

**Technological behaviour of *Homo erectus* in Beds II, III and
IV, Olduvai Gorge (Tanzania)**

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Disclaimer

I, Alexander Titan Kabelindde confirm that the work presented in my thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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Abstract

Technological behaviours of *Homo erectus* are discussed following a comprehensive technological analysis of stone tool assemblages from FC East, JK, and WK sites at Olduvai Gorge, Tanzania. Until recently, most research into the hominin behaviour at Olduvai have focused on Beds I and II sequences, with little focus on the hominin behaviour in upper beds. In addition, most previous studies relied heavily on the interpretation of stone tool types without conducting a full technological analysis of the assemblages. Through a first-hand reanalysis of previously excavated lithic collections by Mary Leakey and the Olduvai Gorge Archaeology Project (OGAP), this study provides evidence of hominin technological behaviour in Beds II, III, and IV, a crucial time period for the existence of the Acheulean technology at Olduvai Gorge. This technological analysis shows occurrence of reduction sequence that indicates that hominins aimed at producing small flakes and cores. Exploitation of cores appears to be expedient and low to medium intensity. Retouched tools are mostly notches, alongside other retouched tool types such as denticulates and sidescrapers. Results on the comparison of technological aspects between sites reveal a well-defined and standardised procedure, ranging from raw material selection to tool making, maintenance and discarding. This technological organisation of the Acheulean sites of Olduvai is indicative of a remarkable technological advancement and organisational skills. This strongly suggests the existence of technical procedures that were systematically executed by hominins at these sites and underscores the organised technological behaviour of the Acheulean hominins at Olduvai Gorge.

Impact statement

The completion of this PhD thesis on hominin technological behaviour marks a transformative milestone in the academia, influencing both the development of the discipline and the future research on Acheulean hominin at Olduvai and elsewhere.

Firstly, an increase of hominin behavioural research at Olduvai's upper beds (Bed III and IV). Through this thesis, a detailed technological analysis of *Homo erectus* lithic materials was conducted, and hominin behaviour and technical skills were presented. This was accomplished through the application of extensive lithic analysis, rigorous methodologies, and constructive theoretical approaches.

Secondly, this thesis will contribute to dissemination of knowledge at present and in the future. This study sheds light on the hominin behaviour at Olduvai, particularly in beds III and IV. Hominin behaviour at this time was poorly known to many researchers due to an immense focus on Beds I and II sites. In addition, some of the findings of this research will be published in peer-reviewed journals, which will amplify the reach and impact of this work within the academic community.

In conclusion, this thesis on hominin technological behaviour has exerted a profound and multifaceted impact to the discipline. It has enriched our understanding of hominin behaviour and provided future research opportunities on hominin behaviour at Olduvai and beyond.

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Abbreviations

Tr.	Trench
NMT	National Museums of Tanzania
JK	Juma's Korongo
WK	Wayland's Korongo
DOC	Developed Oldowan C
EF-HR	Evelyn Fuchs and Hans Reck
HWKEE	Henrietta Wilfrida Korongo East East
HK	Hopwood's Korongo
IPHES	The Catalan Institute of Human Paleoecology and Social Evolution.
MNK	Mary Nikol Korongo
OGAP	Olduvai Gorge Archaeology Project
PDK	Peter Davies Korongo
TK Fish Gully	Teal's Korongo
WK	Wayland's Korongo
SHK	Sam Howard Korongo
BK	Bell's Korongo

Chapter 1: Introduction and Thesis Organisation

1.1 Background

One of the most important events in human history was the emergence of technology that allowed our ancestors to make and use stone tools, which have remained the most important evidence that help in reconstructing hominin behaviour and technological skills. Whilst a large body of research concerning hominin lithic technology and raw material procurement strategies has been developed (Hay, 1976; Jones, 1979; Jones, 1980; Jones, 1981; de la Torre and Mora, 2005c; McHenry and de la Torre, 2018a), much less is known about the technological behaviour of Acheulean hominins at Olduvai.

Previous models that address the lower Pleistocene technologies at Olduvai were focusing on interpreting stone tool types (Leakey, 1971; Leakey, 1975; Leakey and Roe, 1994). The model was commonly utilised to illustrate variations among lithic artefacts based on their morphologies, for example, Oldowan and Developed Oldowan (Leakey, 1971). The typological method was used by the Leakeys as a primary method of artefact description in different sites in East Africa (Leakey, 1951; Leakey, 1971; Leakey, 1975; Leakey and Roe, 1994). It played a key role in influencing subsequent research in the studies of early hominin behaviour. However, it lacked analytical aspects and researchers initiated alternative approaches of studying hominin behaviour using lithic artefacts.

One of the early works of changing models for understanding lithic artefacts was the work of Isaac and Harris (Isaac and Harris, 1997). They devised three categories of classifying lithic artefacts based on their technical attributes. These included flaked

pieces, detached pieces, and pounded pieces (Isaac and Harris, 1997). In addition, other studies initiated experimental studies to understand hominid technology from experimental perspectives (Jones, 1979; Stiles, 1979; Jones, 1981; Toth, 1982; Toth, 1985; Toth, 1987).

More recently, models relevant for analysing hominin lithic technology and behaviour have focused mostly on Olduvai Beds I and II, typical areas of focus for most of researchers working at Olduvai (Mora and de La Torre, 2005; de La Torre and Mora, 2018c; de la Torre *et al.*, 2018). As a result, we lack a detailed understanding of the later Acheulean hominins behaviour and techno-economic strategies that helped them to survive different environments during lower Pleistocene times. This study seeks to understand hominin behaviour by employing a combination of lithic technological analyses and raw material economy perspective. The main aim of this study is to examine the technological capabilities that are documented in Beds II, III, and IV, and to establish whether there is stasis or a technological change in the Acheulean Industry of Olduvai.

An experimental study sheds light on key technological results that can be expected from the smalldebitage Acheulean lithic artefacts, and analysis of previously excavated Acheulean smalldebitage artefacts was undertaken. Three different assemblages were analysed. These include, FC East assemblage, which was recovered during the OGAP excavations, and was not subjected to a technological analysis. Additionally, the JK and WK assemblages, which were excavated by the Leakeys and Kleindienst (Kleindienst, 1973; Leakey and Roe, 1994). Also, these assemblages were not analysed based on technological aspects. It is evident that lack of technological studies of the previously excavated assemblages by the Leakeys

and other teams at Olduvai limit our understanding of technical skills and the behaviour of *Homo erectus*.

Homo erectus was a hominin species with more sophisticated technology (Acheulean) and larger brain and body size than its Oldowan predecessor (Leakey, 1966, 1973; Bilsborough, 1976; Shipman and Walker, 1989; Pante, 2010). *Homo erectus* is distinguished by its more humanlike morphology, which includes larger brain and body size, reduced body size dimorphism between males and females, and smaller jaws and dentition; it has been argued that these characteristics evolved as a result of an increase in nutritional intake via the consumption of higher quality foods (Shipman and Walker, 1989). Additionally, it has been suggested that the *Homo erectus* species was associated with the Acheulean industrial complex at Olduvai (Leakey, 1973; Anton, 2003).

The Acheulean is one of the world's oldest human technologies that contributes discussions on key aspects of current investigation in the archaeology of human evolution (de la Torre and Mora, 2014; Gowlett, 2015). According to this study, it is one of the world's oldest lower palaeolithic technologies, characterized by the production of large cutting tools (LCTs) and small debitage implements associated with *Homo erectus* species, which originated in Africa and spread to most parts of Europe and Asia. The earliest evidence of the Acheulean technology was first documented in eastern Africa about 1.76 Ma and persisted to about 0.1 Ma (Leakey, 1971; Asfaw et al., 1992; Beyene et al., 2013; Gallotti, 2013; de la Torre and Mora, 2014; Diez-Martin et al., 2015; de la Torre, 2016; Uribe Larrea et al., 2017; Sanchez-Yustos et al., 2017).

Palaeolithic research at Olduvai was pioneered by Louis and Mary Leakey since the 1930s (Leakey, 1951), and continued throughout the 1960s and 1970s (Leakey, 1971, 1975; Leakey and Roe, 1994) until present days (de la Torre and Mora, 2005; de La Torre et al., 2011; Diez-Martin et al., 2011, 2015; Proffitt, 2016; Uribelarrea et al., 2017; Proffitt, 2018; McHenry and de la Torre, 2018a). The Leakeys worked at Olduvai for several decades and their research yielded important scientific discoveries, including the famous skull of *Australopithecus boisei* in 1959 (Leakey, 1959) and stone tool remains attributed to the Oldowan and Acheulean (Leakey, 1971, 1975; Leakey and Roe 1994).

Subsequent excavations by Mary Leakey identified seemingly distinct cultural facies between the Oldowan and Acheulean at Olduvai. These were termed the Developed Oldowan and comprised of the Developed Oldowan A, B and C (Leakey, 1971; Stiles, 1979, 1981). Whilst Oldowan sites are known to occur in Bed I and lower Bed II, the Developed Oldowan and Acheulean sites occur in the middle and upper units of Bed II (Leakey, 1975).

Leakey (1975) claims that the Developed Oldowan B industries are within the middle and upper Bed II and probably in Bed III. The industry consists of heavy-duty tools and added poorly made small bifaces, as well as light-duty tools, which consist of burins, scrapers, awls, *outils ecaillés*, and laterally trimmed flakes. Additionally, Leakey (1975) notes evidence of the Developed Oldowan industries in Bed II that were described in the classic monograph (volume 3 of the Olduvai monographs), which mentions six occurrences such as FC West, MNK Main Site, SHK, BK, and Upper and Lower Floors at TK (Leakey, 1971).

The bifacial tools from the MNK Main Site and TKLF exhibit similarities with early Acheulean bifaces, which exhibit a bold and accurate trimming of scars; this indicates that the makers had a full mastery of the materials. Similarly, FC bifacial tools exhibit close similarities with those from MNK, however, they are poorly represented making it impossible to show the status of the industry (Leakey, 1975: 484).

The debate on the Developed Oldowan may be the most important aspect in understanding the cultural sequence of Beds II and III. Although Leakey (1971) claimed that Developed Oldowan and the Acheulean existed side by side in Bed II and IV, other researchers disputed that claim and suggested that all the assemblages fall within the Acheulean Industry (Stiles, 1979). Stiles (1979) argues that the differences in the assemblages could be accounted by factors such as different raw materials. Moreover, the preliminary examination of the lithic industry recovered from Bed III at JK2 by M.R. Kleindienst shows that it is within the Developed Oldowan culture and not the Acheulean; the Acheulean tradition appears to be represented at JK West at the same stratigraphic horizon. This study will not delve deeper into the debate of Oldowan and Developed Oldowan because it is a topic of different research; it focuses on one of the early Acheulean sites within Bed II, the Fuchs Cliff (FC) East, and then Bed III Juma's Korongo (JK), and Bed IV Wayland's Korongo (WK).

An extensive research into the Acheulean at Olduvai became fruitful following the Leakeys 1960s work at Evelyn Fuchs – Hans Reck (EF-HR) site, which Leakey (1971) considered it to be the earliest Acheulean site at Olduvai and hence it was the then world's oldest Acheulean site until the discovery of other sites in Kenya and Ethiopia (Asfaw et al., 1992; Beyene, 2003; Beyene et al., 2013). Since then, Olduvai Acheulean assemblages became the main reference for further investigations on

Acheulean, and a considerable number of researchers focused their investigations on the comparisons between Acheulean and its predecessor, the Oldowan (Kimura, 2002; de la Torre and Mora, 2005), its origin and development (de La Torre et al., 2011; Diez-Martin et al., 2015; Uribe-larrea et al., 2017), palaeontology (Bibi et al., 2018), diet (Uno et al., 2018), site formation processes (de la Torre and Wehr, 2018), raw material procurement and geology (Hay 1976; McHenry and de la Torre 2018b), and technological strategies of the early Acheulean (de la Torre and Mora, 2018b). While there is an ongoing investigation pertaining hominin activities at Olduvai and other eastern Africa sites, these investigations do not focus on Beds III and IV, a time period in which Acheulean hominin behaviour is poorly known.

Technological strategies that may define the technological capabilities of the Acheulean hominins in the upper beds are poorly understood. It is unclear how hominins in Beds II, III, and IV procured raw materials and shaped cores, particularly those of small debitage Acheulean technology. The Acheulean technology at Olduvai began in middle Bed II; it is unclear whether the technology remained static, or it changed in the upper Olduvai Beds. The raw material procurement strategies that ensured constant supply of raw materials for making stone tools are also poorly known. Raw material procurement studies at Olduvai have focused on Beds I and II sites, with less focus in Beds III and IV sites. However, raw material studies supporting research in Beds III and IV are rare and are required to reconstruct the raw material economy of the Acheulean hominins in Beds III and IV sites. Likewise, little is known about how the distances from raw material sources to the sites affected the reduction intensity of cores at these sites. The effects of the distance between raw material sources and sites to the reduction intensity was until recently investigated solely in

Beds I and II sites. Thus, how the distances affected hominins transport behaviours is poorly understood.

This thesis is therefore dedicated to studying *Homo erectus* technological behaviour by analysing lithic artefacts from sites within the Acheulean sequences at Olduvai from time intervals which have received less research attention than the typical Bed I and earlier Bed II units. Thus, this PhD study uses the Fuchs Cliff (FC), Juma's Korongo (JK) and Wayland's Korongo (WK) assemblages (Leakey and Roe, 1994) to undertake in-depth research into the technological strategies of Olduvai hominins during lower Pleistocene times. Such assemblages in the early Acheulean of Olduvai stand as pivotal sources that will shape the empirical and conceptual frameworks of this research, which aim to define the techno-economic behaviour of *Homo erectus* and the Acheulean techno-complex in Olduvai.

1.2 Research objectives and questions

1.2.1 Primary research objectives

The ultimate goal of this study is to investigate the technological behaviour of *Homo erectus* at Olduvai Gorge in Tanzania. To achieve this goal, the following overarching research questions will be addressed:

- 1. Through a technological analysis of relevant smalldebitage lithic assemblages, what were the technological capabilities of Acheulean hominins who lived in Beds II, III, and IV?*

Much of the literature during the Leakeys' time emphasised the typological aspects of earlier periods at Olduvai; for example, the Leakey's monograph on the Oldowan industry of Beds I and II of Olduvai (Leakey, 1971) and an account of the archaeology

of Beds III and IV (Leakey and Roe, 1994). Subsequent researchers, however, focused on understanding hominid behaviour and cultural tradition from a technological perspective, which included research on percussion activities (Mora and de La Torre, 2005), investigating function of pounding tools (de la Torre et al., 2013; Sánchez-Yustos et al., 2015), an assessment of pounding tools in the Early Stone Age (Arroyo and de la Torre, 2016), hominin technological strategies (de la Torre and Mora, 2005a), and reconstruction of landscape and land use patterns that led to distribution of artefact assemblages across the Olduvai basin (Blumenschine et al. 2012; Blumenschine et al. 2012; Blumenschine, Stanistreet & Masao 2012).

This question is addressed through a combination of experimental programs and detailed technological re-analysis of Acheulean assemblages of Beds II, III and IV originally excavated by the Leakeys and the Olduvai Gorge Archaeology Project (OGAP) team. By applying theoretical perspectives into technological organisation, this study will seek to characterise the techno-economic nature of the following sites: FC East, JK West, JK2 and WK site.

2. Is there identifiable stasis or technological change within the Acheulean smalldebitage assemblages in Beds II, III, and IV?

Previous analyses of the lithic materials from Beds II, III, and IV have identified a degree of variability between the archaeological assemblages (Leakey, 1975; Ludwig, 1999). While describing the Developed Oldowan B, Leakey (1971) argued that the industry was a continuation of the Developed Oldowan A, with an addition of poorly made small bifaces and greater number of light-duty tools such as burins, scrapers, awls and *ouils ecailles* (Leakey, 1971, 1975). Leakey (1975) adds that the industry recovered from Bed III at JK East by M.R. Kleindienst appeared to be within the

Developed Oldowan tradition; however, at JK West Leakey described the assemblage as Acheulean. JK East and JK West assemblages occurred on the same horizon (Leakey, 1975). Additionally, upper Bed IV assemblages were termed within the Developed Oldowan C, with sites such as WKE, A and C and PDK (I-III) (Leakey, 1975). The above statements clearly indicate that there is dichotomy between the technological traditions that appeared at Olduvai between Beds II, III, and IV. Thus, this study will point out and explain if there is stasis or change of technology.

1.2.2 Secondary research objectives

A number of secondary research questions have been identified which contribute to the overarching research questions.

- ❖ *What is the raw material economy of Homo erectus during Beds II, III and IV at Olduvai Gorge, and is there a relationship between technological capabilities and organisation and raw material?*

Evidence of raw material availability at different archaeological sites has demonstrated to yield potential for our understanding of hominin technological organisation and assemblage variation (Dibble, 1985; Stout et al., 2005). Previously published studies on the effects of raw material at Olduvai assemblages have established the factors that determine the choice of raw material for stone tool production, the size and shape of rocks available, mechanical properties of the rocks, and the proximity to the raw materials source (Hay, 1976; Jones, 1979; Kyara, 1999). Further studies focused on various aspects to understand effects of different raw material types in stone tool manufacture (Jones, 1979, 1980, 1981). Stiles (1991) and Kyara (1999) discuss the evidence of hominin extraction and transport of raw material from sources to sites and the implication of raw materials to assemblage variation and hominin behaviour, whilst

others investigated the changes of stone tools' weight and size of stone tools in relation to raw material sources and hominin raw material procurement techniques (Blumenschine et al., 2008; McHenry and de la Torre, 2018a). Blumenschine et al. (2008) and McHenry and de la Torre (2018) studies focus were on Beds I and II and not in later periods, Beds III and IV. Similar studies can be undertaken in Beds II, III, and IV. Thus, this question seeks to understand raw material strategies employed by hominins to select, acquire, and transport rocks from sources to sites. Specifically, how raw material procurement process can increase our understanding of *Homo erectus* strategies for raw material selectivity at Olduvai. This was accomplished through a detailed raw materials analysis, and the results of raw material studies are presented in chapter 5.

