge and are not resharpened. Some bear traces of mastic and polish that imply they were hafted.

A total of 462 tools were recognised in the analysis of tools newly excavated by Conard and colleagues, of these 212 are Tongati points, 86 are Ndwedwe points, 36 are naturally backed tools and 10 are *biseaux*. These are the new types defined for the site. Twenty-five 'formal tools, 9 burin-like tools, 21 informal tools, and 53 broken tools are also recorded for the assemblage.

The late-MSA

An occupation hiatus of ~10 ka at the end of the post-Howiesons Poort is followed by the appearance of a late-MSA assemblage (47.7±1.4 Jacobs *et al.* 2008a; Jacobs *et al.* 2008b) which is characterised by flake and blade production (Table 2). Pointed forms and unifacial points in particular dominate. However, while debitage is almost equally split between dolerite and hornfels, 70% of tools and all bladelets (n=6) are of hornfels.

The final-MSA

Another occupation hiatus of ~12ka separates the late-MSA and final MSA assemblage (38.6 ± 1.9ka Jacobs *et al.* 2008) analysed by Wadley (2005) (Table 2). This flake based assemblage is characterised by bifacial tools and rare, hollow based points. Scrapers and a near equal mix of bifacial and unifacial points are common. Rock selection is interesting. Hornfels and dolerite are the most common rock types though most cores are quartz (65.7%). Despite the prevalence of quartz cores, quartz tools, flakes and blades are uncommon. Hornfels is preferentially selected for flakes (60.4%) and blades/bladelets (57%). It is also preferentially selected for retouched tools; 66.2% of points, 55.2% of scrapers, and 60.3% of other retouch. However, for backed tools only 45.5% occur on hornfels Wadley 2005).

These assemblages represent more than 30 ka of technological change and rock selection, and all the reasons for these changes are impossible to discern. Issues of identity and style may be proposed, but will not be considered here. While these undoubtedly have a profound effect on the production of assemblages, they cannot be considered here. Toolmakers had to be pragmatic and produce tools that were fit for everyday purpose at least most of the time. This is the context in which the rock mechanics and the experimental data will be considered.

Table 2. Change through time at Sibudu in terms of technology, rock type selection and interpretations by various analysts.

Pre-Still Bay phase 72.5 ± 2.0 ka Jacobs *et al.* 2008 Not yet published		
Still Bay Industry 70.5 ±.2.0 ka Jacobs & Roberts 2008		
	Technology	**Rock type selection**
Soriano *et al.* 2015	Almost completely oriented towards production of bifacial foliate points. Produced using direct hard hammer percussion followed by thinning and retouch using soft hammer.	Use of dolerite, hornfels and some quartzite. Quartzite debitage almost absent, suggesting production occurred mainly off site.
Soriano *et al.* 2009	Bifacial tools constitute the largest culture element of the Still Bay industry for layers studied (RGS, RGS2). Unifacial points are present	Dolerite (63.1 %) and hornfels (27.8 %) are most commonly used while other types (quartzite, sandstone, quartz and crypto-crystalline silica) are present in very limited quantities. Most of the Still Bay retouched tools are made from dolerite (48%), and specifically points and bifacial tools (54%) (Wadley 2007). Nearly 77 % of

		the flakes and blades, and nearly all the cortical flakes, are made in dolerite
Wadley 2007	Bifacially worked tools form 44% of all retouched pieces. Whole specimens are uncommon. Double pointed bifacial points may not have been designed to be reversible. Other tools include unifacial points, scrapers, a notch, scaled pieces, broken retouched pieces, and backed tools.	Dolerite dominates both tool and debitage components. Hornfels is the next most numerous for both tools and debitage. Unusually, quartzite makes up 15% of retouched tools. Hornfels and quartzite debitage is underrepresented, suggesting some knapping occurred off-site.
Howiesons Poort Industry 61.7 ± 2.0 ka Jacobs *et al.* 2008		
	Technology	**Rock type selection**
Delagnes *et al.* 2006	Lithic production of all raw materials in all layers studied is dedicated to blade production. Backed tools are the most common tool type and raw material selection for fine-grained rocks (quartz & hornfels) seems to be linked to backed tool production. No significant changes occur in the manufacturing process throughout the entire Howiesons Poort sequence.	Lower levels: increased selection for fine-grained rocks for backed tools, especially quartz but also hornfels, especially in the deeper layers. Crystal quartz backed pieces are restricted to the base and middle layers Upper levels: crystal quartz backed pieces are totally absent from the uppermost layers. Use of dolerite increases in upper levels.
Soriano *et al.* 2015	Unifacial points, end scrapers and burins are absent. Marginal percussion is used in blade production. Platform angles and technical features on blade platforms indicate use of soft stone hammer. Single platform cores were used and blades with bi-directional scars are rare. Formal tools are predominantly backed pieces. Between 95 to 99% of backed tools are made on blades.	The high frequency of lipped platforms on blades is due especially to the use of dolerite. Due to its nature (not as brittle as flint for example) bending initiation of the fracture occurs more commonly than hertzian initiations. Dolerite, hornfels and quartz predominate. There is no correlation between rock type and size of pieces, except for quartz, where it is due to size of available blanks.

de la Peña 2015b	Blade production dominates but a clear trend towards flake production can be seen in discoidal cores and Levallois flakes. Blades are produced on Howiesons Poort type cores, cores on flakes and rare prismatic blades. There is also a small bifacial component that occur only on quartz flakes.	Dolerite and hornfels cores are similar, but quartz and quartzite is used very differently, primarily for bipolar reduction. Quartz is used for small bifaces. Hornfels cores are overrepresented.
Wadley & Mohapi 2008	Segments can be separated into three populations, based on length, breadth, thickness and tip cross-sectional area. Most of these were probably parts of hunting weapons.	These three populations are; 1) quartz; short and deep 2) Hornfels; least standardised 3) Dolerite; longest, widest, thickest
post Howiesons Poort Industry / Sibudan Assemblage 58.5±1.5ka Jacobs *et al.* 2008a, Jacobs *et al.* 2008b		
	Technology	**Rock type selection**
Cochrane 2006	Formal tool types are dominated by scrapers and unifacial points.	Vast increase in quartz selection at the layers immediately above the Howiesons Poort.
Conard *et al.* 2012	The assemblage is characterised by unifacial reduction. Several reduction strategies are present, including Levallois-like cores, Howiesons Poort-like cores (Villa *et al.* 2010), platform cores and cores on flakes. Knappers often produced and selected thick, elongated blades and flakes as blanks for making tools. Knappers were willing to modify a wide range of flakes with differing morphologies. Four tool types were defined: Tongati points, Ndwedwe	Assemblage dominated by dolerite and hornfels. No rock selection for tool type has been observed, however, Ndwedwe tools are often made on dolerite blanks.

	tools (long thick blanks selected for distinctive, strong, lateral retouch), naturally backed tools, and biseaux.	
Hiatus 10.8±1.3ka Period of non-occupation may be associated with arid environment Wadley & Jacobs 2006		
late MSA 47.7±1.4ka Jacobs *et al.* 2008a, Jacobs *et al.* 2008b		
	Technology	**Rock type selection**
Villa *et al.* 2005	Mixed flake and blade production Two core types are distinguished: Cores with recurrent unidirectional or bidirectional flaking, only one of which can be considered a Levallois core, and bladelet cores. Pointed forms / unifacial points are the most numerous tool type. Dolerite and hornfels blades are produced with a hard hammer	Dolerite and hornfels constitute the clear majority of the assemblage. Debitage is split almost equally between hornfels (46%) and dolerite (50.5%). Hornfels is preferred for formal tool types (70%). All bladelet cores (n=6) are hornfels.
Hiatus 9.1±3.6ka Period of non-occupation may be associated with arid environment Wadley & Jacobs 2006		
final MSA 38.6.9±1.9ka Jacobs *et al.* 2008		
	Technology	**Rock type selection**
Wadley 2005	Oriented towards flake production rather than blades. Bifacial tools (which are not points) and hollow based points are rare but occur only in the final MSA. Scrapers are the most common retouched tool type. Points are the next most common tools, with bifacial points slightly more common	Hornfels and dolerite are the most common rock types. Most cores are quartz (65.7%) but quartz tools, flakes and blades are uncommon. Hornfels and dolerite tools may have been made or partially prepared off site. Hornfels is most commonly used for flakes (60.4%), blades/bladelets (57%), and

	than unifacial points. Cores are quite rare, and consists mostly of minimal and bipolar. Prepared cores and blade cores are rare.	for retouched tools – 66.2% of points, 55.2% scrapers, and 60.3% of other retouch. For backed tools 45.5% occur on hornfels, and 31.8% on dolerite, despite the irregular rock surface produced.
Villa *et al*. 2005	By-products, especially cores, are poorly represented, suggesting production occurs at least partly off-site.	

The Howiesons Poort

A Howiesons Poort assemblage has been chosen as a case study for this thesis. Layer PGS, which forms the base layer of the Howiesons Poort, has not yet been as well studied as many other layers. It is also an important industry that is presently widely published and debated and subject to revision. Therefore because this Industry provides the context for this study, it is discussed in more detail in the section.

The Howiesons Poort is a Middle Stone Age Industry which occurs widely across Southern Africa south of the Zambezi (Deacon 1992), though predominantly south of the Limpopo River (Lombard 2005a). Howiesons Poort sites have a wider distribution than the Still Bay, and are more numerous (Henshilwood & Dubreuil 2011). Deacon (1992) has suggested that this range of distribution marks the area within which a shared concept of artefact style and information exchange occurred. The Industry was first excavated and defined by Stapleton and Hewitt (1927, 1928) at the Howiesons Poort rock shelter, near Grahamstown, South Africa. Primarily blade-based it is characterised by backed tools, segments and trapezes (Deacon 1995; Deacon & Wurz 1996), though the original collection includes burins and trimmed points (Stapleton & Hewitt 1927, 1928). Because

these tool types bear such a close resemblance to Later Stone Age microlithic industries, and because the type site is a single component site, the Howiesons Poort was at first thought to be an intermediate industry between the Middle and Later Stone Ages (Volman 1984).

Excavations at Klasies River Main Site by Singer and Wymer (1982) entrenched the industry firmly within the MSA. However, due to abrupt changes in typology and a shift in raw material selection they felt the Industry formed a discrete cultural entity so dissimilar to those preceding it that they suggested it be attributed to an invasion of different people. They (Singer & Wymer 1982) felt that the change to backed tools, small, almost microlithic artefacts and selection for fine-grained rocks represented a break in the continuum. However, Thackeray (1989) could show that while clear change was evident, there was continuity between the Howiesons Poort and preceding assemblages. This was particularly evident in the continued presence of typical MSA flake-blades made of quartzite in the Howiesons Poort. Thackeray (1989) describes the introduction of Howiesons Poort type artefacts as introducing a novel typological element to an established sequence.

While initial attempts at dating were beyond the range of conventional radiocarbon dating the Howiesons Poort has been seen as a distinctive horizon marker with assemblages pene-contemporaneous across southern African sites (Deacon 1992), though this view is questioned by current research at Diepkloof (Porraz *et al.* 2013a, 2013b). They (Porraz *et al.* 2008) suggest that the transition from Still Bay to Howiesons Poort assemblages seen at some sites fails to represent all the variation that occurs within this industry. They argue that the Howiesons Poort has a far longer duration at Diepkloof, exhibiting far more variability than has thus far been expected. (Porraz et al 2013a, 2013b). The difficulties in achieving consensus on dating both the earliest and final expression of the Howiesons Poort is compounded by the confusion in dating, especially the

Diepkloof site (Jacobs *et al.* 2008, Jacobs & Roberts 2015, Tribolo *et al.* 2013, Feathers 2015).

TL and OSL dates for Diepkloof place the Still Bay to early Howiesons Poort there to 104 ± 3 ka, well within Oxygen Isotope Stage 5 (OIS5) (Tribolo *et al.* 2013; Porraz *et al.* 2013a, 2013b). Consequently, the authors suggest that various technical traditions co-existed in southern Africa during OIS5 and OIS 4. However, Jacobs *et al.* (2008) produced an OSL date of 72.1 ± 1.7 ka for the same period. There have been further discrepancies in the dating, with Tribolo *et al.* (2013) dating the Intermediate Howiesons Poort (bottom part), to 82 ± 2 ka, and Jacobs *et al* (2008) placing it at 63.3 ± 2.2 ka. Jacobs & Roberts (2015) have since provided an updated chronology for Diepkloof, addressing possible sources of error in their model suggested by Tribolo *et al.* (2013). Unfortunately, there is still no agreement in the dates produced. Feathers (2015) has suggested that the rejection criteria for certain saturated quartz grains needs to be revised, and that doing so results in older age results for samples. Neither Jacobs *et al.* (2008, 2015) nor Tribolo (2013) have accounted for this in their models (Feathers 2015). While the older dates from this model seem to favour the Tribolo *et al.* (2013) dates, there is as yet no resolution. One of the problems is that the two dating specialists sampled different parts of the site and the archaeologists have not yet successfully linked the stratigraphy of the two areas.

A range of methods has been used to date various Howiesons Poort assemblages, though reaching a consensus on dates remains a problem. Radiocarbon dates tend to produce young

dates and most should probably be considered minimum ages (Wadley 2008) not useful for estimating the true age of the Howiesons Poort. Most Howiesons Poort assemblages seem to occur within OIS 4 (Wadley 2008; Wurz 2013). Klasies River, Boomplaas (Vogel 2001), Pinnacle Point (Brown *et al.* 2012), Klipdrift

shelter (Henshilwood *et al.* 2014), Sibudu (Table 2) (Jacobs & Roberts 2008), Rose Cottage (Valladas *et al*. 2005), Border Cave (Grun *et al.* 2003), Umhlatuzana (Lombard *et al.* 2010) and Die Kelders (Feathers & Bush 2000) fall comfortably within the OIS 4 framework. Melikane (Stewart *et al.* 2012) in Lesotho has an OSL date of 61± 3 ka, placing it comfortably within OIS4. Wadley (2015) has provided a comprehensive collection of dates for Middle Stone Age sites, including dated Howiesons Poort sites, for southern Africa.

Currently the Howiesons Poort is recognised on typological grounds, in particular the presence of backed pieces. Many researchers are now also describing the technology of the Industry (Wurz 2000; Soriano *et al.* 2007; Porraz *et al.* 2008; Clarkson 2010, Porraz *et al.* 2013a; Soriano *et al.* 21015; de la Peña 2015a, 2015b) to promote our understanding of temporal and regional diversity.

Clarifying the dating of these sites has added significance because the Howiesons Poort, and preceding Still Bay, are associated with innovation and increasing behavioural complexity (Henshilwood & Dubreuil 2011) synonymous with the Upper Palaeolithic of Europe (Wurz 2013) and the expansion of modern humans out of Africa (Brown *et al.* 2012). New behaviours appear in the Still Bay and the Howiesons Poort such as pressure flaking at Pinnacle Point (Mourre *et al.* 2010), engraved ochre at Blombos (Henshilwood 2009) and Klein Kliphuis (Mackay & Welz 2008), the heat treatment of silcretes as at Pinnacle Point (Brown *et al.* 2009; Wadley & Prinsloo 2014), the use of a soft stone hammer associated with the production of bifacial points (Soriano *et al.* 2009), use of marginal percussion in blade production (Soriano *et al.* 2007), and worked bone at Klasies River (Singer & Wymer 1982), and at Sibudu (Backwell *et al.* 2008; d'Errico *et al.* 2012). Engraved ostrich eggshell, which implies the use of water containers, occurs at Diepkloof (Texier *et al.* 2010) and Klipdrift Shelter (Henshilwood *et al.* 2014). Other complex behaviours are the use of ochre and mastics in hafting technology (Lombard 2007; Wadley *et al.* 2004, Wadley 2010a) and the

suggested use of traps and snares for hunting small game at Sibudu (Wadley 2010b).

The marked change in Howiesons Poort lithic assemblages is frequently interpreted as a response to climate change. At Klasies River the Howiesons Poort coincides with a period of sea level regression equated with a glacial event. This produced a cooler and dryer environment in that region, as indicated by biological and isotopic data (Deacon 1989). Deacon (1989) argues that the occurrence of the Howiesons Poort at a time of variable and deteriorating climate reflects a method of coping with environmental stress. Henshilwood is in agreement, suggesting that a colder and dryer climate prevailed in the cape, based on sea level regressions and sea surface temperatures. Using regional marine and terrestrial evidence, Chase (2010) argues that for marine oxygen isotope stage 4, or the period ~74-58 ka, conditions were relatively cool and moist. At Sibudu there is data to indicate a cooler environment, and data suggests it was humid or moist at the time (Wadley 2008). At Diepkloof, a thousand kilometres from Sibudu (Porraz *et al.* 2013b), there is no floral (Cartwright 2013) or faunal (Steele & Klein 2013) data that indicate dramatic climate change in the MSA sequence.

The industry has traditionally been associated with a change in raw material selection towards fine-grained, siliceous and occasionally 60 or non-local rocks, requiring long distance travel or exchange (Singer & Wymer 1982; Deacon & Wurz 1996; Ambrose & Lorenz 1990). Using raw material data from Klasies River, Ambrose & Lorenz (1990) proposed a model of behavioural modernity based on lithic foraging strategies Deacon and Wurz (1996) further point out that raw material choices at Klasies River have no functional significance as tools of both local and non-local rock share the same attributes, and that the local quartzite in fact produced a more robust tool. Consequently, tools made of non-local material potentially had enhanced value as exchange items (Deacon & Wurz 1996). Porraz *et al.* (2008) describe the fine-grained matricial silcretes favoured

by knappers at Diepkloof as ‘exotic’, with a distance to source exceeding 40km or even perhaps 70km from site. At Sibudu and at Rose Cottage Cave there is no change towards the selection of ‘exotic’ fine-grained rocks (Soriano *et al*. 2007). At Sibudu, there is no use of ‘exotic’ rocks because all materials are available within 20km of Sibudu.

Minichillo (2006) argues that many of the rocks termed ‘exotic’ or non-local at Klasies River were in fact available locally. Lower sea levels at the time may have improved access to rocks and rock variability. Further, rocks deemed non-local do in fact occur locally, but in small numbers. Minichillo therefore argues for an increase in time spent procuring rock locally rather than seeing a need for increasing foraging range. This model would also be consistent with more time spent digging for rock (Frahm *et al.* 2016). In addition to rocks available locally, rock resources would have been collected as part of a seasonal round (Blair 2010) and Daniel (2001) argues that the distribution of good quality stone weighed heavily in foraging considerations.

The frequency of tool types is not constant across sites, with segments more common at Sibudu (Wadley 2008), Border Cave (Beaumont 1978) and Klasies River (Wurz 1997) and backed blades and obliquely backed blades more common at Rose Cottage Cave (Wadley 2008, Wadley & Harper 1989). The size and shape of segments vary considerably at Sibudu depending on the rock type used (Wadley & Mohapi 2008). Scrapers are quite rare at Rose Cottage Cave, Sibudu Cave and Klasies River (Lombard 2005a) but common at Montagu Cave (Keller 1973) and Umhlatuzana (Kaplan 1990). There is therefore variability in Howiesons Poort assemblages even where they are in close proximity (Wadley & Harper 1989), and at Diepkloof there is an argument for both regional and temporal variability (Porraz *et al.* 2013b).

The Howiesons Poort at Sibudu

The Howiesons Poort is represented by three stratigraphic layers (FIG.4), Grey Rocky (GR), Grey Sand (GS) and Pinkish Grey Sand (PGS) and covers $6m^2$ of excavation. PGS is the earliest layer of the Howiesons Poort assemblage at Sibudu and lies directly above the uppermost Still Bay layer. At Sibudu, the Howiesons Poort occupation was brief, and ranges between 61.7 ± 1.5ky to 64.7 ± 1.9ky (Jacobs & Roberts 2008) (Table 2). While there is a hiatus of approximately six thousand years between the Still Bay and the formation of layer PGS, no sterile layer accumulated between the two assemblages (Soriano *et al*. 2015). As such layer PGS exhibits some mixing of Howiesons Poort and Still Bay material and was not included in studies by Soriano *et al*. (2015) of Howiesons Poort and Still Bay assemblages.

The environment surrounding Sibudu at this time would most likely have been variable, and there is data to suggest a cooler environment with humid or moist conditions (Wadley 2008). The riverine habitat was probably quite constant throughout occupation of the site because sedge nutlets from *Schoenoplectus* sp., which only grows in standing water, are present in most layers, including those of the Howiesons Poort (Sievers 2006). Identification of charcoal has also shown the presence of riverine forest taxa such as yellowwood (*Podocarpus* spp.), as well as heather (*Erica* spp.) (Allott 2006). Faunal analyses are in accordance with a varied habitat both cooler and moister than present. The presence of vlei rats (*Otomys irroratus*) (Glenny 2006), freshwater molluscs (Plug 2006), the Gambian giant rat (*Cricetomys gambianus*) (Clark & Plug 2008), Geoffroy's horseshoe bat (*Rhinolophus clivosus*) (Glenny 2006) and the blue duiker (*Philantomba monticola*) (Clark & Plug 2008) all point to a climate not as hot as present and moist rather than arid, with nearby forest (Wadley 2008). While hunting centred on species that preferred a forested or closed environment, the presence of some zebra and roan antelope indicate access to a savanna landscape.

In terms of rock selection dolerite and hornfels are almost always the dominant rock types used (Table 2). This pattern is consistent for the Still Bay and Howiesons Poort, though in the post Howiesons Poort assemblage, this dominance temporarily gives way to quartz and quartzite (Cochrane 2006), but the pattern is restored in the succeeding late MSA and final MSA assemblages. Therefore, while there are rare resources, such as quartz and cryptocrystalline sillicate, and relatively distant sources, such as for hornfels, there are no exotic, fine-grained rocks that were used within the Howiesons Poort. In contrast, it is the rock selection in the post-Howiesons Poort assemblage that is most notable. Therefore, in all but the post-Howiesons Poort assemblages, knappers were prepared to carry rocks for approximately 15km, as well as carry the material up the cliff face, while dolerite was available in abundance immediately below the site.

A study by Delagnes *et al*. (2006) specifically looking at quartz backed pieces in the Howiesons Poort at Sibudu, found raw material changes observed in the Sibudu sequence mirrored by those at Klasies River. Frequencies of fine-grained, non-quartzite materials increased towards the middle of the Howiesons Poort sequence, then declined in the uppermost levels (Wurz 1997). Similarly, at Sibudu the use of fine-grained rock types (quartz and hornfels) decreases towards the middle and upper layers. Though there is a change in the emphasis of rock types used, there is no significant change in the manufacturing process of quartz backed pieces throughout the Howiesons Poort, irrespective of rock type (Delagnes *et al*. 2006).

Table 3. Sibudu Howiesons Poort stratigraphic layers, dating using OSL (after Wadley 2008).

Layer	Age in Ka
Grey Rocky (GR) Grey Rocky 2 (GR2)	61.7 ± 1.5 Jacobs & Roberts 2008
Grey Sand (GS) Grey Sand 2 (GS2)	63.8 ± 2.5 Jacobs & Roberts 2008
Pinkish Grey Sand (PGS) Pinkish Grey Sand 2 (PGS2) Pinkish Grey Sand 3 (PGS3)	64.7 ± 1.9 Jacobs & Roberts 2008

Table 4. Summary of non-quartzite raw material usage in Klasies River Cave 1A, D sample, after Wurz (2000).

	Quartzite %	Non-quartzite %
MSA III (n=4993)	**93.9**	**6.7**
Howiesons Poort (n=10 210)	**67.1**	**32.9**
Upper MSA II (n=12 900)	**77.9**	**2.1**
Lower MSA II (n=9454)	**99.5**	**0.5**
MSA I (n=9944)	**99.8**	**0.2**
Total = 47 501		

Wadley & Mohapi (2008) found that there were statistically significant differences between the sizes of segments made of dolerite (n=23), hornfels (n=43) and quartz (n=13). While dolerite produced the longest, widest and thickest segments, quartz segments are the shortest and narrowest. Segments are interpreted as primarily being parts of hunting weapons. Use-trace analysis reveals animal products on the cutting edges (Lombard 2006, 2007, 2008).

Further analysis revealed a high incidence of ochre and resin residues, suggestive of hafting (Lombard 2006) using both bone and wooden hafts (Lombard 2008). The quartz segments have a highly standardised shape which is probably linked to hafting requirements, possibly for use as arrowheads (Lombard & Pargeter 2008). The attributes of these segments fit within the known ranges of arrowheads irrespective of the angle at which they were hafted (Wadley & Mohapi 2008). A use-trace study of sixteen microlithic backed tools further supports the argument for the use of bows before 60 ka (Lombard 2011). These quartz pieces seem to have mostly been hafted in a transverse position, while some may have been hafted diagonally, signifying that hunting technologies were adaptable. Using use-trace studies, residue studies, and contextual information Lombard and Phillipson (2010) have presented a clear argument for stone-tipped arrow use. If the interpretation of the quartz arrowheads is correct then lithic projectile points occur before 60 ka ago, and may mark the first occurrence of lithic arrowheads in the MSA.

In addition to the production of blades and backed pieces, de la Peña (2015a, 2015b) has found extensive evidence for the use of bipolar core reduction, as well as the incidence of rare large prismatic blade cores previously not described for these layers at Sibudu. She has also described the presence of biface production in the form of small quartz bifacial points in layer Grey Rocky, and discoidal cores and Levallois flakes that indicate intentional flake production (de la Peña 2015a).

At Sibudu the Howiesons Poort is followed by a hiatus of approximately 10 ka (Wadley & Jacobs 2006), and the post-Howiesons Poort is dramatically different. The backed pieces disappear and the most common tool type is the unifacial point, as well as other pointed forms. At Klein Kliphuis rock shelter, the transition to post-Howiesons Poort is gradual (Mackay 2011). Changes in rock type selection as well as in the size and shape of flakes and cores are incremental. Mackay

(2011) finds that this data does not support the theory of explaining the appearance and disappearance of the Howiesons Poort in terms of population expansion and contraction.

Mechanical Properties and their influence on knapping and tool edges for hornfels and dolerite

Dolerite and hornfels

As dolerite and hornfels were the most frequently selected rocks they have been tested (Chapter 4) to characterise their mechanical properties. I have also produced dolerite and hornfels flakes and used them experimentally to understand how these rocks behave during use. These rocks are therefore described below (FIG. 5). The following discussion concerning mechanical properties and their effect on knapping and edge quality provide a context for assessing the differences between these two materials.

Dolerite

Dolerite, also sometimes knows as diabase (Johannsen 1927) is an igneous rock and as such is classified on the basis of composition and texture. The composition of the rock is determined by the chemistry of the magma. There are two major types of magma, basaltic and granitic. Dolerite is produced by basaltic magma, which is typically lower in quartz (Hamblin 1989). Dolerite is intermediate in colour, greyish to salt and pepper, having some dark minerals, pyroxene and hornblende, and lighter minerals, plagioclase (Neuman *et al*. 2011). The physical properties of dolerite vary depending on grain size, chemical composition, degree of weathering and physical defects within the rock (Sloane 1991).

Igneous rocks are either intrusive, cooling slowly beneath the earth's surface, or extrusive, where they reach the earth's surface and cool rapidly. As magma rises, pressure is reduced and dissolved gases separate and collect as bubbles in the solidifying rock. These are sometimes preserved as small spherical or ellipsoidal cavities, called vesicles (Hamblin 1989).

While rapid cooling produces a finer-grained rock, slower cooling produces larger crystals. Dolerite forms in dykes and sills to produce a phaneritic texture, where the grains are large enough to be seen without a microscope, though the margins of dolerite intrusions may cool rapidly to produce a fine-grained chilled dolerite (Neuman *et al*. 2011). This variable grain/crystal size is one of the most important factors affecting the mechanical properties of dolerite, and therefore the knapping and subsequent edge-wear of a tool.

Hornfels

Hornfels is a metamorphic rock which usually has a sedimentary origin. Though lava, schists and other rocks can be baked into a hornfels, the parent rock is typically shale (Hamblin 1985). Solidified mud and clay deposits form shales, or mudstones, where the rock particles are less than $^{1}/_{16}$mm in diameter. These deposits are soft and weather rapidly. However, igneous intrusions can cause partial or complete recrystallization in the surrounding rock through contact metamorphism, altering mudstones to produce a hornfels. This is a very hard, dense, fine-grained rock where the grains are usually microscopic. Platy minerals have a random orientation and the rock is nonfoliated, and usually dark in colour (Hamblin 1985).



FIG. 5. Coarse dolerite (left) and hornfels (right).

As the next step in the chaîne opératoire, knappers progressed from knowledge of the materials available to them, and the costs involved in procuring them, to rock selection. With a long history of mindful rock selection and changing technology over time (Table 2), Sibudu knappers chose rocks for a complex variety of reasons. One of these would have been an appreciation for how rocks behaved during tool production and tool use. In turn it is important for archaeologists to understand the benefits and constraints of the materials available to people in the past. This is necessary for archaeologists to understand the technology and changing typology and technology of assemblages at sites like Sibudu.

Below is a discussion of some mechanical properties of rocks and how these relate to the principles of fracture and wear. The principles of fracture are relevant both the initiating fracture during knapping as well as to fractures that occur during tool use. These properties are also relevant to manner in which tools acquire wear. This is particularly important to the efficacy and durability of a tools working edge, and the subsequent life-cycle of the tool.

Below is a discussion of the mechanical properties and how they affect knapping and the edge qualities of tools. In Chapter 4 I will present the methodology used to test some mechanical properties of hornfels and dolerite, and these rocks are described at the end of this chapter.

Mechanical properties

Did knappers select rocks because of their knappability or because of edge qualities associated with rock types? With recent research, we now know that knappers have been making stone tools for more than three million years

(Harmand *et al*. 2015), and the beginnings of higher quality rock selection and transport can be seen from 2.0 Ma onwards (Goldman-Neuman *et al.* 2012). The intentional selection of rocks by stone-tool-using humans in the deep past is significant because it implies an understanding of the way in which rock attributes affect reduction sequences and edge-wear properties of tools (Goldman-Neuman & Hovers 2009, 2012; Klominsky *et al*. 2004). This means that toolmakers were knowingly selecting rocks they knew would work better, while unknowingly selecting for certain mechanical properties inherent in these rock types.

The knapping process itself, as well as fracture that occurs during use, is governed by principles of fracture mechanics, where each material embodies a set of unique properties. When assessing an assemblage, it is important to understand the constraints imposed by the materials worked, only thereafter can cultural choices be inferred (Inizan *et al.* 1999). Skilled knappers could overcome many of the restrictions of poor quality rock (Erin *et al.* 2014), and for only very few rock types, such as sanukite, is flake production for example difficult, and the production of blades almost impossible (Inizan *et al.* 1999). It is more common that poor quality rocks will produce poor results rather than preclude knapping altogether (Garvey 2015; Inizan *et al.* 1999). Knappers would have been concerned about aspects of rock types available, for instance; how easily does a rock type fracture, and how durable will the flake edge be?

In solid mechanics, as material undergoes three successive responses to stress, or the 'force per unit area', (Whittaker *et al.* 1992: 15). In response to a relatively small force, the material undergoes elastic deformation, returning to its original shape once the load is removed (Cotterell & Kamminga 1992). With increased stress the material undergoes plastic deformation. At this point the material no longer returns to its original shape when the load is removed and the material is permanently deformed. The third response is fracture as the ultimate strength of a

material is exceeded. This is the amount of energy a knapper is required to use to detach a flake from a core.

The toughness of a material is its ability to resist fracture. According to Altingdag and Guney (2010: 2109) "*there is no standardized universally accepted brittleness concept or a measurement method defining or measuring the rock brittleness exactly*." However, brittle materials such as glass, or various minerals and rocks, undergo little or no plastic deformation before they fracture under load (Cotterell & Kamminga 1992). They therefore fracture abruptly with no noticeable change in shape before failure.