❖ *How did raw material availability and distance affect reduction intensity and Homo erectus mobile toolkit design's efficiency compared to other periods such as the Oldowan?*

Jones (1979) describes how the nature of raw material can affect the form and the level of retouch (refinement) of an artefact (Jones, 1979). He conducted experiments using Olduvai raw materials to determine how each raw material can influence the shape effort invested in refinement. He concluded that it is crucial to consider size, shape, and flaking properties of raw materials in the level of sophistication. Kuhn (1994) discusses how transport costs and size of stone artifacts can affect toolkit choices under different conditions. In his study, he explains various aspects that make artifacts become transported toolkits in relation to transport costs. This study uses Kuhn (1994)'s and Jones (1979) models to explore how the nature of raw material and

its availability can be a potential avenue for understanding fundamental aspects on how we think *Homo erectus* organised their toolkit at Olduvai.

- ❖ *What were the palaeogeographical and ecological contexts of sites in Beds II, III and IV during the lake regression and transgression periods; how did they change over time and how the changes influenced hominins behaviour in response to raw material sources?*

Hay (1976) provided a stratigraphic and palaeogeographical framework of Olduvai Gorge. Subsequent studies have undertaken a paleoenvironmental reconstruction of the landscapes where hominins accumulated stone tools (Stanistreet, 2012), while others investigated the hominins' landscape distribution of stone artifacts (Blumenschine et al., 2012a) and hominin activities (Blumenschine et al., 2012b). Additionally, the Olduvai palaeolake had been modified by extensive geomorphological and faulting activities that might have led to various topographical features at hominin sites (Hay, 1976). These features can help in environmental interpretations of sites and determine the ecology of hominin activities. Whilst considerable research has been carried out on the Olduvai palaeogeography; there is still very little understanding of how the environment in Beds II, III, and IV influenced the way hominins behaved. This research uses Hay's and others' works to understand the palaeogeography of the Acheulean hominin environment and its influence on their technological organisation and raw material economy. This will provide new insights into how the lake and environmental variations shaped hominin activities in response to raw material procurement at Olduvai. This will be achieved through a detailed study of published evidence and archaeological assemblages to reconstruct the palaeoenvironment of Acheulean hominins.

❖ *What is the technological organisation during Acheulean times at Olduvai?*

Nelson (1991)'s work provides a theoretical background onto the study of technological organisation. Dynamics of technological behaviour have been defined by Nelson (1991: 57) as “plans or strategies that guide the technological component of human behaviour”. At Olduvai, there has been no detailed investigation of hominins technological organisation, particularly during the Acheulean times. Specifically, this study investigates their economic and social strategies in organising their technology, manufacturing tools, designing mobile toolkits, using and reusing tools.

What were the hominin technological capabilities at FC East, JK West, JK2 and WK sites? Is there a stasis or technological change at FC East, JK West, JK2 and WK sites? What is the raw material economy of *Homo erectus* at FC East, JK West, JK2 and WK sites? Is there a relationship between technological capabilities and the organisation of raw material at FC East, JK West, JK2 and WK sites? How did raw material availability affect reduction intensity and mobile toolkit of *Homo erectus* at FC East, JK West, JK2 and WK sites? What were the palaeogeographical and ecological contexts of FC East, JK West, JK2 and WK sites? What is the technological organisation of *Homo erectus* at FC East, JK West, JK2 and WK sites? All these research questions will be addressed in this thesis and will contribute to increasing our understanding of Acheulean hominin technological strategies at Olduvai and beyond.

1.3 Thesis organisation

This thesis has combined a study of experimental and archaeological assemblages. The experimental assemblages were analysed to create a predictive model in which archaeological materials can be analysed and understood. An outline of the thesis structure is presented below.

Chapter one presents the research problem, research objectives and questions. This chapter sets out detailed overview of how the research problem was developed using evidence from numerous studies and how research questions were posed and detailed explanation on how they will be addressed. Firstly, it begins by outlining studies that have pioneered lithic raw materials studies and behaviour, followed by highlighting the gap of lacking enough research on lithic raw material procurement and behaviour at Olduvai. This is followed by an overview of previous models on studying lithics at Olduvai that were based on typological aspects (Leakey 1971). A debate on Developed Oldowan was discussed to increase our understanding of Leakeys' interpretation of Developed Oldowan and the alternative interpretation from other scholars (Leakey, 1971; Gowlett, 1979). This was followed by the current models in lithic studies that focus on the detailed analysis of lithic artefact from a technological point of view.

Chapter two provides a geological setting of this study. Firstly, it introduces the geographical location of Olduvai Gorge, its geology, stratigraphy, and ecological settings. It also introduces and defines the Acheulean industrial complex and its origins. This is followed by an explanation of the Acheulean technology and different sites where the Acheulean is documented. This is followed by an introduction of the Acheulean maker, *Homo erectus*, and research on the Acheulean at Olduvai. The latter half of this chapter presents and discusses various theoretical aspects of studying technological organisation ranging from studies on raw material economy, distance decay model, tool curation, expedience, toolkit design and mobility patterns, *chaîne opératoire*, and mobility thinking.

Chapter three provides a thorough description of the materials and methods used in this study, both on the experimental sample and archaeological assemblages. This is followed by methods applied to the lithic technological analysis conducted in this thesis. The final parts of this chapter discuss different lithic categories and technological attributes that have been used to provide a detailed analysis of the stone artefacts.

Chapter four sets out the actualistic studies used in this thesis. This study was designed to provide a better understanding of the lithic analyses from Olduvai sites. It analysed experimental materials manufactured using Olduvai lithic raw materials in order to provide predictive answers that can help to better understand Olduvai lithic assemblages. It involves a comprehensive analysis of experimental sample that is then compared with Olduvai published data on Oldowan and Acheulean technological behaviour. Thus, the actualistic studies have provided a predictive model that can be compared to the archaeological assemblages in chapter nine in order to investigate and understand hominin technological behaviour at Olduvai.

Chapter five presents and discusses raw material economy of the Acheulean hominins at Olduvai Gorge. First, it provides a background to raw materials studies from different researchers who have focused on understanding various aspects relevant to the raw materials and technological organisation. This is followed by a detailed description of lithic raw materials found at Olduvai, and then by a presentation of lithic raw material procurement strategies at Olduvai and analysis of Olduvai raw material sample collected during fieldwork. This is followed by a presentation of the results of the analysis of the sample, and how raw material studies have contributed to our

understanding of lithic technology and hominin behaviour. Finally, a detailed discussion and conclusion is presented.

Chapters six, seven, and eight present a comprehensive first-hand analysis of three Acheulean sites (FC East, JK West, JK2 and WK site) which yielded four lithic assemblages from Olduvai Gorge. From each site, a sample of lithic artefacts was selected, and a detailed technological analysis was conducted. The major goal was that each chapter provides comprehensive archaeological data that can be used to address the overarching research question.

Chapter nine compares experimental and archaeological data. It compares results from the analysis of experimental materials with the archaeological materials, both published and unpublished archaeological data. Thus, it is divided into two parts: Part I presents comparisons of experimental data and published archaeological data from HWKEE and EF-HR; Part II compares experimental data with that of analysed archaeological materials from FC East, JK West, JK2 and WK site assemblages. This chapter provides a holistic view on how experimental materials can help in better understanding of archaeological materials.

Chapter ten provides a comparative analysis between archaeological assemblages analysed in chapter six, seven, and eight. This in-depth comparative analysis of assemblages from different Acheulean sites provides a detailed sequence of Acheulean from Beds II (FC East), III (JK West and JK2) and IV (WK site). This helps us to identify and understand the trend of technological developments of Acheulean hominins across the Olduvai sequence, hence being able to address the main research questions on technological capabilities Acheulean hominins and whether if there is stasis or technological change at Olduvai.

Chapter eleven summarizes technological strategies of hominins in Beds II, III, and IV at Olduvai. In this chapter, a detailed lithic technological organisation of each Acheulean site is presented. This is followed by results on raw material selectivity of the Acheulean hominins at Olduvai.

Chapter twelve draws conclusions of the thesis by putting together results presented in previous chapters and offer recommendation for future research on technological behaviour and raw material economy at Olduvai.

Chapter 2: Geological Setting

2.1 Overview

The first part of this chapter reviews and summarises the location of Olduvai, geological settings, history of research, main traits of the Acheulean technology, and the theoretical background followed on this study for reconstructing lithic technology and its organisation. It begins with the description of the location of the Olduvai region in which artefacts for this study were obtained. The second part describes the stratigraphic units in which sites for this study originated. This is followed by the history of research that contributed to the discovery of many archaeological sites and led to various scientific undertakings that are responsible for the discovery of prominent lithic industries such as the Oldowan and Acheulean, and a background to Acheulean research at Olduvai and relevant technological features of Acheulean tool makers in East Africa.

2.2 Geographical location of Olduvai

Olduvai Gorge is a valley located in the Serengeti plains, at the western margin of the East African Rift Valley, in northern Tanzania (Figure 2.1) (Hay, 1976; Deino, 2012). To the south and east, the gorge is bordered by the Ngorongoro volcanic highlands, and to the west and north by the Serengeti plains. The gorge slopes gently in a series of steps from west to east and towards Olbalbal, a basin located at the eastern side of the gorge. With 46 km in length East to West, the gorge is divided into two branches: the main gorge, which originates at the lakes Masek and Ndutu, and the side gorge, originating from Lemagruti, volcanic highlands in the south (Hay, 1976). The main and side gorges meet at the area named junction (Figure 2.2) (Hay, 1976). The western

part of Olduvai gorge is shallow and includes rapids and falls, known as Granite falls; the eastern part is steep-sided and can reach up to 90 m deep and about 0.5 and 1.5 km wide (Hay, 1976).

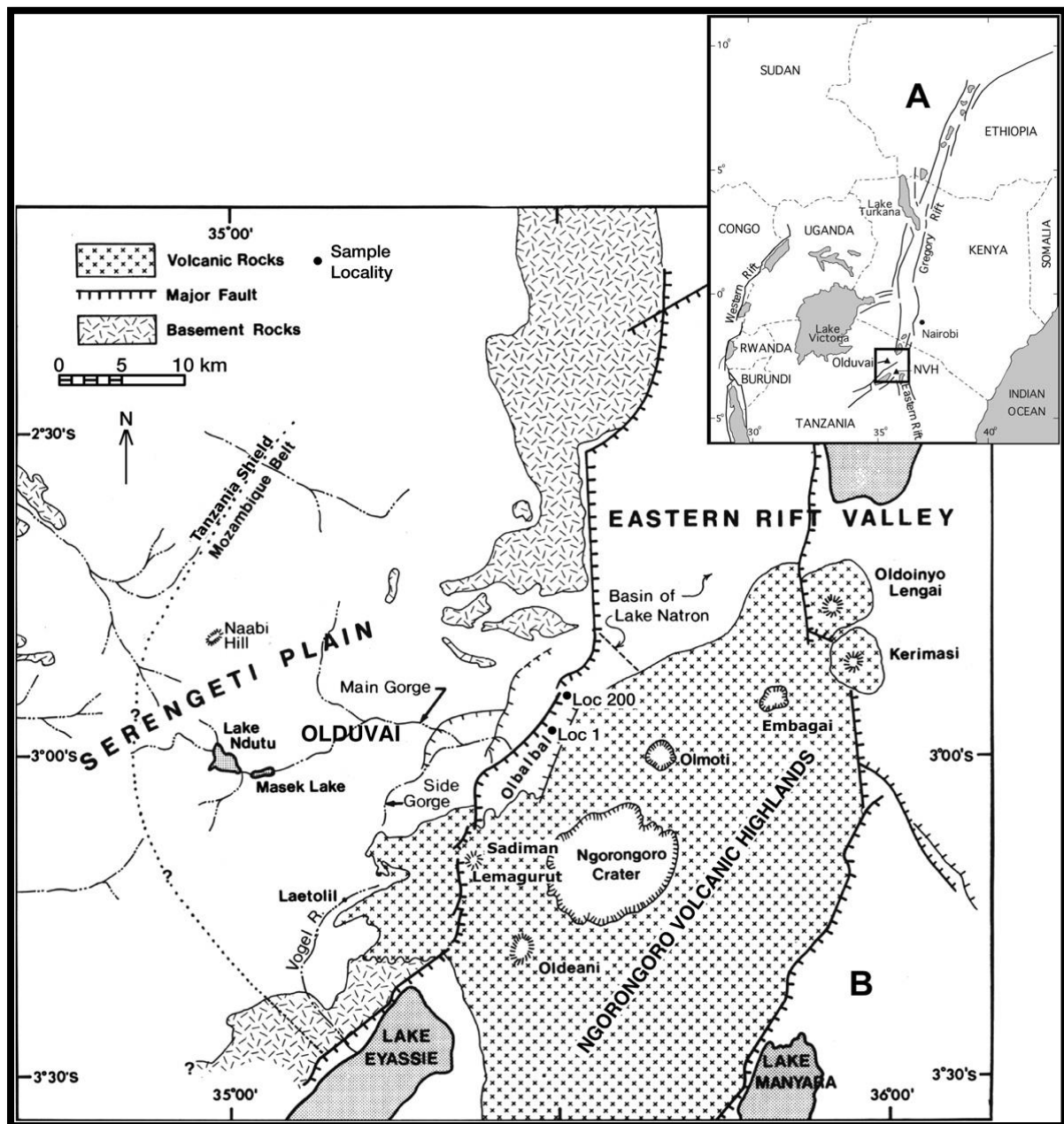


Figure 2. 1: Map showing regional location of Olduvai Gorge in Tanzania within the Rift Valley system on the Serengeti Plains. Map adapted from Hay (1976).

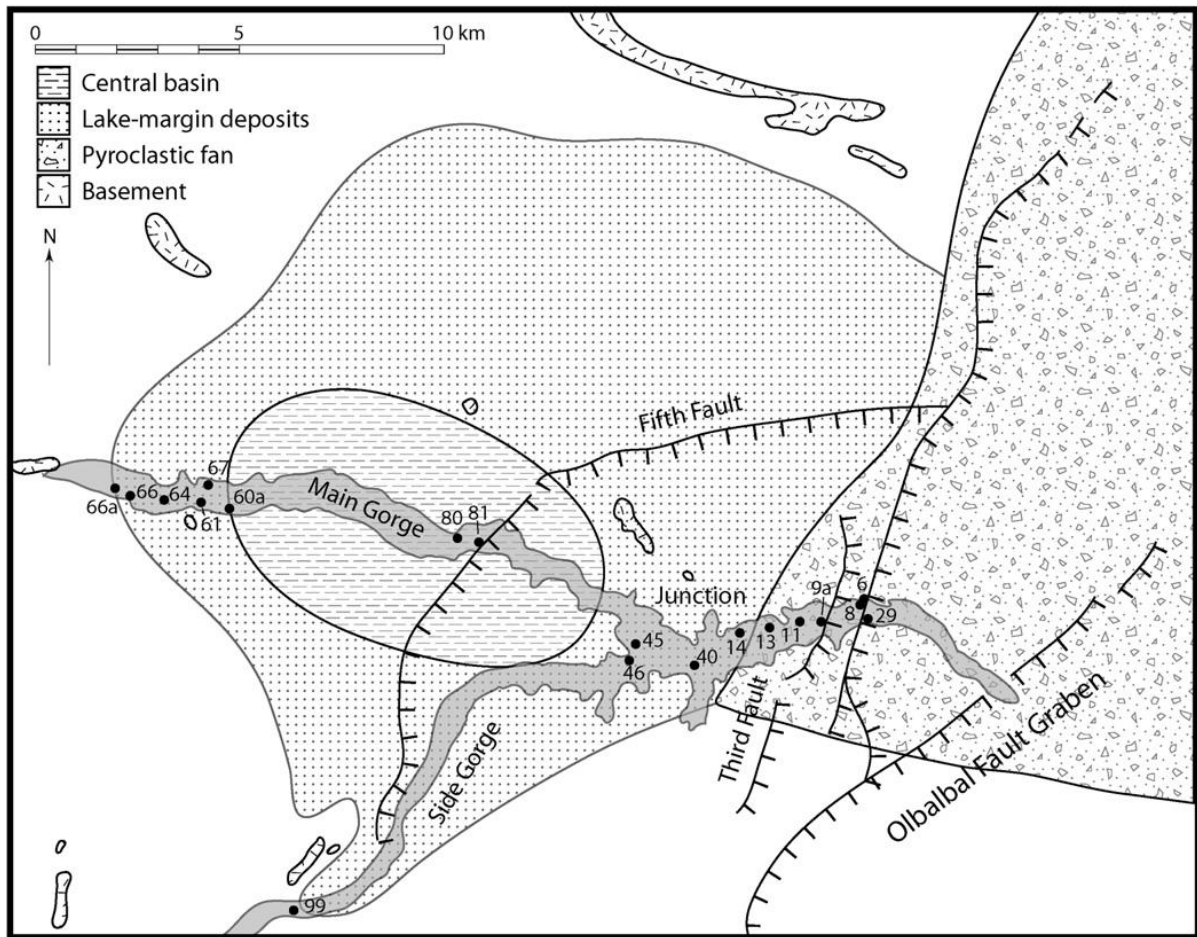


Figure 2. 2: A schematic map showing closer view of the Olduvai palaeo-basin and other features. Map adapted from Hay (1976).

2.2.1 Geological setting of Acheulean localities at Olduvai

The Olduvai geological investigation begun in 1913 when Professor Han Reck was sent to collect fossils after the discovery of the gorge by Professor Kattwinkel in 1911. Reck subdivided the Olduvai sedimentary sequence into five units, termed as *Schichtkomplexes*, which were given numbers 1-5; the term *Schichtkomplexes* was replaced by Beds (Hay, 1976).

Between 1956 and 1957, R. Pickering mapped the Olduvai region and published in a geologic map (Pickering, 1958). Further research by Richard Hay in 1969 uncovered more sedimentary units that were named Ndutu and Naisiusiu Beds (Hay, 1971; Hay,

1976). The Olduvai deposits in which cultural and palaeontological materials originate are known as the Olduvai Beds; these Beds are subdivided into seven major beds which are Beds I, II, III, IV, Masek, Ndutu and Naisiusiu (Hay, 1976). These geological beds represent the time from around 2.1 Ma to about 15000 Ka (Hay 1976).

The Olduvai geological context possesses perhaps the most detailed Plio-Pleistocene sequence in eastern Africa. The importance of this work at Olduvai Gorge was initiated by Hans Reck and developed in detail by Richard L. Hay (Hay, 1976). The geological sequence of Olduvai is well documented and a key aspect to many researchers in understanding the archaeological context and sites from which different lithic assemblages were recovered. Here this study describes the geological sequences which are thought to represent the Olduvai Acheulean deposits.

2.2.2 Stratigraphy of Beds I, II, III, and IV

River erosion and tectonic activities associated with faulting have exposed the Olduvai stratigraphy. This formation comprises of over 100 m thick deposits that were deposited on a shallow palaeobasin approximately 25 m diameter. On the southeast, the paleolake is bordered by Cenozoic rocks and north and west by metamorphic basements. The entire stratigraphy dates from about 2.1 Ma to 15 Ka; there is also Holocene sediments that dates < 10000 Ka (Hay, 1976). Although this thesis uses materials from Beds II, III, and IV, a detailed discussion of the stratigraphy of older Beds is crucial.

2.2.2.1 Bed I

Bed I is the thickest unit of all the Olduvai Beds (Fig. 2.3A). It measures about 60 m thick in the eastern side of the gorge and consists of lava deposits. In the western part,

Bed I has an exposed thickness of about 43 m, whereas the oldest deposits are found and are about 2.0 to 2.1 million years old (Hay, 1976). The Bed I is subdivided into tuffs, namely Tuff IA (1.88 ± 0.05 Ma), Tuff IB (1.848 ± 0.003 Ma), Tuff IE (1.831 ± 0.004 Ma), Ng'eju tuff (1.818 ± 0.006 Ma), and Tuff IF (1.803 ± 0.002 Ma) (McHenry 2012, Deino, 2012). Several archaeological sites are known from the eastern lake margin deposits, including the remains of *Australopithecus boisei* (OH 5) from FLK Zinj Site and *Homo habilis* (OH 7) (Leakey et al., 1961). Leakey (1971) found Oldowan cultural materials in Bed I (Leakey, 1971).

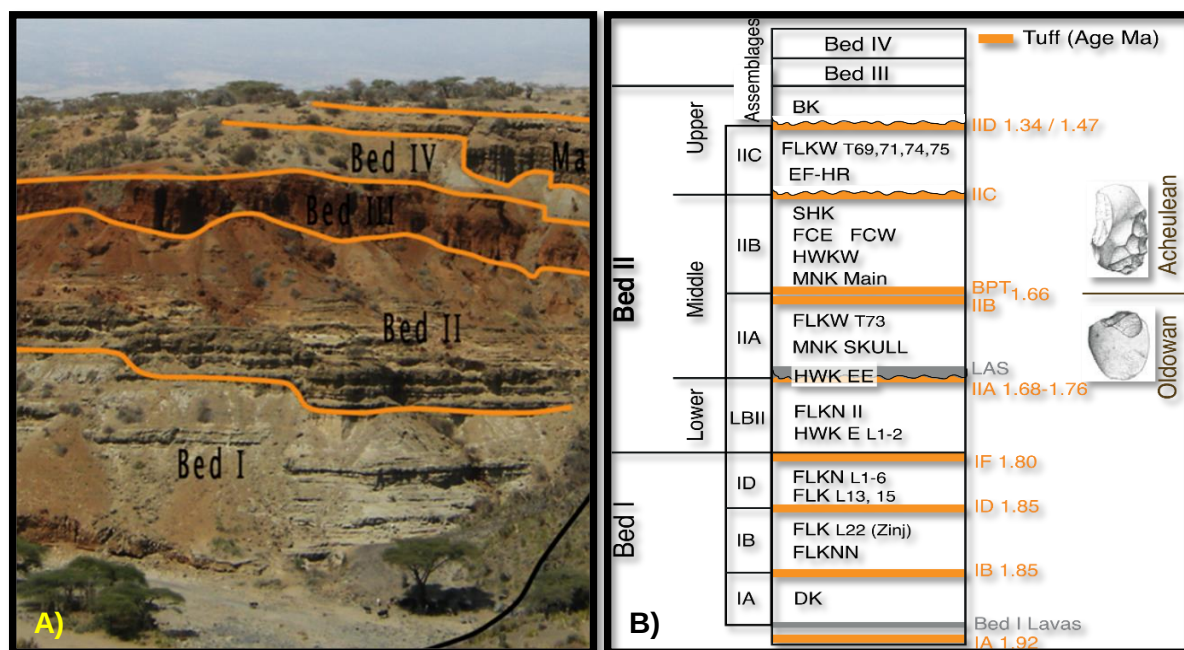


Figure 2. 3: Olduvai stratigraphy, representing Beds I-IV. Adapted from Bibi et al., (2018).

2.2.2.2 Bed II

Bed II is stratigraphically above Bed I, measuring about 30 m in thickness (Hay, 1976), and it is subdivided into tuffs IIA IIB, IIC, and IID (Figure 2.3B). Geologists regard the units between tuff IF and IIA as Lower Bed II, units between tuffs IIA and IIC as Middle Bed II, and units between tuff IIC and Lower Bed III as Upper Bed II (Figure 2.3B)

(Hay, 1976; Bibi et al., 2018). Studies employing $^{40}\text{Ar}/^{39}\text{Ar}$ method have dated Bed II deposits into the following dates: Tuff IIA about 1.66 ± 0.01 Ma, and Tuff IID to be 1.48 ± 0.05 Ma (Manega, 1993). Moreover, the Bed II deposits have numerous lithofacies and environments, whereas the lower part contains lake deposits, lake margin deposits, alluvial-fan deposits, and aeolian deposits (Hay, 1976). Bed II is important because it contains sites that yielded important technological complexes such as the Oldowan and Acheulean (Hay, 1976). The Bed II deposits span from around 1.70 to 1.15 million years old (Hay, 1976).

2.2.2.3 Beds III and IV

The Bed III is dominantly comprised of reddish-brown deposits, mainly volcanic detritus; thus, unit measures about 4.5 to 11 m in thickness. The Bed IV is principally grey or brown deposits that contain both volcanic and metamorphic detritus; it measures about 2.4 to 10 m in thickness (Hay, 1976). Hay (1976) dated Beds III at 1.15 to 0.80 Ma and Bed IV at 0.80 to 0.60 Ma; Manega (1993) dated Beds III tuffs to 1.33 ± 0.06 Ma (Manega, 1993). It is important to understand the stratigraphy of these Beds because they are relevant to the JK (Bed III) and WK sites (Bed IV) studied in this thesis. JK and WK are the main Acheulean sites in which lithic materials analysed were recovered by Leakey's team in the upper beds of Olduvai (Leakey and Roe, 1994).

2.2.3 Ecological setting of the Acheulean sites at Olduvai

The Acheulean assemblages at Olduvai occur mainly in three geological units, Beds II, III, and IV (and also in the Masek beds). Summarising the palaeoenvironment of Olduvai sequences, Hay (1976: 177) states that Olduvai Beds provide evidence of progressive and rapid, generally, short-term environmental changes during the

Quaternary time. These changes are important for understanding the environmental contexts in which hominins lived and reconstructing their ecological settings (Table 2.1).

Hay (1976) states that a relatively rapid environmental changes are exhibited at many levels in the Olduvai Beds. In addition, the Olduvai sequence shows directional trend throughout early Pleistocene from cooler/wetter, more forested ecological settings to warmer/drier and more open environments (Monahan, 1996). Monahan (1996) adds that *Homo erectus* was uniquely adapted to increasing aridification (Table 2.1).

The Beds III and IV times climate appears to have been drier than that of Bed I and II times (Table 2.1). Isotopic evidence shows that near the end of Bed II time there is a major lasting climatic change: the period from uppermost Bed II through the end of Bed IV can be considered together (Cerling and Hay, 1986).

This could indicate a warming of annual temperatures by several degrees centigrade. Carbon isotopes also change, indicating that the C4 pathway was used by 50 to 80 percent of the biomass. If only grasses were present, this could indicate mean annual temperatures ranging from 15° to 18°C based on the previously discussed altitudinal cline (Cerling and Hay, 1986: 75). The climatic change began between 1.3 and 1.17 million years ago and lasted into the Brunhes magnetic interval until about 0.62 million years ago (Cerling and Hay, 1986).

Table 2. 1: Table showing a summary of ecological changes and associated archaeological evidence.

Olduvai Bed	Ecological variables	Archaeological evidence	Associated hominins
IV	Increased aridifications Climate is drier than in Beds I and II ecology Open environments/habitats Fluvial or deltaic environment (for example, WK site).	Acheulean technology	<i>Homo erectus</i>
III	Increased aridifications Climate is drier than Beds I and II ecology Open environments/habitats Fluvial or deltaic environment (for example, JK site).	Acheulean technology	<i>Homo erectus</i>
II	Lake deposits, especially lower bed II Lake margin deposits, The environment is warmer/drier and more open environments Alluvial-fan deposits, Aeolian deposits	Early Acheulean in middle Bed II Late Oldowan technology	<i>Homo erectus</i> <i>Homo habilis</i>
I	Lake margin environment The environment is generally cooler/wetter and more forested	Oldowan technology	<i>Australopithecus boisei</i> (OH 5) <i>Homo habilis</i> (OH 7)

2.3 The Acheulean Industrial Complex

The name Acheulean derives from St. Acheul, France, where handaxe artefacts were first described in the 19th century (Evans, 1863). The term is commonly applied to Lower and Middle Pleistocene artefacts that contain large, retouched artefacts with standardised shapes. The Acheulean Industrial complex first appeared on the African continent around 1.76 million years ago and can be found as recently as 154,000 years ago (Lepre *et al.*, 2011; Beyene *et al.*, 2013; Diez-Martin *et al.*, 2015; Toth and Schick, 2019)

The Acheulean technology or Mode 2, is distributed over Africa (figure 2.4), western and southern Europe and southwest and southeast Asia (Asfaw *et al.*, 1992; Noll, 2000; Toth and Schick, 2019). Toth (2019) asserts that there are contemporaneous industries lacking the Acheulean characteristics such as “Developed Oldowan”, “Mode 1”, or “Tayacian” industries; these industries can be found at sites throughout the Acheulean geographical and temporal range, but they are especially common at archaeological sites in Eastern Europe and East Asia (Toth and Schick, 2019). The Acheulean is often linked to *Homo erectus* (Leakey, 1971; Asfaw *et al.*, 1992; Beyene *et al.*, 2013; Gallotti, 2013; Diez-Martin *et al.*, 2015; de la Torre, 2016).

2.3.1 History of the Acheulean technology and its research at Olduvai

The Acheulean technology was by far the first human technology to have spread across the continent ranging from southern Africa, eastern Africa, north Africa, middle East, Europe, and southeast Asia (Noll, 2000; de la Torre, 2016; Toth and Schick, 2019). The Acheulean technocomplex is characterised by hand-held artefacts (amygdaloidal), having been considered from “weapons of war” to handaxe biface to

large cutting tools (LCT) (de la Torre, 2016). It is also characterised by the production of cleavers, picks and large flake blanks (Ambrose, 2001; Yravedra et al., 2017).

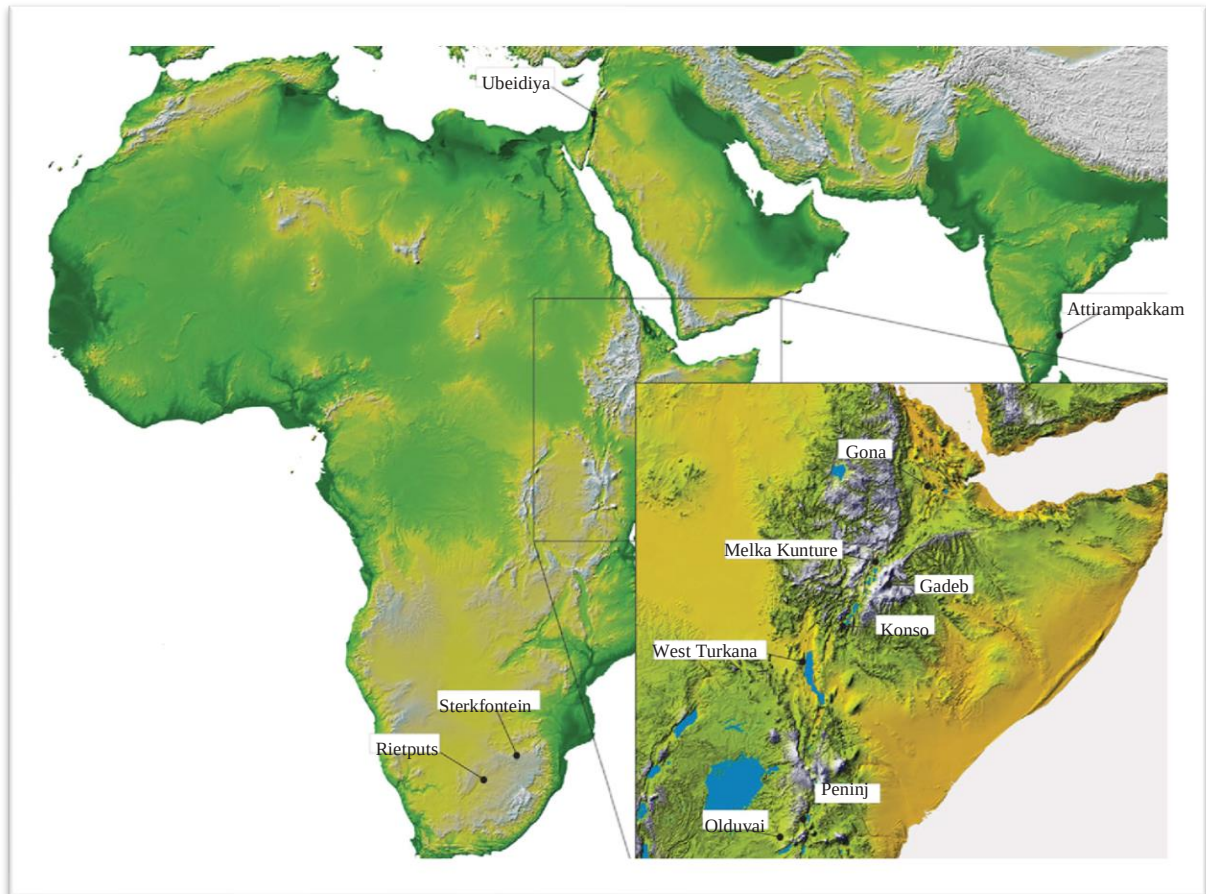


Figure 2. 4: Map showing early Acheulean sites in Africa that are older than 1.2 Myr (Adapted from de la Torre (2016)).

Palaeolithic research at Olduvai was pioneered by Louis and Mary Leakey since 1930s (Leakey, 1951), and continued throughout the 1960s and 1970s (Leakey, 1971; Leakey, 1975; Leakey and Roe, 1994), and investigations on the Olduvai Acheulean have continued until present days (de la Torre and Mora, 2005a; Mora and de La Torre, 2005; de la Torre et al., 2012; Domínguez-Rodrigo et al., 2014; Policarpo et al., 2017; Sanchez-Yustos et al., 2017; Uribe Larrea et al., 2017; de la Torre et al., 2017; de la Torre and Wehr, 2017; McHenry and de la Torre, 2018a).

An extensive research into the Acheulean at Olduvai became fruitful following the Leakeys 1960s work at Evelyn Fuchs – Hans Reck (EF-HR) site, which Leakey (1971) considered it to be the earliest Acheulean site at Olduvai, and hence it was the then world's oldest Acheulean site until the discovery of other, older sites in Kenya and Ethiopia (Lepre et al., 2011; Asfaw et al., 1992; Beyene et al., 2013).