Griffith (1921, 1924) pioneered work in brittle fracture, using glass as the medium in his studies. In a perfectly brittle material, toughness is a measure of the energy required to break the cohesive bonds in the molecular structure at the crack tip (Lawn & Marshall 1979; Webb & Domanski 2008). However, materials have a higher theoretical strength than in practice. Griffith proposed that the presence of microcracks in the surface of glass, and Lawn (1993) confirmed their presence in rock. The presence these microcracks or flaws in a brittle material makes it relatively weak (Cotterell & Kamminga 1992). Under load, elastic strain, or deformation, is evenly distributed throughout the body, but where there is a notch or flaw in the material under load, an area of local stress occurs within the area of average stress. This ratio is the stress concentration factor; the elastic strain (deformation) is no longer distributed evenly at every point in the body but become concentrated at the point of a flaw, and thus fracture occurs more readily at the flaw (Cotterell & Kamminga 1992).

Even brittle rocks are elastic to a point. If they weren't, rocks would shatter rather than allow for controlled fracture during knapping. When a material is

experiencing deformation as a result of applied stress, elastic strain energy is the potential energy stored in the strained, or deformed, portion of the rock. (Cole 2002). More elastic rocks can deform further before fracture, or store more potential energy. When a crack does form, some of this energy is used in crack propagation, and some energy is expended in returning the deformed material to its original state (Cole 2002).

However, rocks have complex structures that influence their toughness. Mineralogy, grain size, interlocking grains, cracks and pores are some of the factors affecting the strength and toughness of materials (Leudke 1992). As the fracture moves through the rock, energy is expended in tracing a path either through or around grains or crystals. When a fracture traces a path around grains (intergranular) less energy is absorbed because the surface atoms are not bonded to the maximum number of the nearest neighbour, as is the case during cleavage of a crystal lattice (Davidge 1979, Faulkner 1972, Webb & Domanski 2008), For this reason, fine-grained, isotropic rocks are often less tough and more likely to produce a smooth fracture surface than coarse-grained rocks (Lawn & Marshall 1979). The mineral quartz for instance frequently shatters, largely due to the presence of internal flaws, and its relatively low compressive strength (Tallavaara *et al.* 2010). Conversely, in tough rocks fracture is not easily propagated once it occurs. The microstructure of some rocks may cause crack branching to occur, which dissipates the energy available to propagate the fracture (Webb & Domanski 2008).

The roughness, or varied micro-topography, of hornfels and dolerite is dependent on grain/crystal-size and on whether the rock contains inclusions with a hardness different from that of the parent rock. Hardness can be described as resistance to damage such as scratching, penetration or wear (Rollason 1970). Hardness relates in part to the stage of plastic deformation, or a material's ability to resist permanent deformation. Materials that can absorb a considerable load during this

stage tend to be hard and resistant to damage. This property is not as important to flaking as it is to the subsequent durability of a tool's edge. While hard rocks produce a robust edge resistant to wear, they are not necessarily brittle and may be difficult to flake.

Bril *et al.* (2011) provide an excellent summary of the elements of conchoidal fracture. To successfully detach a conchoidal flake the appropriate point of percussion must be struck with sufficient precision. At the point of percussion, the core is compressed by the impact of a hard indentor. Where the core is compressed a crack forms and is propagated. The stiffness of the material (or its inability to bend very much), results in a crack that will tend to propagate parallel to the exterior surface of the flake. During blade production a knapper typically exploits a longitudinal ridge on a core. The blow will follow parallel to the ridge and prevent the crack spreading laterally. When a flake fails to detach from the core it is often because insufficient force was used for the location of the point of impact on the core. Step and hinge fractures are knapping accidents typical of novice knappers. Insufficient force may result in a stepped fracture, while an excessive outwardly directed blow may produce a hinge fracture. During step fracture a bending force acts perpendicularly to the initial fracture, and a second fracture is initiated to produce a stepped appearance.

Dibble and Rezek (2009) have shown that flake morphology, especially size, can be controlled through changes to exterior platform angle (measured at the intersection of the platform surface and the exterior surface of the core), platform depth, and the angle of the blow. Knappers could increase the size of the flake by either increasing platform depth or by increasing the exterior platform angle. Increasing flake size potentially extends the use-life of a flake because it allows for resharpening. However, increasing platform depth produces a thicker flake and removes more of the core edge. Dibble and Rezek (2009) show that the advantage of increasing the exterior platform angle, or steepness of the core edge,

is that the strategy will produce a flake with a higher surface area in relation to thickness. This in turn is advantageous for conserving material and for core maintenance. They point out that the downside of this approach is the need for increased knapping accuracy in controlling platform depth.

Dibble & Rezek (2009) suggest that the speed of the blow does not alter the morphology of the resultant flake. So pressure flaking and direct percussion should produce the same flake morphology. However, the advantage of pressure flaking is that the placement of the point of percussion, platform depth, and controlling the angle of the blow, or force, can be more accurately controlled. Typically though, only quite brittle materials can be pressure flaked because they require less energy to initiate fracture. Mourre *et al.* (2010) were able to show that silcrete must be heat treated to lower its fracture toughness and increase brittleness, before it can be pressure flaked.

Knapping qualities of rocks

Rocks that fracture easily and in a predictable manner are most suitable for knapping, so brittle, homogeneous and isotropic rocks are more easily flaked than tough rocks, or rocks that contain flaws or bedding planes. The most knappable rocks are those high in silica (Whittaker 1994), but quartz (also silica-rich) often has so many flaws that it is difficult to control its fracture pattern.

When rocks are isotropic (exhibiting properties with uniform values measured along axes in all directions), they fracture relatively predictably because the path of fracture follows the direction of the applied force rather than that of the internal structure of the rock (Crabtree 1967; Domanski *et al*. 1994). Arguably, knapping predictability is the most important quality of a rock. Crabtree (1967) makes this

clear by stating that by controlling thickness, width, length and curve during knapping, a toolmaker can create any tool he may need.

Obsidian and flint meet knapping requirements well, but neither rock occurs in South Africa (Wadley & Kempson 2011). Instead, cryptocrystalline silicates such as the minerals chert and chalcedony are widely available here and they are well-suited to tool-making because they allow for control and precision during knapping (Andrefsky, 1998; Beck and Jones, 1990). Not all silcrete is fine-grained. However, fine-grained silcretes are considered a high-quality material for knapping because of their low fracture toughness (Webb & Domanski 2008). The flaking properties of silcrete can be improved by heat treatment, as is the case for Blombos (Brown *et al.* 2012). These can be found in South Africa but are extremely rare in the Sibudu area, occurring in low quantity, and small pebble size in conglomerate rock (Clarke *et al*. 2007).

Fine-grained rocks, which produce high quality edges, are particularly favoured to produce retouched artefacts (Orton 2008; Webb & Domanski 2008). This is evident at Klasies River Mouth (Wurz 1999) and other South African MSA sites such as Rose Cottage where knappers sought out opaline rocks (Soriano *et al*. 2007; Wadley & Harper 1989).

Brittle materials are easily flaked (Cotterell & Kamminga 1992) because they require relatively little energy to initiate fracture, whereas more force is required to flake tougher rocks. The Sibudu area lacks cryptocrystalline silicates present in other parts of the country and knappers were obliged to make use of dolerite and hornfels. As knapping Cochrane (2006) noted that dolerite from the Sibudu area requires considerable force for knapping, and it therefore has less potential for

knapping accuracy than hornfels, which flakes more easily. Being able to improve knapping accuracy is advantageous to successful core reduction.

Webb & Domanski (2008) refer to an index of stiffness, or ratio of median compressive strength to median fracture toughness. This balance of brittleness and elasticity is important to blade production. Brittle materials require less energy to knap, or initiate fracture, but flake production, and blade production in particular, are stiffness controlled (Cotterell *et al* 1985; Cotterell & Kamminga 1987). This means that the developing flake or blade must be able to bend (a measure of stiffness) away from the core, but only a little, to ensure that the developing crack continues in the direction of the impact. Where materials have structural defects, or have a low stiffness, the developing crack lacks directional stability and the risk of step fractures developing increases (Web & Domanski 2008). These materials are not well suited to blade production, but the negative effects are less pronounced for detaching large, wide flakes (Cotterell & Kamminga 1987; Hiscock 1993).

Edge qualities of rocks

Sometimes a conflict occurs between rock attributes that are desirable for knapping and those that are advantageous for maintaining a robust working edge during tool use. While the brittle nature of some rocks makes them sought-after for precise flaking and retouch, the sharp edges produced can be susceptible to damage and blunting (Jones 1979, 1981). Obsidian, notwithstanding its excellent knapping properties, is too brittle for tasks such as boring and scraping (Beck & Jones 1990) without incurring significant damage.

Research by Lerner *et al*. (2007) suggests that roughness is linked to the rate of wear on stone tools. Surface heterogeneity and roughness appear to slow down the rate of edge wear. Hardness is also important to produce a strong durable edge and hard rocks develop edge wear and blunting at a slower rate than soft rocks. Rocks that are simultaneously tough and coarse-grained may be unsuitable for re-sharpening through retouch because the flake edges are more likely to crush than to fracture. However, the crystalline structure of some coarse-grained rocks predisposes them to produce a naturally serrated flake edge (Jones 1979), which can be desirable for some tasks.

However, edge wear/damage can be affected and to an extent mitigated by attributes other than those imparted by rocks. McPherron *et al.* (2014) produced flint and hornfels flakes and subjected them to trampling. The differences in mechanical properties were apparent. Flint flakes were thinner than hornfels flakes, and flint has a lower fracture toughness. As predicted, flint flakes sustained more intense damage. Nonetheless when edge angles drop to 30° or below both rocks accrue damage equally.

Tringham *et al.* (1974) found that the more acute the edge angle the more damage a piece was likely to sustain, though the type of damage would remain unchanged. Other variables affecting edge damage include the material to be worked, the use motion (Keeley 1980), mode of prehension and the pressure applied. For instance, Beyin (2010) found that obsidian tools used on hard materials sustained crushing damage, while similar tools used to cut or scrape soft substances slowly accumulated scars with feathered terminations. Lubrication, which may occur in the form of water or animal fat, can decrease the degree of abrasion (Hurcombe 1992), while the addition of abrasives (Brink 1978) can change not only the intensity, but also the type of wear.

Flake morphology affects tool performance, and hence the frequency with which a tool will need rejuvenation (Collins 2008). Edge morphology also affects the distribution of wear. When the edge is not straight in plan and side-view, forces generated during use cannot act uniformly along the length of the edge. Using flakes with irregular edges concentrates damage in some areas and reduces it in others (Hurcombe 1992). Convex edges tend to have fewer scars following use, and a larger number of these have step or hinge fractures than occur on concave edges (Hurcombe 1992).

Summary

This chapter introduced the site and its place within the local geology of the area. In addition to Chapter 2, it established rock variability and distribution in the area, which is crucial to understanding some of the constraints of rock procurement.

This chapter then presented a summary of the Sibudu assemblages, from the oldest pre-Still Bay, to the youngest final MSA collections. In doing so it also established diachronic change in terms of both technology and rock selection. This data was also presented graphically in Table 2.

A sample assemblage was needed as a case study, to provide material to test in terms of chemical and mechanical properties. A Howiesons Poort sample was decided upon (layer PGS, square C4). As such, a summary of Howiesons Poort sites was presented, followed by a more detailed description of the Howiesons Poort at Sibudu.

Because the sample assemblage will be analysed in terms of chemical and mechanical properties of the selected rocks, an explanatory section was included to discuss mechanical properties, an explanation of how these affect the knapping qualities of rocks, and an explanation of how these affect the edge qualities of rocks. The section ends with a description of dolerite and hornfels, the two rock types that form the basis of this study.

The following chapter, Methodology, will describe the methods used to measure chemical and mechanical properties. It will also describe an experiment to produce and use flakes of dolerite and hornfels to see how they behave. Lastly, it will describe the methods used to analyse the PGS assemblage so that the tools can be interpreted in terms of both rock properties and the observed behaviour of flakes during production and use.

CHAPTER 4

METHODOLOGY

This chapter has three parts. First, it describes the methods used to measure rock properties and determine rock chemistry. Rock variables affect flake production as well as the suitability of the flake during use. In chapter two, a similar methodology was described for determining rock properties and rock chemistry. However, a repetition of the methods is necessary here. Only geological samples were tested and reported in the Wadley and Kempson (2011) paper, though this study includes the testing of archaeological samples as well as geological samples. The results of both are important. The geological results show the range of material present, while the archaeological samples highlight what was selected and used. The intentional selection of rocks illustrates instances of past choice, and understanding the characteristics that accompany those choices provides insight into the priorities of ancient knappers.

Because of the relationship between rock type (with its inherent properties), and tool function, it is important to produce and use flakes experimentally to understand the effect in practise. The second section therefore describes the way experimental flakes were produced and used. I decided to carry out two activities that would have been relevant in the past, experimental cutting and scraping, to see if the materials behaved as expected with regard to their properties. This is not intended as a comprehensive test of how materials react to various tasks and worked materials, but rather as a general indication of differences between the two rock types.

With a theoretical and experimental understanding of the material established, the next step is to analyse an archaeological assemblage. The data from this study will be interpreted considering the mechanical properties established earlier and insights gained from the experimental tool production and use. The final section therefore presents the methodology used to analyse a Howiesons Poort assemblage from square C4, layer PGS. Material from layer PGS was selected because it had not been included in any of the many lithic analysis papers published for Sibudu. The Howiesons Poort is also an important and interesting Industry, and at Sibudu it shows an increasing trend in the use of hornfels. As such is presents an excellent assemblage for this study. Furthermore, I excavated this collection and therefore understand the way in which it was obtained.

There are many tests that have the potential to characterise aspects of rock properties. Many of these require rock samples of either a large piece of rock, or require a large amount of small rock pieces. The locally available hornfels occurs as smallish, thin slabs and it was not large enough for the fracture toughness tests or for the elasticity tests. We have surveyed all the geological occurrences of hornfels in the Sibudu area, have consulted with several local geologists and we still cannot find the source of the Sibudu hornfels. Since dune formation in the area is relatively recent, it is possible that the sources of hornfels available in the MSA are now buried. Hornfels samples from the Magaliesberg, the Vaal River basin, the Karoo, and Pretoria (east) were therefore used as substitutes for the KwaZulu-Natal hornfels. While this is not ideal, it was essential to acquire appropriate rock for testing. Hornfels tends to be variable in nature. It forms when mud is heated and compressed, and the degree of metamorphism is largely what influences its properties. As a result, hornfels is variable both regionally as well as within an outcrop. At Sibudu both very well metamorphosed and poorly metamorphosed hornfels occur, and the substitute rocks probably reflect the upper limits for hardness and fracture toughness.

Because rock is not a homogeneous material the values for rock properties are not as consistent as for other materials such as metals. In hardness tests, each sample was tested up to ten times and then averaged to produce a single averaged value of hardness for each sample. This variability is compounded by natural flaws or weathered planes within the rock, as well as by differences in grain/crystal size. Most results from future tests would probably fall within the range of results reported for these tests, though it is likely that the upper and lower values for each test would be extended by further sampling.

Chemical and mechanical properties

The table below provides relevant data for samples used in XRF, hardness and roughness testing, and production of thin sections.

Table 5. Summary of the geological and archaeological samples used for XRF analysis, hardness and roughness tests, and rock identification through the analysis of thin sections.

Sample	Origin	Provenance	Rock type	Method used
1a	Geological	uThongathi River	Dolerite	XRF
1b	Geological	uThongathi River	Dolerite	Hardness, roughness, thin section
2a	Geological	Sibudu dyke	Dolerite	XRF
2b	Geological	Sibudu dyke	Dolerite	Hardness, roughness, thin section
3a	Geological	Black Mhlasini River	Hornfels	XRF
3b	Geological	Black Mhlasini River	Hornfels	Hardness, roughness, thin section
4a	Geological	Roadside	Shale/hornfels	XRF

4b	Geological	Roadside	Shale/hornfels	Hardness, roughness, thin section
5	Archaeological		Dolerite	XRF
6	Archaeological		Dolerite	XRF
7	Archaeological		Dolerite	XRF
8	Archaeological		Dolerite	XRF
9	Archaeological		Hornfels	XRF
10	Archaeological		Hornfels	XRF
11	Archaeological		Hornfels	XRF
12a	Geological	uThongathi River	Dolerite	XRF
12b	Geological	uThongathi River	Dolerite	Hardness, roughness, thin section
13a	Geological	uThongathi River	Dolerite	XRF
13b	Geological		Dolerite	Hardness, roughness, thin section
14	Archaeological Scraper		Hornfels	Hardness, roughness, thin section
15	Archaeological Point		Hornfels	Hardness, roughness, thin section
16	Archaeological Scraper		Hornfels	Hardness, roughness, thin section
17	Archaeological Scraper		Hornfels	Hardness, roughness, thin section
18	Archaeological Point		Hornfels	Hardness, roughness, thin section
19	Archaeological Point		Hornfels	Hardness, roughness, thin section
20	Archaeological Scraper		Hornfels	Hardness, roughness, thin section
21	Archaeological Point		Hornfels	Hardness, roughness, thin section
22	Archaeological Scraper		Hornfels	Hardness, roughness, thin section
23	Archaeological Scraper		Hornfels	Hardness, roughness, thin section
24	Archaeological Scraper		Dolerite	Hardness, roughness, thin section
25	Geological		Dolerite	Hardness
26	Geological		Hornfels	Hardness

XRF

Rock samples of both archaeological and geological origin were submitted for analysis of major and trace elements using wave dispersive XRF. Thirteen samples (Table 6), were processed with a PANalytical PW2404 WDXRF. The results of six geological samples, recorded below, were published in Wadley and Kempson (2011). The seven archaeological samples (highlighted) recorded below provide new data. It was necessary to test both geological as well as archaeological material, to see if any anomalies occurred in either group. This would have facilitated geochemical sourcing of rock types. The geological samples of dolerite were collected from precisely known sources. For example, I tested the dolerite dyke next to Sibudu as well as dolerite recovered from the uThongathi River directly below the shelter. For the archaeological sample, it was necessary to test pieces such as large flakes. The retouched tools were too small to test.

Table 6. Data for XRF samples.

Rock type	**Origin**	**Provenance**	**Rock**
1a	Geological	uThongathi River	Dolerite
2a	Geological	Dyke	Dolerite
3a	Geological	Black Mhlasini River	Hornfels
4a	Geological	Black Mhlasini River	Hornfels
5	Archaeological	Sibudu	Dolerite
6	Archaeological	Sibudu	Dolerite
7	Archaeological	Sibudu	Dolerite
8	Archaeological	Sibudu	Dolerite
9	Archaeological	Sibudu	Hornfels
10	Archaeological	Sibudu	Hornfels
11	Archaeological	Sibudu	Hornfels
12a	Geological	uThongathi River	Dolerite
13a	Geological	uThongathi River	Dolerite

Neither dolerite nor hornfels are well suited to geochemical sourcing, and dolerite in particular is largely similar across large distances. However, this test was conducted because it was important to establish if geological sourcing of the two rock types might be possible in the Sibudu area.

Rock identification

Geological and archaeological samples were tested (Table 5). For the archaeological samples, retouched tools from the site were used (see introduction for permit details). Ten of these were hornfels and only one was dolerite. Petrographic thin sections were ground from seventeen samples (Table 5). These include two geological and ten archaeological hornfels samples and four geological and one archaeological dolerite sample. Thin sections can be cut from very small pieces of rock. Therefore the archaeological samples were submitted to attain the maximum amount of information from them, and to accurately identify the rock type of the tools. The remaining geological samples were tested because they would be used in hardness and roughness tests and rock type had to be established accurately. The eleven archaeological samples tested here did not form part of the Wadley & Kempson (2011) study.

These samples were glued to glass slides so that the total thickness of each section was about 0.03mm (30 microns). The thin sections were used to confirm the rock type of all archaeological tools, as well as some of the geological samples. The thin sections were prepared by the Geology department at the University of the Witwatersrand and analysed by Professor Grant Cawthorn using a petrographic microscope, using 5x and 10x magnification.

Hardness

A total of nineteen samples (Table 5), seven dolerite and fourteen hornfels, of mixed geological and archaeological origin, were collected for hardness tests. The eleven archaeological samples, and geological samples 24 and 25, did not form part of the Wadley & Kempson 2011 study. Sections of rock were cut and mounted in 25 mm epoxy moulds and their surfaces were polished by the Department of Geology. The tests were done by me using the Vickers Test, and an applied load of 1kg. Ten readings were taken and averaged to produce the hardness value for each sample.

One measure of hardness is resistance to penetration. The Vickers test is similar to the Brinell test, but is adapted for testing hard materials (Rollason 1970). The Vickers hardness number (Hv) is defined as the applied load (kg) divided by the contact area of the indenter (mm^2). Therefore:

$$Hv = \frac{\text{Applied load (kg)}}{\text{Contact area of indenter } (mm^2)}$$

$$Hv = \frac{2P \sin\theta/2}{d^2}$$

$$Hv = 1.85437\ P/d^2$$

Where P is the applied load, θ is the angle between opposite faces (136˚), and d is the diagonal of indentation (mm).

Elasticity (elastic modulus)

None of the data for Elasticity was presented in Wadley and Kempson (2011). Seven cylinders, four of hornfels and three of dolerite were drilled for compression testing by the department of Mining Engineering at the University of the Witwatersrand. No hornfels samples from the region were large enough for the test, so samples of hornfels were collected from the Magaliesberg and the Vaal River. The cylinders had lengths approximately twice their diameters (Table 7). Two electronic gauges were glued to the sides of each cylinder; a vertically-placed gauge measured strain, through change in length, and a horizontally-placed gauge measured stress, through change in thickness. A standard compression test, using an Amster machine, was conducted. The machine applied pressure until the samples broke or failed. Readings from the gauges were then used to calculate the elastic modulus (E) as shown below:

$$\text{Strain} = \frac{\text{change in length (during compression)}}{\text{original length}}$$

The measurement is in Pa or kPa (N (Newtons) /m^2 =Pa)

$$\text{Stress} = \frac{\text{load kN}}{\text{area } m^2}$$

Elastic modulus (E) = stress divided by strain

Table 7. Provenance and dimensions of uniaxial compression tests used to establish elasticity.

Rock type & provenance	Diameter	Length (mm)	L/D	Mass (g)
Hornfels Magaliesberg	42,0	117,1	2,8	413,5
Hornfels Magaliesberg	42,0	118,1	2,8	413,2
Hornfels Vaal River gravels	30,0	87,7	2,9	171,6
Dolerite cobble	41,8	100,3	2,4	413,0
Hornfels Vaal River gravels	41,8	100,8	2,4	364,2
Dolerite Dyke	30,0	87,8	2,9	184,3
Dolerite Dyke	34,7	96,6	2,8	276,5

Roughness

The geological thin sections (Table 5) used for rock identification were also used to determine roughness. Six geological samples were reported in Wadley & Kempson (2011), the remaining eleven archaeological samples did not form part of the paper. I examined the thin sections under a petrographic microscope with a measuring scale embedded in the eyepiece. I then used 5x and 10x objective lenses to measure grain-sizes on the dolerite and hornfels sections. First, the largest crystal in the field of vision was selected and its longest dimension was measured; secondly, the lengths of the nine next largest neighbouring crystals were measured and the average of the ten crystal lengths was calculated for each slide. The long axes of plagioclase crystals were measured on dolerite samples, while the maximum dimensions of quartz crystals were measured on the hornfels samples.

Fracture toughness

A total of 18 fracture toughness tests were reported in Wadley and Kempson (2011).

In these tests the Department of Metallurgy used a low energy Charpy pendulum impact testing machine (Alfred J. Amsler & Co machine, Amsler 125/74 with a Charpy 0,4 kpm scale according to DIN 51222). The machine has a rated initial potential energy of 50 J or less. It tests fracture toughness variability within a single rock.

In such tests a notched bar, measuring 10mmx10mmx100mm, is impacted and the energy transferred to the material is inferred. The fracture toughness is measured in joules/mm^2 when fracture is initiated. Fracture toughness (brittleness) readings were measured for 26 samples, including fourteen dolerite and twelve hornfels samples.

The further test was done testing variability within a single piece of rock. These test results were not included in the Wadley and Kempson 2011 paper. Three samples were prepared from a single piece of dolerite, and three samples from a single piece of hornfels. Because the values for the initial tests were very low, the test was modified. The same dimensions of sample size were used, but no notch was cut into the samples. Also, the arm of the Charpy machine was only raised to 60° so that less energy was used to break the sample. However, it should be noted that even with these measures, the values for the tests remain very low which is a concern. However, averaged values for both methods show that hornfels has a lower fracture toughness than dolerite.

Table 8. Samples prepared for fracture toughness test with notch cut into sample.

Sample	Provenance	Rock type
H1b	Magaliesburg	Hornfels
H1a	Magaliesburg	Hornfels
H2a	Magaliesburg	Hornfels
H2b	Magaliesburg	Hornfels
D2b	uThongathi River	Dolerite
D1a	uThongathi River	Dolerite
D1b	uThongathi River	Dolerite
D2a	uThongathi River	Dolerite
Q	uThongathi River	Dolerite
R	Vaal River gravels	Hornfels
S	Vaal River gravels	Hornfels
P	uThongathi River	Dolerite
2	uThongathi River	Dolerite
d	Karoo	Hornfels
a	Karoo	Hornfels
3	uThongathi River	Dolerite
4	uThongathi River	Dolerite
1	uThongathi River	Dolerite

Table 9 Samples prepared for fracture toughness test with no notch cut into sample.

Sample	Provenance	Rock type
Hornfels 1	Pretoria - Rosemary Hill	Hornfels
Hornfels 2	Pretoria - Rosemary Hill	Hornfels
Hornfels 3	Pretoria - Rosemary Hill	Hornfels
Dolerite 1	Sibudu	Dolerite
Dolerite 2	Sibudu	Dolerite
Dolerite 3	Sibudu	Dolerite

Production of dolerite and hornfels flakes and experimental cutting and scraping

Knapping

All flakes were produced from a single core of each rock type. This was to minimise the difference in rock quality that can be expected to occur within all rock types. Flakes were knapped from dolerite and hornfels because these are the rock types most commonly knapped at Sibudu. A small number of chilled dolerite flakes were made from a cobble collected from the uThongathi River near Sibudu. Chilled dolerite is quite rare, and the piece I found was small and blocky with all angles at about 90°. I found it very difficult to produce sufficient flakes for use.

The dolerite flakes were produced from a slab of rock removed from the dolerite dyke 200 m from the site. Although the rock is extremely tough, it is available in large pieces that make it easier to flake than the small chilled dolerite cobble. The hornfels flakes were produced from a single, small slab of rock collected from the banks of the Black Mhlasini River, approximately 15 km from Sibudu. After a few days of rock collecting, it proved impossible to collect any large pieces of hornfels so flakes from this core are also rather small. Despite the small size of the piece the core was much easier to flake, and much less force was required on impact to detach a flake.

I also attempted knapping shale, but it was not possible to produce useful flakes from this soft and anisotropic material. Knapping tended to produce a mass of shattered rock pieces and small debris. None of the debris produced was useful because of the weakness of the rock, with each piece crumbling or snapping immediately upon use.

Photography and recording

Before use, each flake was photographed with an Olympus Optical DP12 camera. The flakes were photographed again after five minutes of use, and then again after ten minutes of use.

The edge thickness (Table 10) was measured using digital callipers, at 3 mm from the edge selected for use. An edge angle was not established as the edge angle is not constant along the edge (Hurcombe 1992). The shape of the selected edge was noted as straight, convex or concave (Table 10). Edges were described as either regular, or irregular (Table 10) where small notches or protuberances occurred along the length of the piece. The flake length was also measured by recording the maximum dimension of the piece.

Experimental cutting and scraping

Because of the small size of two of the cores both broken and complete flakes were selected for use, but none of these was retouched prior to use. The flakes were not hafted and all experimental cutting and scraping was carried out using hand-held flakes. Every effort was made to keep the variables that affect the edge wear of a tool's edge constant.

None of the flakes used for cutting or for scraping were retouched, using only natural edges. Approximately half of the experimental flake sample was used to scrape 2 mm thick suede leather (FIG. 6). Suede is smooth on one side, and rather fibrous on the other. Suede was chosen for two reasons. It is easily available (it was purchased from a shoe repair shop), and it preserves one fibrous side suitable

for scraping. The scraping action visibly removed much of the fibrous layer. The remaining flakes were used to cut the leather (FIG. 6). Flakes used as scrapers that are described below as effective are those that easily removed fibrous material. Effective cutting tools are those that easily cut the leather and tended to produce a clean rather than a ragged cut edge. Each flake was used for two periods of five minutes because time is more accurately measured than a standard amount of work. However, for scrapers, the number of strokes was recorded (Table 10).

Those flakes selected for cutting were held in a position more-or-less perpendicular to the leather that was being cut. The cutting motion and amount of pressure applied were held constant as far as possible. Similar attempts at consistency were made with the flakes selected for scraping, and these were held at a relatively constant contact angle, while maintaining a constant pressure and work action. The activities were repeated after photography and recording, so that each flake was used for a total of ten minutes for the same activity.



FIG. 6. Suede leather, 2 mm thick, used for cutting and scraping.

In total, the experimental assemblage consists of 29 pieces (Table 10). Of these, seven are chilled dolerite pieces, comprising four scrapers and three cutting tools. The hornfels component consists of ten pieces, including five scrapers and five cutting tools. Lastly, the dolerite consists of twelve pieces, with six scrapers and six cutting tools.

Table 10. Edge characteristics (thickness, regularity and shape) of experimental flakes before use

Flake #	Rock type	Activity	Strokes	Regularity	Shape	Thickness
#19	Chilled dolerite	Scraping	981	Regular	Straight	2.5mm
#20	Chilled dolerite	Scraping	1015	Regular	Straight	2.8mm
#21	Chilled dolerite	Scraping	951	Regular	Straight	2.3mm
#22	Chilled dolerite	Cutting	N/A	Slightly irregular	Slightly concave	1.6mm
#23	Chilled dolerite	Cutting	N/A	Irregular	Slightly convex	2.2mm
#24	Chilled dolerite	Cutting	N/A	Slightly irregular	Straight	4.3mm
#25	Chilled dolerite	Scraping	969	Regular	Concave	2.8mm
HS1	Hornfels	Scraping	956	Regular	Straight	2.9mm
HS2	Hornfels	Scraping	975	Regular	Straight	1.2mm
HS3	Hornfels	Scraping	972	Regular	Straight	3.3mm
HS4	Hornfels	Scraping	947	Irregular	Slightly convex	2.3mm
HS5	Hornfels	Scraping	890	Regular	Straight	1.7mm
HC1	Hornfels	Cutting	N/A	Regular	Convex	1.3mm
HC2	Hornfels	Cutting	N/A	Irregular	Straight	1.9mm
HC3	Hornfels	Cutting	N/A	Irregular	Convex	1.5mm
HC4	Hornfels	Cutting	N/A	Irregular	Straight	1.9mm
HC5	Hornfels	Cutting	N/A	Regular	Straight	2.4mm
DS1	Dolerite	Scraping	890	Regular	Straight	2.7mm
DS2	Dolerite	Scraping	936	Regular	Straight	1.5mm
DS3	Dolerite	Scraping	926	Irregular	Convex	2.5mm
DS4	Dolerite	Scraping	941	Irregular	Straight	2.3mm
DS5	Dolerite	Scraping	913	Irregular	Straight	3.9mm
DS6	Dolerite	Scraping	926	Regular	Slightly convex	2.6mm
DC1	Dolerite	Cutting	N/A	Irregular	Straight	2.4mm
DC2	Dolerite	Cutting	N/A	Irregular	Straight	2.8mm
DC3	Dolerite	Cutting	N/A	Regular	Slightly convex	3.2mm
DC4	Dolerite	Cutting	N/A	Irregular	Straight	1.8mm
DC5	Dolerite	Cutting	N/A	Irregular	Straight	2.9mm
DC6	Dolerite	Cutting	N/A	Irregular	Slightly convex	2.9mm

Analysis of Howiesons Poort material

This study looks at rock use in a single square and layer of the Howiesons Poort at Sibudu, and particularly the selection and use of rock types in this sample assemblage.

A typological analysis was carried out on all lithic material from the layer PGS in square C4, the results of which are presented in the next chapter. For this study, complete flakes are complete or very near complete, incomplete flakes are broken but retain the platform, and flake fragments do not have a platform but can confidently be considered to be part of a flake. Chunks are those pieces that result from knapping, tend to be thick, blocky pieces, and cannot readily be defined as being a part of a flake or blade.

Blades are flakes that are at least twice as long as they are wide, irrespective of knapping intent. Blade fragments are pieces that can reasonably be considered to have been part of a blade. These pieces may have a platform but most do not. All pieces were also assigned to a rock type, except for pieces less than 10mm in maximum dimension.