The EF-HR assemblage, representing early Acheulean, contained 53.8 percent of bifaces, with absence of burins, awls and *outil ecaillés*. light-duty scrapers that were common in Developed Oldowan accounted 3.3 percents. Additionally, most flakes were typically handaxe flakes and exhibited attributes that were absent in Developed Oldowan series (Leakey, 1971). In addition, Leakey (1971) recovered many artefacts that enabled most researchers to conduct studies comparing Oldowan and the Acheulean technologies. Leakey (1971) interpreted the site as the living floor, a place where hominins camped and conducted their daily activities. Recent studies (de la Torre et al., 2017; de la Torre and Wehr, 2018; de La Torre and Mora, 2018c) have suggested that the site is positioned between tuff IIC and IID and date around 1.5 Ma (Stanistreet et al., 2018), and therefore younger than previously suggested.

2.3.2 The maker of the Acheulean lithic assemblages at Olduvai, *Homo erectus*

The appearance of *Homo erectus* around 1.8-1.9 million years ago marks an important turning point in human evolution (Rightmire, 1990). At roughly the same time as the appearance of *Homo erectus*, there is a significant climatic shift from humid to drier conditions at 1.70-1.76 Ma (Hay, 1976; Noll, 2000). *Homo erectus* was the first hominin species to exhibit near modern human features (Shipman and Walker, 1989). It also had near-modern limb proportions when compared to modern humans in tropical environments, indicating that it was well adapted to the Pleistocene's drier,

hotter climate and high-endurance bipedal locomotion (Noll, 2000). It is argued that *Homo erectus* spread and occupied Africa and much of Asia by at least one million years ago. Skeletal material attributed to *Homo erectus* overlaps Acheulean lithic assemblages between >1.5 and 0.5 million years ago. Acheulean assemblages in Africa, Asia, and Europe after 0.5 million years ago are frequently attributed to *Homo heidelbergensis* (also known as archaic *Homo sapiens*) (Noll, 2000).

2.4 Theoretical considerations on lithic technological organisation

The past three decades have seen a growing interest in our understanding of lithic technologies of prehistoric groups, with an increase of extensive research in lithic technologies and analyses (Inizan, 1992; de la Torre, 2004; de La Torre and Hirata, 2015; de La Torre and Mora, 2018c; de la Torre et al., 2014; Sharon et al., 2009; Gallotti, 2016; Gallotti, 2013; Gallotti and Mussi, 2017; Diez-Martín et al., 2014; Domínguez-Rodrigo et al., 2017), technological organisation (Bamforth, 1986; Nelson, 1991; Bamforth and Bleed, 1997), lithic raw material studies (Kuhn, 1991; Kuhn, 1995a; Blumenschine et al., 2008), lithic tool curation and toolkit designs (Kuhn, 1992; Shott, 1996). The existing research recognises the role played by lithic artefacts in understanding past humans technological organisation (Nelson, 1991; Kuhn, 1991; Kuhn, 1995b; Kuhn, 1995a; Kuhn, 1992; Andrefsky, 1994; Shott, 1986; Binford, 1979; Bamforth, 1991).

This study reviews this body of lithic technological organisation associated with stone tool analysis and raw material economy. Specifically, this review attempts to incorporate various technological organisation aspects into a wider framework for our understanding of hominin behaviour from the procurement of raw material, tool manufacture, maintenance/recycling, and discard of stone tools. Generally, these

variables are considered as part of technological organisation (Shott, 1986; Andrefsky, 2009). It should be noted that studies that intersect with lithic technological organisation are linked with hunter-gatherer communities; present and past hunter-gatherers have helped researchers to understand human engagement with landscapes and how the environment influenced hunter-gatherer behaviour and their technological efficiency (Binford and Binford, 1966; Binford, 1978; Binford, 1979; Binford, 1985; Bamforth, 1985; Bamforth, 1986). In these studies, aspects such as curation and maintenance were established, and played a crucial role in understanding technologies of prehistoric groups. Several lines of evidence suggest that curation and maintenance were linked with raw material shortage (Bamforth, 1986), whilst Binford (1979) explains that curation is linked with efficiency and can be measured with utility resulting from tools.

2.4.1 General background on the study of technological organisation

The literature on the organisation of technology studies is diverse. It deals with varied theoretical and practical aspects of hominin land-use, mobility strategies, raw material procurement, stone tool production, artefact functional studies (Toth, 1985; Toth, 1987; Kuhn, 1991; Nelson, 1991; Andrefsky, 1994; Brantingham, 2003; Goldman-Neuman and Hovers, 2012), and also linking human adaptations with paleoenvironmental variables (Brantingham and Kuhn, 2001; Amick and Mauldin, 1997; Stiles, 1991; Hardy et al., 2001; McCall, 2007; Kelly, 1983).

The organisation of technology refers to “the selection and integration of strategies for making, using, transporting, and discarding tools and the materials needed for their manufacture and maintenance” (Nelson, 1991: 57). It also refers to “the manner in which human toolmakers and users organise their lives and activities with regard to

lithic technology” (Andrefsky, 2009: 66). The organisation of technology combines different aspects that determine how toolmakers obtained raw materials for making tools and how they curated and discarded their products. Different environmental conditions such as resource distribution, predictability, periodicity, and mobility influence the organisation of technology (Bamforth, 1986; Kelly and Todd, 1988). Nelson (1991) argues that technological plans are responsive to conditions of resource availability and economic and social strategies, and distinguishes two major strategies for the technological organisation, namely curation and expedience, to which opportunistic behaviour is added as a third strategy.

Curation includes activities such as transport, reshaping, and storage of tools for future use. Also, it involves the transport of cores or tools to different places to perform certain tasks. Expediency, however, involves stockpiling of material for future use, time availability for tool manufacture, and prolonged occupation of a site to gain advantage of piled materials (Nelson, 1991). Although Binford (1979) characterises expedient tools as situational gear, in which they were used in response to certain conditions, Andrefsky (1994) argues that expedient technology is wasteful regarding the use of lithic raw material; it mainly produces simpler tools than formal (curated) patterns of shapes or designs. Much uncertainty still exists about the relationship between curation and expedient technologies with regards to their association with raw material economy.

2.4.2 Raw material economy

Lithic technological organisation and raw material economy have been discussed with regards to procurement strategies by the stone toolmakers (Stiles, 1991; Kuhn, 1991; Jones, 1979; Andrefsky, 1994). Several researchers have been studying the effects

of raw materials availability to stone tool making and technology (Andrefsky, 1994; Kuhn, 1991; Stout et al., 2005; Blumenschine et al., 2008).

Lithic raw material distribution and availability are certainly important to aid our understanding of how hominins procured, manufactured, and used stone tools in the past. Since raw material sources can often be located, they can help in understanding how raw materials sources got to sites and how hominins might have transported raw materials or stone tools across the landscape (Andrefsky, 2009). Because of this, we can use raw material sources to understand how the availability of rocks affected their lithic technology.

Kuhn (1995a) explains that the cost of obtaining raw material for stone tool manufacture depends on the natural distribution of raw material sources, the mobility of the human groups, and labour investment in foraging groups. Aspects such as natural distribution and mobility of prehistoric groups provide information on our understanding of lithic raw material economy and reduction intensity of stone tools.

Reduction intensity is influenced by raw material availability, residential mobility, differential transport of artifacts, duration of occupation events, and tool function (Kuhn, 1991). Kuhn (1991) evaluates the degree to which these factors affect reduction of core in a Mousterian site in Italy. Kuhn discusses the distance between sites and sources of raw materials against the variations to which cores were utilised and reduction of tools (Kuhn 1991). In doing so, he found that differential transport caused the variation in reduction stages within the assemblage. Additionally, reduction of cores and tools show that not all artefacts within an assemblage responded to transportation costs of raw materials. Hence, core reduction should be linked to geological characteristics of a certain location. Therefore, it is expected that distance

from sources of raw materials and sites should have effects on both core reduction and strategies for making flakes. In essence, this emphasises the significance of raw material economy on stone tool manufacture and reduction techniques.

Andrefsky (1994) explains how raw material influences the manufacturing of formal (curated) versus informal (expedient) tools. Formal tools undergo additional effort such as resharpening, hafting and so on (for example, bifaces, prepared cores, retouched flakes). Informal tools undergo less effort in production, and they tend to be discarded over a short period of time. Additionally, formal tools are often associated with mobile groups and informal tools to sedentary groups (Andrefsky, 1994).

Andrefsky (1994) found that lithic production technology may not necessarily be attributed to settlement patterns. The availability of good quality and poor quality did not necessarily affect the use of formal or informal tools, and some groups use formal and informal tools similarly, and this happened when locally abundant and high-quality raw materials were available. These results suggest that lithic raw material availability and quality are important in understanding lithic technology, but each case study should be studied thoroughly, and all aspects should be considered before drawing conclusions.

Raw material selectivity and proximity also has been discussed as an important aspect in the technological organisation and the degree to which stone tools are reduced (Stout et al., 2005; Goldman-Neuman and Hovers, 2012; Andrefsky, 2009). Stout et al. (2005) compared artefact assemblage from Oldowan sites in Gona, Afar, Ethiopia, with natural cobbles randomly collected from similar sources to those used by hominins. In doing so, they studied six Pliocene archaeological sites by analysing rock types, rock phenocrysts, size of phenocryst, and groundmass texture to understand

hominid choices of raw materials for stone tool production. Their results demonstrate that raw material selectivity was important in the technological organisation of even the earliest stone toolmakers.

Studies on more recent assemblages are also important for the scope of this thesis; Andrefsky (2008) studied Great Basin forager residence, which had abundance of lithic raw materials. In his work, he found that hafted bifaces were discarded once damaged, especially when toolmakers were within the proximity of two days away from their local residence. Sometimes, they resharpened hafted bifaces and used them as knives. This clearly suggests that stone tool makers considered a variety of aspects before discarding or reusing tools. More importantly, the toolmakers considered the distance from the original source of raw materials and their location at a particular time.

Reaching similar conclusions while investigating raw material selectivity, transport behaviour, and land-use patterns of Oldowan sites in the Makaamitalu Basin, Hadar, Ethiopia, Goldman-Neuman and Hovers (2012) demonstrated an increased raw material selectivity and transport behaviour of hominins around 2.3 Ma. Their work also contributes an understanding of hominins technological decision-making activities.

2.4.3 Distance- decay model and land use pattern

Distance from raw material sources has a clear effect on the organisation of lithic technology (Blumenschine and Masao, 1991; Stout et al., 2005; Stiles, 1991; Blumenschine et al., 2008; Andrefsky, 1994). The distance-decay model, borrowed from economic geography, predicts that if the distance from the source of raw materials for stone artifacts increases, the cores and flakes made from that raw

material tend to be highly reduced in size and they occur in low quantities (Blumenschine et al., 2008).

In a study investigating the efficiency of stone tools and curation, distance had an important effect in the retouching processes (Bamforth, 1986), with stone tools from distant sources being retouched frequently. In other words, tools manufactured from raw material available from distant indicate resharpening and reuse because of scarcity of raw material for making new tools. Blumenschine et al., (2008) provide an evaluation of the effects of distance to raw material sources in Oldowan assemblages from lowermost bed II eastern Olduvai Gorge. The results show that there is a decrease in weight density with increasing distance from the raw material sources.

This study uses the distance-decay model to understand reduction intensity of Acheulean stone tools and hominins land-use at Olduvai. This is accomplished by measuring the size of stone tools, the weight of pieces, several scars on pieces, and relate the distance from sites where the assemblages came from with the distance from raw materials sources.

2.4.4 Tool curation

Binford (1979) distinguished curated and expedient technologies among the Nunamiut groups of Alaska. Curation includes effective tools for various tasks, made and maintained for future use, transported from site to site, and recycled for other uses. Bamforth (1986a) reassessed Binford (1979)'s curation concept and reported that two aspects of curation, maintenance, and recycling. These aspects are related to availability of raw material because maintenance and recycling of a worn tool tend to be of lower cost if the raw material source is nearby.

Considering these curation aspects, this study will address the Acheulean tools maintenance from the tool curation perspective. Since these aspects are related to raw material accessibility, it investigates if curation occurs due to raw material scarcity or because of various patterns of behaviour that can be influenced by different conditions, such as mobility and toolkit designs.

2.4.5 Expediency

The organisation of technology involves how stone toolmakers and users organised lives and activities with regards to the lithic technology (Nelson, 1991). The organisation of technology combines different aspects that determine how toolmakers obtained raw materials for making tools and how they curated and discarded their products. Different environmental conditions such as resource distribution, predictability, periodicity, and mobility, influence the organisation of technology (Bamforth, 1986; Kelly and Todd, 1988).

In lithic analysis, most analysts have contrasted “curated tools” and “expedient tools” (Bamforth, 1986; Andrefsky, 2008). Nelson (1991) categorised three (tripartite) categorisations of technological strategies where she added opportunistic behaviour, which she contrasted with expediency. Nelson (1991) notes that the tripartite categorisation of technological strategies varies from common distinction, whereas curation as planned and expediency as situational; opportunistic behaviour being included in expediency.

Andrefsky (2008: 8) asserts "Curated" tools were frequently identified as having extensive retouch, whereas "expedient" tools were identified as having very little retouch. He adds that curated tools were often associated with foragers whereas expedient tools were associated with collectors. However, this is not a realistic

relationship; the arrangement of stone tools is influenced by many other factors such as raw materials, shape, and functional considerations (Bamforth, 1991; Andrefsky, 2008). Since this strategy is associated with lithic technological organisations, this research investigates if expediency strategy occurs in the analysed lithic assemblages and establish how this technique influenced hominin technological strategies and behaviour.

2.4.6 Toolkit designs and mobility patterns

Design, as defined by Nelson (1991: 66), “refers to conceptual variables of utility that condition the forms of tools and the composition of toolkits”. Mobile toolkits are intended to reduce transport cost and ensure that the artifacts within the mobile toolkit are durable and multifunctional (Kuhn, 1994). Kuhn (1994) defines mobile toolkit as the artifacts that are always kept by mobile individuals; these are implements that are under continuous transport. Binford (1979) describes them as personal gear. Nevertheless, a transported artefact is not necessarily part of a mobile toolkit. Tool users tend to transport artifacts and raw materials to most visited sites for future use (Kuhn, 1994).

Mobility patterns are recognised as an integral part of the technological organisation (Andrefsky, 2009). There are several factors that constrain the composition of a mobile toolkit. Mobile toolkit’s greatest limitation is portability or transport cost (Kuhn, 1994). Nelson (1991) argues that transportable design occurs when the toolkit is transported to the site for use other than being manufactured at the site. Additionally, the toolkit must be small (in size and number), lightweight and resistant to breakage (Nelson, 1991). This study uses Nelson’s aspects of mobile toolkit to establish an understanding of *Homo erectus* toolkit at Olduvai.

2.4.7 Chaîne opératoire

The concept of operational chain or *chaîne opératoire* was developed by the work of Andre Leroi-Gourhan in the 1940s (Leroi-Gourhan, Bostock and White, 1993; Ludwig, 1999; Shott, 2003; Bar-Yosef and Van Peer, 2009). Sellet (1993: 106) states that *chaîne opératoire* “aims to describe and understand all cultural transformations that a specific raw material had to go through. It is a chronological segmentation of actions and mental processes required in the manufacture of an artifact and in its maintenance into the technical system of a prehistoric group. The initial stage of the chain is raw material procurement, and the final stage is the discard of the artifact”. Thus, the *chaîne opératoire* divulges the processes of stone tool production stages from idea of making a stone tool, to procurement of raw material, artefact manufacture, maintenance, up to its placement in the archaeological context (Sellet, 1993; Odell, 2001). Odell (2001: 81) connects the concept to Schiffer's behavioural archaeology, which considers objects in their systemic contexts from procurement to disposal and beyond. It practically denotes the application of kinetics to cores in order to produce ideal forms (templates) and the tools and debris that result, all of which are determined by arbitrary cultural norms (Shott, 2003). Thus, this study uses the concept of *chaîne opératoire* to understand reduction sequence of different Acheulean sites at Olduvai, and hence reconstruct hominin technological strategies.

2.4.8 Mobility thinking

In 1990s, mobility became central in many Palaeolithic lithic technology studies (Kuhn, 2020). A significant inspiration came from a series of influential papers that synthesised evidence about mobility among recent hunter-gatherers (Binford, 1980; Kelly, 1983). Several models were proposed to explain how the movement of groups

or individuals can influence the designs and life histories of artifacts, as well as how assemblages form (Shott, 1986; Kelly and Todd, 1988; Nelson, 1991; Kuhn, 1992). Artefacts deposited at a site not only tell us about what happened there, but also about what happened elsewhere in the landscape (Kuhn, 2020). In light of the mobility, artefact features, and assemblage could provide information about land use, foraging, group size, and other behavioural elements of people in the remote past.

More recently, most Palaeolithic archaeologists have incorporated the concept of 'mobility thinking' as a fundamental part of research on palaeolithic hominin and hunter-gatherers (Kuhn, 2020). Kuhn (2020) adds that the incorporation of 'mobility thinking' in Palaeolithic studies has provided significant insight into the understanding of behaviour of Palaeolithic hominins. Kuhn (2020) suggests that mobility can show how it resolves key questions in human evolution issues; he discusses three areas of focus that can help in answering larger scientific questions. These include: (1) territories and ranging patterns; (2) (re)construction of social networks; and (3) intra-group variation in landscape use (Kuhn, 2020). This thesis focuses on questions that arise from behavioural perspectives of *Homo erectus*. The research adopts mobility thinking because it is suitable understanding how movement of groups or individuals influenced raw material economy, land use, and the organisation of technology among Acheulean *Homo erectus* at Olduvai Gorge.

The next chapter presents the materials and methods used in this study. It explains how the experimental and archaeological materials will be analysed and interpreted in order to address the research questions.

Chapter 3: Materials and methods

3.1 Methods

This thesis uses both experimental and archaeological materials. The archaeological materials include original lithic artefacts from Beds II, III, and IV excavated by M.D. Leakey, M.R. Kleindienst, and the OGAP team in the 1960s-70s and 2014, respectively (Table 3.1) (Leakey, 1971; Leakey and Roe, 1994). The archaeological materials will be analysed from a technological perspective and will aid in addressing the research questions (see chapter 6, 7, 8, and 9). The experimental materials (see chapter 4) are experimental artefact samples made from Olduvai raw materials that serve as models for understanding and interpreting archaeological assemblages. This chapter focuses solely on the archaeological materials analysed and methods used in the analyses.

Table 3. 1: A table showing the Olduvai sites studied in this PhD Thesis.

Site	Stratigraphic unit	Age (Ma)	Year Analysed	Sample	Technology
WK	Bed IV	0.80 to 0.60	2022	200	Acheulean
JK West	Bed III	1.15 to 0.80	2019 + 2020	475	Acheulean
JK2	Bed III	1.15 to 0.80	2020	1237	Acheulean
FC-East	Middle Bed II	1.66 ± 0.01	2018 + 2019	599	Early Acheulean

3.2 Archaeological sample (FC East, JK West, JK2, and WK site)

Leakey (1971) reports on excavation from several sites in Beds I and II. Within these Beds, Leakey (1971) presents DK (lower Bed I), FLK NN (Middle Bed I), FLK Zinj (Middle Bed I), FLK North (Upper Bed I), HWK East (Lower Bed II), MNK (Middle Bed II), FC West and FC (Middle Bed II), TK and BK (Upper Bed II) (Leakey, 1971; Hay, 1976; de la Torre and Mora, 2005c; Domínguez-Rodrigo et al., 2009; de la Torre and

Mora, 2018a). Leakeys' discoveries sparked various research projects that focused on understanding hominins' activities across the landscape (Blumenshine and Masao, 1991), hominin tool-using techniques (Kimura, 1999), and systematic study of lithic materials from the technological standpoint (de la Torre and Mora, 2005a).

In 1971, M.D. Leakey argued that Olduvai Gorge Developed Oldowan and Acheulean co-existed, particularly in Beds II and IV (Leakey, 1971; Gowlett, 1988). However, Stiles (1979) disputed Leakey's argument and suggested that the assemblages belong to the Acheulean industrial complex (Stiles, 1979; Gowlett, 1988). This complex discussion arises because M.D. Leakey classified assemblages belonging to Lower Bed II as Developed Oldowan A (DOA); DOA consists of a little bit of bifacial working on stone tools. Also, Middle and Upper Bed II's assemblages were classed as Developed Oldowan B (DOB), which M. D. Leakey regarded as the continuation of the DOA, and Bed IV assemblages classed as Developed Oldowan C (DOC) (see table 3.2) (Leakey, 1971; Leakey, 1975; Dave, 1980). DOB, however, contains a small number of bifaces (Leakey, 1971; Leakey, 1975; Gowlett, 1988). Stiles (1979) examined assemblages from DOB and Acheulean sites and concluded that the bifaces from the two groups were not as separable as Leakey proposed, they belonged to Acheulean but the differences may have occurred due to different raw materials used (Stiles, 1979; Gowlett, 1988).

Dave (1980) opposed Stile (1979)'s conclusion and argued his recommendation was premature on the theoretical grounds; he insisted on considering the frequency composition of assemblages in Bed II (Dave, 1980).

Table 3. 2: Table showing the Developed Oldowan Sites (Adapted from Davis 1980).

Bed	Industry	Occurrence
Upper II (1.2 m.y.a)	Developed Oldowan B2	BK TK Upper TK Lower
	Developed Oldowan B1	SHK FC West MNK Main (2-5) FLKN Conglomerate
Middle II (1.4 m.y.a)	Developed Oldowan A	HWKE 3/5 MNK Skull
Lower II (1.6 m.y.a)	Oldowan Developed Oldowan A	HWKE-2
	Oldowan	HWKE-1
Upper I (1.8 m.y.a)	Oldowan	FLKNN-2/1 FLKN-3 FLKN-4 FLKN-5 Zinjanthropus Floor DK

Nevertheless, the overall aim of this thesis is to examine *Homo erectus* technological behaviour. Thus, it was decided that it is crucial to study lithic assemblages that can provide vivid evidence of these hominins' early technology and its development across the Olduvai sequence (Table 3.3). Therefore, a full technological analysis of lithic samples from FC East, JK West, JK2, and WK site was undertaken. To understand the hominin transport of raw material to the site, the weight of flake fragments from certain samples was also undertaken. The FC East assemblage studied originated from level 80; JK assemblage from JK grey sand and ferruginous sand levels, WK assemblage from WK main channel. All these sites were selected to provide relevant information towards the accomplishment of the research goals.

Table 3. 3: Table showing Leakeys' original sample and selected sample for this study.

Leakey Category		Leakeys' original sample		This study	Selected sample	
		n	%		n	%
WK	Wholeflake	405	8.4	Flake	103	51.5
	Broken flakes	4357	90.3	Flake fragment	10	5
	Cores	4	0.1	Core	41	20.5
	Scrapers, light-duty	57	1.2	Retouched piece	46	23
	Total	4823	100.0	Total	200	100
JK2	Flake	919	56.8	Flake	641	53.0
	Flake fragment	0	0.0	Flake Fragment	122	10.1
	Core	247	15.3	Core	190	15.7
	Retouched piece	452	27.9	Retouched tool	256	21.2
	Total	1618	100.0	Total	1209	100.0
JK West	Tools	81	2.3	Flake	202	43
	Utilised piece	81	2.3	Flake Fragment	83	17
	Debitage	3341	95.4	Core	88	19
	N/A	0	0.0	Retouched tool	102	21
	Total	3503	100.0	Total	475	100
FC East	Flake	279	17.8	Flake	240	40.1
	Flake Fragment	1191	75.8	Flake Fragment	318	53.1
	Core	101	6.4	Core	41	6.8
	N/A	0	0.0	Retouched tool	0	0.0
	Total	1571	100.0	Total	599	100.0

FC is one of the earliest Acheulean sites, and as such it helps in providing evidence of some of the earliest *Homo erectus* technologies which are crucial to understanding their behaviour. JK West, JK2, and WK are some of the classic Acheulean sites that have not been studied in detail since Kleindienst (1973) and Leakey and Roe (1994)'s publications. Thus, it was deemed reasonable to conduct a full technological analysis of each tool category from these sites (i.e cores, flakes, and retouched tools). Regarding FC East, a detailed study of its assemblage, focusing on its techno-economic aspects is provided in chapter six of this thesis, followed by JK West and JK2 in chapter seven, and WK in chapter eight.

3.3 Methods

3.4 Lithic technological analysis

During the Leakeys' time, most stone tool materials were analysed based on a typological approach which did not rely on understanding technological aspects of manufacturing stone tools (Leakey, 1971; Leakey and Roe, 1994). However, subsequent researchers began to incorporate new technological approaches in lithic analyses (Toth, 1982; Toth, 1985; de la Torre and Mora, 2005c; de la Torre, 2011). Since technological approach relies on understanding technological aspects during stone tools manufacture, it was thought reasonable to use this approach to reconstruct hominins technical processes during stone tool production.

Therefore, a full lithic technological analysis was employed to all lithic assemblages, both experimental and archaeological assemblages (following Toth's and de la Torre's methodologies) (Toth, 1982; de la Torre and Mora, 2005a; de la Torre, 2011). A lithic technological analysis approach seeks to extract as much information as possible. In particular, stone artefacts are identified, described and analysed based on various

technological steps undertaken by the toolmakers. This helps us to fully understand the techniques used during the manufacture of lithic artefacts.

3.5 Database structure

All experimental and archaeological data were recorded into a database. An excel database template was used for the analysis. An individual excel file was created for each site's assemblage, and each site had corresponding details which could allow all databases to be merged into one large database. Hence, it allowed an easy analysis of each technological attribute, sorting of data entered and sharing the excel file with other statistical packages such as SPSS for further analyses. A separate file for the experimental sample was designed for the analysis of the experimental assemblages. Both experimental and archaeological databases have similar templates that allow data to be combined smoothly. Thus, various technological attributes recorded from both samples could be analysed simultaneously.

3.6 Techno-economic approach

This study employs the techno-economic approach, which is based on the organisation of the stone tool technology as proposed by Binford (1979) and expanded by Nelson (1991) (Binford, 1979; Nelson, 1991). Nelson (1991) defines the organisation of technology as the study that involves the selection and incorporation of procedures for producing, using, transporting and discarding stone tools and the raw materials required for their production and maintenance. The technological organisation concept is combined with ideas presented by Kuhn (1991), who explored the causes of variations in the stone tool assemblages by looking at different factors that affected the reduction intensity of stone artefacts (Kuhn, 1991). These are raw material availability, residential mobility patterns, different ways used in

the transportation of artefacts, kinds of activities that tools might have been used for, and duration of occupation events. Thus, this study uses Kuhn (1991)'s and Nelson (1991)'s perspectives to learn about the organisation of technology and reduction intensity of the Acheulean technology in Olduvai's context.

3.7 Taphonomic attributes

Taphonomy is an important component in palaeolithic archaeology and plays a key role in understanding hominin behaviour using artefacts. Many researchers have utilised taphonomic attributes to measure taphonomic changes that had occurred on lithic artefacts after the deposition (Isaac, 1967; Binford, 1980; Schiffer, 1983). Researchers conduct taphonomic analysis by using different proxies such as artefact features, topographic information, and orientation patterns (de la Torre and Wehr, 2018).

Taphonomic studies are relevant to assemblage analysis and site interpretation because of a number of reasons; firstly, they enable us to assess the effects of various natural agents on an assemblage. This approach aids an understanding of natural agents such as fluvial actions on assemblages (de la Torre and Wehr, 2018). Secondly, they help archaeologists to understand and recognise the “dichotomy between living floors’ and palimpsests” (Malinsky-Buller et al 2011: 89).

In the past few decades, taphonomic attributes have played a crucial role in assessing post-depositional disturbances (Schick, 1984; de la Torre, Benito-Calvo and Proffitt, 2018). Thus, an analysis of taphonomic changes on lithic artefacts can provide an understanding of various modifications that might have occurred to a tool; for example, artefact rounding, size, and weight (Petraglia and Potts, 1994; de la Torre, Benito-Calvo and Proffitt, 2018). Hence, taphonomic analyses are important because they

help in recognising artefacts' origin when recovered (i.e., primary or secondary context).

3.8 Pseudoretouch

This occurs naturally on the edges of artefacts, and are caused by post-depositional processes such as animal trampling, sediment pressure, etc. Stone tools with pseudoretouch attribute show some modifications on their edges and do not indicate the intentional modification.

During analysis, artefacts with pseudoretouch were marked **YES** and those with none as **NO**. The identification of pseudoretouch is crucial in this study because it helps to distinguish intentional versus unintentional modification of artefacts. Hence, during statistical analysis, the results will help to determine the frequency of artefacts with pseudoretouch versus artefacts with no pseudoretouch.

3.9 Roundness

This feature was assessed macroscopically by looking at the rounding on edges of a stone tool. Thus, the degree of measurements consisted of rounding: R1 – this means no rounding on the edge of artefacts, the edges are fresh; R2 – this is when artefact edge exhibit light damages; R3 – this is when the edges of an artefact are rounded; R4 – this is when edges of artefacts are heavily rounded. Rounding helps in understanding whether an artefact has been transported by water or any other agent or it was found in its primary position.

3.10 Patina

According to Inizan et al (1999) patina is the natural change of the external part of an object after intentional knapping (Inizan, Féblot-Augustins and Cercle de Recherches

et d'Etude, 1999, p.: 147). Patina can help to understand to what extent an artefact has been exposed on the surface. During analysis, the patina was recorded as present or absent.

3.11 Description of technological groups for this study

3.11.1 Introduction

This thesis' sampling focused on cores and flakes. These categories are frequently overlooked by researchers who prefer to focus on handaxes. Martin-Ramos (2022), for example, analysed the same assemblages as this study, but focused precisely on handaxes.

3.11.2 Flaked pieces

These are stone artifacts that show flake scars from removed flakes. They consist of cores, core fragments, retouched pieces, shaped tools, and large cutting tools (LCT) (Table 3.4). The quantitative measurements include the maximum length (mm), width (mm), thickness (mm), weight (g), cortex percentage, number of platforms, and number of flake scars.

3.11.3 Core attributes

3.11.3.1 Core blank

Core blanks help the analyst in identifying the raw material sources from which the rock originated. Different core blanks were identified during analysis: cobble, block, flake and indeterminate blanks. Core blanks were identified by examining the morphology of the cortical parts of the core, for example, a rounded cortical surface indicated cobble, a flat and blocky surface indicated block blanks.

3.11.3.2 Core cortex coverage

Cortex is a natural surface on a cobble, block, or a nodule of unmodified raw material; it is also termed as an external part of a block of raw material, which in geology is termed as patina (Inizan et al., 1999). At Olduvai, different raw material types contain varied cortex characteristics. Lava cobbles have rounded heavily worn cortex, which is smooth from rolling on riverbeds. It is different from its counterpart, non-cortical surface which is usually rough and uneven.

The cortex of quartzite or quartz is extremely difficult to identify as it does not contain characteristics like those on lava cobbles; quartzite blocks cortex is cloudier compared to the non-cortical surface which is normally brighter. Chert cortex is usually chalky and sometimes more yellowish if heavily weathered.

Cortex coverage was approximately recorded to indicate discrete percentage of cortex coverage on an artefact. In this study, cortex coverage was measured by examining the level of cortex coverage and estimated to percentages as follows:

- Non-cortical: no cortex preserved on an artefact (0% cortex)
- Cortical: fully cortical, for example on a butt or dorsal surface (100% cortex)
- Non-cortical dominant (Ncd-c) over cortical. This means less than half of the butt is covered by cortex (<50% cortex)
- Cortical dominant (Cd-Nc) over non-cortical. This means more than half of the butt is covered by cortex (>50% cortex)

Table 3. 4: Table showing terminologies of East African artefact categories developed by previous researchers and those used in this study.

This Study	Noll (2000)	Isaac & Harris (1997)	Toth (1982)	M.D Leakey (1971)
Flaked pieces	Flaked pieces	Flaked pieces	Cores/Retouched	Tools
Cores	Choppers	Choppers	Choppers	Choppers
Retouched pieces	Polyhedrons	Polyhedrons	Polyhedrons	Polyhedrons
	Discoids	Discoids	Discoids	Discoids
	Scrapers, core	Scrapers, core	Scrapers, core	Scrapers
	Scrapers, flake	Scrapers, flake	Scrapers, flake	Protobifaces
	Unifacial	Others & miscellaneous	Picks and handaxes	Burins/Awls
	Bifacial	Acheulean forms		Outils ecaillés
	Multifacial			Laterally trimmed
	Bipolar			Bifaces (handaxes and cleaver)
	Large cutting tools			
	Other & miscellaneous			
	Core fragments			
Detached pieces	Detached pieces	Detached pieces	Flakes/Fragments	Debitage
Flakes	Whole flakes	Whole flakes	Whole flakes	Unmodified flakes
Flake fragments	Flake fragments	Broken flakes	Flake fragments	Other fragments
	Angular waste	Angular fragments	Other fragments	
		Core fragments		

3.11.3.3 Core flake scar

These were the scars from previous flake removals on core surfaces. The maximum lengths and widths measurements were recorded to estimate flake sizes and the number of flakes per core. Many flake scars on the core are usually used as proxies for determining the reduction intensity of a core (Braun et al., 2005). Ripple marks on flake scars were used to identify the directionality of a detached flake (Rajendran, 1977). During the analysis, the length and width of flake scars were measured with a digital calliper to compare them with the maximum lengths and widths of actual flakes in the assemblage.

3.11.3.4 Core reduction intensity

This involves the extent to which the core has been reduced by the toolmaker (Kuhn, 1991). Reduction intensity is measured by the amount of cortex found on core. All core samples from the archaeological assemblages were analysed and cortex and scars were used to determine the level of reduction intensity.

Reduction intensity has been instrumental in our understanding of hominin stone tool manufacture and behaviour. Understanding reduction intensity is therefore a vital component of understanding hominins' early lithic technologies and behaviour at Olduvai and requires that we identify various components for assessing reduction for stone tool materials, particularly cores.

While reduction intensity can be presented for cores, flakes and retouched tools, this subsection determines the extent to which cores were reduced in different levels over time. Previous research has established that reduction intensity can be determined using different factors such as raw material size and proximity influence core reduction

technology (Andrefsky, 2005). Andrefsky (2005) argues that to understand fully the processes of stone tool production, it is important to include detached pieces such as flakes in the analysis; detached pieces such as flakes help in identifying and approximating the reduction process as well as measuring the intensity of flaking on-site (Noll, 2000).