Sibudu's Howiesons Poort artefacts occur mostly in dolerite and hornfels, but also in quartz, quartzite, sandstone and crypto-crystalline silicates (CCS). However, when considering the blade assemblage, only 3.6% of the material occurred on rocks other than dolerite or hornfels. For that reason, only dolerite and hornfels will be considered here.

Within the dolerite assemblage, there is quite a clear difference between the 'normal' grainy dolerite, which appears similar to sandstone in texture but with a grey colour. The fine-grained dolerite tends to be a darkish blue and crystals are not necessary visible. However, this rock tends to produce a 'knobbly' fracture surface, even though the material itself is very fine. There are often fine air bubbles or vesicles visible to the naked eye. For this reason, the dolerite component will be separated into dolerite and fine-grained dolerite categories.

Measurements that were taken include the maximum dimension of all pieces 10mm or above. For pieces 20mm and above, the maximum length perpendicular to the platform, and maximum width were also measured. For blades and blade fragments, the thickness of the blade was also measured where possible, as well as the length and width of the platform where this was clear.

Summary

In this chapter I have provided information on the methods chosen for characterising hornfels and dolerite, discussed problems encountered, and considered the lack of homogeneity of rock. I have also made my choices in rock sampling clear, and indicated the geological or archaeological nature of the samples.

Following this I presented the methods used to experimentally knap three cores, one each of dolerite, fine dolerite, and hornfels. A variety of flakes were selected and the nature of their edges was recorded and photographed. These tools were then used for cutting and scraping leather. The edges were then photographed after five minutes and again after 10 minutes.

Finally, I presented the methods used to analyse a sample Howiesons Poort assemblage from layer Pinkish Grey Sand (PGS, square C4). Only dolerite and hornfels pieces were analysed. Of this, the core, tools and blades were selected for analysis.

These three sets of methods provide a structured approach to investigating the role of mechanical properties in the Sibudu assemblages. Rock is first characterised, then experimentally used, to provide a context to analyse a sample assemblage. This knowledge will then be used to interpret rock selection at Sibudu. The results of these three methodologies will be presented in the next chapter.

CHAPTER 5

RESULTS

As with the methods chapter, this section reports the results in three parts, mechanical and chemical properties of the geological and archaeological specimens of dolerite and hornfels, experimental flake production and use, and the analysis of archaeological material. No interpretation of the data will be offered in this section; it is reserved for the Discussion, Chapter 6.

Limited results of various tests were reported in Wadley and Kempson (2011), but these were for geological samples only. No archaeological results were included for any tests. In addition, new geological data are reported here.

For the purposes of the analysis of PGS material, the category for dolerite was split into dolerite (which is quite coarse), and fine dolerite (or fine-grained dolerite). This is because there was a distinct difference in texture between the two. Despite this, the fine-grained dolerite discussed here and listed in the results, is not the same as the chilled dolerite, which was experimentally knapped. This chilled dolerite was exceptionally fine-grained and almost indistinguishable from hornfels.

Chemical and mechanical properties

XRF

Thirteen samples were submitted for XRF analysis of major and trace elements. Of these six are geological samples, and were reported in Wadley and Kempson (2011). The remaining seven samples are archaeological and are new data.

Table 11. XRF results of archaeological and geological samples.

Sample #	Rock	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	L.O.I	Total
		(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
#5	Dolerite	50,23	1,44	15,72	11,67	0,19	6,10	8,59	2,09	1,15	0,29	1,38	98,85
#6	Dolerite	64,25	1,50	12,49	8,73	0,11	0,87	3,34	2,27	3,62	0,85	0,81	98,84
#7	Dolerite	63,61	1,51	12,77	9,32	0,11	1,28	3,85	2,24	3,30	0,36	0,72	99,07
#8	Dolerite	63,71	1,63	13,18	9,23	0,10	1,23	3,64	2,06	3,50	0,48	1,32	100,08
#9	Hornfels	64,09	0,88	20,29	5,25	0,07	1,11	0,43	1,54	1,97	0,21	3,45	99,29
#10	Hornfels	63,28	0,87	20,39	4,66	0,03	1,09	0,37	1,16	2,41	0,63	4,11	99,00
#11	Hornfels	64,95	0,88	20,68	5,54	0,09	1,22	0,52	1,41	2,08	0,27	2,91	100,55
1A	Dolerite	50,85	1,12	14,60	13,00	0,20	5,84	9,12	2,58	0,74	0,16	1,15	99,36
2A	Dolerite	51,97	1,50	13,33	13,99	0,22	4,81	9,04	2,47	0,98	0,26	2,14	100,71
3A	Hornfels	63,36	0,79	20,63	4,12	0,02	0,96	0,36	1,06	2,17	0,24	6,38	100,09
4A	Shale/hornfels	62,35	0,79	20,45	4,59	0,02	0,94	0,57	1,04	1,94	0,34	6,15	99,18
12A	Dolerite	51,35	1,35	14,59	13,35	0,21	5,17	9,08	2,50	0,96	0,22	0,67	99,45
13A	Dolerite	51,03	1,60	13,56	14,65	0,20	4,72	8,28	2,50	0,84	0,23	2,30	99,91
Sample #		**Rb**	**Sr**	**Y**	**Zr**	**Nb**	**Co**	**Ni**	**Cu**	**Zn**	**V**	**Cr**	**Ba**
		(ppm)	**(ppm)**	**(ppm)**	**(ppm)**	**(ppm)**	**(ppm)**	**(ppm)**	**(ppm)**	**(ppm)**	**(ppm)**	**(ppm)**	**(ppm)**
LLD		**3**	**3**	**3**	**8**	**3**	**6**	**6**	**6**	**6**	**12**	**12**	**20**
#5	Dolerite	52	257	35	182	12	36	54	19	101	175	183	331
#6	Dolerite	108	198	65	408	19	9	<6	10	122	101	<12	1041
#7	Dolerite	92	218	61	381	18	10	9	11	113	126	15	975
#8	Dolerite	100	230	62	373	18	13	6	9	108	131	27	922
#9	Hornfels	135	168	42	233	22	19	41	43	119	115	85	881
#10	Hornfels	133	158	44	201	18	16	52	45	101	127	111	673
#11	Hornfels	137	171	49	232	21	18	69	38	133	114	157	870
1A	Dolerite	40	184	35	141	12	36	54	125	114	287	148	485
2A	Dolerite	33	181	32	129	9	42	53	73	108	245	129	512
3A	Hornfels	137	126	47	202	17	16	53	40	115	134	96	798
4A	Shale/hornfels	123	115	42	202	18	17	47	40	106	136	92	708
12A	Dolerite	47	188	38	155	13	38	39	144	120	307	149	484
13A	Dolerite	32	230	38	171	13	41	<6	11	130	310	41	316

When results of archaeological samples are added to the geological samples more variability can be seen in proportion of SiO_2 in the dolerite samples (Table 11). The SiO_2 content of the dolerite now range between 50.23% and 64.25% of dolerite (Table 11). However, the SiO_2 and other major elements are roughly consistent with a study by Clarke *et al*. (2007), and a study of Kwa-Zulu Natal dolerites by Bell & Jermy (2000). Percentages of Al_2O_3 at Sibudu fell within the 12% and 17% reported for various sites in the province. The high SiO_2 count overlaps with hornfels. However, all other mineral compositions effectively separate dolerite and hornfels. There is also no indication in the trace elements or

the constituent minerals that it would be possible to geochemically discriminate between various sources of dolerite.

There is almost no difference in the values for both major elements and trace elements across five samples of hornfels. There is almost no variation in trace elements or in values for SiO_2, Al_2O_3 and TiO_2. Again, hornfels can be distinguished from dolerite samples, but geological sources cannot be distinguished chemically.

Hardness test

A total of 26 samples were tested. Of these eleven are archaeological and seven are geological. Six of eight geological samples were presented in Wadley & Kempson (2011). The remaining two geological samples and the archeologically data were not presented before.

The results of the Vickers hardness tests (Table 12) show an overlap between hornfels and dolerite samples (FIG. 7). Hornfels has the widest range of hardness values, with both the softest rock (Hv 210) and the hardest rock samples (Hv 551).

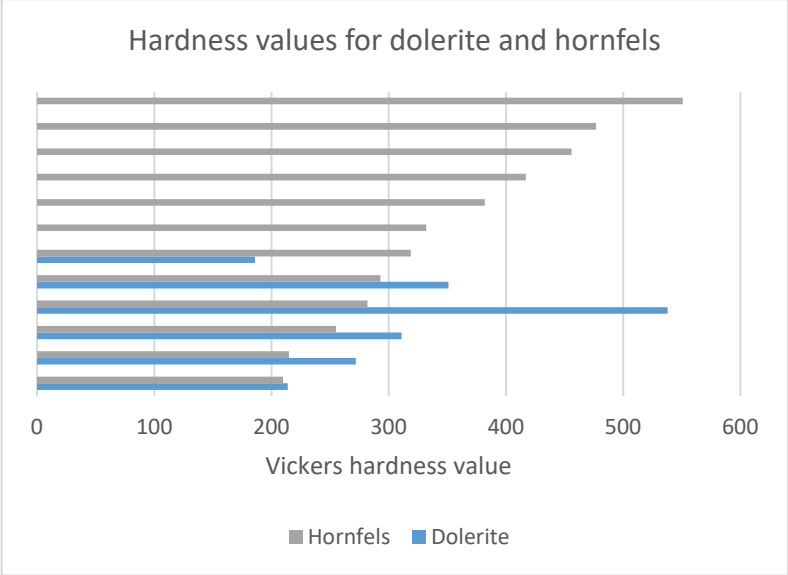


FIG. 7. Hardness values (Hv) of dolerite and hornfels samples.

Elasticity

A total of seven samples were submitted for uniaxial compression tests. None of these data were presented in Wadley and Kempson (2011). Due to the size requirements of the test, all samples are geological in origin.

By measuring the amount of energy (stress) needed to break a sample of rock while simultaneously recording deformation (strain) it is possible to determine the stiffness, or brittleness, of a material. There is a slight overlap in the elastic values for dolerite and hornfels though the sample size is small (Table 13). Hornfels from the Magaliesberg has the lowest value for Young's Modulus (E)

and is therefore the most rigid, or brittle, rock type. Dolerite from the dyke near Sibudu Cave has the highest value for E and can flex more, increasing the potential for bending fractures as well as the greater fracture toughness of the material.

Table. 12. Provenance of hardness samples and their hardness values (Hv).

Sample #	Source	Rock type	Average Hv	Minimum Hv	Maximum Hv
1b	Geological	Dolerite	351	276	453
2b	Geological	Dolerite	311	239	401
3b	Geological	Hornfels	215	175	251
4b	Geological	Hornfels	293	214	368
12b	Geological	Dolerite	214	162	276
13b	Geological	Dolerite	272	168	401
14	Archaeological	Hornfels	319	283	358
15	Archaeological	Hornfels	332	276	533
16	Archaeological	Hornfels	477	378	551
17	Archaeological	Hornfels	456	339	551
18	Archaeological	Hornfels	382	321	453
19	Archaeological	Hornfels	551	482	660
20	Archaeological	Hornfels	255	205	330
21	Archaeological	Hornfels	282	321	498
22	Archaeological	Hornfels	417	368	453
23	Archaeological	Hornfels	210	182	234
24	Archaeological	Dolerite	538	413	613
25	Geological	Hornfels	268	247	283
26	Geological	Dolerite	186	175	207

Sloane (1991) reports lower values for dolerite during uniaxial compression when slight weathering and defects in the rock were evident. This is possible for the Sibudu samples because they are recovered from a riverine environment and

because it has already been noted that blocks of dolerite from the nearby dyke exhibit brown, weathered surfaces within the rock.

Hornfels can similarly be affected where material is only weakly metamorphosed. This is not the case for the two hornfels materials tested here. However, where the uniaxial compressive strength (UCS) is a measure of the strength of the rocks, it is not a measure of hardness, or resistance to wear. Importantly this test does not measure the strength of a material on impact but under a much slower loading of stress which is why fracture toughness was determined using the Charpy impact test.

Table 13. Results of uniaxial compressive strength test (UCS), with E (Young's Modulus) and n (Poisson's ratio).

Rock type & provenance	Diameter	Length	L/D	Mass	Density	Failure	E	n	UCS	Max axial strain	Max axial strain
		(mm)		(g)	(kg/m^3)	Load (kN)	(GPa)		(MPa)	($x10^{-3}$)	
Hornfels Magaliesberg	42,0	117,1	2,8	413,5	2549	430,9	**74,1**	0,20	**311,0**	4,73	0,00473
Hornfels Magaliesberg	42,0	118,1	2,8	413,2	2525	464,0	-	-	**334,9**	no data	
Hornfels Vaal River gravels	30,0	87,7	2,9	171,6	2769	247,0	**74,8**	0,27	**349,4**	4,54	0,00454
Dolerite cobble	41,8	100,3	2,4	413,0	3000	498,0	**79,1**	0,30	**362,9**	4,34	0,00434
Hornfels Vaal River gravels	41,8	100,8	2,4	364,2	2629	545,0	**81,0**	0,26	**396,8**	8,89	0,00889
Dolerite Dyke	30,0	87,8	2,9	184,3	2970	150,0	**83,6**	0,37	**212,2**	9,35	0,00935
Dolerite Dyke	34,7	96,6	2,8	276,5	3027	204,0	**89,2**	0,28	**215,7**	1,95	0,00195

Roughness

The geological thin sections (Table 5) used for rock identification were also used to determine roughness. Six geological samples were reported in Wadley and Kempson (2011), the remaining eleven archaeological samples did not form part of the paper.

There is no overlap in the grain size of hornfels and dolerite samples (FIG. 8). Hornfels is consistently more fine-grained than dolerite. Of the eleven hornfels samples tested, nine are archaeological tools. Their roughness values vary between 0.037mm and 0.168mm. The two geological samples fall within this range (0.037mm, 0.049mm). Only one dolerite tool was available for testing, and this value (0.262mm) falls within the range of the four geological samples tested.

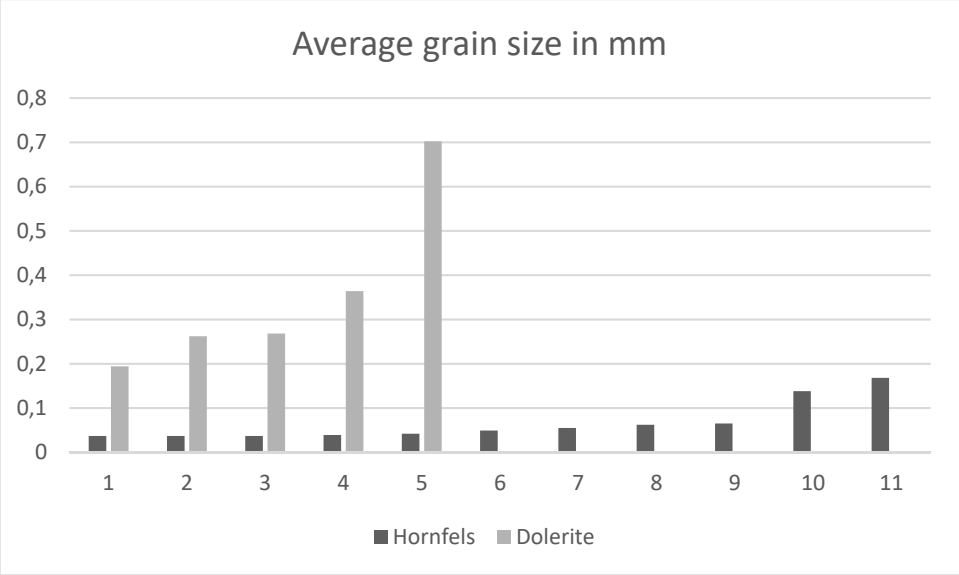


FIG. 8 Average grain size in mm of hornfels and dolerite samples tested for roughness.

Fracture toughness

A total of eighteen samples was tested for fracture toughness and published in Wadley and Kempson (2011). Subsequently six new samples were added to tests variability within a single rock piece.

There is overlap in the results for fracture toughness (Table 14, FIG. 9). On average it takes 0.000388 joules of energy per square millimetre to fracture hornfels. To fracture dolerite requires an average of 0.005832 joules per square millimetre of rock. It therefore requires 33.42% more energy (on average) to break the same volume of dolerite rock compared to hornfels. However, hornfels from three different regions has a widely varying fracture toughness. The Magaliesberg hornfels has the lowest values and the Karoo hornfels is the toughest of the hornfels samples.

The subsequent test had a different methodology in that the samples cut were not notched, and the arm of the Charpy machine was only raised to 60°. This was an attempt to control for the brittleness of the rock and the low energy readings produced in the previous test. Therefore, the two tests cannot be directly compared.

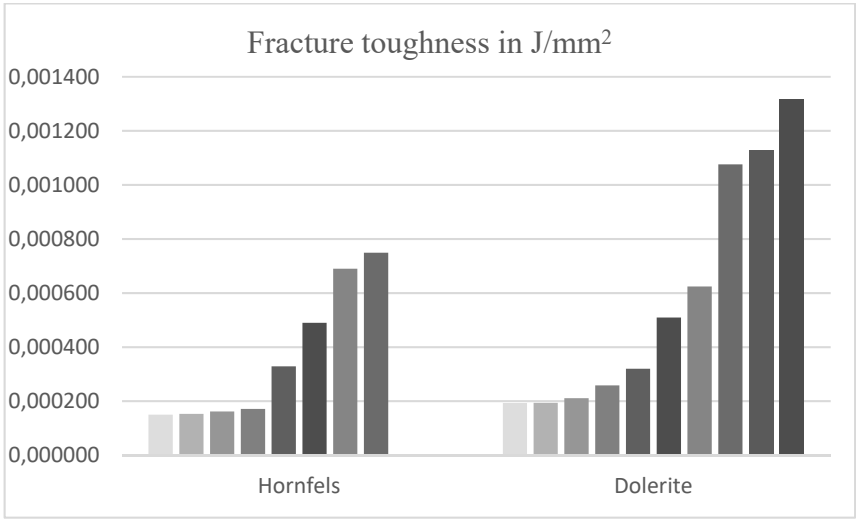


FIG. 9. Fracture toughness of hornfels and dolerite samples.

The second test shows less difference in the fracture toughness of the two materials. However, dolerite is more consistently tough, while hornfels shows a much wider range of fracture toughness values within a single piece of rock. In this instance, only an additional 8.8% of energy is required on average to fracture the individual dolerite sample than the individual hornfels sample.

Table 14. Results of fracture toughness tests of dolerite and hornfels samples from various proveances.

Sample #	Source	Rock type	J/mm^2
H1a	Magaliesberg	Hornfels	0,000153
H1b	Magaliesberg	Hornfels	0,000150
H2a	Magaliesberg	Hornfels	0,000162
H2b	Magaliesberg	Hornfels	0,000171
D1a	uThongathi	Dolerite	0,000194
D1b	uThongathi	Dolerite	0,000211
D2a	uThongathi	Dolerite	0,000258
D2b	uThongathi	Dolerite	0,000193
P	uThongathi	Dolerite	0,000509
Q	uThongathi	Dolerite	0,000320
R	Vaal River	Hornfels	0,000329
S	Vaal River	Hornfels	0,000490
1	uThongathi	Dolerite	0,001318
2	uThongathi	Dolerite	0,000624
3	uThongathi	Dolerite	0,001076
4	uThongathi	Dolerite	0,001129
a	Karoo	Hornfels	0,000749
d	Karoo	Hornfels	0,000690

Table 15. Results of fracture toughness tests on a single dolerite rock sample, and a single hornfels rock sample.

Sample	Provenance	Rock type	J/mm2
Hornfels 1	Pretoria - Rosemary Hill	Hornfels	3,0
Hornfels 2	Pretoria - Rosemary Hill	Hornfels	0,5
Hornfels 3	Pretoria - Rosemary Hill	Hornfels	1,6
Dolerite 1	Pretoria - Rosemary Hill	Dolerite	1,3
Dolerite 2	Pretoria - Rosemary Hill	Dolerite	1,25
Dolerite 3	Pretoria - Rosemary Hill	Dolerite	3

Experimental cutting and scraping

The results of cutting and scraping experiments are recorded below. First, the cutting and scraping using the dolerite sample are presented, followed by the results using the chilled dolerite sample. The results of the hornfels sample follow. In each instance the edge thickness and edge shape are presented. The scraping tools are discussed, followed by the cutting tools. Selected images of tools edges are included. Appendix A provides more images at the end of the thesis.

Dolerite

The dolerite flakes form the largest rock sample (n=12)in this study. The dolerite scrapers were very effective. Edge thicknesses varied from 1.6 mm to 3.9 mm at 3 mm from the edge (Table 10). Edge shapes varied from straight to convex, and half had regular edges (Table 10). Despite this, there was no obviously bad scraper. However, amongst the cutting tools, only one of six was very good. The biggest hindrance to cutting was that protuberances and half-moon scars would snag on the leather and make it difficult to complete a cutting motion.

Of the six scrapers, four produced very little damage (DS2, DS4, DS5, and DS6). Damage was limited almost exclusively to occasional small snaps along the edge that in some cases created a slightly denticulated appearance. More obvious damage occurred on scraper DS1, and especially on DS3. Scraper DS1 produced a flake with a feathered termination after five minutes, and a hinged flake after ten, as well as a few small snaps along the edge (FIG. 10b & 10e). Small snaps and a few step flakes occurred on DS4, and in particular resulted in the loss of edge volume on scraper DS3. After ten minutes of scraping the edge of DS3 became blunt due to snapping along the edge.

The regularity and thickness of the edge have an impact on edge damage, but no single variable seems very important. Edges tend to snap and produce half-moon scars, primarily at pre-existing irregularities on the tools' edges. Significantly, the damage done to the scrapers does not have much impact on the ability of the tool to remove fibrous material. Fresh breaks keep the edge sharp and the flake edge bites into the leather to effectively remove material.

Dolerite cutting tools display even less damage to their edges and surfaces than the scrapers. Small flakes, mostly with step terminations, occur along the edge (DC1, DC3 and DC6), though these are very small. No damage occurred on the edge of DC4 (FIG. 10a). The most visible damage is in the form of small half-moon snaps. In one case in particular (DC6), these snaps remove irregularities and produce a more regular edge (FIG.10c & 10d).

One of the six cutting tools DC5 was very efficient. The edge was straight and had a relatively steep angle (2.9 mm at 3 mm from the edge) (Table 10). However, though the edge was a little irregular very little damage occurred, and was limited to a few very small snaps along the edge. The small scale of these fractures produced an edge that was suitable for cutting.

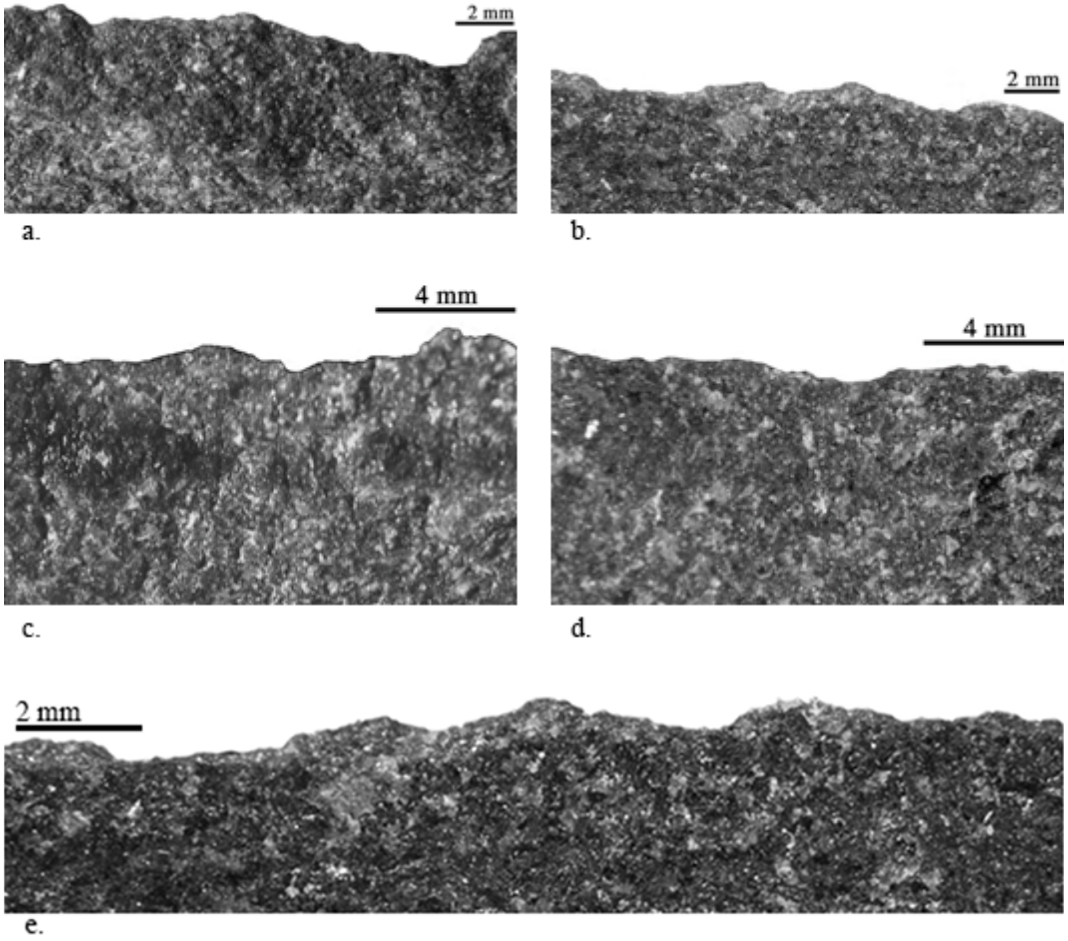


FIG.10. Use-wear images for experimentally used dolerite flakes. a) DC4 after 10 minutes of cutting, b) DS1 after 10 minutes of scraping, showing fresh snaps along the edge, c) Flake DC6 before use, d) Flake DC6 after 10 minutes of use for cutting leather, e) DS1 after 10 minutes of scraping, showing breakage and crushing of the edge.

Chilled dolerite

This is the smallest sample tested. Of the four flakes used for scraping, one in particular was very effective. This flake (EX20) (FIG. 12e) is almost 5 cm in length, with a straight and regular edge, and an edge thickness of on average 2. 85 mm measured 3 mm from the edge (Table 10). Two scrapers EX19 (FIG. 12b) and EX21 (FIG. 12a) also have a straight and regular edge, with a slightly lower edge thickness (2.58 mm and 2.36 mm) (Table 10), yet they were not as effective

as the other pieces. It seems the larger edge thickness of scraper #20, and therefore the steepest edge angle, produced the most effective scraper. The large size of the flake also made it easier to use than the remaining scrapers, two of which are below 3 cm in maximum length. The last scraper (EX22) (FIG. 11a) has a slightly concave and slightly irregular edge. This, in combination with a thinner edge (1.65 mm), produced the least effective scraper and it was not as useful at removing the leather fibres.

Of the three cutting tools, the most effective flake (EX24) was straight, with a slightly irregular edge, and 1.4 mm thick at 3 mm from the edge (Table 10). Notches formed at irregularities in the rock though the flake remained sharp and the notches could be avoided (FIG.12c). The least effective (EX23) (FIG. 11b) is slightly convex, with an irregular edge, and a thickness of 2.2 mm (Table 10). The remaining flake (EX25) (FIG.11c) is concave, with a regular edge, and a thickness of 2.8 mm (Table 10). It therefore seems that the thickness is the most important attribute, followed by the regularity of the edge, for chilled dolerite cutting tools.

The chilled dolerite flakes generally sustained less damage than the dolerite ones. There was very little damage to two of the cutting tools (EX23 & EX25). These tools probably had less edge damage in part because they were less effective and did less cutting work. Damage occurred mostly as half-moon lateral snaps rather than conchoidal fractures (FIG. 11b & 11c). The three cutting tools sustained no significant damage other than notches at pre-existing irregularities on their edges. However, at the end of ten minutes of use, some notches became smooth, thereby producing better cutting edges on the flakes than were present in the first five minutes of use.

Conversely, the scrapers showed a range of damage including some small flakes, step flaking, and tip damage. One flake (EX21) (FIG. 12a) showed edge damage that occurred at a natural flaw in the rock. The more effective scraper (#24) (FIG. 12c) sustained more damage, with a number of small snaps producing a blunting of the edge in places. For sample #19, a clearly visible flake detached after five minutes of scraping (FIG. 12d), and part of the edge and tip broke during the second period of use (FIG. 121b).

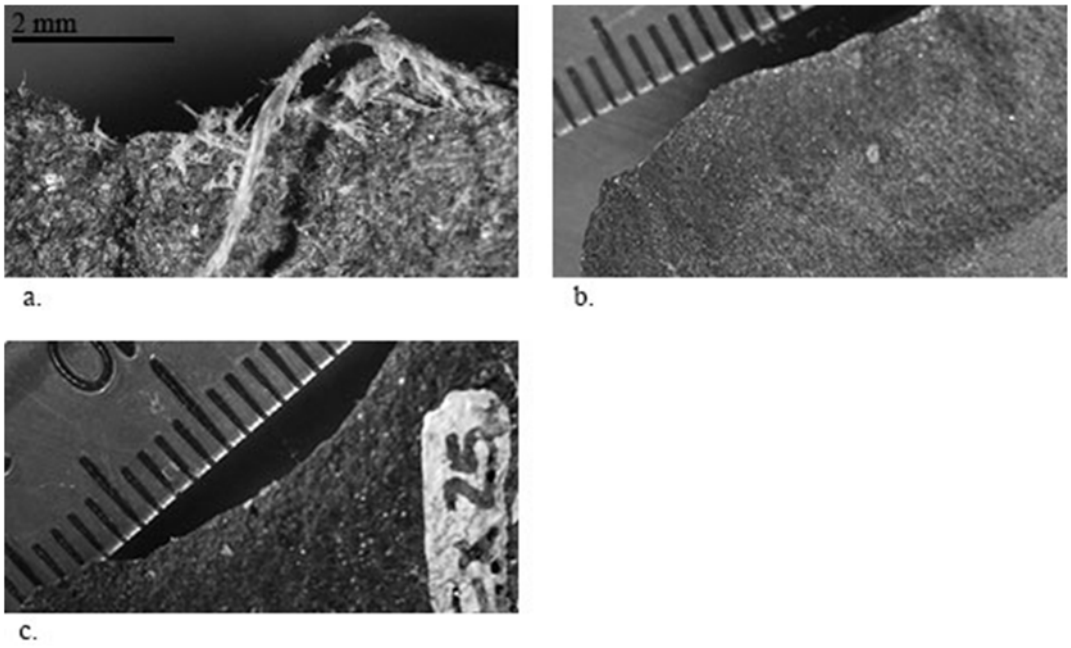


FIG 11. Use wear images for experimentally used chilled dolerite flakes. a) EX22, after five minutes scraping, b) EX23 after 10 minutes of cutting, c EX25, after 10 minutes of cutting.