This study uses both detached and flaked pieces to understand the reduction process at Olduvai. It must be noted that the reduction intensity of cores was measured by using a number of flake scars, weight, and cortex coverage on a core. The number of flake scars can be compared with the number of flakes within the detached assemblage and hence help us to have an overall understanding of the reduction sequence.

3.11.3.5 Core knapping accidents

Knapping accidents are particularly useful in understanding knapper's skills and ability to withstand accidents that occur during the knapping process (Ludwig, 1999; Hovers, 2009; Delagnes and Roche, 2005). Hovers (2009) explains that knapper's skills are expressed through the integration of motor ability and perception, technological background as well as dynamic processes of making decision and action; due to this complex activity, flaking accidents are inevitable (Hovers, 2009: 137). Delagnes and Roche (2005) add that hinged removals on abandoned cores suggest that the knapper's persistence in attempting to exploit the core. In this study, identification of knapping accidents helped to better understand knappers skills, the ability to choose certain natural angles, and manual dexterity during knapping activities. Within cores, step fractures were identified as common knapping accidents that occurred during stone tool manufacture.

3.11.3.6 Core flake scar count

During core analysis, a number of flake scars were counted to determine the level of reduction intensity of different assemblages. Only large flake scars were counted to have clear counts that could be correlated with the number of flakes within the assemblages. During analysis, the scar counts were clustered into different extraction ranges as follows:

- 1-3 scars
- 4-6 scars
- 7-9 scars
- >9 scars

Each of these scar count range meant a certain level of reduction intensity; for example, 1-3 scars meant low reduction intensity while 7-9 scar and >9 scars meant high reduction intensity. At this stage, a core may have little or no cortex on its surface.

3.11.3.7 Core flake scar dimensions

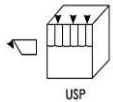
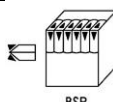
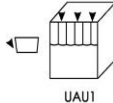
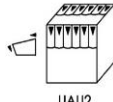
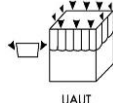
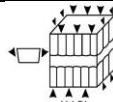
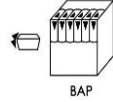
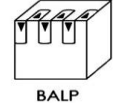
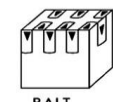
To understand the number of complete flakes extracted from a core, flake scar dimensions were recorded. The conventional length of a standard flake is 20mm, and therefore the maximum lengths of flake scars and widths were measured. The length was measured from the impact point to the distal end of the flake scar, and width was measured orthogonal to length. This was undertaken to be compared with the flake assemblages' dimensions.

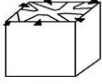
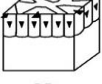
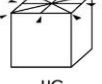
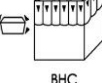
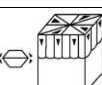
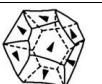
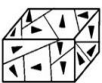
3.11.3.8 Core exploitation strategy

When a core was exploited, hominins used different techniques that led to the reduction of the core; these techniques are known as core exploitation strategies. The core exploitation strategies can be grouped based on different variables such as scar angles, location, and directionality of flaking (de la Torre et al., 2003; Proffitt, 2016). Researchers have set out different exploitation strategies that help lithic analysts to understand prehistoric stone tools reduction processes (table 3.5) (de la Torre et al., 2003; de la Torre and Mora, 2005c). These strategies provide information on the understanding of different complexities involved in core exploitation and cultural variation within assemblages (Proffitt, 2016).

While other researchers have analysed cores by using attributes such as directionality of flaking and unifacial or bifacial characters, de la Torre et al (2003: 211) proposed and developed a more advanced way of analysing cores in which the authors considered a core as “geometric volume” in which flaking of the core is viewed in different interactions such as unifacial, bifacial, trifacial, and multifacial systems (table 3.5). Additionally, the directionality of flaking determines different directions such as unipolar, bipolar and centripetal flaking techniques. Moreover, the angle in which different knapping surfaces intersect can be defined as either a simple or abrupt angle (de la Torre et al., 2003). All these strategies help the lithic analyst to record and document hominins’ core exploitation strategies at Olduvai Acheulean sites. Table 3.5 shows an example of the schematic diagrams, which depict details of core exploitation strategies.

Table 3. 5: Schematic diagrams showing descriptions of core exploitation strategies used in this thesis (adapted from de la Torre et al., 2003; de la Torre and Mora, 2005c; de la Torre, 2011).

Diagram	Description (de la Torre et al., 2003; de la Torre and Mora, 2005c; de la Torre, 2011)
 USP	USP: Unifacial simple partial exploitation. Flaking is unidirectional and restricted to one plane, from a natural striking platform, and the angle between the striking platform and the knapping surface is simple ($<45^\circ$). Classic choppers fall into this category. USP2 Flaking is unidirectional and limited to one plane, originating from a natural striking platform, with a 45-degree angle between the striking platform and the flaking surface. Despite the presence of two knapping surfaces, there is no interaction between their striking platforms and flaking surfaces.
 BSP	BSP: Bifacial simple partial exploitation. Flaking is unidirectional but in two adjacent surfaces, separated by a simple-angled bifacial edge. Chopping tools or bifacial choppers (Leakey, 1971) fall into this category.
 UAU1	UAU1: Unidirectional abrupt unifacial exploitation on one knapping surface: Flaking is unidirectional and limited to one surface, and the angle between the striking platform and the knapping surface is abrupt ($>45^\circ$). Many of Leakey's (1971) heavy-duty scrapers fall into this category.
 UAU2	UAU2: Unidirectional abrupt unifacial exploitation on two independent knapping surfaces: although there are two exploitation planes, there is no interaction between their respective striking platforms and knapping surfaces. Flaking is unidirectional, and the angle between the striking platform and the knapping surface is abrupt.
 UAUT	UAUT: Unifacial abrupt unidirectional total exploitation. There is only one striking platform, an abrupt angle of interaction between the striking and knapping surfaces, and flaking takes place all over transversal and sagittal planes of the core.
 UABI	UABI: Unifacial abrupt bidirectional exploitation: Two opposed striking platforms are used to flake the same knapping surface, but there is no exchange between the striking and the knapping surfaces (hence unifacial).
 BAP	BAP: bifacial abrupt partial exploitation. Flaking takes place in two adjacent surfaces separated by an abrupt angle, and the volume is exploited partially (i.e., some planes remain unworked). Some of Leakey's (1971) heavy-duty scrapers fall into this category.
 BALP	BALP: bifacial alternating partial exploitation. Two adjacent surfaces are partially knapped by means of alternate flaking, using scars on the knapping surface of one plane as the striking platform for obtaining flakes on the other plane.
 BALT	BALT: bifacial alternating total exploitation. The whole circumference of the core is exploited following the same bifacial alternating strategy as in the previous method.

 UP	UP: Unifacial peripheral exploitation. The horizontal plane is exploited unifacially through the rotation of the transversal and sagittal planes, but extractions do not meet in the centre of the volume and reduction is limited to the edge of the core
 BP	BP: bifacial peripheral. Exploitation concentrates on the horizontal plane but there are two interactive surfaces, with the transversal and sagittal planes sometimes acting as preparation striking platforms for extractions on the horizontal plane.
 UC	UC: Unifacial centripetal exploitation. The horizontal plane is exploited unifacially through the rotation of the transversal and sagittal planes, and extractions are radial and usually meet towards the centre of the knapping surface, facilitating the reduction of the volume.
 BHC	BHC: Bifacial hierarchical centripetal. An intersection plane divides the core into two asymmetrical and hierarchized volumes. Transversal and sagittal planes act as a subordinated volume (preparation surface) to obtain flakes in the main exploitation surface (see full discussion of this method and its implications in de la Torre, 2009).
 DISCOID	Discoid: this method, widely known in the Middle Palaeolithic literature (see Boëda, 1993; Peresani, 2003), is similar to the BHC, except for the unclear hierarchization of surfaces and the systematic alternating of strikes on the bifacial edge.
 POLYHEDRAL	Polyhedral: cores with three or more knapping surfaces, which become spherical, whether intentional (Texier and Roche, 1995) or the unplanned result of continued reduction sequences (Schick and Toth, 1994).
 MULTIFACIAL	Multifacial: cores with three or more knapping surfaces which show no clear organization of flaking but the irregular use of any available flaking angles.

3.11.4 Metrics and weights

All lithic artefacts dimensions were measured in millimetres (mm). The length was measured based on the maximum length of the artefact, width as the maximum width of the artefact, and thickness as the maximum thickness of the artefact. Weight was measured in milligrams (mg) by using digital scales; during analysis, the mg was converted into grams. Thus, statistical results are presented in grams.

3.11.5 Detached pieces

These include flakes, flake fragments, and debris that have been detached from flaked pieces (Table 3.4). The quantitative measurements include the maximum length (mm),

width (mm), thickness (mm), weight (g), cortex coverage, and number of extractions on the dorsal face.

3.11.5.1 Flake attributes

The following section presents the inferences of flake attributes for understanding the behavioural implication of flake assemblages. Although some flake attributes are descriptive, most have relevant technological and behavioural implications. Below is the list of flake attributes used in this study:

- Flake blank
- Flake impact point morphology
- Flake cortex coverage
- Dorsal face
- Flake striking platform facet
- Flake knapping accident
- Toth types

3.11.5.2 Flake blank

This can be described as the original raw material which was knapped to obtain a flake; it can be a cobble, block or flake. Flake blanks inform of the source of raw material used by the knapper. For example, at Olduvai lava cobbles originate from riverbeds and quartzite blocks originate from outcrops or hillslopes.

3.11.5.3 Flake impact point morphology

This is the exact point at which hammerstone blow hit to detach a flake. The impact point, located on the knapping platform, allows lithic analysts to understand motions

employed during lithic production. It also helps to determine knappers' manual dexterity by identifying their abilities to place hammerstone blows unmistakably and detach a flake. In this study, the impact point was recorded as centred non-faceted (Cnf), centred unifaceted (Cuf), centred bifaceted (Cbf) decentred non-faceted (Dnf), decentred unifaceted (Duf), and decentred bifaceted (Dbf).

3.11.5.4 Flake cortex coverage

Flake cortex coverage is also an important attribute that provides technological information. During the analysis of the flake, the corticality was examined on both the striking platform and dorsal face of the flake. Corticality in the flakes informs on the level of reduction intensity (de la Torre and Mora, 2005b). During the analysis, flake cortex coverage was recorded as Non-cortical (0% cortex), cortical (100% cortex), non-cortical dominant over cortical (<50% cortex), and cortical dominant over non-cortical (>50% cortex).

3.11.5.5 Dorsal face

This includes analysis of the exterior part of a flake. Identification of cortex coverage, number of extractions and scar directions were undertaken. The analysis of dorsal face morphology provides information about the impact points of flake scars, number of detaches flakes, cortex coverage, which is crucial in understanding reduction stages, and traces of platform preparation on the butt (Inizan et al., 1999). Dorsal face on archaeological flakes were analysed to understand different reduction processes.

3.11.5.6 Flake striking platform facet

The striking platform is also known as the flake butt. The butt preserves the impact point and is associated with different facets; platform facets show the extent to which

the platform was shaped, and it can be presented as non-faceted (cortical butt), unifaceted (single scar platform), bifaceted (two scars on the platform), and multifaceted (more than two scars on the platform). These platform facets normally have distinct morphologies; these are such as rectilinear (RT), convex (CX), concave (CC), uni-angular (UA/dihedral), sinuous (SIN/irregular), and others (OTH).

The flake striking platform facets can help in the understanding of knappers skills such as core preparation to detach a flake. This involved the analysis of butt, particularly the impact point's morphology; also, the amount of cortex on the butt, number of facets, and type of platform to understand type of hammer used during knapping. Similarly, the amount of cortex on the platform helps to determine the reduction stages. For example, a full cortical (100%) or cortical dominant (>50%) platform indicate early stages of reduction, whereas a non-cortical dominant (<50%) or non-cortical (0%) platform indicate later stages in the reduction process. This attribute has been used in archaeological assemblage analysis to determine whether flakes were detached at which stage of production.

3.11.5.7 Flake knapping accidents

The flake knapping accident is another important attribute that contributes to our understanding of lithic technology. These accidents may occur either due to the technical expertise of the craftsmen and poor quality of raw material (de la Torre and Mora, 2005b; Hovers, 2009). Knapping accidents can inform on the knowledge of hominins in selecting good raw materials; for example, at the DK site, flake assemblages show few knapping accidents because DK hominids were knowledgeable of the mechanical properties of rocks, in which they avoided vesicular lavas and selected good quality raw materials for knapping activities (de la Torre and

Mora, 2005b). Different knapping accidents occur during flake production; these are plunging (produced due to an excessive force which removes part of the at the distal end of the flake), silet – also described as a split fracture, step and hinge flakes – the sudden terminations that look similar and occur when little force has been applied; step scars these are not considered as accidents on flakes but provide technological information on the accidents that had occurred during knapping activities.

3.11.5.8 Toth's flake types

Toth (1982) developed a flake classification for examining flake cortical surfaces. This system determines the degree and distribution of cortex on flake's platforms and dorsal faces. This classification helps in understanding the initial forms of raw materials used by hominins, approximate the level of reduction sequence, and identify the intensity of flaking activities at a site (Toth, 1982). Toth (1982) described six flake types (I-VI) which were classified according to the amount of cortex on dorsal surfaces and platform. Specifically, Toth (1982, 1985) suggests that a set of cores produce an expected set of flake types in an assemblage; each type of a whole flake documents a certain stage of flaking. Type I, contains cortical platform and dorsal face; Type II, cortical platform and partially cortical dorsal face; Type III, cortical platform and non-cortical dorsal face; Type IV, non-cortical platform and cortical dorsal face; Type V, non-cortical platform and partially cortical dorsal face, and Type VI non-cortical platform and dorsal face; it represents late stages of reduction sequence (Toth, 1982; Toth, 1985). Moreover, Toth's flake category is useful in comparing experimental and archaeological assemblage. Also, it helps to understand hominin transport behaviours when examining presence of cortex on dorsal face of a flake, and on the platform of a flake (Figure 3.1).

Toth's classification has been widely used by many palaeolithic archaeologists to (1) measure the intensity of flaking at a site, (2) determine initial raw material forms, and (3) assess the point in the reduction process (Toth, 1982; Toth, 1985; Toth, 1987; Noll, 2000; Tactikos, 2005).

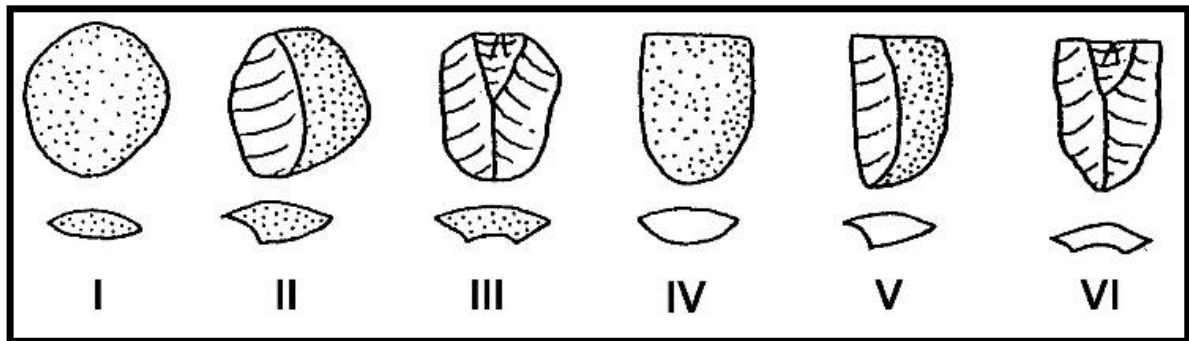


Figure 3. 1: Illustration of Toth's flake types (Adapted from Toth 1982, 1985).

3.11.6 Flake attributes discussion

Flake metrics help to understand core size, while the cortex on the dorsal face helps to understand reduction intensity. Dorsal flake scar count helps to understand how many previous flakes were detached and hence gives a deeper understanding of the reduction sequence. Moreover, the impact point on a flake's platform allows a better understanding of the knapper's skill, particularly the ability to control blows on a core using hammerstone. The striking platform morphology can inform on the type of percussion used, for example, 1. the platform is associated with hard hammer percussion; 2. The linear platform being associated with soft hammer percussion, and 3. punctiform platforms being related to pressure flaking. However, most of the flake analysed indicated mostly platform types; linear and punctiform platforms are not common during this period.

3.11.7 Retouched pieces attributes

Retouched tools are flakes that have been modified by one or several retouches; these may include scrapers, backed knives, awls, points, and so forth (Shea, 2013). The retouch process can occur on one side of an artefact (unifacial retouch) or two sides (bifacial retouch) (Shea, 2013). Shea (2013) explains that the most prevalent retouch is unifacial retouch whereby shaping occurs mostly on the dorsal face of a flake. And if the retouch occurs on the ventral face, it is known as “inverse retouch” (Shea, 2013).

Several techniques have been developed to analyse retouched tools from palaeolithic sites. A major advantage of these techniques is that they help to understand how prehistoric stone artefacts were retouched or reworked. Since most retouched tools are shaped from a flake blank, the analytical attributes for the retouched tools will be the same as the flake attributes as follows:

- Retouched pieces blank
- Retouched tool dimensions eg weight, length, widths, thickness
- Retouched pieces edge length
- Retouched pieces patination
- Retouched pieces roundness
- Retouched pieces knapping accident
- Retouched pieces striking platform cortex
- Retouched pieces striking platform facets
- Retouched pieces striking platform type
- Retouch pieces type

3.11.7.1 Retouched pieces blank

This is the original blank that was modified to obtain a retouched artefact. In most cases, a blank for retouched tools is a flake (Shea, 2013).