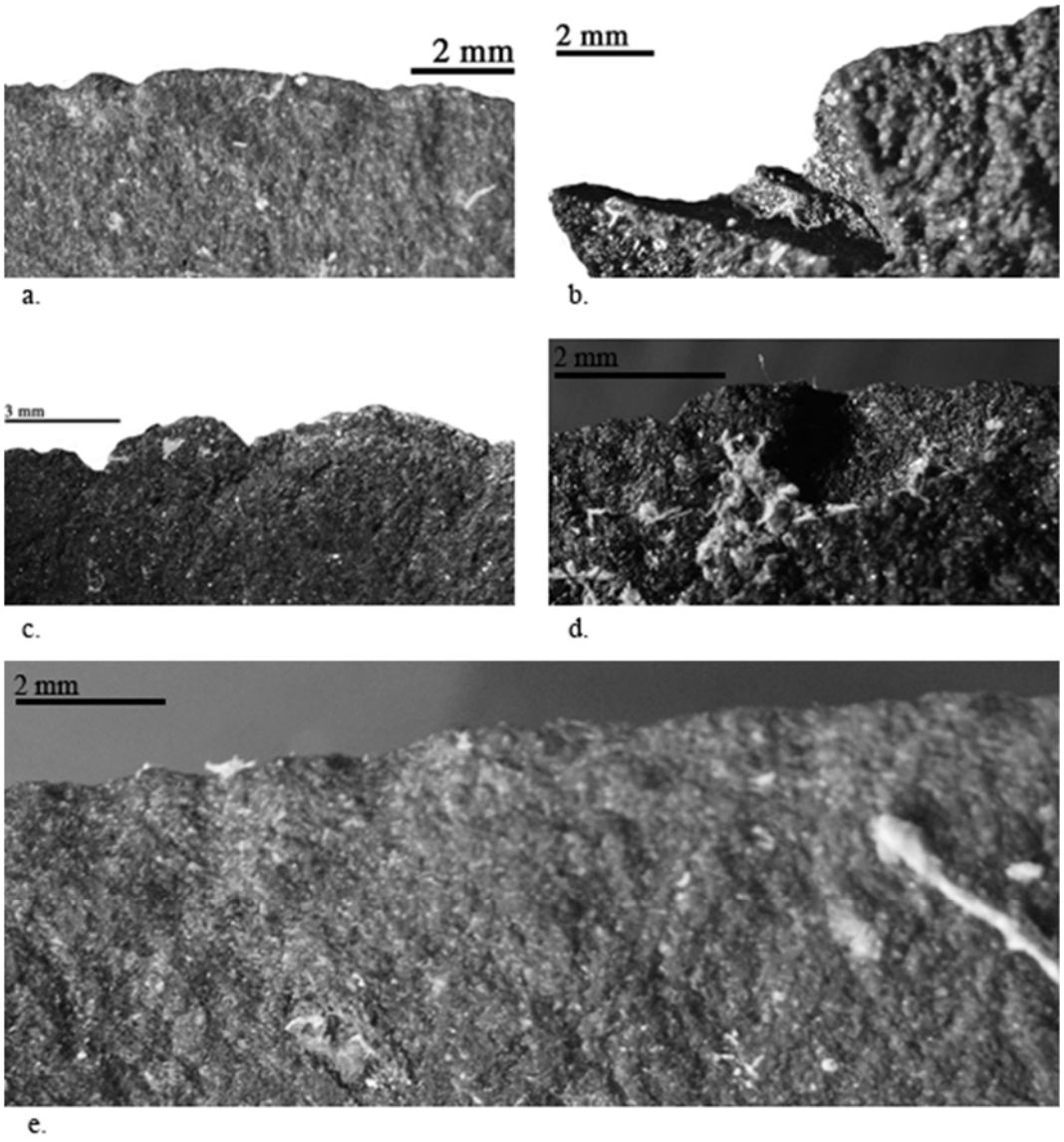


FIG. 12. Use wear images for experimentally used chilled dolerite flakes. a) EX21, after 10 minutes of scraping, showing minimal signs of damage, and vesicles (or small gas bubbles) in the rock. A small vesicle occurs at the left side of the edge and is responsible for some breakage and the irregular edge at left, b) EX19, sustained damage to the edge and tip, c) EX24, showing snaps where irregularities occur in the rock, d) a small hinged flake on the edge of EX19, e) EX20 after 10 minutes of scraping. The edge is straight and small flakes and step flakes occur on the edge.

Hornfels

Hornfels tools sustained the most damage. Typically, their use produced more and larger snaps along the edge as well as tool failure than for dolerite tools. This material produced scrapers that were adequate but not as effective as dolerite ones. One scraper (HS5), sustained step flaking along the length of its straight, regular edge (FIG.13e). Both straight and convex edges were selected for scraping, and all but one had a regular edge (Table 10). Edge thicknesses ranged from 1.2 mm to 3.3 mm (Table 10). No flake characteristic seems significant other than edge thickness, where more robust edges are desirable.

Conversely three of the five cutting tools were exceptionally good at cutting the leather easily and smoothly, while only one was poor. The most effective cutting tool (HC2) was straight with an irregular edge (Table 10). The edge was 1.9 mm thick at 2 mm from the edge. The significant variable here seems to be the thickness. The edge was thick enough to be stable, and thin enough to cut effectively. The lack of edge regularity was not a problem for cutting leather. After ten minutes of use, the irregular edge was altered to produce a slightly wavy edge that replaced the notched or denticulated appearance (FIG.13a & 13b). The least effective cutting tool (HC3), snapped in half in the first minute of use becasue the flake was too thin (FIG. 13d). It had an edge thickness of 1.5 mm and curved slightly towards the tip.

With the exception of the broken tool (HC3), the least effective tool (HC5) had an edge thickness of 2.4 mm with a regular and straight edge (Table 10). The edge sustained limited damage, in the form of a few localised, small step flakes. The smallness of the damage probably reflects in part the robust nature of the flake, but also that less cutting work was performed. The three effective scrapers (HC1, HC2 and HC4) all experienced varying degrees of snapping of their edges. In HC1, with an edge thickness of 1.3 mm, cutting produced a large snap that

removed almost half the cutting edge (FIG. 13c), and relatively extensive step flaking. Tool HC4 also sustained damage in the form of snaps and a few small step flakes.

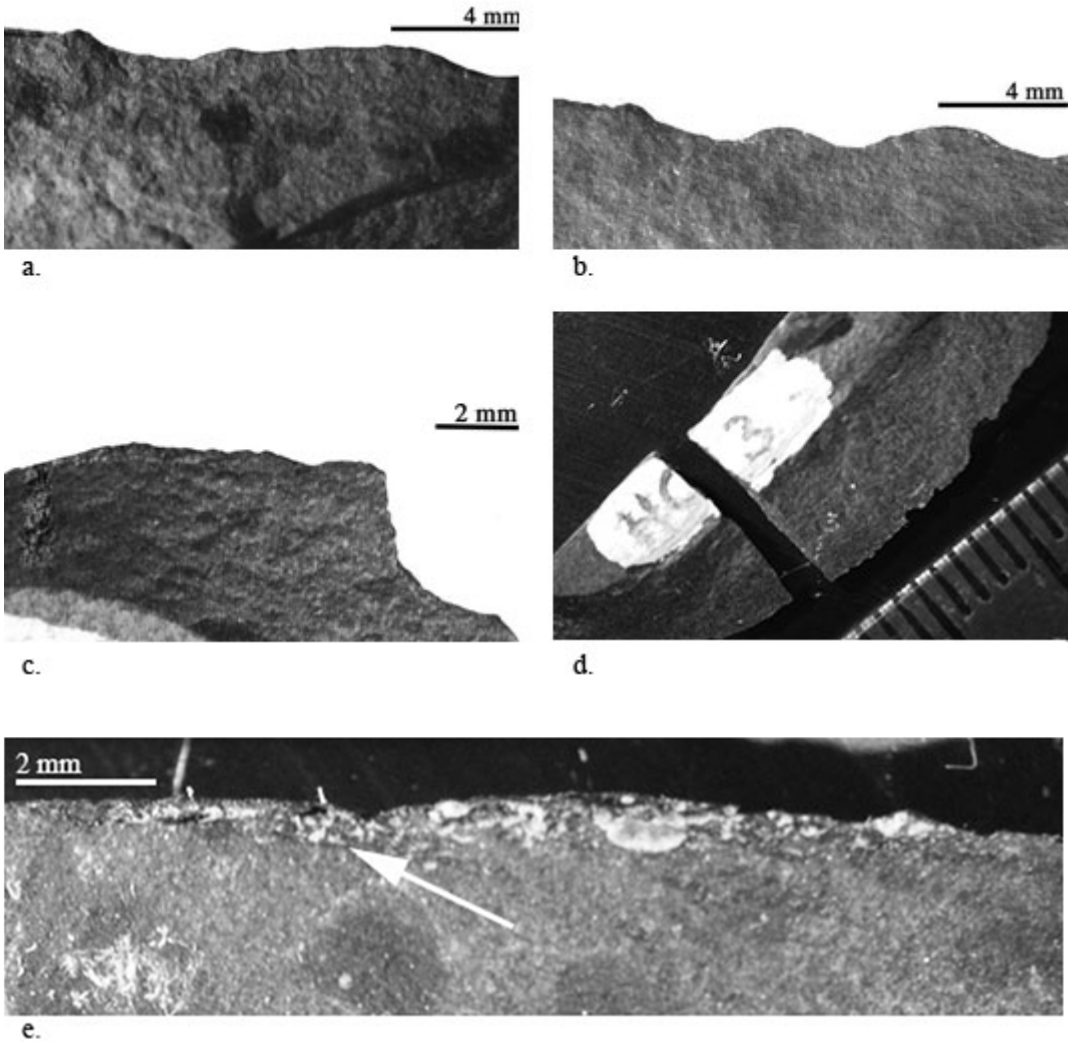


FIG. 13. Use wear images for experimentally used hornfels flakes. a) Flake HC2 before use, b) flake HC2 after 10 minutes of use cutting produced wavy edge, c) HC1 which broke in the first minute of cutting, d) flake HC3 snapped in half in the first five minutes of use, e) HS5, after five minutes of scraping, sustained step flaking along the edge at arrow.

Comparison of rock types

Dolerite flakes have edges that are well-suited to scraping, but the rock's coarseness means that flake edges tend to be irregular (often naturally denticulated) and that they are therefore not as suitable for cutting activities as finer-grained rocks like hornfels. A dolerite flake edge cuts into leather by hooking into it with its denticulated edges and this snags the leather to produce a ragged cut mark. Due to the crystalline nature of dolerite, fresh breaks were often sharp and effective.

Chilled dolerite is different from other dolerite because it is finer-grained and it consequently produces an even flake edge without notches because there are fewer points of weakness along the edge. It is suitable for both cutting and scraping, but it also incurs more damage than is expected for dolerite flakes. Its fine-grained composition seems to reduce both its toughness and its ability to absorb shock so that, during use, more fracture damage occurs to chilled than to coarse-grained dolerite. A chilled dolerite scraper (#19) had a portion of its tip broken during the first five minutes of use. Nonetheless, this conclusion about the vulnerability of chilled dolerite (compared with 'regular' dolerite) is based on observations from a small sample (n=7), so it must be made cautiously. Furthermore, the sample sizes were too small to allow mechanical testing, so we do not have empirical data for the properties of chilled dolerite.

The use damage to hornfels is greater than that to dolerite flakes, but given the different properties of the two rock types, it is surprising that the finer-grained hornfels did not incur more damage than it did. Hornfels is brittle and not as tough or resistant to wear as dolerite, nor does it absorb shock as well as dolerite. Hornfels flakes are less likely to survive intact than dolerite ones when flakes are

thin. A thin hornfels flake (HC1), with an average edge thickness of 1.3 mm, produced a large crescent-shaped lateral snap at its distal end during the first five minutes of use. One hornfels flake (HC3) broke and could not be used after the first minute of use. The edge of this flake, measured at 3 mm from the edge, was 1.5 mm thick before its destruction. In comparison, a dolerite flake (DS2) with the same edge thickness was used for ten minutes without producing any scars or significant signs of damage. Consequently, hornfels is clearly more fragile and accumulates more damage than dolerite.

Analysis of Howiesons Poort material

The assemblage is largely a mixed production of blades and flakes (Table 16). Blades and blade fragments constitute 435 pieces alongside 539 flakes or flake fragments, however, some flakes may have been produced during blade production. There are twelve retouched tools or tool fragments for an assemblage of 1022 pieces, or 1.2% of the analysed assemblage (see Methods). Ten of these tools are backed tools and only two are retouched pieces. There are nine cores, six of which are complete, forming 0.9% of the assemblage.

There is a clear selection for dolerite and hornfels (Table 16). While quartz pieces occur, quartz, quartzite, and sandstone form only 4.4% of the total assemblage before removing the hornfels and dolerite component. Hornfels forms 30.4% of this assemblage with dolerite making up the remaining 69.6%. There is however an emphasis on selection of fine-grained rock (FIG. 14a), especially for blade production (FIG. 14b) where only 28% of blade products are made using the coarse dolerite. This is contrasted against flake production where 54% of flake products are made using coarse dolerite (FIG. 14c).

Tools

Of the twelve retouched or backed tools recovered; seven are of hornfels and the remaining five occur on fine-grained dolerite (Table 17). There are two segments, one complete (FIG. 15d) and one with a broken tip (FIG. 15c), one trapeze (FIG. 15a), and one obliquely backed blade (FIG. 15b). These tools in particular meet the typological definition of the Howiesons Poort (de la Peña 2015). The remaining six tools are broken backed pieces. The majority of tools are made from blades. Four of the blanks are unclear, but two are probably blades, and two probably not. Only two are retouched rather than backed, and both are broken, indeterminate tool types. Most tools in square C4 layer PGS are broken. The fine

dolerite tool component is a little less damaged than the hornfels tools, where two of five pieces, the segment and trapeze, are complete. Six of seven hornfels tools are broken; it is only the obliquely backed blade that is complete.

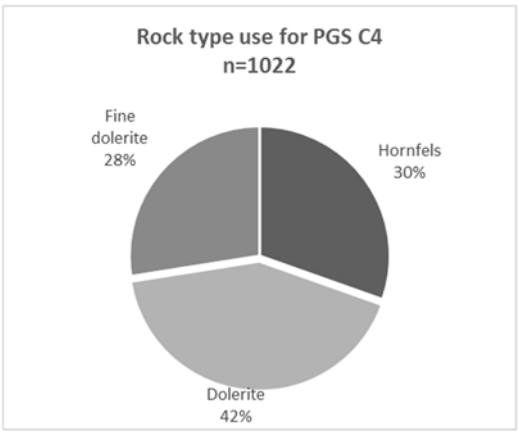
The tools show considerable variation in size. Hornfels produces the widest range of tool sizes. One broken backed piece was made on a bladelet only 4.2 mm in width (after fine backing) (FIG. 15e). Though broken, it has a maximum dimension of 14.3 mm, and seems unlikely to have been much longer prior to being broken. The largest complete tool is an obliquely backed hornfels blade, with a length of 44.4 mm and a width of 19.9 mm.

Cores

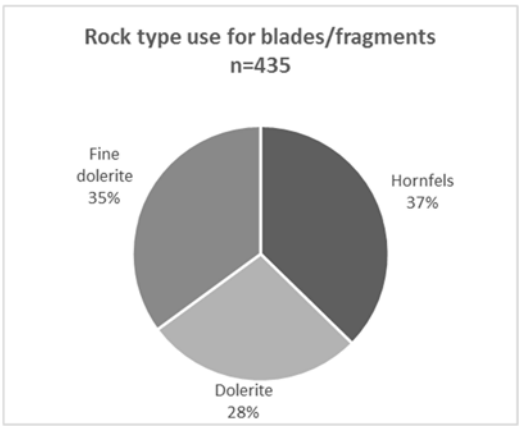
Though the sample size is small, all cores (n=9) are made exclusively of hornfels and fine dolerite (Table 18). For the most part the cores do not reflect the assemblage well because they are very small and heavily reduced with an average maximum dimension of only 37.2 mm. The largest core is of hornfels with a maximum dimension of 52.8mm (FIG. 16b). While prismatic cores are numerous at Klasies River (Wurz 2002), and occur in the Grey Rocky Howiesons Poort layer at Sibudu (de la Peña 2015b), they are absent from this sample.

Coarse-grained dolerite cores are absent. However, while 42% of the study material is coarse-grained dolerite, flakes and flake fragments account for 54% of flakes. This probably implies that flake production, specifically on coarse material, occurs within layer PGS, and that fine-grained rocks were particularly selected for blade production.

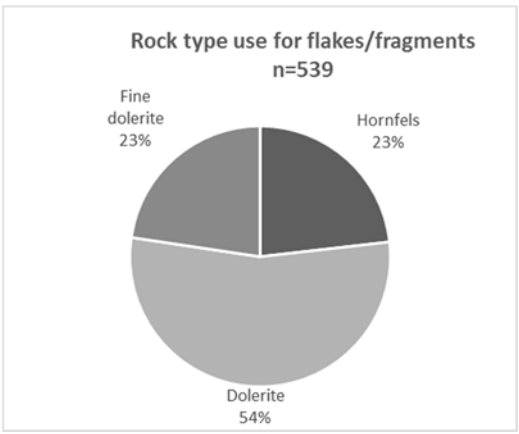
Though relatively small three hornfels cores, including two cores on flakes and one Howiesons Poort type core (Villa *et al*. 2010) (FIG. 16a) are not exhausted and could have been further reduced. Though cores in non-local rock are more methodically worked at Klasies River, (Singer & Wymer 1982), it is the hornfels cores here that are generally not fully exploited. This may be explained in part by the difference in knapping qualities of the rock types. The dolerite cores tend to become unworkable due to knapping errors because step flakes occur more frequently and produce a core with a high centre. Exhausted cores typically preserve a centripetal pattern of flake removals.



a.



b.



c.

FIG. 14. Proportion of rock type use, a) for the of the PGS lithic sample b), for PGS blades/blade fragments c), and for PGS flakes/fragments

Table 16. Assemblage composition for layer PGS.

Type	Dolerite	Fine dolerite	Hornfels	Sub-total
	42,1%	**27,5%**	**30,4%**	**100,0%**
Blades (435)				
Blade	11	9	16	36
Blade fragment	110	140	149	399
Flakes (539)				
Flake	137	48	54	239
Flake fragment	110	43	49	202
Flake incomplete	45	31	22	98
Other (27)				
Chunk	17	1	9	27
Cores (9)				
Core fragment	0	2	1	3
Exhausted core	0	2	1	3
Core on flake	0	0	2	2
Howiesons Poort type core	0	0	1	1
Tools (12)				
Segment	0	1	0	1
Segment (broken tip)	0	0	1	1
Trapeze	0	1	0	1
Broken backed piece	0	2	4	6
Broken retouched piece	0	1	1	2
Obliquely backed blade	0	0	1	1
Total	**430**	**281**	**311**	**1022**

Table 17. Description, rock type, length and width of tools from layer PGS.

Rock type	Tool type	Length (mm)	Width (mm)	Thickness (mm)
Fine dolerite	Segment	29,7	18.8	6.5
Fine dolerite	Broken backed piece	-	14.6	4.5
Fine dolerite	Broken retouched piece	-	-	7.9
Fine dolerite	Trapeze (broken tip)	-	18.1	4.5
Hornfels	Obliquely backed blade	44,4	19.9	5.2
Hornfels	Segment (tip broken)	-	14.4	5.7
Hornfels	Broken backed piece	-	13.2	3.5
Hornfels	Broken retouched piece	-	-	6.7
Fine dolerite	Broken backed piece	-	-	5.0
Hornfels	Broken backed piece	-	12.1	4.2
Hornfels	Broken backed piece	-	9.1	2.6
Hornfels	Broken backed piece	-	4.2	2.5

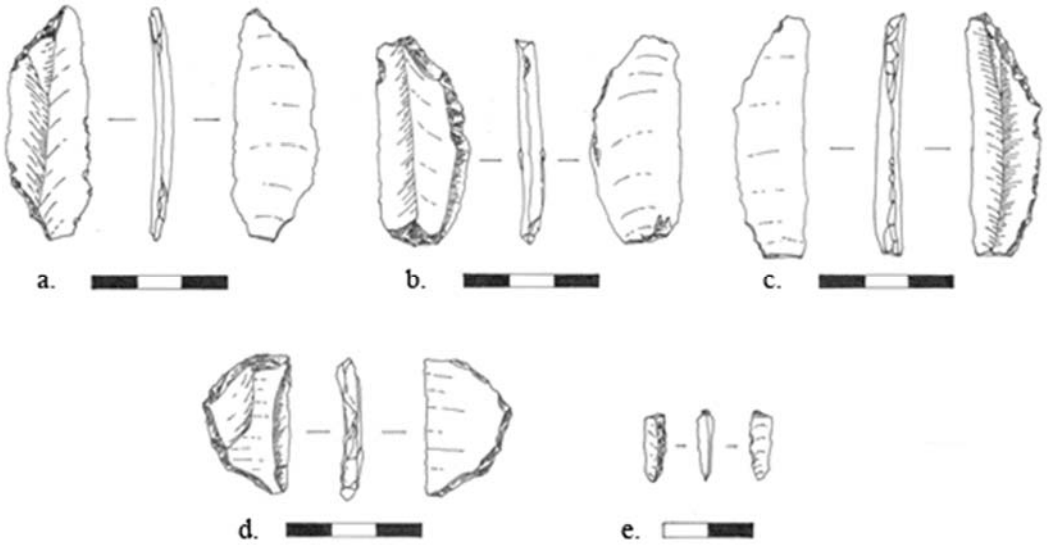


FIG. 15. Backed tools from Sibudu layer PGS. a) Dolerite trapeze, b) hornfels obliquely backed blade c) hornfels segment with broken tip, d) dolerite segment, e). hornfels backed bladelet, incomplete. Drawings by Wendy Voorvelt.

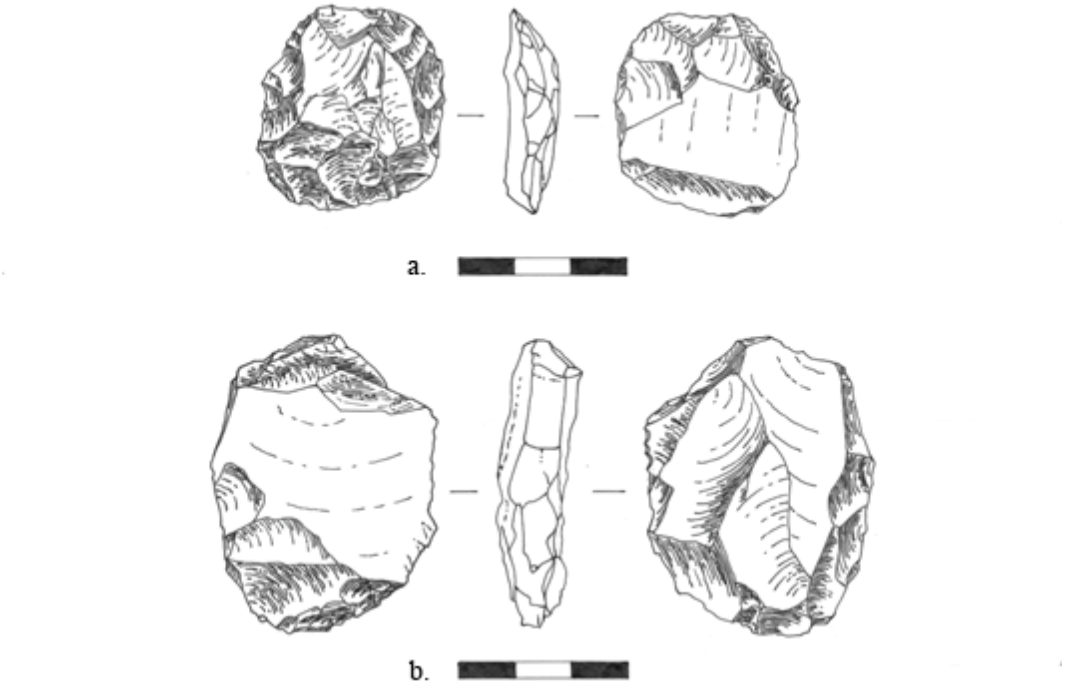


FIG. 16. Cores from layer PGS. a) Hornfels Howiesons Poort type core, b) hornfels core on flake. Drawings by Wendy Voorvelt.

Table 18. Description, rock type and maximum dimension of cores from layer PGS

Description	Rock	Max. dimension (mm)
Exhausted core	Fine dolerite	39,4
Core fragment- blade removals	Fine dolerite	46,3
Core fragment	Fine dolerite	32,5
Exhausted core	Fine dolerite	34,1
Exhausted core	Hornfels	31,4
Howiesons Poort type core	Hornfels	38,1
Core on flake	Hornfels	36
Core on flake	Hornfels	52,8
Core fragment	Hornfels	25

Blades and blade fragments

The complete blades in the assemblage tend to be small and thin, with an average length of 35.2 mm, width of 13.6 mm and a thickness of 3.8 mm . The ratio of blades to blade fragments is low, with only 36 blades to 399 blade fragments. Most blades must therefore have been removed from the site or been extensively broken to make tools. For the most part complete blades represent the early stages of reduction (FIG. 17). They are typically irregular, cortical, or narrow and triangular in section and may therefore not have been as suitable for tool use.

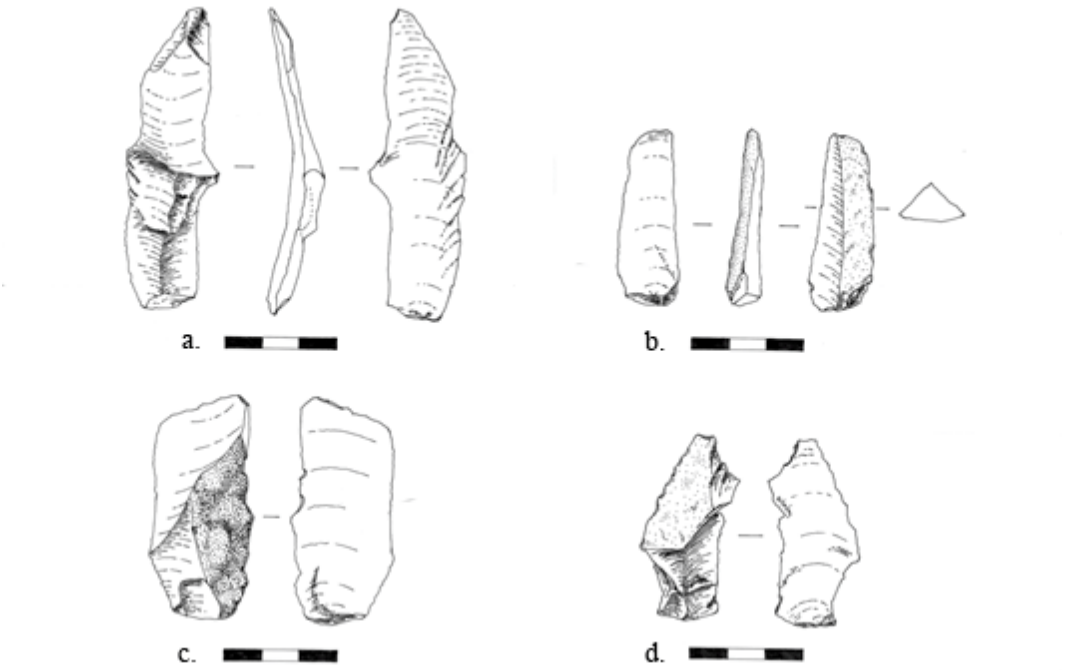
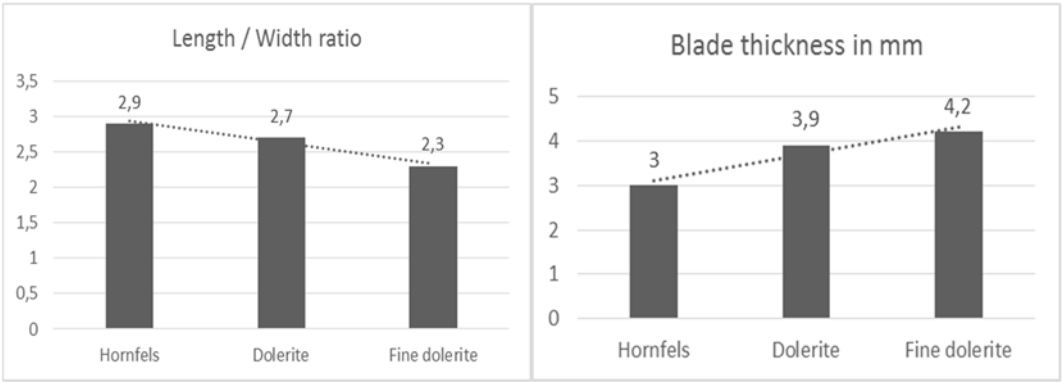


FIG. 17. Complete unretouched blades from layer PGS. Drawings by Wendy Voorvelt.

Table 19. Average length, width, Length/Width ratio and thickness for complete blades, and average width and thickness for blade fragments of hornfels, dolerite and fine dolerite.

	Length (mm)	Width (mm)	L/W	Thickness (mm)
Blades (n=36)				
Average	35,2	13,6	2,7	3,8
Dolerite	**35,2**	13,5	2,7	4,9
Fine dolerite	39,6	18,0	2,3	6,6
Hornfels	32,8	11,3	2,9	2,5
Blades and fragments (n=399)				
Average		15.03		3.6
Dolerite	-	15	-	3,9
Fine dolerite	-	16,9	-	8,3
Hornfels	-	12,5	-	3

There is a considerable difference in the dimensions of blades across rock type (FIG. 18). For example, at one extreme, hornfels blades are on average 2.9 times as long as they are wide, while at the lower end, fine dolerite blades are only 2.3 times as long as they are wide (FIG. 18a). Similarly, hornfels blades are on average 3 mm thick, while fine dolerite blades are on average 4.2 mm thick. In both examples, the more common dolerite is intermediate between hornfels and fine dolerite (FIG. 18b). Hornfels not only produces the blades with the highest ratio of length to width (L/W), but also the thinnest blades. In this sample hornfels appears to be a more productive rock. Three hornfels cores in this sample could have been further reduced though even though two of them were small (38.1 mm, 36 mm and 52.8 mm). Also the high length to width ratio produces more cutting edge per blade than for dolerite. This mitigates the increased time and energy required to collect hornfels and carry it back to site.



a. b.

FIG. 18. a) Average ratio of length to width for hornfels, dolerite and fine dolerite b) average blade thickness.

When looking at the widths of blades and incomplete blades combined it is clear that there is a distinction between the hornfels and fine-grained dolerite components (FIG. 19, FIG. 20). The width of hornfels pieces peaks at 10 mm in width, while fine-grained dolerite widths peak at 16 mm. With hornfels, the majority of pieces have a width of between 4 mm and 20 mm, and no pieces have a width wider than 28 mm. fine-grained dolerite has a wider range, extending to 38 mm, but the very narrow component is absent up to 7 mm. This fine-grained type of dolerite tends to produce the thickest, widest blades. Probably due to the knobbly irregular surface it produces it does not seem to be as suitable for bladelet production. The distribution of coarse-grained dolerite seems anomalous, with no pieces below 20 mm in size, and no pieces above 50 mm. The 50 mm -60 mm and above size ranges may have been highly selected for tool use.

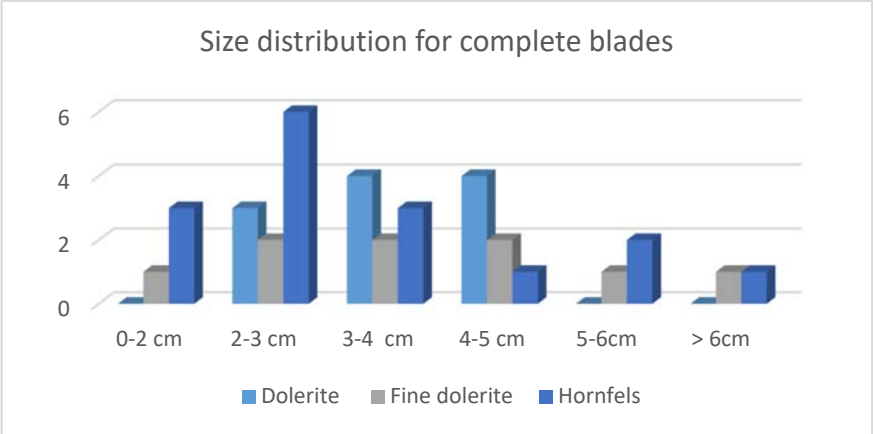


FIG. 19. The size distribution of complete blades made on hornfels, coarse-grained dolerite and fine-grained dolerite.