3.11.7.2 Retouched pieces dimensions

Dimensions can be categorised into length, width, thickness, and weight. Dimensions attributes inform on the size of a flake blank detached from a core and hence enables us to estimate core sizes; dimensions also enable us to estimate the total weight of raw material transported to sites. In this study, lengths were subdivided into several classes (e.g. 20-39 mm, 40-59 mm, 60-79 mm, 80-99 mm); widths followed similar subgroups as lengths. Thickness, however, followed a slightly different classification (<10 mm, 10-19 mm, 20-29 mm, 30-39 mm). This classification enabled the analyst to collect as much information as possible from the retouched artefacts.

Weight was classified into different grams (e.g. 1-9 g, 10-19 g, 20-29 g, 30-39 g, 40-49 g), for artefacts such as flakes, flake fragment and retouched pieces; core weight was classified as follows: <50 g, 50-100 g, 101-200 g, 201-400 g, 401-800 g, and >800 g. In the traditional system of analysis, weight attribute is important in understanding the amount of efforts hominins invested in bringing raw materials to the knapping sites. The more the weight available represents the amount of work in terms of hours, days, or years invested in fetching raw materials to a site. Also, the weight attribute can be analysed based on raw material types and hence enables us to understand what raw material types hominins sacrificed time and energy to bring to their sites. Thus, we may have a deeper understanding of raw material preference at a site.

3.11.7.3 Retouched pieces edge length

Generally, edge length provides information on the cutting-edge length of an artefact. During the analysis of retouched artefacts, the cutting-edge lengths were measured using a tape measure (in mm). Edge length on retouched tools is particularly informative in measuring retouched edges that were meant for use. The edge length of retouched tools contributes to the overall cutting edges produced at the studied sites.

3.11.7.4 Retouched pieces patination

So far, all studied retouched artefacts were subjected to a patination analysis. The reasons for this analysis are because the majority of the artefacts were exposed to different environments that may have altered their original conditions. The degree of patination may suggest that the artefacts were exposed before becoming part of the archaeological record (Proffitt, 2016). Basalt, quartzite, chert, phonolite, and trachyte patinate in different degrees. Chert material from MNK-CFS is the most easily patinated rock type (Ludwig, 1999). The analysis of the patina is also very important because it helps to understand if a flake was reworked after it has been exposed for some time. This can be identified when finding retouch scars show the removal of the patina on an artefact (Andrefsky, 2005). In this study, patination was recorded as follows: 1 – for pieces that exhibited the presence of patina on one side and 2 for pieces that exhibited double patina.

3.11.7.5 Retouched pieces roundness

Roundness can be regarded as the degree of bluntness identified on lithic edges; it is classified into four stages which are fresh/unabraded, slightly rounded, medium, and

severe (de la Torre and Wehr, 2017). Rounding on lithic edges can be caused by water action and chemical diagenesis (Ludwig, 1999; de la Torre and Wehr, 2018). Thus, rounding informs us of the understanding of water and chemical actions that may have occurred on artefacts after being discarded. In this study, rounding was recorded as R1, fresh/unabraded, R2, slightly rounded, R3, medium and R4, severely rounded.

3.11.7.6 Retouched pieces knapping accidents

The presence of knapping accidents on retouched tools indicated accidents occurred during knapping activities. Knapping accidents inform us of the knappers skills in overcoming accidents and the quality (e.g. good quality of chert, phonolite and some basalts) of raw material used during artefact production (Ludwig, 1999; de la Torre and Mora, 2005b; Hovers, 2009; Proffitt, 2016). Knapping accidents occur in split fractures, step terminations, and silet (split flakes). In this study, knapping accidents were recorded following the above knapping accident types or none for retouched pieces with no recorded knapping accidents.

3.11.7.7 Retouched pieces striking platform cortex

Cortex coverage is generally classified into two types: cortex on the dorsal side of a flake/blank and cortex on a striking platform. The latter is the focus of this subsection. The striking platform cortex of retouched tools informs on original Toth's flake types before being retouched. During the analysis, the striking platform cortex was recorded as follows: non-cortical (0% cortex), cortical (100% cortex), non-cortical dominant over cortical (<50% cortex), and cortical dominant over non-cortical (>50% cortex).

3.11.7.8 Retouched pieces striking platform facets

As recorded in flakes, the retouched pieces striking platforms contain facets that show how the platform was shaped. The striking platform facets were recorded as follows: non-faceted, unifaceted, bifaceted, and multifaceted. A detailed description can be found on the flake attributes section.

3.11.7.9 Retouched pieces striking platform type

During knapping activities, prehistoric knappers produced different striking platform types which were associated with different hammers. Therefore, striking platform types inform us of the type of hammer/hammerstone employed. In this study, the following knapping platforms were recorded: platform, associated with hard hammer percussion; linear, associated with soft hammer percussion; and punctiform, associated with pressure flaking.

3.11.7.10 Retouched type

Retouched types can be categorised into denticulates, scraper, and notch. The flake blank can be shaped into different angles to produce different retouched artefacts; for example, when a flake is unifacially retouched to form very sharp edges ($>70^\circ$), it is known as a “scraper retouch”; a unifacially retouched flake with a steep edge angle $>70^\circ$, is called backed retouch. Notching occurs when a flake is unifacially retouched and creating a single big concavity on a flake’s edge. Denticulation is formed by a series of small concavities on an edge. Moreover, composite retouched tools are artefacts with a combination of more of these retouched tools (for example, burin-awl, denticulate-notch) (Shea, 2013). In this study, retouched tool types were recorded following the classification above.

3.12 Fieldwork method

Fieldwork observation is one of the most common procedures employed in archaeological research. This method is particularly useful in understanding the natural environment where artefacts originate. In this study, fieldwork was undertaken through a systematic survey of the major raw material sources to collect samples of rocks that were analysed for comparison with archaeological assemblages from FC East, JK West, JK2, and WK site.

3.12.1 Raw material survey

A systematic survey of the major raw material sources was undertaken in February 2020. During fieldwork, a survey of the sources of major lithics raw materials (Naibor Soit, Engelosin, Kelogi, and local stream channels), was undertaken to measure the distance between these sources and sites and map the location of raw material sources to understand how raw material distance affected the reduction intensity during stone toolmaking (Figure 5.4). Moreover, random samples of rocks were collected from sources near the sites' surrounding areas and the actual sources for further raw material analysis.

3.12.2 The geological sample

Sites included in this study (FC East, JK West, JK2, and WK) were associated with conglomerate that contained the pene-contemporaneous materials from river drainage originated from the volcanic highlands. These conglomerates were named RMS1 (Bed II) and RMS2 (Bed III/IV) (figure 5.3; both lie stratigraphically within the same horizon as the sites studied. Random geological samples (n = 200) of different raw materials and dimensions were collected from sources nearby each archaeological site (table

5.1). The cobbles samples represent a range of raw material availability for the sites studied. These sampling points were chosen in order to monitor raw materials availability for each site, and each sources provided 100 cobbles of appropriate size that were collected from particular section of conglomerate (Figure 5.5).

3.13 Raw material analysis

The Olduvai lithic raw materials in Beds II, III, and IV of Olduvai Gorge sites are represented by various raw materials groups which are volcanic, metamorphic and sedimentary rocks (Hay, 1976; McHenry and de la Torre, 2018a), namely quartzite, basalt, phonolite, gneiss, chert, trachyte, and andesite (Hay, 1976; McHenry et al., 2016; McHenry and de la Torre, 2018a). All these raw materials were utilised by hominins in manufacturing stone tools and originate from various localities across the gorge. The quartzite rocks come from Naibor Soit, about 2km from the confluence of the main and side gorges; the lava originate from the volcanic highlands to the southern part of the gorge; and the chert from Mary Nikol Korongo Chert factory site (MNK-CFS) (Hay, 1976; Stiles, Hay and O'Neil, 1974; Kimura, 1999; Kyara, 1999).

Raw material analysis informs upon the types of rocks preferred by hominins during stone tool production process. Also, they provide quantitative and qualitative data that can be used to understand the level of technological skills of the hominins represented in the archaeological record.

A detailed study on the raw materials and sources is discussed in chapter 5 of this study. McHenry and de la Torre (2018) conducted a systematic analysis of these raw materials (lava, chert, and quartzite) and produced a comprehensive dataset that can be used as a referential framework for the studies of Olduvai raw materials. During my

first-hand study of the archaeological assemblages, I used this dataset to identify and understand various raw materials groups and rock types employed by hominins.

3.14 Analysis of geological samples

Recent studies have employed different methods in measuring different qualities of raw materials used by hominins to manufacture stone tools (Noll, 2000; Stout et al., 2005; Braun et al., 2008; Goldman-Neuman and Hovers, 2012; McHenry and de la Torre, 2018). Some used geochemical and material engineering methods (Noll, 2000; Braun et al., 2008), others used experimental work to understand decision-making processes by the prehistoric flintknappers (Harmand, 2009; Goldman-Neuman and Hovers, 2012), and others used hand lenses and quantitative analyses to study the rock properties (Stout et al., 2005), and determine raw material qualities. This study follows the approach employed by Stout *et al* (2005) and Goldman-Neuman and Hovers (2012), focusing on rock type, groundmass texture, sphericity (cobble angularity), vesicularity, phenocryst size and metrics (maximum length, width, thickness) and weight measurements. These variables are relevant to ancient toolmakers because they could be conducted in the field without the use of sophisticated methods (Stout et al., 2005; Goldman-Neuman and Hovers, 2012).

3.14.1 Rock type

The cobble samples collected during the 2020 field season enabled the identification of three major volcanic rock types: basalt, phonolite, and trachyte. These samples were identified based on the mineral appearance using a hand lens and the macroscopic classification scheme developed by McHenry and de la Torre (2018). An analyst quantifies the relative frequencies of the samples and classifies the rocks using the above classification scheme. A sample of conglomerate cobbles was examined

and compared to archaeological samples (see chapter 5). It should be noted that no petrological analysis was performed for the purposes of this study; only a field identification was performed.

3.14.2 Groundmass

Groundmass is an important factor that can influence raw material quality (Stout et al., 2005). Although the majority of the geological samples collected from RMS1 and RMS2 have fine-grained groundmass, some of the cobbles have coarse-grained and very coarse-grained groundmass. In this study, samples were classified as fine-grained, extra-fine-grained, coarse-grained, and extra-coarse-grained.

3.14.3 Shape of raw material

Goldman-Neuman and Hovers (2012) state that angular or sub-angular cobbles or nodules bear natural facets that can be converted into striking platforms. Thus, the initial process of selecting a cobble with a shape as per the technological plans simplify the knapping process of stone tools. During the Oldowan times, nodules with angular facets may have been advantageous because they facilitated the flake removal process and the initiation of knapping process. In this study, cobble shapes were categorised into four morphological categories: angular cobble, elongated disk, rounded disk, and sub-spheroid.

3.14.4 Metrics

A metric comparison of geological samples and archaeological artifacts was performed to investigate the effects of cobble size on the selection process. According to Goldman-Neuman and Hovers (2012: 356), cobble sizes differed depending on lithology, which would be reflected in the artefact size distribution. The clasts from the

conglomerate resemble the archaeological cobbles prior to the initiation of lithic reduction, whereas detached pieces are products removed from the clasts and, by default, are smaller than the source cobbles. In this study, the size (maximum length, width, and thickness) and weight of the cobbles and archaeological artefacts were recorded variables.

3.14.5 Vesicularity

Rock quality is important in determining fracture and easier control of knapping process. Rocks that are isotropic, elastic and brittle are regarded as high-quality raw material because they fracture predictably and are easier to control during knapping process (Andrefsky, 1994; Goldman-Neuman and Hovers, 2012). Macroscopic traits on rocks can be observed visually; these are such as phenocryst coverage or banding. Also, some other traits can be evaluated by testing cobbles (Goldman-Neuman and Hovers, 2012).

In this study, rock quality was measured on the basis of permutation of phenocryst size and abundance together with the vesicles abundances within the studied datasets. The quality categories were ranked on a scale from fine, coarse, very coarse and vesicular. McHenry and de la Torre (2018)'s classification scheme has helped in ranking these categories, and data results are presented in chapter 5. It should be noted that only a visual inspection of the variables was undertaken by using a hand-lens; no petrological analysis of the materials was conducted. Thus, this allowed a better understanding of the characteristics of raw materials that were potential for knapping qualities that were preferentially selected by hominins. Therefore, fieldwork surveys provided data for comparison of the archaeological and geological materials

that helped in demonstrating the raw material preferences of the Acheulean toolmakers at Olduvai.

This chapter has presented and discussed the materials and methods used in this thesis. The theoretical approaches discussed in this chapter set the ground for the interpretation of data in chapters 6, 7, and 8. The next chapter presents the experimental studies that guide the interpretations of archaeological assemblages.

Chapter 4: Actualistic studies

4.1 Introduction

Experimental studies are important components in archaeology and play a key role in understanding past technologies (Sánchez-Yustos et al., 2015; de la Torre and Mora, 2018b). Technological analysis is at the heart of our understanding of lithic reduction sequence of the Acheulean industry. Recently, researchers have shown an increased interest in reduction sequence and hominin knapping skills of the Oldowan and Acheulean technologies (Kimura, 2002; de la Torre, 2004; de la Torre, Mora and Martínez-Moreno, 2008; Stout et al., 2010). In their studies of the Oldowan and Acheulean materials from Olduvai, de la Torre and Mora (2005) and de la Torre et al. (2008) have proposed two separate reduction sequences. These were the *chaînes opératoires* of small debitage and Large Cutting Tools (LCT) (Gallotti, 2013; de la Torre and Mora, 2018b). However, research has consistently shown that these reduction sequences are yet to be explored in some Acheulean sites of Olduvai.

Stone tool making by hominins can be understood using experimental studies that allow archaeologists to establish the full understanding of raw material economy and their roles in shaping lithic technology (Jones, 1979, 1981; Diez-Martin, Dominguez-Rodrigo and Prendergast, 2011; de la Torre et al., 2013; Sánchez-Yustos et al., 2015; Byrne et al., 2016). In this chapter, an experimental approach is used for identifying predictive models of small flake reduction in each Olduvai raw material. These models are compared to published technological analyses of both Oldowan and Acheulean assemblages to test their feasibility for understanding reduction intensity and raw material use, as well as providing a means for understanding missing components of the lithic reduction sequence at each site.

4.2 Aims and research questions of the experimental study

The main purpose of this chapter is to develop an understanding of technological skills, specifically the variable use of different raw materials through comprehensive technological analysis of experimental materials and compare them with the archaeological assemblages studied in this thesis. This chapter explains how the results from experimental data can be compared with the results from archaeological dataset to address the main research questions of this study. In particular, this chapter will examine the following research question.

1. *How can experimental assemblage help the understanding of archaeological assemblage and understand hominin raw material economy at Olduvai Gorge?*

A number of secondary research questions are posed to further contextualise the primary research question.

1. *Does the raw material type influence the level of reduction intensity within both Oldowan and Acheulean assemblages?*
2. *Can the number of flake scars on cores and flakes be a reliable indicator of reduction intensity in each raw material type?*
3. *What effects does the size and weight of stone tools have on the understanding of raw material procurement and levels of technological skills of hominins?*
4. *What are the effects of raw material types to the type of reduction sequence?*

These experimental research questions address key technological attributes that aid in understanding hominin technological skills. They focus on establishing an understanding of hominin raw material preferences and how raw material influences reduction intensity, how number of flake scars can indicate the level of reduction, how

size and weight of raw material affect raw material procurement strategies and the level of technological skills, and how different raw material types affect reduction sequence. To accomplish this, different methods were employed as follows.

4.3 Materials and Methods

4.3.1 Materials

This study uses experimental and archaeological materials. The experimental assemblages were produced at the UCL Institute of Archaeology, and the flintknappers (Drs. Tomos Proffitt, UCL-IoA and Adrian Arroyo, IPHES) used three major raw material types locally collected from Olduvai Gorge, Tanzania. These are basalt, quartzite, and chert. These raw materials represent major raw materials used by hominins in Beds I, II, III, and IV (Leakey, 1971; Leakey and Roe, 1994).

In this study, a total of twelve (12) experimental sets were analysed. This assemblage consists of 841 stone artefacts (Table 4.1). All experimental products (complete and broken) were analysed and measured by their length, width, thickness, and weight. However, here the analysis focuses on materials with complete reduction sequence (cores, flakes, flake fragments and chunks).

The analysis of the experimental materials focused on cores, complete flakes, fragmented flakes, and small (less than 20 mm) debitage. However, the analysis of small debitage is excluded in this report since they are mostly informative on taphonomic aspects rather than technological characteristics. Table 4.1 shows a sample of experimental materials analysed and raw materials used. The ratio of artefact frequency between experimental and archaeological artefacts was a useful

representation when comparing the two assemblages. However, the comparisons focused on attributes that were only available within the experimental assemblage.

Table 4. 1: Table showing experimental assemblage artefact samples analysed for this study.