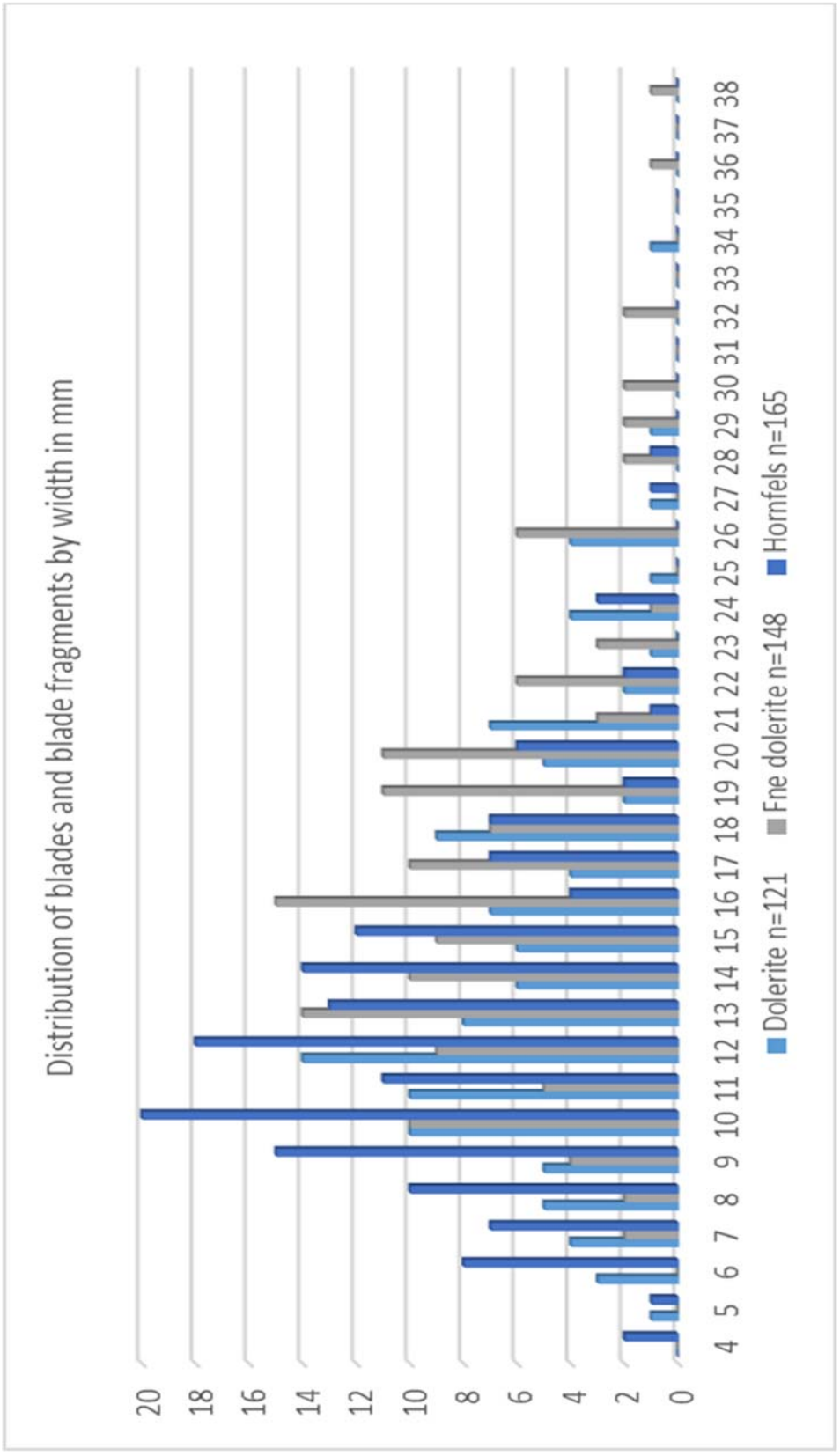


FIG. 20. The distribution of blades and blade fragments by width in mm, for hornfels, coarse-grained dolerite and fine-grained dolerite.

Summary of results

It is clear from the results of the chemical and mechanical tests that dolerite and hornfels provide two rock resources with diverse properties. Each presents the knapper with a suite of characteristics that present both advantages and disadvantages in terms of procurement, knapping, tool and core maintenance and edge properties. Some of these properties can be seen in the results of the experimental cutting and scraping of leather. Both materials produced excellent tools, particularly when rock type was well matched to activity type. For instance, 1) dolerite produces robust edges, suited to scraping, unless the edge is regular and thin, in which case it produces good cutting edges, 2) hornfels produces thin, sharp, relatively weak edges, well suited to cutting, though thicker edges will perform well as scrapers although accruing damage. The experiment also highlighted that 3) hornfels is easier than dolerite to knap, requiring less energy to fracture and permitting greater knapping accuracy than dolerite.

These data provide insight into the archaeological assemblage. It is clear that knappers were prepared to carry hornfels to Sibudu Cave despite the fact that it produces weaker edges, that tools will break more often, and that tools will need resharpening more often. It is also more suited than dolerite to the production of blades and is more versatile in terms of reduction strategies because it allows for greater knapping accuracy. Fine-grained rocks are selected for in layer PGS, with all cores and tools occurring on either hornfels or fine-grained dolerite. The absence of coarse-grained dolerite cores may reflect off-site knapping, or the preferential conservation of fine-grained material. However, knappers could produce the same types of cores and products in dolerite and hornfels. For instance, blade production occurs in both rock types, though the dolerite produces the larger blades, and hornfels the smaller range of blades. There is substantial overlap of rock type use in the middle size range of blades. The prevalence of dolerite shows that it is an excellent resource and not surprisingly it forms the

bulk of the archaeological assemblage in PGS and many other lithic assemblages at Sibudu.

CHAPTER 6

DISCUSSION

It is the mechanical properties, and therefore the knapping and edge wear properties of a rock, that are immediately relevant to a knapper during rock procurement. This is deliberated in the context of 1) an accumulated knowledge of the suitability of a rock to an intended reduction strategy and function, and 2) rock distribution in the surrounding landscape and foraging range.

To understand these choices, it is necessary to understand how rocks break and the principles of fracture mechanics that apply in the solid, brittle materials that are rocks. These principles are discussed below, and used to interpret the results of the experimental production and use of flakes for cutting and scraping. Finally, these insights are used to interpret the archaeological assemblage from the earliest Howiesons Poort occupation, PGS, from Sibudu.

Mechanical properties and XRF

Not all rocks are amenable to geochemical sourcing, specifically dolerite. XRF samples that were submitted did not encourage further testing. The major elements analysis did not reveal anything unusual that might be used to discriminate between geological sources. Clarke *et al.* (2007) found that silica

values vary widely amongst dolerite samples, with low values of 50.58 wt%, in contrast to Effingham dolerite sills, which are characterised by high silica contents sometimes in excess of 63 wt%. Despite this, dolerite is typically chemically similar across large regions. Equally the results of major elements and trace elements show that it will be impossible to discriminate between geological sources or hornfels as experienced by Sampson and Youngblood (2006). The Black Mhlasini hornfels and the Sibudu shale quarry have chemical compositions that demonstrate their similar origins.

Since rock is not a perfect solid, hardness is difficult to measure accurately and the results of the Vickers hardness test show that both dolerite and hornfels have hardness values that occur on a continuum and overlap. Hornfels values vary as a result of varying grain size and relative degree of metamorphism. Dolerite values are largely determined by weathering, chemical composition and rate of cooling.

Being constituted of plagioclase and pyroxene crystals, each with different properties, it was important to take multiple readings for dolerite samples in particular to find the average hardness. Therefore, ten hardness readings were taken for all samples, including hornfels.

Neither rock type therefore has a very restricted range of hardness values. The results do show that both rocks have the potential to be considered hard or even very hard. This is especially true in the case of dolerite. The degree of metamorphism in hornfels makes it more susceptible to being weak though well metamorphosed rock is hard. Consequently, both rocks should provide strong durable edges. However, hornfels is granular in nature and breaks around grain boundaries. Because it is fine-grained it tends to produce a thin edge. However, while it is a hard rock it seems prone to blunting. The small grains that make up hornfels are more likely than dolerite to be abraded and removed from the edge

because they are not held as tightly to the surface as rocks with an intermeshing crystal structure.

Conversely, it is harder to initiate fracture in an intermeshing crystal structure, thus producing a more robust edge in dolerite. Fracture in dolerite is through the crystal structure, which can produce very sharp edge, though these may be thin and break to form a dull edge. Though dolerite has a crystal structure it does not necessarily produce a thin regular edge, when flaked, in the sense that quartz might. Dolerite often has a grainy texture and can produce 'lumpy', irregular surfaces when flaked.

Of the 11 archaeological tools sampled, only one was dolerite, and this was the second hardest sample tested. The remaining ten tools were hornfels, and their hardness values ranged significantly. Five of six geological samples tested had lower hardness values, both for dolerite and hornfels, than for archaeological tools. This reflects the wide range of values that can occur within a rock type. What is interesting is that there seems to have been selection for the harder, or better metamorphosed hornfels, and better qualities of dolerite. This is the same pattern that Yonekura *et al*. (2008) observe, where Palaeolithic tools often display hardness values that are higher than the average values for geological samples of the same rock type. Thus stone knappers consciously selected hard rock. Harder rocks are more useful, because harder materials are resistant to wear.

There is a significant difference in the roughness of dolerite and hornfels. Dolerite is not just hard; it is also consistently rough relative to hornfels. This roughness, and system of interlocking crystals, contributes to creating the high fracture toughness of the rock. The data shows no overlap between the rock types, with dolerite always presenting a far rougher surface than hornfels. For

hornfels, this relative smoothness may increase the rate of wear of a tool's edge, but it also easier to knap because the force of the blow travels more cleanly through the fracture path. It also tends to produce flakes with straight, sharp edges, and flakes with quite regular profiles. Experimental data suggest that it is harder to detach large flakes from coarse-grained rocks (Jones 1979, 1994), yet coarse rocks are preferentially selected in the Acheulean for large cutting tools, even when fine-grained rock is available (Sharon 2008). Sharon (2008) speculates that while coarse rocks may not produce a particularly sharp edge, the edge produced will not be as susceptible to blunting.

In practical use, the coarseness of dolerite has two outcomes that separate it from hornfels. Firstly, the increased fracture toughness leads to differences in fracture properties. It requires more energy to fracture, it is more likely to produce a bending fracture (Soriano *et al*. 2015), and is more likely to produce knapping accidents such as split flakes (Cochrane 2006). Secondly, the flakes produced are more likely to be irregular and less suitable for retouch. Because dolerite is both coarse-grained and tough, there is an increased chance that the edge will crush and acquire a denticulated appearance (Jones 1979). Flakes also tend to accumulate edge damage that may have a negative effect on cutting hard materials such as leather, due to snagging.

Of the many measurable rock properties, fracture toughness in particular has been viewed as an objective measure of raw material quality (Domanski & Webb 1992; Webb & Domanski 2008). Heat treatment of some rocks, notably silcretes (Toyoda & Ikeya 1993), lowers their fracture toughness, allowing fractures to propagate more readily, and improving knapping quality; Borradaile *et al.* 1993; Domanski & Webb 1992; Brown *et al.* 2009). Neither dolerite nor hornfels are suitable for heat treatment (Wadley & Kempson 2011), and hornfels will sometimes split along any remaining bedding planes in the material when heated. In an interesting study Dunnell & McCutcheon (1994) show that chert used in the

manufacture of hoes was not heat treated. However, when the material was recycled, and a lower fracture toughness was desirable, the piece would be heat treated for other uses.

The elasticity of a material describes its ability to be deformed elastically (non-permanently) when a force is applied. The higher the elasticity of the rock, the more energy it absorbs before it breaks. The elasticity tests demonstrate that dolerite is more elastic than hornfels. The results of the compressive strength tests, which determine elasticity, were partly mixed. To some extent this is a function of the actual sample size (n=7). The minimum size for a test piece is a cylinder with a diameter of 5cm and a length of 10cm. Therefore, most tests were done on rock from the dolerite dyke. Because of the scarcity of hornfels in the area, and the large size needed to produce the sample, hornfels was used from three other locations, the Vaal river gravels and the Magaliesberg. These samples were taken from very large, thick pieces of hornfels and they probably have a greater strength value than that of most hornfels in the Sibudu area.

The fracture toughness test used here determines the energy required to fracture rock samples on impact, as happens during knapping. The eighteen samples tested show variable results for the fracture toughness of the two materials. As rocks are not homogeneous, this reflects the range of the two rock types. Unfortunately, as none of the hornfels pieces from the Sibudu area was large enough for this test it does not provide an accurate range for local hornfels, which probably has lower fracture toughness. This is evident during experimental knapping. Also, hornfels samples collected in the area do not seem to be as well metamorphosed, or occur in as thick slabs, as the samples used in this test. However, the lower range of values for hornfels, and the lower average value for fracture toughness, show that hornfels, particularly in the Sibudu area, requires less energy to knap than dolerite. A subsequent test was conducted to show variability in fracture toughness readings within a single rock. Three samples

were produced from a single rock piece, for dolerite and for hornfels. This showed substantial differences in fracture toughness within a single clast. Both rock types had a maximum value of 3.0 Joules/mm^2, but hornfels had the lowest reading by far at just 0.5 Joules/mm^2. An average of the three reading showed that for this test, dolerite required an additional 8.8% of energy to knap. It also showed that hornfels is extremely variable in nature.

Fracture toughness is a very important rock property for knapping. For the first test (eighteen samples of mixed origin) it required on average almost a third more energy to fracture dolerite than hornfels. This means that the knapper does not have to strike the hornfels platform as hard, allowing for greater accuracy in placement of the blow. When the grain size is small the fracture path is smoother and more stable, and hinge fractures are less likely to occur. Less energy is wasted in moving around grains or in splitting them so less energy is needed to propagate the fracture. The result is generally a smooth fracture surface with sharp edges. This combination of stable fracture propagation, brittleness, and reduced energy loss during crack propagation make hornfels a versatile rock to use in general and a very suitable material for blade production in particular.

Experimental flake production and use

The formation of flake attributes (Damlien 2015), and both macro- and microscopic use-wear traces are affected by rock type, with coarser rocks exhibiting less developed traces, though the microwear features remain the same (Rots 2010). Fine-grained flint may be favoured for experimental work for example because it facilitates the observation of trace production. However, the purpose of the experiment was to replicate two activity types, cutting and scraping, that would have been necessary in the past, and to compare the

differences between dolerite and hornfels in tool production and edge damage seen in the tools. Hide preparation for instance would have required tools for cutting and scraping purposes. For the experiment, cutting and scraping was conducted using tools on leather. Similar results cannot be expected for working bone or cutting meat for instance, but using one material only (leather) served to reduce the variables in the experiment.

Even though the experimental hornfels core was small and only about 2 cm thick, it produced numerous flakes compared with the dolerite core. Hornfels must be characterised cautiously though because of differences in quality due to the degree of metamorphism. Where bedding planes in the experimental hornfels core had not been well metamorphosed, the resulting flakes have stepped contours rather than smooth, feathered shapes. Dolerite on the other hand is freely available in any size, from pebble to boulder, and also in tabular form from the nearby dyke. It was more difficult to knap, especially due to the blocky nature of the piece. However, with no shortage of material it was not a problem to produce sufficient flakes for use.

All six dolerite flakes used produced excellent scrapers. This was irrespective of the edge thickness, edge shape, or regularity of the edge. The edge damage that did occur is mostly in the form of small half-moon snaps along the edge that may produce a slightly denticulated appearance. Importantly, this did not have much effect on the usefulness of the flakes as scrapers. Conversely, only one of six flakes was good for cutting. This was mostly a function of the irregular edges of the flake, which tended to catch on the leather rather than cut it.

Chilled dolerite flakes developed more variety in terms of damage. Part of the edge and tip of one flake broke during scraping, and a small flake was detached

from the edge. Not much damage occurred on the flakes used for cutting, though in one instance an irregular edge became a little smoother, and a little easier to use, during the second period of use. These flakes are not as strong as dolerite flakes, but they are better at cutting than dolerite because when damage does occur it is less jagged.

Hornfels sustained the most damage, particularly to flakes used for scraping. This is to be expected for a brittle rock. One flake broke in half and another sustained a large snap during cutting, but nonetheless these flakes produced the most effective cutting edges. When used for scraping more robust edges need to be selected for use.

Accidental conchoidal flake detachments are not common during tool use; they are usually only formed by quite a hard indentor. Where the material being worked is softer than the tool (Cotterell & Kamminga 1987), and where the contact area is broad (Lawrence 1979) the tool edge is more frequently broken by bending. This is certainly the case in this study where soft leather was worked and where the majority of damage occurred as snaps along the tool edge.

The susceptibility of hornfels to edge damage is reflected in the data collected by Cochrane (2006) where he found that 96.7% of retouched pieces at Sibudu (for post-HP layers) are made of hornfels and dolerite, yet 73.6% of this component is hornfels. Knappers therefore were aware that hornfels tools would break or need resharpening more often, but accepted the higher degree of edge failure in anticipation of the favourable qualities of the rock.

The wear sustained by a tool is a direct result of the structure and mineralogy of lithic materials (Greiser & Sheets 1979; Lerner *et al.* 2007). The mechanical properties of hardness and surface roughness seem to dictate the rate at which edge wear forms during tool use. Lerner and colleagues (2007) found that during their experiments, scrapers made on rocks with a high degree of surface regularity, such as Yellow Silicified Wood and Brushy Basin Chert, developed invasive wear. The higher hardness values as well as the rougher nature of dolerite (Wadley & Kempson 2011) confirm that it is more resistant to edge damage than hornfels.

Brittle rocks such as obsidian are particularly prone to damage, and edge attrition can be rapid, leading to high discard rates for artefacts (Braun *et al.* 2008). Jones (1981) carried out an experiment where phonolite and basalt flakes were used for butchery. He found that the brittleness of phonolite meant that the edge had to be strengthened using retouch. Brittleness may not have been as great a cause of edge damage on stone tools at Sibudu because the local hornfels, although more brittle than dolerite, is still relatively tough. In general, rather little edge damage was produced on either dolerite or hornfels flakes during the ten minutes that each was used, although as would be expected, hornfels sustained more damage than dolerite. The negligible edge damage to dolerite can be explained by its hardness and its coarse-grained, rough microtopography, but the minimal wear even to hornfels flakes is not totally unexpected because working leather or hide acts in the same way as a blunt indenter on a tool; the contact area is large and the incidence of fracture is therefore reduced (Odell 1981). Dolerite is not only elastic and hard, but it also absorbs shock, which further prevents it from incurring damage during use.

This experiment demonstrates that dolerite produces flake edges that are well-suited to scraping, but due to the coarse-grained character of dolerite flakes, edges tend to be irregular, sometimes naturally denticulated, and therefore not as

suitable as fine-grained rocks for cutting tough materials. Conversely, hornfels flake edges tend to be thin and sharp, but less robust. They are ideal for cutting, though without retouch they have a tendency to break when they are too thin.

Dolerite and hornfels from the Sibudu area have different mechanical properties and behave differently during knapping and tool use, but successful flakes provide edges that are resistant to damage not only during manufacture, but also during use. Fine-grained brittle rocks like hornfels flake easily and predictably to create more predictable products. However, this brittleness also means that more edge damage occurs during use.

Dolerite is a useful resource in the Sibudu area because of its local abundance, both in blocks that can be quarried from the dyke and in cobbles and boulders from the uThongathi River. Acquisition is easy, but considerable force is required to produce flakes and this makes it more difficult to produce thin flakes or blades. The fact that Sibudu artisans sometimes knapped thin flakes and blades from dolerite is testament to their considerable skill. Depending on the coarseness of the rock, the flakes tend to have irregular edges that are sometimes naturally denticulated. Although chilled dolerite is finer-grained than the 'regular' dolerite, it can be awkward to flake where core size is small, and not many flakes of usable size were produced in this experiment.

Knappers selected rocks for the suite of properties inherent to each rock type. Understanding the implications of these choices provides insight into hominid behaviour. At Sibudu, dolerite provided a valuable resource, occurring in large quantities in the immediate area. It produces exceptional scrapers and potentially useful cutting tools. Informal use by myself of dolerite flakes to cut meat was successful. It is therefore possible that using dolerite flakes for soft material

would be convenient, and they may have been expediently used as such. However, hornfels excels at cutting and it is unlikely that it would not have been valued for cutting purposes. When flakes with thin and regular edges are selected, knappers would have been aware that hornfels tools were more likely to break and material would have to be carried some distance, yet they chose to expend energy procuring hornfels. I suggest that hornfels was selected for two reasons: its knapping flexibility, and to produce tools that would have a cutting function.

A preliminary analysis of Howiesons Poort material

Despite efforts to define the Howiesons Poort technologically, it is still more often than not recognised typologically (de la Peña 2015b). This is the case here. Typologically the assemblage is consistent with a traditional definition for the Howiesons Poort (Henshilwood *et al.* 2014; Wurz 2013). As blades are rare in the preceding Still Bay layers (Soriano *et al.* 2015), the production of blades in this sample is immediately noticeable. The assemblage therefore shows a considerable shift towards blade production (Table 16). In addition, backed tools are the dominant tool type (ten of twelve tools), as is the case for Rose Cottage (Villa *et al.* 2010). These include two segments, a trapeze and an obliquely backed blade. The remaining tools consist of six broken backed pieces, and two broken retouched pieces.

It is important to note that all twelve tools were produced on fine-grained rocks. Hornfels makes up 58.3%, and fine-grained dolerite constitutes the remaining 41.6%. No tools were made using coarse rock. Most tools are broken (66.6%). The sample is small, but of these, only one in seven hornfels pieces is complete (14.2%), whereas 2 in 5 (40%) of fine-dolerite tools are complete. Because of the fragmentation of the tools a maximum thickness was taken for all pieces. Fine

dolerite tools are thicker, averaging 5.68mm. Hornfels tools average 4.3mm. The thinnest fine dolerite tool is 4.5mm, which is thicker than the average hornfels tool. Based on a very small sample, it seems that hornfels fulfilled a specific role in tool production. Even with such strong selection for fine-grained rocks, hornfels seems to have been used to produce thin tools, despite being the more fragile rock.

Bifacially flaked pieces are recorded at Sibudu for the middle and upper layers of Grey Sand (de la Peña & Wadley 2014b), and Grey Rocky (de la Peña 2015). However, most of these are made of quartz which has been excluded from this study. Bifacial pieces in silcrete occur at Diepkloof though these are rare and are only characteristic of the early Howiesons Poort there (Porraz *et al*. 2013a). While bifaces are not typically thought of as forming part of the Howiesons Poort, they are associated with the industry (Goodwin & van Riet Lowe 1929; Singer & Wymer 1982).

The same pattern of fine-grained rock selection in tools is mirrored in rock selection for cores. Of the nine cores, all occur in fine dolerite (44.4%) or hornfels (55.5%). Both the largest (52.8mm) and the smallest (25.0mm) core are hornfels, and all the cores are small. Again, no cores occur in coarse dolerite. This might in part reflect rock collection practises. Because both hornfels and fine-grained dolerite are high quality materials with a higher procurement cost, it is likely that toolmakers collected these when they were encountered in the landscape, as well as purposely collecting these materials and returning them to site. Numerous artefacts of coarse dolerite occur, forming 42% of the assemblage. It is possible that these cores were intentionally discarded as no forward planning is necessary because the material is immediately available.

Exhausted cores typically preserve a centripetal pattern of flake removals. One such dolerite core had become unworkable due to knapping errors, where the accumulated step flakes had produced a high centre. Three of the hornfels cores, though small, could have been further reduced. This is probably in part because fewer knapping errors occur on these cores to hinder further flaking. While non-local rocks are more methodically worked at Klasies River (Singer & Wymer 1982), it is the hornfels cores that are less intensively worked in this assemblage. The average maximum dimension of dolerite cores is 38.0mm, while hornfels cores average a maximum dimension of 36.6mm. One complete hornfels blade (FIG) is more than 6cm long, and preserves a pattern of bidirectional flake removals, both resulting in a step flake. This is the best indicator for maximum core length for this assemblage. The cores are largely uninformative as they are largely broken or exhausted and cannot provide a comparison of core types, except for one Howiesons Poort type (Villa *et al.* 2010) core. While the reduction of bipolar quartz cores is recorded for the Howiesons Poort layers (de la Peña & Wadley 2014a, 2014b), their presence here cannot be confirmed because the quartz element of this assemblage did not form part of this study.

Prismatic cores have a long expression at Klasies River, occurring in the MSA1 (Klasies River Sub-Stage) and persisting into the Howiesons Poort. These cores predominate at Klasies River (Wurz 2002), and are so far present, but rare at Sibudu (de la Peña & Wadley 2014a; de la Peña 2015b). Howiesons Poort type cores (Villa *et al.* 2010) seem to be the most representative type across Howiesons Poort sites, occurring as slight variants at Klasies River, Sibudu and Diepkloof (Villa *et al.* 2010, Porraz 2013a; de la Peña 2015). They also occur at Rose Cottage though blade cores there are chiefly oriented towards bladelet production on small opaline nodules (Soriano *et al.* 2007). The Howiesons Poort core type is represented in layer PGS (square C4) while prismatic core types are absent. However, most cores are heavily reduced, broken or exhausted and no longer embody most core reduction for this assemblage.

de la Peña (2015b) also describes intentional flake production in the Howiesons Poort. This is seen in the presence of Levallois flakes, as well as in the presence of discoidal cores. No Levallois flakes or cores were recovered from this small sample. Cores are typically found in quite small numbers at Sibudu. The nine cores in this sample are typically broken, exhausted, and indeterminate in form. No discernible discoidal cores are present. Despite this the number of flakes indicate a component of intentional flake production.

There is an argument in the data for flake production, particularly on coarse-grained material. The overrepresentation of flakes in coarse dolerite implies some flake production though there are no coarse dolerite cores in this material. Coarse dolerite forms 42% of the total (N=1022) assemblage. Nevertheless it only comprises 28% of blade products. More than half (54%) of the flake component is of course dolerite (Fig). This selection of fine-grained materials for blade production and coarse-grained materials for flake production is also seen for the Howiesons Poort levels at Klipdrift (Henshilwood *et al*. 2014), where silcrete, quartz and cryptocrystalline silicate is selected for blade production, while quartzite was used for flake production which tended to be expedient and less formal.

Intentional flake production has also been noted for the middle and upper layers at Klasies River (Villa *et al.* 2010, Wurz 2013) and the upper layers of Rose Cottage (Soriano *et al.* 2007). At Diepkloof the intentional production of naturally backed flakes also occurs near the top of the sequence (Porraz *et al.* 2013a). It is probable that intentional flake production occurs throughout the Howiesons Poort at Sibudu.

Blades here are preferentially made using fine-grained rock. Both hornfels and dolerite are preferentially selected for this purpose. Fine dolerite constitutes 28% of total rock selection, but 35% of blades and fragments. Similarly, hornfels forms 30% of rock selection, but 37% of blades and fragments. It is important to note that there are only 36 complete blades in the assemblage, and that many of these appear to be from the early stages of knapping, as can be seen in the presence of cortex, and one blade preserves knapping errors that preclude it from being used for tool manufacture. However, while the width of incomplete blades (n=399), as well as the thickness of blade fragments (n=399), is consistent with that established for complete blades (Table 19). Therefore, even if the values would change with a bigger sample of complete blades, the pattern would most likely remain the same.

Complete blades in layer PGS are similar to those described for Klasies River in that they are small and thin (Wurz 2002), though the Sibudu ones are smaller, with an average length of 35.2 mm (43.9 mm at Klasies River), an average width of 15.0 mm (18.8 mm at Klasies River), and an average thickness of 3.6 mm (4.9 mm at Klasies River). It is difficult to decide whether the smaller size at Sibudu is a function of raw material, though it seems unlikely. Rose Cottage blades are small and so are the opaline nodules they exploited. This is seen in the small size of blades (n=678) that have an average length of only 28.1 ± 6.9mm (Soriano *et al.* 2007). The average length of Sibudu blades is therefore almost exactly midway between that for Rose Cottage (Soriano *et al*. 2007) and Klasies River (Wurz 2002) (28.1mm, 35.2mm, 43.9mm). At Sibudu, dolerite is not size restricted, though hornfels is to some extent. However, large pieces of hornfels were available and one hornfels complete blade was over 6cm long. The length/width ratio is 2.9 for hornfels, 2.7 for coarse dolerite, and 2.3 for fine dolerite. It is surprising that the fine dolerite had a lower length/width ratio than coarse dolerite. The same pattern is seen in blade thickness. The higher the length/breadth ratio, the more edge per unit of material is achieved. This, in conjunction with the thickness of the piece, shows that hornfels is the most

economical material to work, followed by dolerite, and finally fine dolerite. This ability to create more edge per unit volume of material mitigates the cost involved in procuring more distant or relatively scarce materials (Brantingham *et al.* 2000).

The Howiesons Poort is synonymous with a selection bias towards fine-grained rocks (Stapleton & Hewitt 1928; Wurz 2000; Delagnes *et al.* 2006). In the PGS assemblage there is a clear preference for fine-grained materials. While 30% of artefacts are hornfels, a further 28% are of fine grained dolerite. There is a further bias in blade production, where 72% of blades and blade fragments occur on fine-grained rock. More importantly, all cores and all tools occur on fine dolerite or hornfels.

Rock procurement at Rose Cottage during the Howiesons Poort is similar to that of Sibudu in the sense that fine-grained rocks (opaline nodules) are selected, and these occur locally with no introduction of 'exotic' rock types. However, there is little change in rock selection practises for the post-Howiesons Poort at Rose Cottage, where there is a minimal increase in the use of tuff. It is not surprising that there is a continued preference for the use of opaline; Soriano *et al.* describe it as a high-quality material similar to flint.

At Sibudu, there is however a noticeable change in rock selection in the period immediately following the Howiesons Poort (Cochrane 2006). However, the same materials are exploited, just in varying proportions across time. Sibudu rock procurement therefore remains local, with all materials available within a 15km radius. However within this local zone at Sibudu, quartz is rare and hornfels is more distant. Therefore there is no reason to consider long distance trade, reciprocal exchange, or expanded foraging range to obtain resources. However, in

the case of Diepkloof there is evidence for non-local sourcing of good quality rock perhaps as far as 70 km distant (Porraz *et al.* 2013a).

There are no data from Sibudu to support the Ambrose and Lorenz (1990) model for increased mobility, because the materials used at Sibudu remain the same. The data from Sibudu rather favour a model of resource intensification where foraging is time dependent rather than distance dependent (Minichillo 2006). However, the selection of 'non-local' fine-grained materials such as silcrete and quartz at Klasies River and Nelson Bay cave are more controversial. This has been used to support both the model for increased mobility (Ambrose & Lorenz 1990), and the resource intensification model of Minichillo (2006), who argues these materials are local, but scarce. As Wurz (2013) points out, whether sources are local or non-local, what is relevant is that fine-grained rocks are preferentially selected.

Temporal and regional variation within the Howiesons Poort is expressed at several sites, though it is generally a subtle change, as at Rose Cottage (Soriano *et al.* 2007). Porraz *et al.* (2013a, 2013b) have argued for an extended and more variable regional and temporal changeability. The Howiesons Poort at Sibudu though is brief, representing roughly three thousand years of occupation. Within these layers diachronic change is evident (Delagnes *et al.* 2006) in rock selection, though on a much subtler level than that suggested for Diepkloof. The PGS sample studied here would correspond with the late Howiesons Poort expression at Diepkloof, where the presence of backed pieces that are particularly well represented at Sibudu and lack of earlier type tools, such as strangulated pieces, are better suited to this phase. Similarly, the production of Howiesons Poort type cores and the presence of (possibly) intentional flake production, though on coarse material, are shared traits.

Interpreting the archaeological assemblage in terms of mechanical properties and experimental tool production and use

Blade production

Though blades were regularly produced on coarse-grained rock, there is a strong selection here for high quality rocks (Webb & Domanski 2008) (Inizan *et al.* 1999), especially rock types that flake predictably, such as hornfels, and to a lesser degree fine-grained dolerite. Dolerite is isotropic, as is good quality hornfels, and when this quality is combined with a fine grain-size, which promotes crack stability, it is easier to control both knapping and planning during the reduction process.

Domanski and Webb (1992:612) describe fracture toughness as the 'the best independent measure of the flakeability of an artefact material, and show that heat treating of cryptocrystalline siliceous artefact lithologies are improved by heat treatment, by lowering their fracture toughness. Hornfels (Table 7, Table 8 & FIG. 9) has a low fracture toughness. While no toughness tests were carried out on fine-grained dolerite due to size constraints of the available pieces, it is probable that the fine grain size will reduce fracture toughness, as less energy is absorbed in tracing a path around or through the grains, the elongated plagioclase crystals in particular (Wadley & Kempson: Page 101, FIG1a). When less energy needs to be used in detaching a flake, greater knapping accuracy can be achieved during core reduction. In addition, when such a brittle (inelastic) rock is knapped the energy of the blow is stiffness controlled. The flake being detached resists bending, and energy is directed in the direction of the blow (Cotterell & Kamminga 1987). This tends to produce elongated flakes, which in fine-grained rock produces a stable fracture path and a smooth surface.

It therefore makes sense that hornfels and fine-grained dolerite were preferentially used for blade production. However, with lower fracture toughness and reduced grain-size, blades, or the tools produced from them, have edges that are similarly more susceptible to damage.

Tools

Ten of twelve tools in the PGS material are incomplete (Table 17), and though the sample size is small it would seem that hornfels tools are more likely to break. No tools of coarse-grained dolerite occur, so it is not possible to compare the two types of dolerite. Fine-grained rocks are more frequently selected for retouch (Orton 2008), and this is the case here.

This breakage pattern can be attributed to two causes. First, hornfels blades tend to be thinner (FIG. 18b), and have a greater length to width ratio (FIG. 18a). Secondly, while hornfels has a hardness value that is similar to that of dolerite, it is less elastic and has lower fracture toughness. These factors combine to produce a more fragile tool. Despite this, hornfels is selected even though it might have taken considerably more time and energy to procure. Minichillo (2006) argues that where an increase in time or distance is involved in rock procurement, subsequent artefacts have increased value. Disregarding any symbolic reasons (e.g. Deacon 1995), which are beyond the scope of this thesis, the value of hornfels must be in knapping properties or the characteristics of a tool's working edge.

As discussed, the knapping properties of fine-grained dolerite, and hornfels in particular, are excellent. This is especially so when high quality versions of these

rocks are selected, as can be seen in the hardness data. Knappers at Sibudu selected well metamorphosed hornfels with high Hv values (Table 12) when compared with geological samples tested. This pattern, where Palaeolithic tools often display hardness values that are higher than the average values for geological samples of the same rock type was observed by Yonekura *et al*. (2008). Thus, stone knappers consciously selected hard rock, a property that determines the rate of wear (Lerner *et al.* 2007).

Harder rocks are more useful, because harder materials are resistant to wear. The results of the cutting and scraping experiment show that dolerite flakes provide robust edges that resist damage and are excellent for scraping. These flakes were not good as cutting tools, though the experimental results come from use on tough leather. They would probably cut meat or other softer materials quite well. Because fracture in dolerite is through the crystal rather than around it, a sharp, thin edge is sometimes produced. However, this edge generally breaks with use, though this might not be the case for cutting soft materials. This can be seen in the research of McPherron *et al.* (2014). The degree of damage to experimentally trampled flakes is greater for rock types with a low edge toughness, however, once edge angles become low enough, damage occurs irrespective of material type. The hornfels flakes produced excellent cutting tools, though the brittle nature of the rock resulted in less effective scraping tools on such a tough material as leather. They might produce more effective scrapers on softer materials.

Backed tools (segments) for hunting

Research by Lombard (2005b, 2008), and Lombard and Pargeter (2008) provides insight into the use of some backed tools for hunting purposes, as arrowheads and as spears. Lombard and Pargeter (2008) have referenced ethnographic material

(Rudner 1979) that records the belief by some hunters that it is more lethal for a projectile to break up in the prey, as this increases tissue damage and bleeding. At Sibudu segments are typically made of dolerite, hornfels and quartz, and their length, breadth, width, and the cross-sectional area of their tips place them in three distinct populations (Wadley & Mohapi 2008). Wadley and Mohapi (2008) suggest that they are not intended as a single tool type and show flexibility in the way they could be hafted. Hornfels is the dominant rock type for segments (54.4%), followed by dolerite (29.1%), and quartz (16.5%). Of these, dolerite segments are the longest, widest and thickest, and quartz the shortest and narrowest. Hornfels segments have the least standardised shapes of all three, and quartz is the most standardised.

Segments are typically made from blade blanks, and Wadley and Mohapi's (2008) data are in agreement with the blade morphology data from PGS (FIG. 18a, 18b). Dolerite blades generally represent the larger, wider and thicker blade component (FIG. 19). Hornfels has the widest range of blade sizes, from very small bladelets not seen in dolerite, to the rare blades over 6 cm long. This can be explained in terms of rock conservation. Large hornfels cores would be scarce, and the blades from the early production would be long, but infrequent. Hornfels cores would be extensively reduced both to conserve the material, but also because hornfels is suitable for bladelet production due to its knapping qualities discussed earlier. This wider range of blank size would facilitate the lower standardisation of hornfels segments. However, if standard segment sizes were desired, then hornfels provides the best material for accurately producing desired blade morphologies.

If knappers wanted to deliberately produce tool components that would break up on impact with bone for example, hornfels is the better material to select. It produces edges that are both hard and sharp to pierce the animal, but are simultaneously more likely to fracture, because the material is brittle. Hornfels

also produces blades with the highest surface area (length/width ratio) (FIG. 18a) and the lowest thickness (FIG. 18b). These factors would combine to create a sharp but relatively fragile tool when compared to dolerite. Quartz was not included in this study, but it is brittle and would most likely produce a relatively fragile tool if thin. However, their morphology (short and narrow) would possible mitigate against catastrophic break up. Dolerite, however, would produce a tool least likely to break. Compared to hornfels, dolerite absorbs more energy on impact (Table 14, Table 15, FIG. 9) and has a higher blade thickness (FIG. 18b) with a lower surface area (FIG 18a). This material would be more useful for a tool that needs to have a dependable working edge, such as a spear, which may be used to stab repeatedly.

The higher proportion of hornfels segments in Wadley and Mohapi's (2008) data shows the importance of this material. There is overlap in the morphology of dolerite and hornfels blades and segments, so it is likely that each rock fulfilled a specific function or range of functions. If both materials had the same function, knappers would probably not use a valuable, distant resource like hornfels when dolerite is immediately available. Due to the low incidence of non-backed tool types, it is likely that segments and other backed pieces were differently hafted for a variety of functions. Hafting hornfels segments or other backed tools would probably fulfil a cutting function as well as hunting function. Dolerite segments however would probably perform better where a robust edge is required. This would make it suitable for hunting as well as any hard duty task such as scraping. In layer PGS only two segments occur, one, long and narrow and made of hornfels, had a broken tip. The other is a complete segment of dolerite and is short and broad. The sample size is too small to draw any meaningful conclusions for PGS.

Rock selection at Sibudu

It is possible that toolmakers at Sibudu selected dolerite when durable edges were important or when it was important that a tool be less likely to break. Dolerite is also an excellent material for scraping. Due to the abundance of dolerite in the vicinity it is also likely that this rock was often used expediently.

It is possible that toolmakers selected hornfels when more time and energy went into core reduction, and when more precise control of knapping was valued. This rock might also be selected for tools when a cutting function was required. Artefacts made on rocks that are not hard-wearing have rapid edge attrition and high discard rates (Braun *et al*. 2008), and hornfels edges are not as tough and required more frequent retouch. Whatever their use, stone tools eventually break or develop signs of wear, but hard rocks develop edge or surface wear at a slower rate than soft or brittle rocks and tough rocks require more energy to break (Wadley & Kempson 2011).

CHAPTER 7

CONCLUSION

The purpose of this study is to understand the role that rock properties, specifically of dolerite and hornfels, played in the formation of the Howiesons Poort (Middle Stone Age) lithic assemblage at Sibudu, KwaZulu-Natal. The work began with an examination of principles involved in rock selection for stone tool knapping, how rock properties affect the reduction sequence, and how rock properties affect tool performance. I have focussed here on a sample assemblage (one square, C4) from one of the Howiesons Poort layers, layer PGS.

A review of the literature has made it possible to establish diachronic change at Sibudu both in the technology of the different assemblages, but importantly, also in the use of rock types. It was also necessary to establish rock type availability and the distribution of rock in the area, to understand the cost implications for rock procurement. This project also assumed that knappers were aware of the differences in rock types, and that this formed part of the basis on which they were selected. This seems to have been the case. At Sibudu, rock selection is not erratic. The primary rock types used at Sibudu are always dolerite and hornfels, except for one brief period at 58ka, following the Howiesons Poort.

What does change throughout the sequence at Sibudu is the emphasis on dolerite or hornfels use. During the Howiesons Poort there is a bias towards the use of fine-grained rocks. This trend can also be seen in dolerite and there is a definite

selection for fine-grained dolerite which is not abundant in the environment. All materials used at Sibudu are local, the farthest rocks were sourced about 20 km from the site. An attempt was made to determine the source of dolerite and hornfels material using XRF. However, there was insufficient chemical difference between the samples collected to discriminate between potential sources.

Dolerite (in its usual coarse form) is available to knappers within 200 m of the cave, as either pebbles, cobbles or boulders from the river, or in tabular form, from the dyke. Procuring hornfels required a travel distance of approximately 15 km. There must be a trade-off in benefits to justify the increased time and energy in selecting and transporting rock (Ditchfield 2016). For this reason, a range of mechanical and chemical tests was carried out to characterise the two rocks. Because rocks are not homogeneous, results for mechanical properties can vary significantly and there is a range of values for these tests which sometimes overlaps. However, the results of these tests show that there is a clear difference between the two rock types. Dolerite and hornfels from the Sibudu area have different mechanical and chemical properties and behave differently during knapping and tool use.

Some problems were encountered in procuring rocks of appropriate size from the Sibudu area for some of these tests. Consequently, proxy hornfels was collected from the Magaliesberg, Vaal River gravels, the Karoo and Pretoria for two tests, fracture toughness, and uniaxial compressive strength tests. This was not ideal, but was a necessary compromise. It was ultimately possible to characterise the mechanical properties of the two rock types.

Despite variability in selection over time, dolerite forms the majority of the lithics in the Sibudu collection. It is typically a hard rock, resistant to wear. It is also a tough rock, requiring a lot of energy to initiate fracture. The rock is relatively elastic, and is able to absorb some shock, or impact that occurs during knapping and tool use. This fracture toughness is partly a function of its structure (interlocking plagioclase crystals), and partly due to grain size. In knapping terms, dolerite is a coarse rock, though fine-grained rock occurs on the margins of dolerite intrusions and these should have a lower fracture toughness.

Hornfels is also a hard rock, though weakly metamorphosed rock is less hard. It has a lower fracture toughness than dolerite and is inelastic. It therefore does not absorb shock as well as dolerite. It is a fine-grained rock, and is consistently finer-grained than dolerite. Hardness values for hornfels and dolerite overlap, but dolerite tends to have slightly higher Hv values.

The experimental production and use of flakes was extremely valuable. It showed that in practice hornfels is easier to knap because it is more brittle than dolerite. Dolerite is relatively difficult to knap because of its higher fracture toughness. The same principle applies to flake edges. During tool use, factors such as hardness, resistance to fracture, sharpness and strength are important. At Sibudu, dolerite is most suited to producing robust tool edges. Fine-grained brittle rocks like hornfels flake easily, but this brittleness also means that more edge damage occurs during use.

The results of the experiments imply that the different edge properties of flakes have consequences for tool use. Dolerite produces flake edges that are well-suited to scraping, but due to the coarse-grained character of dolerite flake edges, they tend to be irregular, sometimes naturally denticulated, and therefore not as

suitable as fine-grained rocks for cutting tough materials. Conversely, hornfels flake edges tend to be thin and sharp, but less robust. They are ideal for cutting; though without retouch they have a tendency to break if they are thin. They are not as well suited as dolerite flakes to scraping.

During knapping, rocks that fracture easily and predictably are most desirable. With access to a variety of rock types, toolmakers will always select better-quality rock to produce complex or technically demanding tools (Mellars 1996). At Sibudu, hornfels best meets this requirement. Its low fracture toughness requires less energy in the blow than dolerite, and therefore it has potential for greater knapping accuracy than dolerite. The isotropic and fine-grained nature of hornfels make the process of core reduction predictable. Materials that flake predictably have the added benefit of reducing the overall cost of rock procurement and tool manufacture. This is because such rocks allow the knapper to produce more useful blacks per unit volume (Cole 2002).

Having the rock characterisation and experimental flake use data was extremely beneficial for interpreting the Howiesons Poort PGS assemblage. This made it possible to see the implications for choices of both rock selection and the production of the assemblage.

The predictable rock characteristics allow the knapper significant flexibility of design and forward planning. The brittleness of hornfels makes it possible to reduce small cores far more than is possible with dolerite. Consequently, hornfels can support the production of numerous flake and blade products per volume of core. Its fine-grained structure and brittleness mean that hornfels can be used regularly to produce thinner, sharper flakes or blades than dolerite, though the hornfels edges may need more frequent resharpening than the dolerite ones.

This does not mean that dolerite was a second-choice rock, though it probably was occasionally used expediently at Sibudu. There were times when a tough rock was required and then dolerite was deliberately sought. There are data that imply that some segments were hafted for hunting. Lombard & Pargeter (2008) suggest that tools that break within an animal are more effective during hunting and hornfels would have been an excellent choice for this purpose. However, during hunting with spears, it is important that the tool does not break during repeated thrusts; thus dolerite would have been the perfect choice for spear tips. Dolerite is also an excellent choice for scraping activities, especially for working hard materials.

Understanding the implications of rock choice provides insight into hominid behaviour. At Sibudu, dolerite provided a valuable resource, occurring in large quantities in the immediate area. I suggest that it was selected primarily to produce robust tools with strong edges, particularly for scrapers and probably for spears. In contrast, I suggest that hornfels was selected for two different reasons: its knapping flexibility, and successful cutting function. Hornfels blade production may have included the creation of segments for hafting as hunting tools, particularly where the projectile was intended to fail catastrophically so that stone splinters caused bleeding inside the victim.

The limitations of this project are primarily in the experimental programme. Further experiments, using a greater variety of worked materials and activity types, would greatly add to our ability to interpret the role of mechanical properties in archaeological assembles. It is also important for researchers to test the materials in their own excavations. Rocks are extremely variable, sometime even within a single rock outcrop. Relying on literature to understand the effects of rock types in assemblages is useful but cannot provide the depth of

understanding that actual rock testing can provide. One of the difficulties experienced here was getting rock samples large enough for mechanical testing, and then getting access to appropriate laboratory equipment and technicians.

Notwithstanding the shortcomings of the experiments here, which would have benefitted from larger samples, the knowledge provided by the experimental production and use of flakes was extremely useful. Amongst other insights, they revealed the value and usefulness of dolerite which was initially, and incorrectly, viewed as an inferior rock, used expediently. In short, dolerite and hornfels were proved to be valuable complementary rocks that enabled tasks with very different technical requirements and behavioural outcomes. There is little doubt that the makers of the Howiesons Poort lithic assemblages at Sibudu had a good grasp of geology, at least in the sense that they understood where they could find rocks with properties needed for particular tools. Furthermore, they were such skilled knappers that they could, with ease, knap tough dolerite knowing the advantages this difficult task would bring in the form of long-lasting flake edges and robust spear tips.

REFERENCES

Alberti, J. & Cardillo, M. 2015. Primary and secondary lithic raw material sources along the western coast of San Matias Gulf (Rio Negro province, Argentina): a first approach to their spatial variability. *Quaternary International* **373**: 63-71.

Allott, L.E. 2006. Archaeological charcoal as a window on palaeo-vegetation and wood-use during the Middle Stone Age at Sibudu Cave *Southern African Humanities* **18**(1): 173-201.

Altindag, R. & Guney, A. 2010. Predicting the relationships between brittleness and mechanical properties (UCS, TS and SH) of rocks. *Scientific Research and Essays* **5**(16): 2107-2118.

Ambrose, S.H. & Lorenz, K.G. 1990. Social and ecological models for the Middle Stone Age in South Africa. In: P. Mellars, ed., *The Emergence of Modern Humans: an archaeological perspective*. Edinburgh: Edinburgh University Press, pp. 3–33.

Ambrose, W., Allen, C., O'Connor, S., Spriggs, M., Oliveira, N.V. & Reepmeyer, C. 2009. Possible obsidian sources for artifacts from Timor: narrowing the options using chemical data. *Journal of Archaeological Science* **36**: 607–615.

Andrefsky, W. 1998. *Lithics: macroscopic approaches to analysis*. Cambridge: Cambridge University Press.

Antonelli, F. & Lazzarini, L. 2010. Mediterranean trade of the most widespread Roman volcanic millstones from Italy and petrochemical markers of their raw materials. *Journal of Archaeological Science* **37**: 2081-2092.

Asrat, A. & Ayallew, Y. 2011. Geological and geothechnical properties of the medieval rock hewn churches of Lalibela, Northern Ethiopia. *Journal of African Earth Sciences* **(50)**: 63-71.

Backwell, L. d'Errico, F. & Wadley, L. 2008. Middle Stone Age bone tools from the Howiesons Poort layers, Sibudu Cave, South Africa. *Journal of Archaeological Science* **35**: 1566-1580.

Beaumont, P.B. 1978. Border Cave. MA Thesis, University of Cape Town.

Beck, C. & Jones, G.T. 1990. Toolstone selection and lithic technology in early Great Basin prehistory. *Journal of Field Archaeology* **17**: 283–299.

Bednarik, M., Moshammer, B, Heinrich, M., Holzer, R., Laho, M., Rabeder,J., Uhlir, C. & Unterwurzacher, M. Engineering geological properties of Leigha Limestone form historical quarries in Burgenland and Styra, Austria. *Engineering Geology* **176**: 66-78.

Bell, F.G. & Jermy, C.A. 2000. The geotechnical character of some South African dolerites, especially their strength and durability. *Quarterly Journal of Engineering* **33**(1): 59-76.

Bellot-Gurlet, L., Dorighel, O. & Poupeau, G. 2008. Obsidian provenance studies in Columbia and Ecuador: obsidian sources revisited. *Journal of Archaeological Science* **35**: 272–289.

Beyin, A. 2010. Use-wear analysis of obsidian artifacts from Later Stone Age shell midden sistes on the Red Sea coast of Eritrea, with experimental results. *Journal of Archaeological Science* **37**: 1543-1556.

Binford, L.R. 1978. *Nunamiut Ethnoarchaeology*. Academic Press: New York.

Blair, S.E. 2010. Missing the boat in lithic procurement: watercraft and the bulk procurement of tool-stone on the Maritime Peninsula. *Journal of Anthropological Archaeology* **29**: 33–46.

Borradaile, G.J., Kissin, S.A., Stewart, J.D., Ross, W.A. & Werner, T. Magnetic and optical methods for detecting heat treatment of chert. *Journal of Archaeological Science* **20**: 57-66.

Bradák , B., Szakmány, Gy., Józsa, S. & Přichystal, A. 2009. Application of magnetic susceptibility on polished stone tools from Western Hungary and the Eastern part of the Czech Republic (Central Europe). *Journal of Archaeological Science* **36**: 2437–2444.

Brantingham, J.P. & Olsen, J.W. 2000. Raw material quality and prepared core technologies in northeast Asia. *Journal of Archaeological Science* **27**: 225-271.

Braun, D.R., Pobiner, B.L. & Thompson, J.C. 2008. An experimental investigation of cut mark production and stone tool attrition. *Journal of Archaeological Science* **35**: 1216–1223.

Braun, D.R., Plummer, T., Ferraro, J.V., Ditchfield, P. & Bishop, L.C. 2009. Raw material quality and Oldowan hominin toolstone preferences: evidence from Kanjera South, Kenya. *Journal of Archaeological Science* **36**: 1605–1614.

Bril, B., Smaers, J., Steele, J., Rein, R., Tetsushi, N., Dietrich, G., Biryukova, E., Hirata, S & Roux, V. 2011. Functional mastery of percussive technology in nut-cracking and stone-flaking actions: experimental comparison and implications for the evolution of the human brain. *Philosophical Transactions of the Royal Society B, Biological Sciences* **367**(1585): 59-74.

Brilli, M., Antonelli, F., Giustini, F., Lazzarini, L. & Pensabene, P. 2010. Black limestones used in antiquity: the petrographic, isotopic and EPR database for provenance determination. *Journal of Archaeological Science* **37**: 994–1005.

Brink, J. 1978. The role of abrasives in the formation of lithic use-wear. *Journal of Archaeological Science* **5**: 363–371.

Brown, K.S., Marean, C.W., Herries, A.I.R., Jacobs, Z., Tribolo, C., Braun, D., Roberts, D.L., Meyer, M.C. & Bernatchez, J. 2009. Fire as an engineering tool of early modern humans. *Science* **325**: 859–862.

Brown, K.S., Marean, C.W., Jacobs, Z., Schoville, B.J., Oestmo, S., Fisher, E.C., Bernatchez, J., Karkanas, P & Matthews, T. 2012. An early and enduring advanced technology originating 71, 000 years ago in South Africa. *Nature* **491**: 590-593.

Byrne, L. 2004. Lithic tools from Arago Cave, Tautavel (Pyrénées-Orientales, France): behavioural continuity or raw material determinism during the Middle Pleistocene? *Journal of Archaeological Science* **31**: 351–364.

Carò, F., Douglas, J.G. & Im, S. 2010. Towards a quantitative petrographic database of Khmer stone materials - Kohker style sculpture. *Archaeometry* **52**: 191–208.

Carter, T. & Shackley, M.S. 2007. Sourcing obsidian from Neolithic Catalhoyuk (Turkey) using energy dispersive X-ray fluorescence. *Archaeometry* **49**: 434–454.

Cartwright, C. 2013. Identifying the woody resources of Diepkloof Rock Shelter (South Africa) using scanning electron microscopy of the MSA wood charcoal assemblages. *Journal of Archaeological Science* **40**: 3463-3474.

Chase, B.M. 2010. South African palaeoenvironments during marine oxygen isotope stage 4: a context for the Howiesons Poort and Still Bay industries. *Journal of Archaeological Science.* **37**: 1359-1366.

Clark, J.L. & Plug, I. 2008. Animal exploitation strategies during the South African Middle Stone Age: Howiesons Poort and post-Howiesons Poort faunal from Sibudu Cave. *Journal of Human Evolution* **54**: 886-898.

Clarke, B.M., Schoeman, P. & Kota, M.W. 2007. *The geology of the Verulam area*. Council for Geoscience: D&V Premier Print.

Clarkson, C. 2010. Regional diversity within the core technology of the Howiesons Poort techo-complex. In: Lycett, S. & Chauhan, P. eds. *New perspectives on old stones: analytical approaches to Palaeolithic technologies*. New York: Springer, pp 43-60.

Cochrane, G.W.G. 2006. An analysis of lithic artefacts from the ~60 ka layers of Sibudu Cave. *Southern African Humanities* **18** (1): 69–88.

Cole, S.C. 2002. Lithic raw material exploitation between 30 000 BP and 40 000 BP in the Perigord, France. PhD dissertation, University of Washington.

Collins, S. 2008. Experimental investigations into edge performance and its implications for stone artefact reduction modelling. *Journal of Archaeological Science* **35**: 2164–2170.

Conard, N., Porraz, G. & Wadley, L. 2012. What is in a name? Characterising the 'Post-Howieson's Poort' at Sibudu. *South African Archaeological Bulletin* **67**(196): 180-199

Cotterell, B., Kamminga, J. & Dickson F.P. 1985. The essential mechanics of conchoidal flaking. *International Journal of Fracture* **29**: 205-221.

Cotterell, B. & Kamminga, J. 1987. The formation of flakes. *American Antiquity* **52**(4): 675-708.

Cotterell, B. & Kamminga, J. 1992. *Mechanics of pre-industrial technology*. Cambridge: Cambridge University Press.

Crabtree, D.E. 1967. Notes on experiments in flintknapping: 3. The flintknapper's raw materials. *Tebiwa* **10**: 8–25.

Craig, N., Speakman, R.J., Popelka-Filcoff, R.S., Glascock, M.D., Shackley, S.M. & Aldenderfer, M.S. 2007. Comparison of XRF and PXRF for analysis

of archaeological obsidian from southern Peru. *Journal of Archaeological Science* **34**:2012-2024.

Craig, N., Speakman, R.J., Popelka-Filcoff, R.S., Aldenderfer, M., Blanco, L.F., Brown Vega, M., Glascock, M.D & Stanish, C. 2010. Macusani obsidian from southern Peru: A characterization of its elemental composition with a demonstration of its ancient use. *Journal of Archaeological Science* **37**: 569–576.

Damlien, H. 2015. Striking a difference? The effect of knapping techniques on blade attributes. *Journal of Archaeological Science* **63**: 122-135.

Daniel, R. I. 2001. Stone raw material availability and Early Archaic settlement in the Southeastern United States. *American Antiquity* **66**(2): 237-265.

Davidge, R.W. 1979. *Mechanical behaviour of ceramics*. Cambridge University Press: Cambridge

Delgado-Raack, S., Gomez-Gras, D. & Risch, R. 2009. The mechanical properties of macrolithic artefacts: a methodological background for functional analysis. *Journal of Archaeological Science* **(36)** 1823-1831.

d'Errico, F., Henshilwood, C, Vanhaeren, M. & van Niekerk, K. 2005. Nassarius kraussianus shell beads from Blombos Cave, evidence for symbolic behaviour in the Middle Stone Age. *Journal of Human Evolution* **48**(1):3-24

d'Errico, F., Backwell, L.R. & Wadley, L. 2012. Identifying regional variability in Middle Stone Age bone technology: The case of Sibudu Cave. *Journal of Archaeological Science* **39**: 2479-2495.

de Francesco, A.M., Crisci, G.M. & Bocci, M. 2008. Non-destructive analytic

method using XRF for determination of provenance of archaeological obsidians from the Mediterranean area: a comparison with traditional XRF methods. *Archaeometry* **50**: 337–350.

de la Peña, P. 2015a. The interpretation of bipolar knapping in African Stone Age studies. *Current Anthropology* **56**(6): 911-923.

de la Peña, P. 2015b. Refining our understanding of Howiesons Poort lithic technology: The evidence from Grey Rocky Layer in Sibudu Cave (KwaZulu-Natal, South Africa). *PLoS ONE* 10(12): 1-52.

de la Peña, P. & Wadley, L., 2014a. New knapping methods in the Howiesons Poort at Sibudu (KwaZulu-Natal, South Africa), Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.03.043

de la Peña, P. & Wadley, L., 2014b. Quartz knapping strategies in the Howiesons Poort at Sibudu (KwaZulu-Natal, South Africa). *PLoS ONE* **9**(7): 01534

Deacon, H.J. 1989. Late Pleistocene palaeoecology and archaeology in the Southern Cape, South Africa. In: Mellars, P.A. & Stringer, C. eds, *The Human Revolution: Behavioural and Biological Perspectives on the origins of modern humans*. Edinburgh University Press and Princeton University Press, pp 547-565.

Deacon, H.J. 1992. Southern Africa and modern human origins. *Philosophical Transactions of the Royal Society B: Biological Sciences* **337**(1280): 177-183.

Deacon, H.J. 1995. Two late Pleistocene-Holocene archaeological depositories from the southern Cape, South Africa. *Southern African Archaeological Bulletin* **50**: 121-131.

Deacon, H.J. & Wurz, S. 1996. Klasies River Main Site, Cave 2: a Howiesons Poort occurrence. In:, G. Pwiti & R. Soper eds,. *Aspects of African Archaeology,* Harare: University of Zimbabwe Press.

Delagnes, A., Wadley, L., Villa, P. & Lombard, M. 2006. Crystal quartz backed tools from the Howiesons Poort at Sibudu Cave. *Southern African Humanities* **18**: 43-56

Dibble, H.L. & Rezek, Z. 2009. Introducing a new experimental design for controlled studies of flake formation: results for exterior platform angle, platform depth, angle of blow, velocity, and force. *Journal of Archaeological Science* **(36):** 1945-1954.

Ditchfield, K. An experimental approach to distinguishing between different stone artefact transport patterns from debitage assemblages. *Journal of Archaeological Science* **65**:44-56.

Domański, M. & Webb, J.A. 1992. Effect of heat treatment on siliceous rocks used in prehistoric lithic technology. *Journal of Archaeological Science* **19**: 601–614.

Domański, M., Webb, J.A. & Boland, J. 1994. Mechanical properties of stone artefact materials and the effect of heat treatment. *Archaeometry* **36**: 177–208.

Duke, C. & Steele, J. 2010. Geology and lithic procurement in Upper Palaeolithic Europe: a weights-of-evidence based GIS model of lithic resource potential. *Journal of Archaeological Science* **37**: 813–824.

Dunnell, R.C., McCutcheon, P.T., Ikeya, M. & Toyoda, S. 1994. Heat treatment of Mill Creek and Dover cherts on the Malden Plain, Southeast Missouri. *Journal of Archaeological Science* **21**: 79-89.

Eerkens, J.W., Spurling, A.M. & Gras, M.A. 2008. Measuring prehistoric mobility strategies based on obsidian geochemical and technological signatures in the Owens Valley, California. *Journal of Archaeological Science* **35**: 668–680.

Erin, M.I., Roos, C.I., Story, B.A., von Cramon-Taubadel, N. & Lycett, S.J. 2014. The role of raw material differences in stone tool shape variation: an experimental assessment. *Journal of Archaeological Science* **49**: 472-487.

Evans, A.A., Wolframm, Y.B., Donahue, R.E. & Lovis, W.A. 2007. A pilot study of "black chert" sourcing and implications for assessing hunter-gatherer mobility strategies in Northern England. *Journal of Archaeological Science* **34**: 2161–2169.

Faulkner, A. 1972. *Mechanical principles of flintworking*. PhD thesis, Washington State University.

Feather, J.K. 2015. Luminescence dating at Diepkloof rock shelter, new dates from single-grain quartz. *Journal of Archaeological Science* **63**:164-174.

Feathers, J.K. & Bush, D.A. 2000. Luminescence dating of Middle Stone Age deposits at Die Kelders. *Journal of Human Evolution* **38**: 91-119.

Frahm, E., Feinberg, J.M., Schmidt-Magee, B.A., Wilkinson, K.N., Gasparyan, B., Yeritsyan, B. & Adler, D.S. 2016. Middle Palaeolithic toolstone procurement bahaviours at Lusakert Cave 1, Hrazdan valley, Armenia. *Journal of Human Evolution* **91**: 73-92.

Garvey, R. 2015. A model of lithic raw material procurement. In: N. Goodale, W. Anderefsky eds, *Lithic technological systems and evolutionary theory*. Cambridge University Press: USA, pp 156-171.

Gazzola, J., Sánchez Del Río, M., Solís, C. & Calligaro, T. 2010. Particle–induced x-ray emission (PIXE) analysis of obsidian from Teotihuacan. *Archaeometry* **52**: 343–354.

Glascock, M.D., Speakman, R.J. & Neff, H. 2007. Archaeometry at the University of Missouri research reactor and the provenance of obsidian artefacts in North America. *Archaeometry* **49**: 343–357.

Glenny, W. 2006. Report on the micromammal assemblage analysis from Sibudu Cave. *Southern African Humanities* **18**(1): 279-288.

Gluhak, T.M. & Hofmeister, W. 2009. Roman lava quarries in the Eifel region (Germany): geochemical data for millstone provenance studies. *Journal of Archaeological Science* **36**: 1774–1782.

Goldberg, P., Miller, C., Schiegl, S., Ligouis, B., Berna, F., Conard, N.J. & Wadley, L. 2009. Bedding, hearths, and site maintenance in the Middle Stone Age of Sibudu Cave, KwaZulu-Natal, South Africa. *Archaeological and Anthropological Sciences* **1**(2): 95-122.

Goldman-Neuman, T. & Hovers, E. 2009. Methodological considerations in the study of Oldowan raw material selectivity: insights from AL 894 (Hadar, Ethiopia). In: *Interdisciplinary approaches to the Oldowan* pp. 71-84. Springer Netherlands.

Goldman-Neuman, T. & Hovers, E. 2012. Raw material selectivity in Late Pliocene Oldowan sites in the Makaamitalu Basin, Hadar, Ethiopia. *Journal of Human Evolution* **62**(3): 353-366

Goodwin, A. J.H. & Van Riet Lowe, C. 1929. "The Stone Age Cultures of South Africa" *Annals of the South African Museum* **27**:1-289.

Gould, R. 1978. The anthropology of human residues. *American anthropologist* **65**: 215-235.

Gould, R.A. & Saggers, S. 1985. Lithic procurement in central Australia: a closer look at Binford's idea of embeddedness in archaeology. *American Antiquity* **50**: 117-136.

Greiser, S.T. & Sheets, P. D. 1979. Raw Material as a Functional Variable in Use-Wear Studies. In: Haden, B. ed., *Studies in archaeology: lithic use wear analysis*. New York: Academic Press, pp 289-296.

Griffith, A.A. 1921. The phenomena of rupture and flow in solids. *Philosophical Transactions of the Royal Society of London Series A*, **221**: 163-198.

Griffith, A.A. 1924. The theory of rupture and flow in solids. In: *Proceedings of the First International Congress of Applied Mechanics*, (eds) Biezeno,. pp. 55-63

Grün, R., Beaumont, P.B., Tobias, P.V., Eggins, S.M., 2003. On the age of the Border Cave 5 human mandible. *Journal of Human Evolution* **45**:155-167.

Hamblin, K.W. 1989. *The earth's dynamic systems: a textbook in physical geology* – 5th ed. New York: MacMillan Publishing Company.

Harmand, S., Lewis, J.E., Feibel, C.S., Lepre, C.J., Prat, S., Lenoble, A., Boes, X., Quinn, R.L., Brenent, M., Arroyo, A., Taylor, N., Clement, S., Daver, G., Brugal, J-P., Leakey, L., Mortlock, R.A., Wright, J.D., Lokorodi, S., Kirwa, C., Kent, D.V. & Roche, H. 2015. 3.3-million-year-old stone tools from Lomekwi 3, West Turkana, Kenya. *Nature* **521**:310-315.

Henshilwoold, C.S., d'Errico, F., Vanhaeren, M, van Niekerk, K. & Jacobs, Z. 2004. Middle Stone Age beads from South Africa. *Science* **304**(5669): 404

Henshilwood, C.S., d'Errico, F. & Watts, I. 2009. Engraved ochres from the Middle Stone Age levels at Blombos Cave, South Africa. *Journal of Human Evolution* **57**: 27-47.

Henshilwood, C.S. & Dubreuil, B. 2011. The Still Bay and Howiesons Poort, 77-59 ka: symbolic material culture and the evolution of the mind during the African Middle Stone Age. *Current Anthropology* **52**(3): 361-400.

Henshilwood, C.S., van Niekerk, K.L., Wurz, S., Delagnes, A., Armitage, S.J., Rifkin, R.F., Douze, K., Keene, P., Haaland, M.M., Reynard, J., Discamps, E. & mienies, S. 2014. Klipdrift Shelter, southern Cape, South Africa;

preliminary report on the Howiesons Poort layers. *Journal of Archaeological Science* **45**: 284-303.

Hiscock, P. 1993. Bondaian technology in the Hunter Valley, New South Wales. *Archaeology in Oceania* **28**(2): 65-76.

Hughes, R.E. 1994. Intrasource chemical variability of artefact-quality obsidians from the Casa Diablo area, California. *Journal of Archaeological Science* **21**: 263–271.

Humphreys, A.J.B. & Thackeray, A.I. 1983. *Ghaap and Gariep: Later Stone Age studies in the Northern Cape*. Cape Town: South African Archaeological Society

Hurcombe, L.M. 1992. *Use-wear analysis and obsidian: theory, experiments and results. Sheffield Archaeological Monographs 4.* Dorset: Henry Ling Ltd.

Inizan, M-L., Reduron-Ballinger, M., Roche, H. & Tixier, J. 1999. *Technology and Terminology of Knapped Stone*. Cercle de Recherches er d'Etudes Prehistoire: Nanterre.

Iriarte, E., Foyo, A., Sánchez, M.A., Tomillo, C. & Setién, J. 2009. The origin and geochemical characterization of red ochres from the Tito Bustillo and Monte Castillo Caves (Northern Spain). *Archaeometry* **51**: 231–251.

Jacobs, Z. & Roberts, R.C. 2008. Testing time: old and new chronologies for the Howieson's Poort and Still Bay Industries in environmental context. *African Archaeological Society Goodwin Series* **(10)**: 9-34.

Jacobs, Z., Wintle, A.G., Duller, G.A.T. Roberts, R.G. & Wadley, L. 2008a. New ages for the post-Howiesons Poort, late and final Middle Stone Age at Sibudu Cave, South Africa. *Journal of Archaeological Science* **35**: 1790–1807.

Jacobs, Z., Roberts, R.G., Galbraith, R.F., Deacon, H.J., Grün, R., Mackay, A., Mitchell, P.J., Vogelsang, R. & Wadley, L. 2008b. Ages for the Middle Stone Age of Southern Africa: Implications for Human Behaviour and Dispersal. *Science* **322**: 733–735.

Jacobs, Z. & Roberts, R.G. 2015. An improvd single grain OSL chronology for the sedimentary depostis from Diepkloof Rockshelter, Western Cape, South Africa. *Journal of Archaeological Science*

Johannsen, A. 1927. On the use of the terms 'diabase' and 'dolerite'. *Journal of Geology* **35**(3): 270-275.

Jones, P.R. 1979. Effects of raw material on biface manufacture. *Science* **204**(25): 835-836.

Jones, P.R. 1994. Results of experimental work in relation to the stone industries of Olduvai Gorge. In: M.D. Leakey & D.A. Roe, eds, *Olduvai Gorge, Volume V.* Cambridge: Cambridge University Press, pp. 254–309.

Jones, P.R. 1981. Experimental implement manufacture and use: a case study from Olduvai Gorge, Tanzania. *Philosophical Transactions of the Royal Society of London. Series B, Biological Science* **292** (1057): 189–195.

Kaplan, J. 1990. The Umhlatuzana rock shelter sequence: 100 000 years of stone age history. *Natal Museum Journal of Humanities* **2**: 1-94.

Kasztovszky, Z.S., Biró, K.T., Markó, A. & Dobosi, V. 2008. Cold neutron prompt gamma activation analysis – a non-destructive method for characterisation of high silica content chipped stone tools and raw materials. *Archaeometry* **50**: 12–29.

Keller, C. 1973. Montagu Cave in Prehistory: a descriptive analysis. *Anthropological Records* **28**: 1– 98.

Keeley, L.H. 1980. *Experimental determination of stone tool uses*. University of Chicago Press, Chicago.

Khalidi, L., Gratuze, B. & Boucetta, S. 2009. Provenance of obsidian excavated from Late Chalcolithic levels at the sites of Tell Hamoukar and Tell Brak, Syria. *Archaeometry* **51**: 879–893.

Klominsky, J., Fediuk, F., Schovanek, P. & Gabasova, A. 2004. The hornblende-plagioclase hornfels from the contact aureole of the Tanvald granite, northern Bohemia – the raw material for Neolithic tools. *Bulletin for Geosciences* **79**(1): 63-70

Lancaster, L.C., Sottili, G., Marra, F. & Ventura, G. 2010. Provenancing of lightweight volcanic stones used in ancient Roman concrete vaulting: evidence from Turkey and Tunisia. *Archaeometry* **52**:949-961.

Langejans, G.H.J. 2007. PIXE and residues: examples from Sterkfontein and Sibudu, South Africa. *South African Archaeological Bulletin* **62**: 71–73.

Lawn, B.R. 1993. *Fracture of brittle solids.* Second Edition. Cambridge University Press, Cambridge, England.

Lawn, B.R. & Marshall, D.B. 1979. Mechanisms of microcontact fracture in brittle solids, In: Haden, B. ed., *Studies in archaeology: lithic use wear analysis*. New York: Academic Press, 63–82.

Lawrence, R.A. 1979. Experimental evidence for the significance of attributes used in edge-damage analysis, In: Haden, B. ed., *Studies in archaeology: lithic use wear analysis*. New York: Academic Press, 113-121.

Lebo, S.A. & Johnson, K.T.M. 2007. Geochemical sourcing of rock specimens and stone artefacts from Nihoa and Necker islands, Hawai'i. *Journal of Archaeological Science* **34**: 858–871.

Lerner, H., Xiagdong, D, Costopoulos, A. & Ostoja-Starzewski, M. 2007. Lithic raw material physical properties and use-wear accrual. *Journal of Archaeological Science* **34**: 711–722.

Lombard, A., De Bruiyn, H., Scholz, N., Praekelt, H.E., Wilson, A.H. & Schoch, A.E. 2003. The Thauthe meteorite fall of 21 July 2002. *South African Journal of Science* **99**: 160–162.

Lombard, M. 2005a. The Howiesons Poort of South Africa: what we know, what we think we know, what we need to know. Southern African Humanities **17**, 33–55.

Lombard, M. 2005b. Evidence of hunting and hafting during the Middle Stone Age at Sibudu Cave, KwaZulu-Natal, South Africa: a multianalytical approach. *Journal of Human Evolution* **48**: 279-300.

Lombard, M. 2006. Direct evidence for the use of ochre in the hafting technology of Middle Stone Age tools from Sibudu Cave. *Southern African Humanities* **18**(1): 57-67.

Lombard, M. 2007. The gripping nature of ochre: the association of ochre with Howiesons Poort adhesives and Later Stone Age mastics from South Africa. *Journal of Human Evolution* **53**: 406-419.

Lombard, M. 2008. Finding resolution for the Howiesons Poort through the microscope: micro-residue analysis of segments from Sibudu Cave, South Africa. *Journal of Archaeological Science* **35**: 26-41.

Lombard, M. 2011. Quartz-tipped arrows older than 60 ka: further use-trace evidence from Sibudu, KwaZulu-Natal, South Africa. *Journal of Archaeological Science* **38**: 1918-1930.

Lombard, M., & Philipson, L. 2010. Indications of bow and stone-tipped arrow use 64 000 years ago in KwaZulu-Natal, South Africa. *Antiquity* **48**(635-648.

Lombard, M. & Pargeter, J. 2008. Hunting with Howiesons Poort segments: pilot experimental study and the functional interpretation of archaeological tools. *Journal of Archaeological Science* **35**: 2523-2531.

Lombard, M., Wadley, L., Jacobs, Z., Mohapi, M. & Roberts, R. 2010. Still Bay and serrated points from Umhlatuzana Rock Shelter, KwaZulu-Natal, South Africa. *Journal of Archaeological Science* **37**: 1773-1784.

Luedke, B.E. 1992. *An archaeologists guide to chert and flint*. Institute of Archaeology, University of California, Los Angeles, CA.

Lundblad, S.P.,Mills, P.R. & Hon, K. 2008. Analysing archaeological basalt using non-destructive energy-dispersive x-ray fluorescence (EDXRF): effects of post-depositional chemical weathering and sample size on analytical precision. *Archaeometry* **50**: 1–11.

Mackay, A. & Welz, A. 2008. Engraved ochre from a Middle Stone Age context at Klein Kliphuis in the Western Cape of South Africa. *Journal of Archaeological Science* **35**: 1521-1532.

Mackay, A. 2011. Nature and significance of the Howiesons Poort to post-Howiesons Poort transition at Klein Kliphuis rockshelter, South Africa. *Journal of Archaeological Science* **38**(7): 1430-1440.

Mallory-Greenough, L.M., Greenough, J.D. & Owen, V.J. 1999. The stone source of predynastic basalt vessels: mineralogical evidence for quarries in northern Egypt. *Journal of Archaeological Science* **26**: 1261–1272.

Marsh, J.S. 2004. Rare earth element geochemistry of the Insizwa lobe of the Mount Ayliff Complex, Eastern Cape, South Africa. *South African Journal of Science* **100**: 556–560.

McPherron, S.P., Braun, D.R., Dogandzic, T., Archer, W., Desta, D. & Lin, S.C. 2014. An experimental assessment of the influences on edge damage to lithic artefacts: a consideration of edge angle, substrate grain size, raw

material properties, and exposed face. *Journal of Archaeological Science* **49**: 70-82.

Mellars, P. 1996. *The Neanderthal legacy: an archaeological perspective from Western Europe*. Princeton University Press: Princeton

Minichillo, T. 2006. Raw material use and behavioural modernity: Howiesons Poort lithic foraging activities. *Journal of Human Evolution* **50**: 359–364.

Mourre, V., Villa, P., Henshilwood, C.S., 2010. Early use of pressure flaking on lithic artifacts at Blombos Cave, South Africa. Science **330**, 659-662.

Negash, A., & Shackley, M.S. 2006. Geochemical provenance of obsidian artefacts from the MSA site of Porc Epic, Ethiopia. *Archaeometry* **48**: 1–12.

Neumann, E-R, Svensen, H., Gelerne, C.Y. & Planke, S. 2011. Multistage evolution of dolerites in the Karoo Large Igneous Province, central South Africa. *Journal of Petrology* **52**(5): 959-984.

Niknami, K.A., Amirkhiz, A.C. & Glascock, M.D. 2010. Provenance studies of Chalcolithic obsidian artefacts from near Lake Urmia, Northwestern Iran using WDXRF analysis. *Archaeometry* **52**: 19–30.

Odell, G.H. 1981. The mechanics of use-breakage of stone tools: some testable hypotheses. *Journal of Archaeological Science* **8**(2): 197–209.

Orton, J. 2008. A useful measure of the desirability of different raw materials for retouch within and between assemblages: the raw material retouch index (RMRI). *Journal of Archaeological Science* **35**: 1090–1094.

Pickering, R. 2002. A sedimentological analysis of six archaeological soil samples from Sibudu Cave, KwaZulu-Natal, South Africa. Unpublished report, University of the Witwatersrand.

Plug, I. 2006. Aquatic animals and their associates from the Middle Stone Age levels at Sibudu. *Southern African Humanities* **18**(1) 289-299.

Pollard, A.M., Batt, C.M., Stern, B. & Young, S.M.M. 2007. *Analytical chemistry in archaeology.* Cambridge: Cambridge University Press.

Porraz, G., Texier, P-J., Rigaud, J-P., Parkington, J., Poggenpoel, C. & Roberts, D. 2008. First characterisation of an MSA lithic assemblage stratified between Still Bay and Howiesons Poort sub-stages at Diepkloof Rock-Shelter (western province, South Africa). In: Lombard, M. (Ed.), Current themes in Middle Stone Age research, *South African Archaeological Society, Goodwin Series* **10**: 105-121

Porraz, G., Texier, P.-J., Archer, W., Piboule, M., Rigaud, J.-P. & Tribolo, C. 2013a. Technological successions in the Middle Stone Age sequence of Diepkloof Rock Shelter, Western Cape, South Africa. *Journal of Archaeological Science* **40**: 3376-3400.

Porraz, G., Parkington, J.E., Rigaud, J-P, Miller, C.E., Poggenpoel, C., Tribolo, C., Archer, W., Cartwright, C.R., Charrie-Duhaut, A., Dayet, L., Igreja, M., Mercier, N., Schmidt, P, Verna, C. & Texier, P-J. 2013b. The MSA sequence of Diepkloof and the history of southern African Late Pleistocene populations. *Journal of Archaeological Science* **40**: 3542-3552.

Poupeau, G., Le Bourdonnec, F-X., Carter, T., Delerue, S., Shackley, M.S., Barrat, J-A., Dubernet, S., Moretto, P., Calligaro, T., Milić, M. & Kobayashi, K. 2010. The Use of SEM-EDS, PIXE and EDXRF for Obsidian Provenance Studies in the Near East: A case study from Neolithic Çatalhöyük (central Anatolia). *Journal of Archaeological Science* **37**(11): 2705-2720. DOI: 10.1016/j.jas.2010.06.007

Rollason, E.C. 1970. *Metallurgy for Engineers.* London: Edward Arnold (Publishers) Ltd.

Rots, V. 2010. *Prehension and hafting traces on flint tools: A methodology*. Leuven, Belgium: Leuven University Press.

Rudner, J. 1979. The use of stone artefacts and pottery among the Khoisan peoples in historic and protohistoric times. *South African Archaeological Bulletin* **34**:3-17.

Sampson, C.G. & Youngblood, D. 2006. Hornfels artefact sourcing by instrumental neutron activation analysis (INAA) in the Karoo region of South Africa. Paper presented to the SAFA conference, Calgary, 25 June 2006.

Santi, P., Renzulli, A., Antonelli, F. & Alberti, A. 2009. Classification and provenance of soapstones and garnet chlorite schist artifacts from medieval sites of Tuscany (Central Italy): insights into the Tyrrhenian and Adriatic trade. *Journal of Archaeological Science* **36**: 2493–2501.

Seelenfreund, A., Fonseca, E., Llona, F., Lera, L., Sinclaire, C. & Rees, C. 2009. Geochemical analysis of vitreous rocks exploited during the Formative Period in the Atacama Region, Northern Chile. *Archaeometry* **51**: 1–25.

Serra, M., Borghi, A., D'amicone, E., Fiora, L., Mashaly, O., Vigna, L. & Vaggelli, G. 2010. Black and red granites in the Egyptian Antiquity Museum of Turin: a minero-petrographic and provenance study. *Archaeometry* **52**:962-986.

Shackley, M.S. 2008. Archaeological petrology and the archaeometry of lithic materials. *Archaeometry* **50**: 194–215.

Sharon, G. 2008. The impact of raw material on Acheulian large flake production. *Journal of Archaeological Science* **35**: 1329-1344.

Sibley, D.F. & Gregg, J.M. 1987. Classification of dolomite textures. *Journal of Sedimentary Research* **57**(6): 967-975.

Sievers, C. 2006. Seeds from the Middle Stone Age layers at Sibudu Cave. *Southern African Humanities* **18**(1): 203-222.

Singer, R. & Wymer, J. 1982. *The Middle Stone Age at Klasies River Mouth in South Africa*. Chicago: Chicago University Press.

Sloane, J.D. 1991. Some physical properties of dolerite. Tasmania Department of Resources and Energy, Division of Mines and Mineral Resources – Report 1991/22.

Soriano, S., Villa, P. & Wadley, L. 2007. Blade technology and tool forms in the Middle Stone Age of South Africa: The Howiesons Poort and post-Howiesons Poort at Rose Cottage Cave. *Journal of Archaeological Science* **34**: 681–703.

Soriano, S., Villa, P. & Wadley, L. 2009. Ochre for the toolmaker: shaping the Still Bay points at Sibudu (KwaZulu-Natal, South Africa). *Journal of African Archaeology* **7**(1): 41-54.

Soriano, S., Villa, P., Delagnes, A., Degano, I., Pollarolo, L., Lucejko, J.J., Henshilwood, C. & Wadley, L. 2015. The Still Bay and Howiesons Poort at Sibudu and Blombos: Understanding Middle Stone Age Technologies. *PLoS ONE* **10**(7): 1-46

Speakman, R.J. & Glascock, M.D. 2007. Acknowledging fifty years of neutron activation analysis in archaeology. *Archaeometry* **49**: 179–183.

Stapleton, P. & Hewitt, J. 1927. Stone implements from a rockshelter at Howieson's Poort near Grahamstown. *South African Journal of Science* **24**: 574-587.

Stapleton, P. & Hewitt, J. 1928. Stone implements from Howiesons Poort, near Grahamstown. *South African Journal of Science* **25**: 399-409.

Steele, T., & Klein, R.C. 2013. The Middle and Later Stone Age faunal remains from Diepkloof Rock Shelter, Western Cape, South Africa. *Journal of Archaeological Science* **40**: 3453-3462.

Stewart, B.A., Dewar, G.I., Morley, M.W., Inglis, R.H., Wheeler, M., Jacobs, Z. & Roberts, R.G. 2012. Afromontane foragers of the later Pleistocene: site formation, chronology and occupational pulsing at Melikane Rockshelter, Lesotho. *Quaternary International **270**: 40-60*

Tallavaara, M., Manninen, M., Hertekk, E. & Rankama, T. 2010. How flakes shatter: a critical evaluation of quartz fracture analysis. *Journal of Archaeological Science* **37**: 2442-2448.

Texier, P.-J.., Porraz, G., Parkington, J., Rigaud, J.-P., Poggenpoel, C., Miller, C., Tribolo, C., Cartwright, C., Coudenneau, A., Klein, R.G., Steele, T., Verna, C. 2010. Howiesons Poort tradition of engraving ostrich eggshell containers dated to 60, 000 years ago at Diepkloof Rock Shelter, South Africa. *Proceedings of the National Academy of Sciences* **107**: 6180-6185.

Thackeray, A.I. 1989. Changing fashions in the Middle Stone Age: the stone artefact sequence from Klasies River Mouth main site, South Africa. *African Archaeological Review* **7**: 33-57.

Toyoda, S., Ikeya, M., Dunnell, R.C. & McCutcheon, P.T. 1993. The use of electron spin resonance (ESR) for the determination of prehistoric lithic heat treatment. *Applied Radiation and Isotopes* **44**(1-2): 227-231.

Tribolo, C., Mercier, N., Valladea, H., Joron, J.L., Guibert, P., Lefrais, Y., Selo, M., Texier, P.J., Rigaud, J.P., Porraz, G. & Poggenpoel, C. 2009. Thermoluminescence dating of a Stillbay-Howiesons Poort sequence at Diepkloof rockshelter (Western Cape, South Africa). *Journal of Archaeological Science* **36(3)**: 730-739.

Tribolo, C., Mercier, N., Douville, E., Joron, J.L., Reyss, J.L., Rufer, D., Cantin, N., Lefrais, Y., Miller, C.E., Porraz, G., Parkington, J., Rigaud, J.P.,

Texier, P.J., 2013. OSL and TL dating of the Middle Stone Age sequence at Diepkloof Rock Shelter (South Africa): a clarification. *Journal of Archaeological Science* **40** (9): 3401-3411.

Tringham, R., Cooper, G., Odell, G., Voytek, B. & Whitman, A. 1974. Experimentation in the formation of edge damage: a new approach to lithic analysis. *Journal of Field Archaeology* **1**: 171–196.

Tsobgou, R.A. 2009. Mapping Mesolithic and Neolithic cultures behaviours and interactions with nature and properties of rocks in Western France. *Journal of Archaeological Science* **36**: 1615–1625.

Tykot, R.H. 1997. Characterization of the Monte Arci (Sardinia) Obsidian sources. *Journal of Archaeological Science* **24**: 467-479.

Uchida, E., Ito, K. & Shimizu, N. 2010. Provenance of the sandstone used in the construction of the Khmer Monuments in Thailand. *Archaeometry* **52**: 550–574.

Valladas, H., Wadley, L., Mercier, N., Froget, C., Tribolo, C., Reyss, J-L. & Joron, J.-L. 2005. Thermoluminescence dating on burnt lithics from Middle Stone Age layers at Rose Cottage Cave, South Africa. *South African Journal of Science* **101**: 169-174.

Villa, P., Delagnes, A. & Wadley, L. 2005. A late Middle Stone Age artefact assemblage from Sibudu (KwaZulu-Natal). Comparisons with the European Middle Paleolithic. *Journal of Archaeological Science* **32**: 399-422.

Villa, P, Soriano, S, Teyssandier, N, & Wurz, S. 2010. The Howiesons Poort and MSA III at Klasies River main site, Cave 1A. *Journal of Archaeological Science* **37**:630-655

Villa, P., Pollarolo, L., Degano, I., Birolo, L., Pasero, L., Biagioni, C., Douka, K., Vinciguerra, J., Lucejko, J. & Wadley, L. 2015. A milk and ochre paint

mixture used 49,000 years ago at Sibudu, South Africa. PLOS one http://dx.doi.org/10.1371/journal.pone.0131273

Vogel, J.C. 2001. Radiometric dates for the Middle Stone Age in South Africa. In: Tobias, P.V., Raath, M.A., Moggi-Cecchi, J. & Doyle, G.A. eds, *Humanity from African naissance to coming millennia.* Johannesburg: University of the Witwatersrand Press, pp 261-268.

Volman, T.P. 1984. Early prehistory of southern Africa, In: R.G. Klein Ed., *Southern African prehistory and palaeoenvironments*, Balkema, Rotterdam, pp 169-220.

Wadley, L. 2005. A typological study of the final Middle Stone Age stone tools from Sibudu Cave, KwaZulu-Natal. *South African Archaeological Bulletin* **60**(182): 51-63

Wadley, L. 2007. Announcing a Still Bay Industry at Sibudu Cave. *Journal of Human Evolution* **52**:681-689.

Wadley, L. 2008. The Howiesons Poort industry of Sibudu Cave. *South African Archaeological Society Goodwin Series* **10**: 122-132.

Wadley, L. 2010a. Compound-Adhesive manufacture and a behavioural proxy for complex cognition in the Middle Stone Age. *Current Anthropology* **51**(S1): 111-119.

Wadley, L. 2010b. Were snares and traps used in the Middle Stone Age and does it matter A review and case study from Sibudu, South Africa. *Journal of Human Evolution* **58**(2): 179-192.

Wadley 2010c. Compound-adhesive manufacture as a behavioural proxy for complex cognition in the Middle Stone Age. *Current Anthropology* **51**(S1): S111-S119.

Wadley, L. 2011. Complex cognition required for compound adhesive manufacture in the Middle Stone Age implies symbolic capacity. In: Henshilwood, C.S. & d'Errico, F. eds., *Homo Symbolicus.* Amsterdam: John Benjamin Publishing Co., pp 97-110.

Wadley, L. 2015. Those marvellous millennia: the Middle Stone Age of southern Africa. *Azania* **50**: 155-226.

Wadley, L. & Jacobs, Z. 2006. Sibudu Cave: background to the excavations, stratigraphy and dating. *Southern African Humanities* **18**: 1–26.

Wadley, L. & Harper, P. 1989. Rose Cottage Cave revisited: Malan's Middle Stone Age collection. *South African Archaeological Bulletin* **44**: 23–32.

Wadley, L. & Kempson, H. 2011. A review of rock studies for archaeologists, and an analysis of dolerite and hornfels from the Sibudu area, KwaZulu-Natal. *Southern African Humanities* **23**:87-101.

Wadley, L. & Mohapi, M. 2008. A segment is not a monolith: evidence from the Howieson's Poort of Sibudu, South Africa. *Journal of Archaeological Science* **35**: 2594–2605.

Wadley, L. & Prinsloo, L.C. 2014. Experimental heat treatments of silcretes implies analogical reasoning in the Middle Stone Age. *Journal of Human Evolution* **70**: 49-60.

Wadley, L., Sievers, C., Bamford, M., Goldberg, P., Berna, F. & Miller, C. 2011. Middle Stone Age bedding construction and settlement patterns at Sibudu, South Africa. *Science* **334**(6061): 1388-1391.

Wadley, L., Williamson, B. & Lombard, M. 2004. Ochre in hafting in Middle Stone Age southern Africa: a practical role. *Antiquity* **78**: 661-675.

Webb, J.A. & Domanski, M. 2007. A review of heat treatment research. *Lithic Technology* **32**(2): 153-194.

Webb, J.A. & Domanski, M. 2008. The relationship between lithology, flaking properties and artefact manufacture for Australian silcretes. *Archaeometry* **50**: 555–575.

Whittaker, J.C. 1994. *Flintknapping. Making and understanding stone tools*. Austin: University of Texas Press.

Wurz, S. 1997. *The Howiesons Poort at Klasies River: from artefacts to cognition*. MA dissertation. University of Stellenbosch.

Wurz, S. 1999. The Howiesons Poort at Klasies River – an argument for symbolic behaviour. *Southern African Archaeological Bulletin* **54**: 38–50.

Wurz 2000. The Middle Stone Age sequence at Klasies River, South Africa. D.Phil Thesis, University of Stellenbosch.

Wurz, S. 2002. Variability in the Middle Stone Age lithic sequence, 115,000-60,000 years ago at Klasies River, South Africa. *Journal of Archaeological Science* **29**:1001-1015.

Wurz, S. 2013. Technological trends in the Middle Stone Age of South Africa between MIS 7 and MIS 3. *Current Anthropology* **54**: S305-S319.

Wynn, T. 2009. Hafted spears and the archaeology of mind. *PNAS* http://dx.doi.org/10.1371/journal.pone.0131273

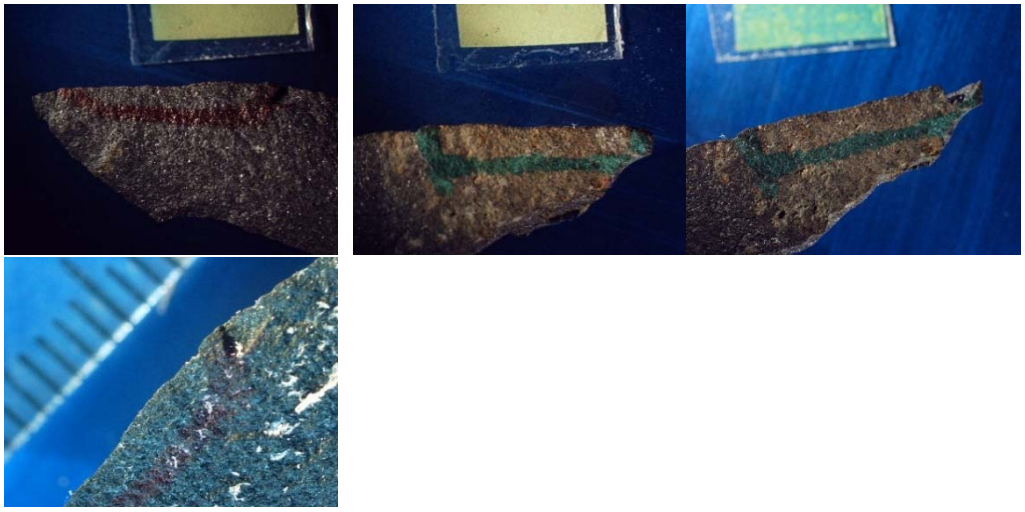
Yonekura, K., Hasegawa, H., Hotta, A. & Suzuki, T. 2008. A novel approach to studies of prehistoric exploitation of stone tool materials using material composition, surface morphology, microstructure and mechanical properties. *Archaeometry* **50**: 727–746.

Appendix A

Chilled dolerite

Sample #19 – scraper

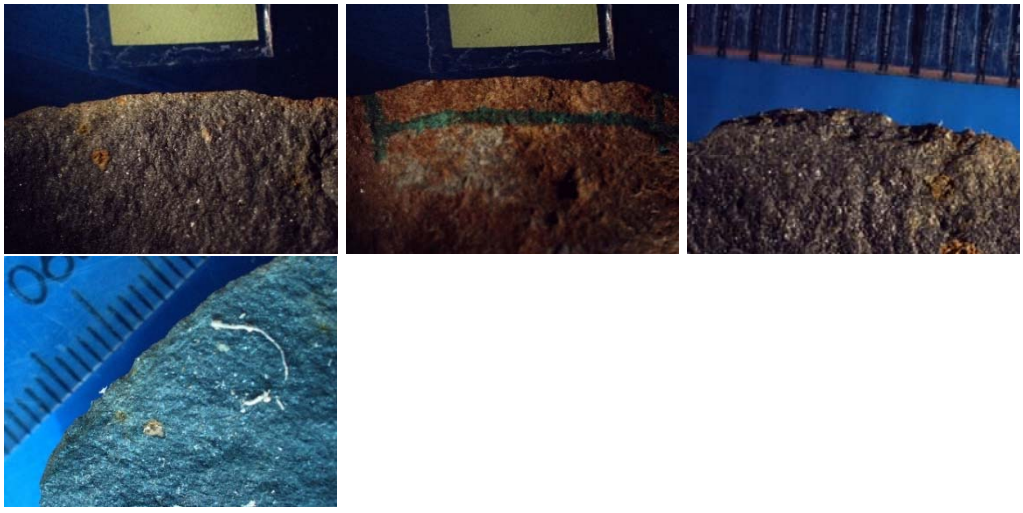
Scale: yellow bar = 14mm, ruler gradations are 1mm each



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5 minutes; bottom left, damage after 10 minutes.

Sample #20 – scraper

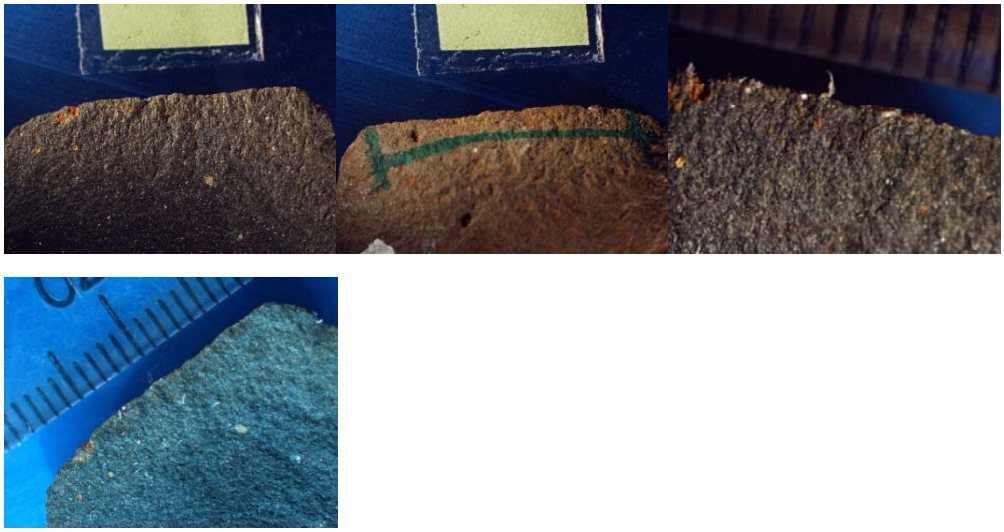
Scale: yellow bar = 14mm, ruler gradations are 1mm each



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5 minutes; bottom left, damage after 10 minutes.

Sample #21 – scraper

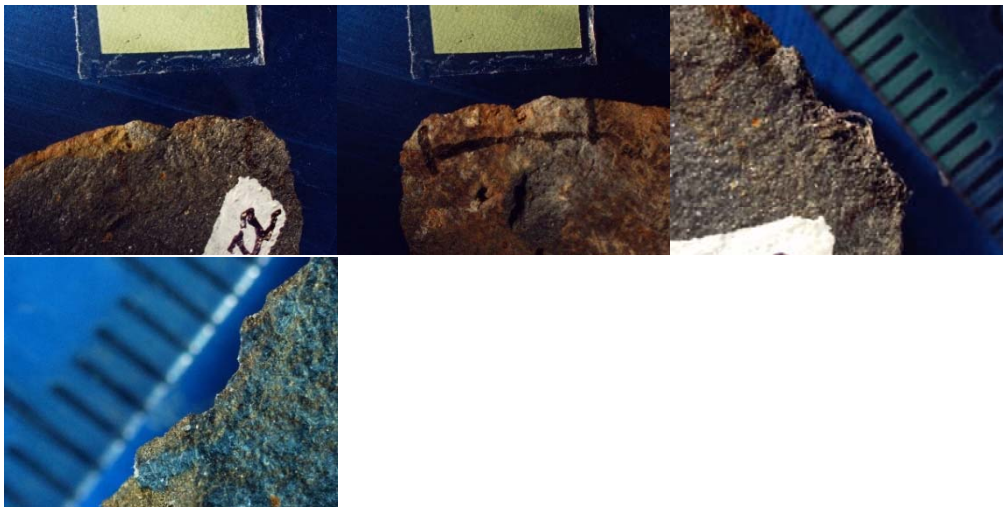
Scale: yellow bar = 14mm, ruler gradations are 1mm each



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5 minutes; bottom left, damage after 10 minutes.

Sample #22 – cutting tool

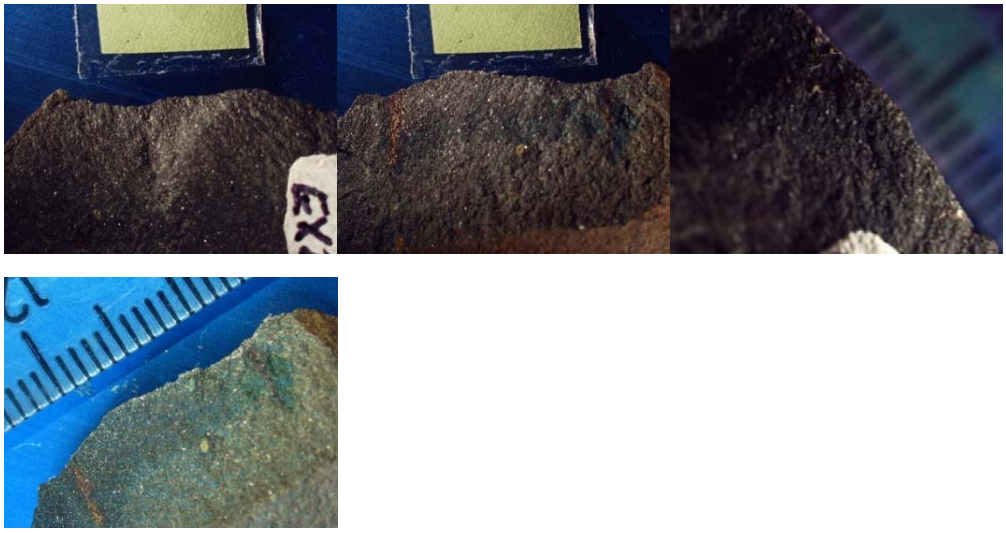
Scale: yellow bar = 14mm, ruler gradations are 1mm each



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5 minutes; bottom left, damage after 10 minutes.

Sample #23 – cutting tool

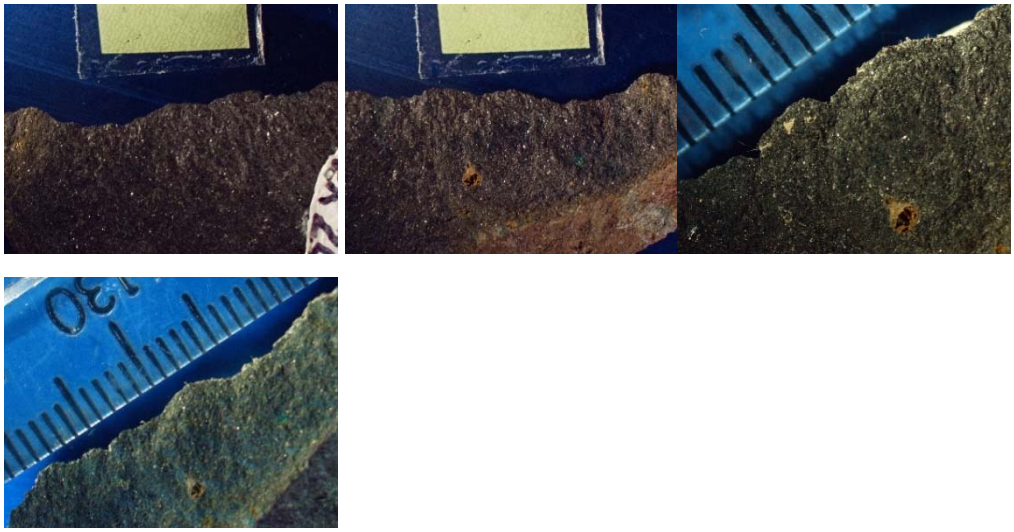
Scale: yellow bar = 14mm, ruler gradations are 1mm each



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5 minutes; bottom left, damage after 10 minutes.

Sample #24 – cutting tool

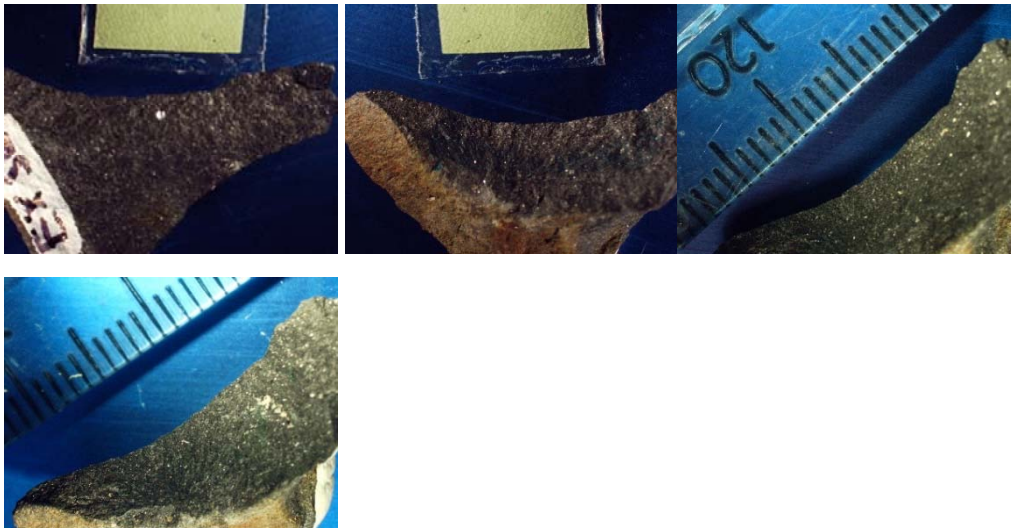
Scale: yellow bar = 14mm, ruler gradations are 1mm each



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5 minutes; bottom left, damage after 10 minutes.

Sample #21 – scraper

Scale: yellow bar = 14mm, ruler gradations are 1mm each



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5 minutes; bottom left, damage after 10 minutes.

Hornfels

Sample HS1 – scraper

Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10mm



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5 minutes; bottom left, damage after 10 minutes.

Sample HS2 – scraper

Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10mm



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5 minutes; bottom left, damage after 10 minutes.

Sample HS3 – scraper

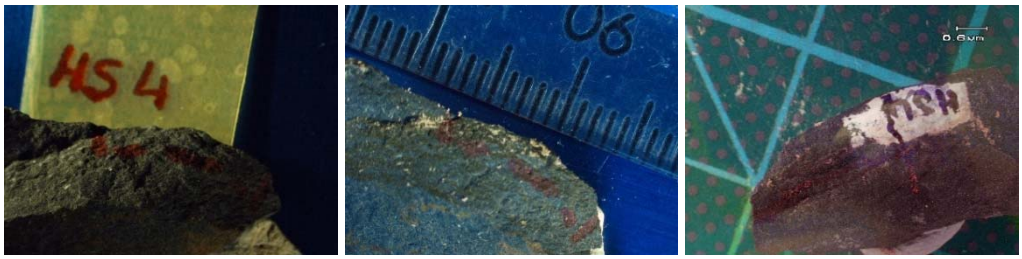
Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10mm



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5 minutes; bottom left, damage after 10 minutes.

Sample HS4– scraper

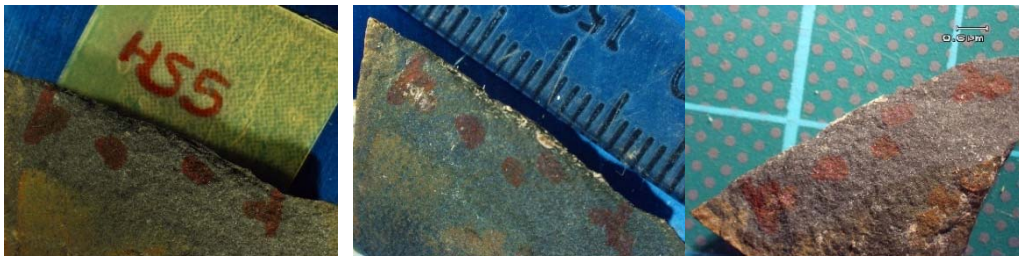
Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10mm



Top left, ventral surface before use; top centre, damage after 5 minutes; top right, damage after 10 minutes.

Sample HS5– scraper

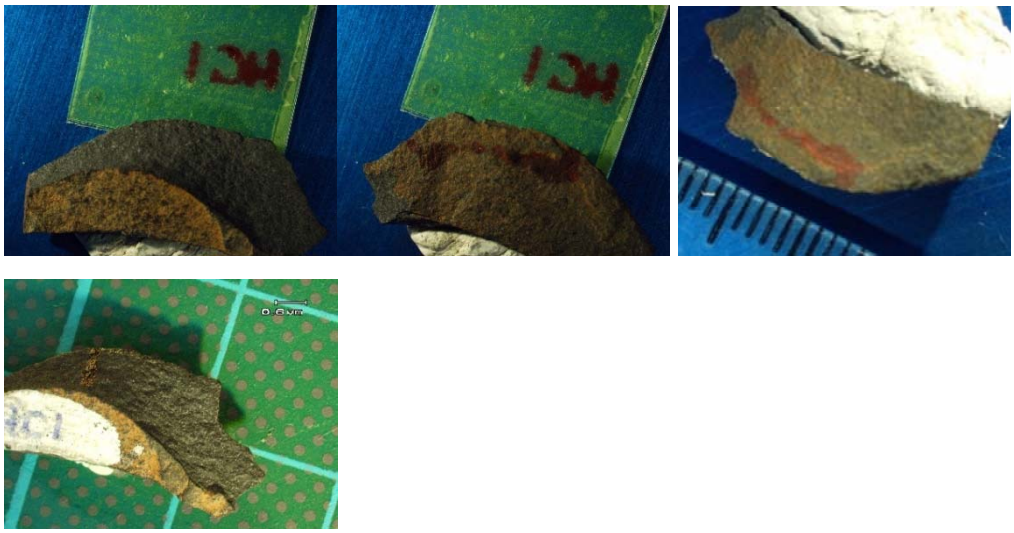
Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10mm



Top left, dorsal surface before use; top centre, damage after 5 minutes; top right, damage after 10 minutes.

Sample HC1 – cutting tool

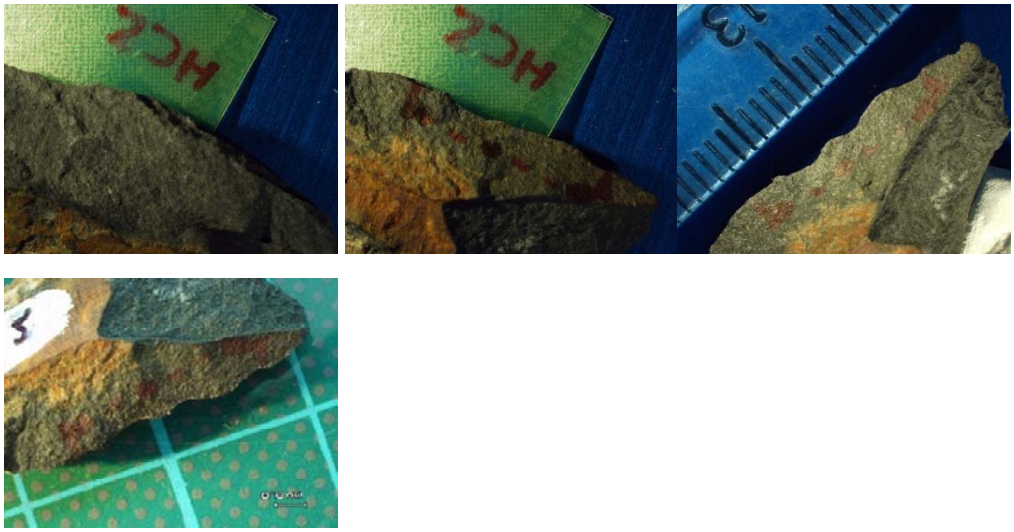
Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10mm



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5 minutes; bottom left, damage after 10 minutes.

Sample HC2 – cutting tool

Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10m



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5 minutes; bottom left, damage after 10 minutes.

Sample HC3 – cutting tool

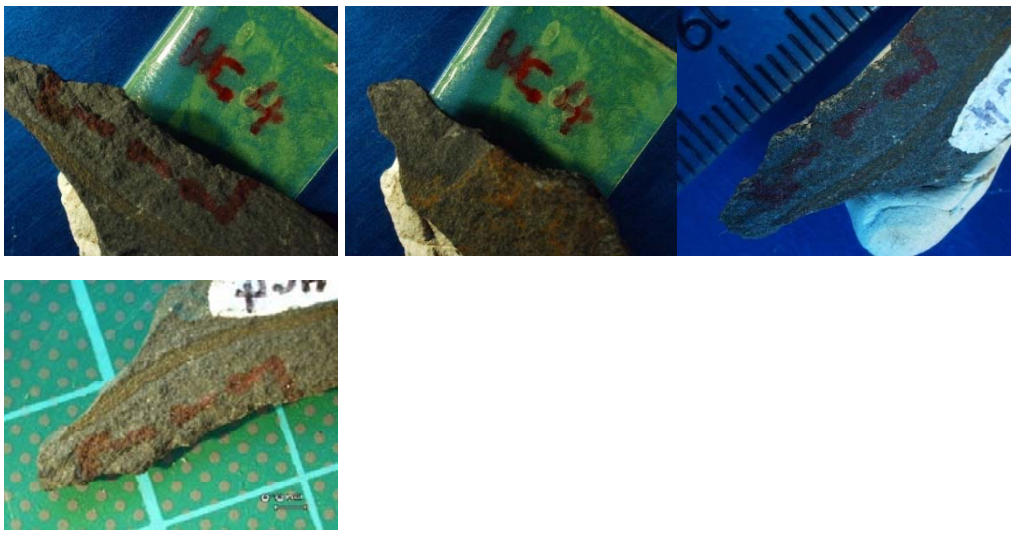
Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10m



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5 minutes

Sample HC4 – cutting tool

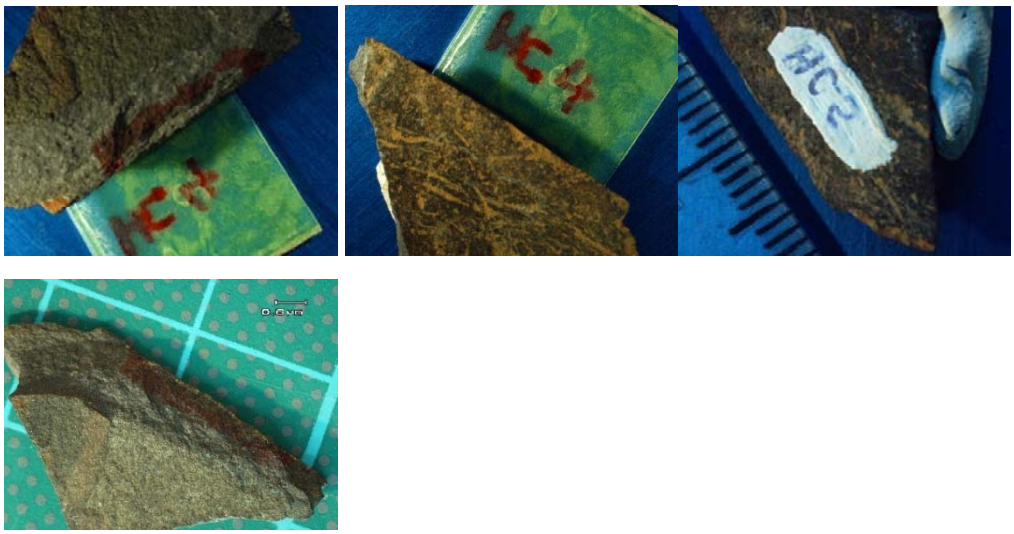
Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10m



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5 minutes; bottom left, damage after 10 minutes.

Sample HC5 – cutting tool

Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10m

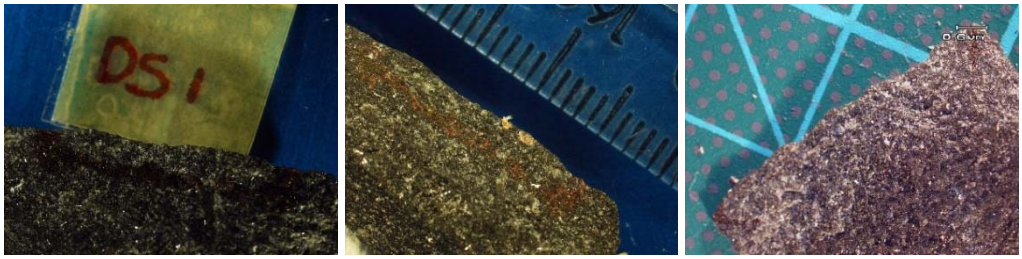


Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5 minutes; bottom left, damage after 10 minutes.

Dolerite

Sample DS1 - scraper

Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10m



Top left, ventral surface before use; top centre, damage after 5 minutes; top right, damage after 10 minutes

Sample DS2 – scraper

Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10m

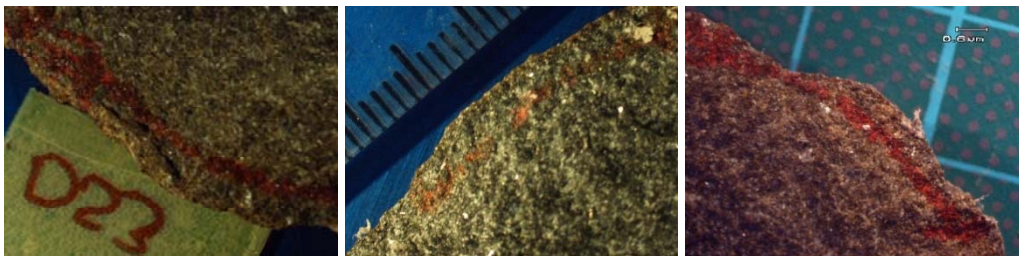




Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5minutes; bottom left, damage after 10 minutes.

Sample DS3 – scraper

Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10m



Top left, ventral surface before use; top centre, damage after 5 minutes; top right, damage after 10 minutes

---

Sample DS4- scraper

Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10m





Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5minutes; bottom left, damage after 10 minutes.

Sample DS5- scraper

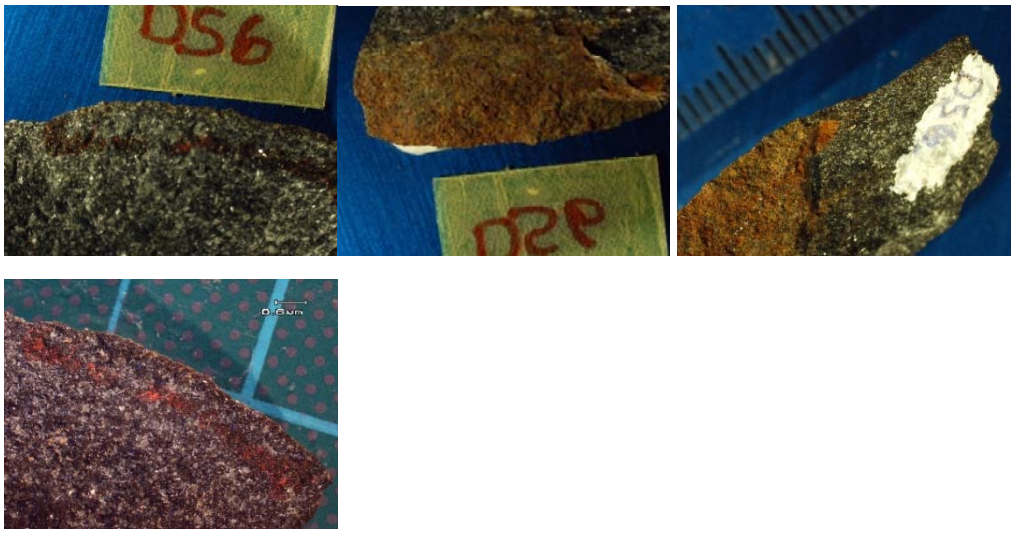
Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10m



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5minutes; bottom left, damage after 10 minutes.

Sample DS6- scraper

Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10m



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5minutes; bottom left, damage after 10 minutes.

Sample DC1- cutting tool

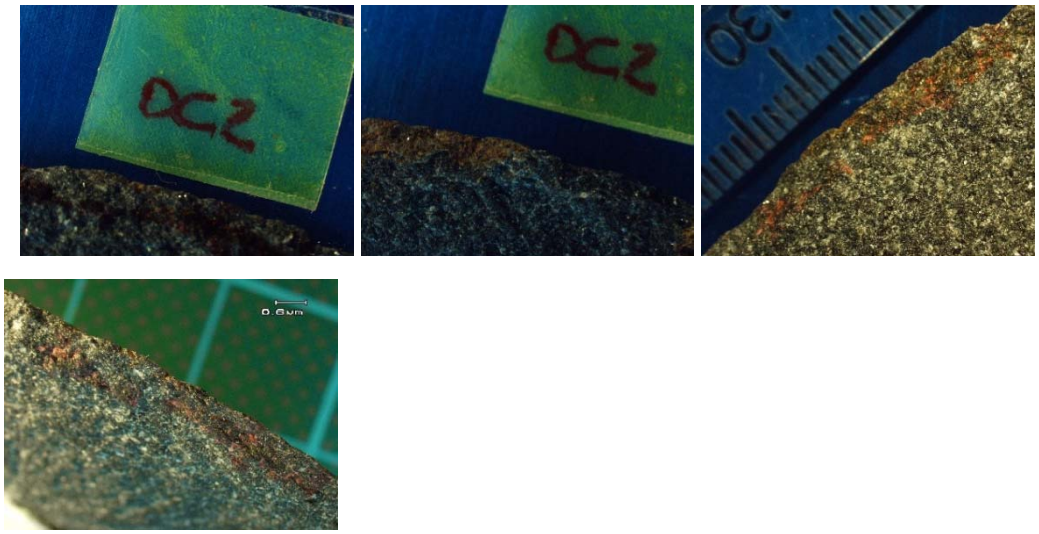
Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10m



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5minutes; bottom left, damage after 10 minutes.

Sample DC2- cutting tool

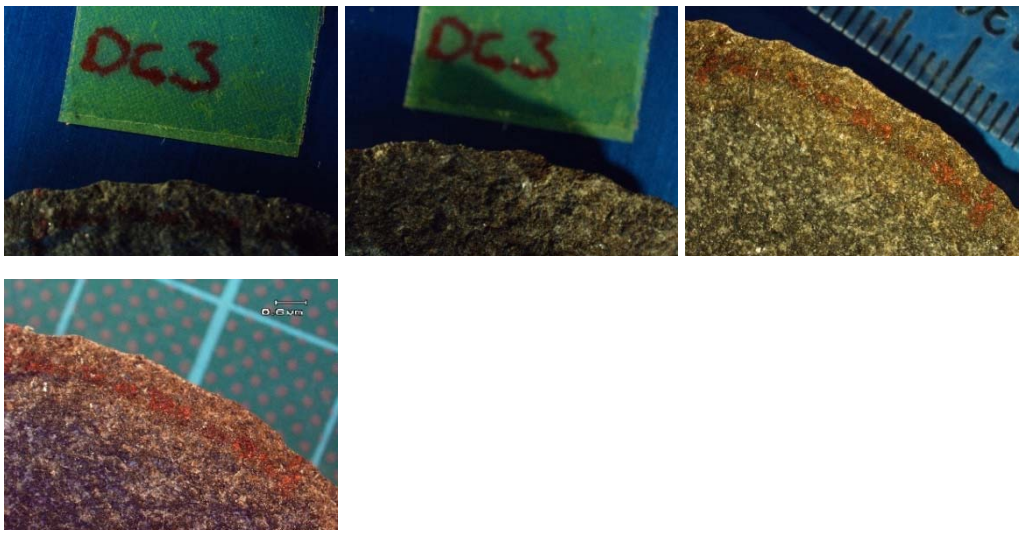
Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10m



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5minutes; bottom left, damage after 10 minutes.

Sample DC3- cutting tool

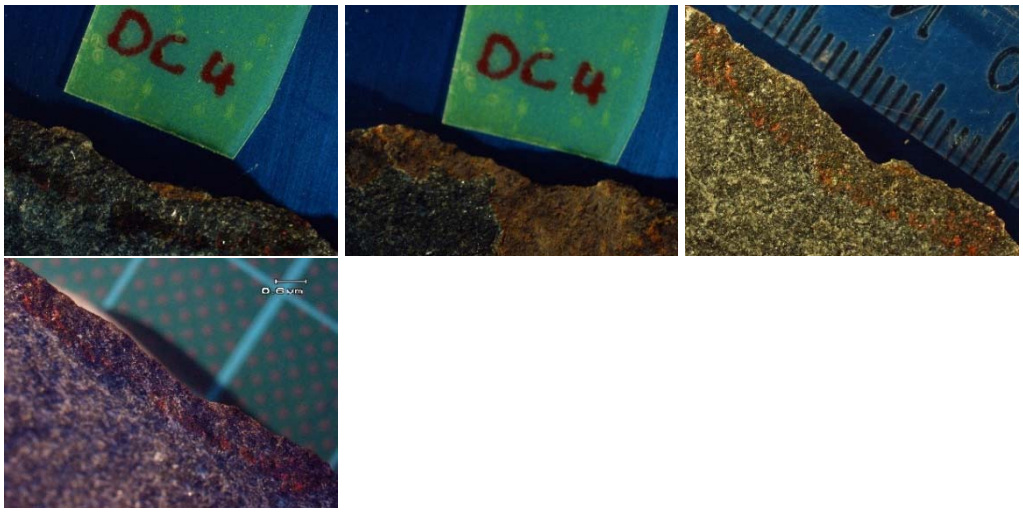
Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10m



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5minutes; bottom left, damage after 10 minutes.

Sample DC4- cutting tool

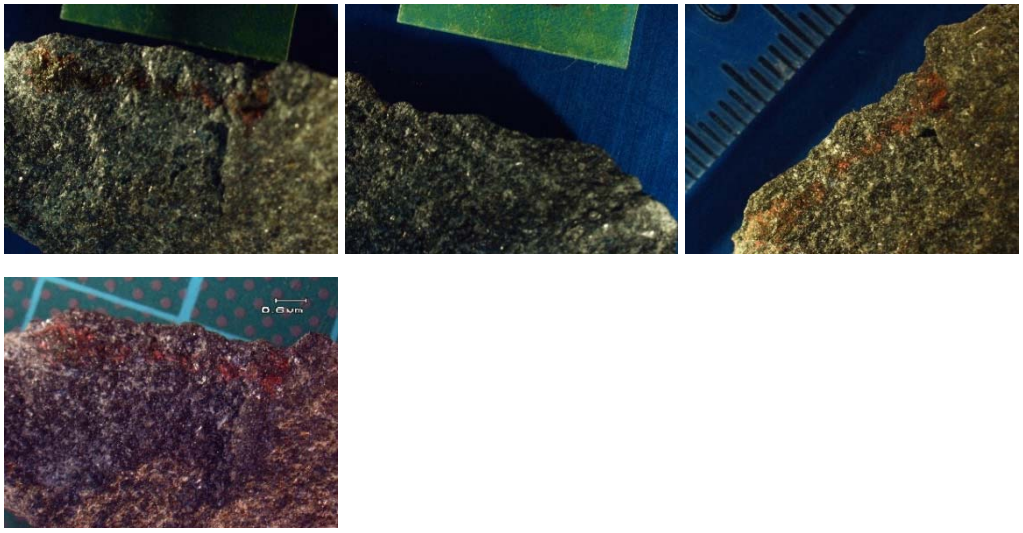
Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10m



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5minutes; bottom left, damage after 10 minutes.

Sample DC5- cutting tool

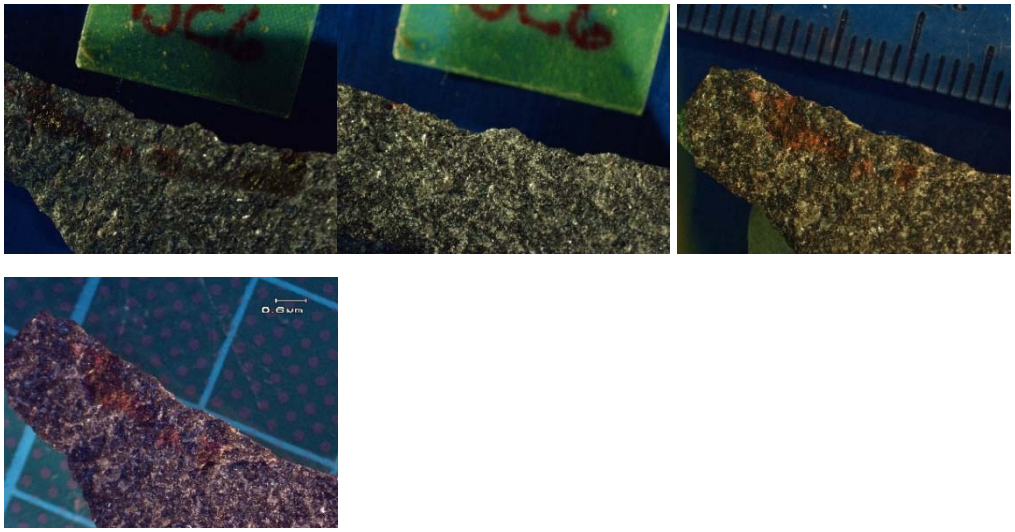
Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10m



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5minutes; bottom left, damage after 10 minutes.

Sample DC6- cutting tool

Scale: yellow bar = 14mm, ruler gradations are 1mm each, squares measure 10m



Top left, ventral surface before use; top centre, dorsal surface before use; top right, damage after 5minutes; bottom left, damage