Experiment #	Chert	Lava	Quartzite	n	%
20	64			64	7.6
21	62			62	7.4
33		41		41	4.9
34			112	112	13.3
46	34			34	4.0
47	89			89	10.6
48			82	82	9.8
49			102	102	12.1
50			87	87	10.3
52		51		51	6.1
53		25		25	3.0
57			92	92	10.9
Total	249	117	475	841	100.0

4.3.2 Methods

This chapter focuses on the technological aspects of the experimental stone tool collection that weigh about 17.6 kg (Table 4.2). All experimental artefacts were measured and weighed based on raw material types and technological categories. Artefacts' maximum length, widths and thickness were measured using callipers, and raw materials were grouped into Olduvai's locally available raw materials, lava, quartzite and chert (McHenry and de la Torre, 2018). Results from the analysis are presented below.

Table 4. 2: Table showing technological categories of the entire experimental assemblage.

Technological Category		Frequency		Weight (g)	
		n	%	n	%
Detached Pieces	Flake	291	35	7996.8	45
	Flake Fragment	474	56	4246.6	24
	Chunk	58	7	1048.7	6
	Total	823	98	13292.1	75
Flaked Pieces	Core	18	2	4352.3	25
	Total Flaked	18	2	4352.3	25
Grand Total		841	100	17644	100

Weight in grams (g)

4.4 Results

Results are presented according to raw material types and general technological categories are compared between the experimental and archaeological assemblages. Statistical data for comparisons are presented by using Pearson's chi-square test. Results from chi-square tests are presented in the text and in the appendices section.

4.5 Assemblage composition

Quartzite dominates statistically (n = 473, 56.2%), followed by chert (n = 251, 29.9%), while lava is slightly (n = 117, 13.9%) represented (Table 4.3). Quartzite dominance is also supported by its weight contribution (10.7 kg, 61%), contrary to Lava artefacts (4 kg, 23%) (Table 4.4).

4.5.1 Detached pieces

Detached pieces (n = 823, 98%) dominate the entire experimental assemblage (Table 4.3), with high frequency of Quartzite (n = 466, 55.4%) dominance, followed by Chert (n = 243, 28.9%), whereas Lava (n = 114, 13.5%) being less represented (Table 4.3).

There are minor differences in the relative frequencies per technological category and weight, with the highest percentage of detached pieces in flake fragments, followed by flakes (Tables 4.4 and 4.5; Figure 4.1).

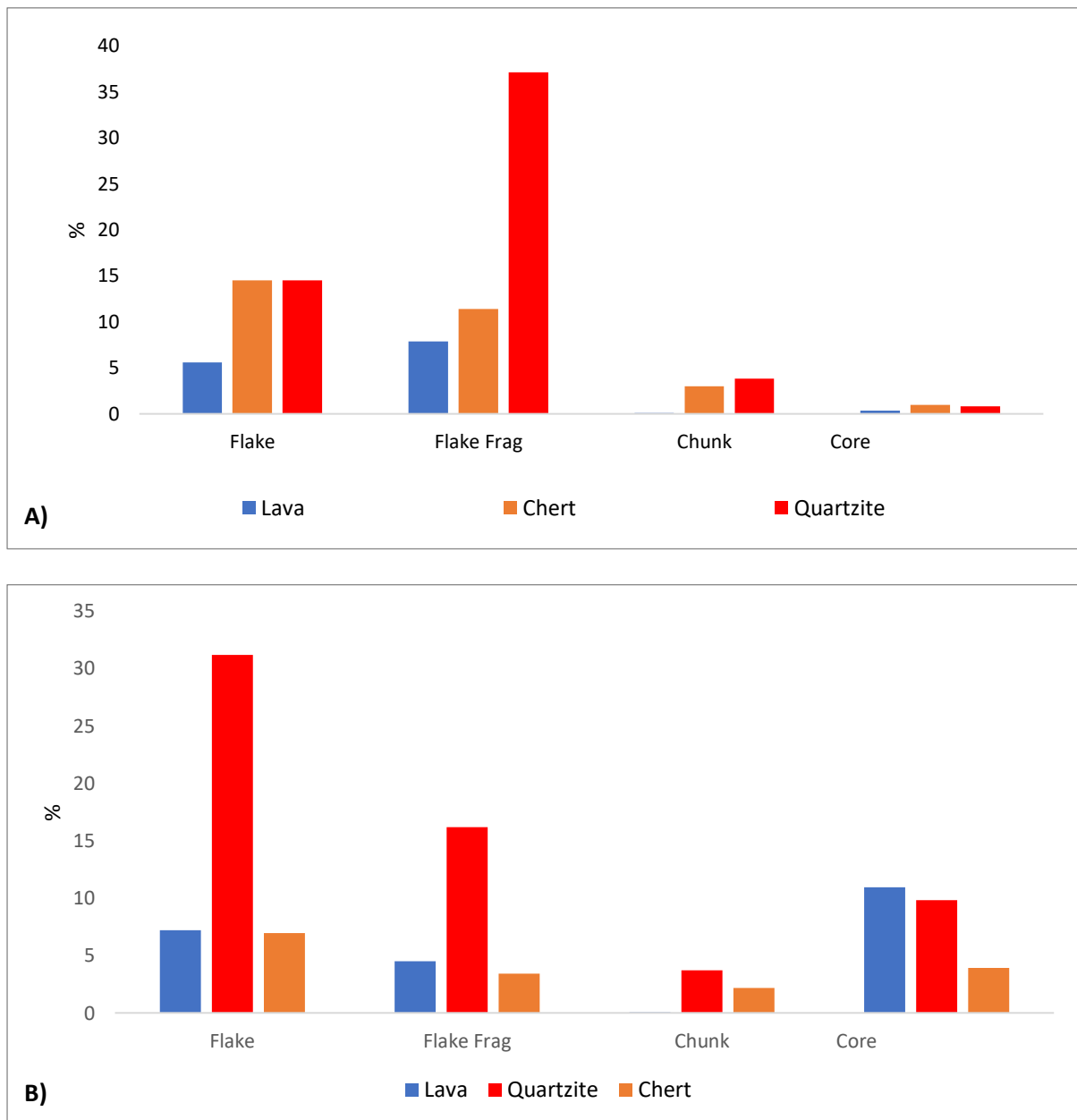


Figure 4. 1: Frequency of artefacts categories per raw materials (A) and frequency of artefact weight (g) (B) per raw materials in the experimental assemblage. Lava core is not clearly seen in Figure 4.1A due to its low frequency (0.4%) in the whole assemblage.

Table 4. 3: Table showing technological categories of experimental assemblage per raw materials.

		Lava		Quartzite		Chert		Total	
		n	%	n	%	n	%	n	%
Detached Pieces	Flake	47	5.6	122	14.5	122	14.5	291	34.6
	Flake Fragment	66	7.8	312	37.1	96	11.4	474	56.4
	Chunk	1	0.1	32	3.8	25	3	58	6.9
	Total Detached	114	13.5	466	55.4	243	28.9	823	97.9
Flaked Pieces	Core	3	0.4	7	0.8	8	1	18	2.1
	Total Detached	3	0.4	7	0.8	8	1	18	2.1
Grand Total		117	13.9	473	56.2	251	29.9	841	100

As shown in table 4.4, detached pieces weigh a little over 13 kg. Table 4.3 shows that the most prevalent category being flake fragments (56.4%), followed by flakes (34.6%), whereas chunks (6.9%) are numerically less important. In addition to being marginally represented, chunks (n = 58) remain less represented even in terms of weight contribution to the assemblage (1 kg; Table 4.4 and 4.5), whereas quartzite (n = 32, 0.6 kg, 3.8%) being its predominant raw material represented in the assemblage, followed by chert (n = 25, 0.3 kg, 2.2%), and lava (n = 1, 0.013 kg, 0.1%) (Tables 4.4 and 4.5). In terms of weight, flakes ~7.9 kg (45.3%) dominate the group of detached pieces; flake fragments contribute ~4.2 kg (24.1%), whereby chunks contribute ~1.0 kg (5.9%) (Table 4.4).

Flake fragments (n = 474, 56.4%) dominate the entire detached pieces (Tables 4.4 and 4.5). This category is mainly represented by quartzite raw material, which contributes 37.1% of all flake fragments, whereas lava (7.8%) and chert (11.4%) are also documented (Table 4.5).

In terms of length ranges, there is high proportion of flake fragments ranging 20-39 mm, of which quartzite is the most abundant material, followed by chert and basalt (Figure 4.2A). Most of the flake fragments weight less than 50 g, whereas weight between 50-100 g being marginally represented, with the lava being the highest followed by chert and quartzite. Nevertheless, weight between 101-200 g remained less important, although lava is the only visible raw material in that particular weight range (Figure 4.2B).

Table 4. 4: Table showing total weight (g) per technological category in the entire experimental assemblage.

	Basalt	Quartzite	Chert	Total
Flake	1267	5500.7	1229.1	7996.8
Flake Frag	793.4	2851.5	601.7	4246.6
Chunk	13.1	654.72	380.9	1048.72
Total detached	2073.5	9006.92	2211.7	13292.12
Core	1929.8	1729.8	692.7	4352.3
Total flaked	1929.8	1729.8	692.7	4352.3
Total (n)	4003.3	10736.7	2904.4	17644.4

	Basalt	Quartzite	Chert	Total
Flake	7.2	31.2	7.0	45.3
Flake Frag	4.5	16.2	3.4	24.1
Chunk	0.1	3.7	2.2	5.9
Total detached	11.8	51.0	12.5	75.3
Core	10.9	9.8	3.9	24.7
Total	23	61	17	100.0

Table 4. 5: Absolute and relative frequencies of experimental assemblages from all experiments per raw material.

	Basalt	Quartzite	Chert	Total
Flake	47	122	122	291
Flake Frag	66	312	96	474
Chunk	1	32	25	58
Total detached	114	466	243	823
Core	3	7	8	18
Total flaked	3	7	8	18
Total (n)	117	473	251	841

	Basalt	Quartzite	Chert	Total
Flake	5.6	14.5	14.5	34.6
Flake Frag	7.8	37.1	11.4	56.4
Chunk	0.1	3.8	3.0	6.9
Total detached	13.6	55.4	28.9	97.9
Core	0.4	0.8	1.0	2.1
Total flaked (%)	13.9	56.2	29.8	100

Complete flakes (n = 291, 34.6%) are the second most abundant category after the flake fragments (Table 4.5). Weighing up to 7.9 kg, complete flakes make the highest weight contribution (45.3%) within the detached pieces and the weight of the whole assemblage (Table 4.4).

In absolute terms, chert (n = 122) and quartzite (n = 122) flakes are more abundant than lava (n = 47) flakes (Table 4.5). This is supported with evidence of relative frequencies in chert (14.5%) and quartzite (14.5%) flakes, which are equally important compared to lava (5.6%) that is marginally represented (Table 4.5).

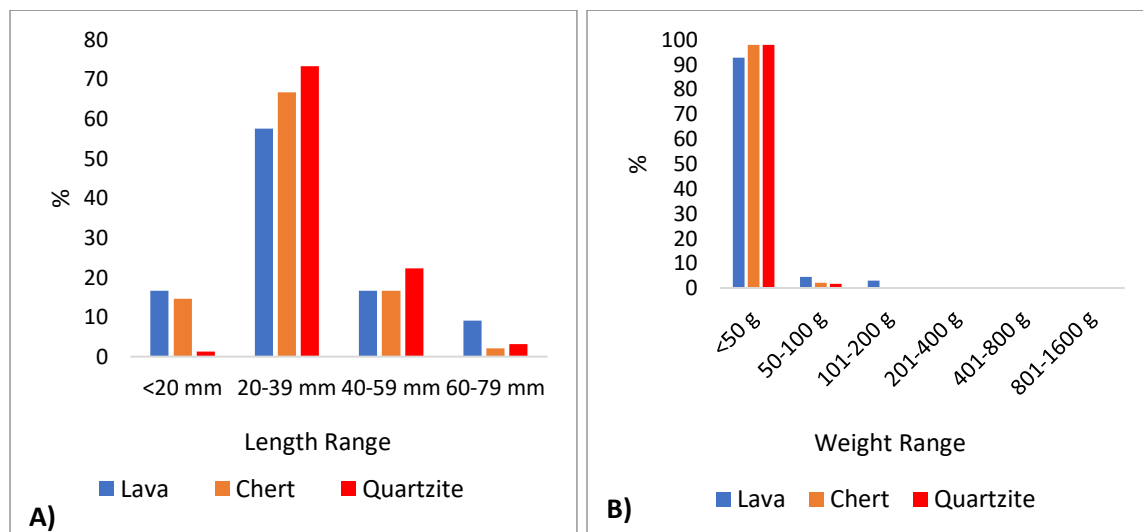


Figure 4. 2: A-B) Flake fragments length per raw materials (A) and weight ranges per raw materials (B).

Figure 4.3 shows that most of complete flakes have length dimensions between 20 and 40 mm, with an average length of 46.4 mm (Table 4.6). However, there is a substantial variation amongst flake categories per raw materials, with flakes measuring 130 mm long and some flakes as small as 12 mm in length (Table 4.6).

In terms of weight, there is significant number of flakes that weigh under 50 g within the sample (Figure 4.4). Flake striking platforms cortex are mostly dominated by non-cortical and cortical platforms, whereas cortical dominant and non-cortical dominant

platforms fall in between the border line, with highest representation from chert materials, followed by lava and quartzite (Figure 4.5).

Whole flake dorsal cortex results show that there is high percentage of non-cortical dominant dorsal cortex amongst flake category, with chert represented in high proportion, followed by quartzite and lava (Figure 4.6D). This cortex pattern according to raw material helps to understand which stages of reduction intensity before a flake was removed from a core and a number of dorsal scars can support this.

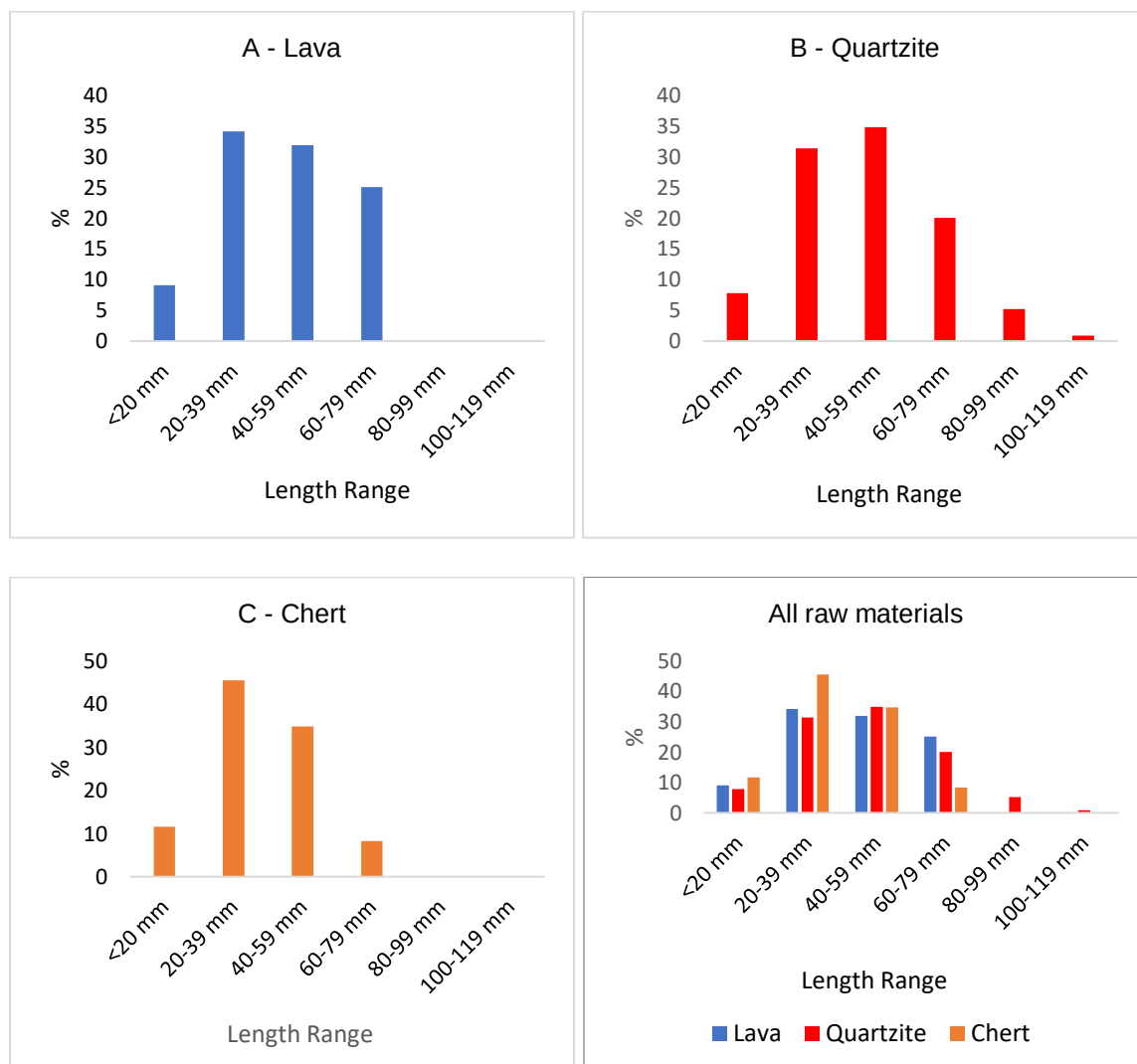


Figure 4. 3: A-D) Flake length ranges – lava raw materials (A); quartzite raw materials (B); chert raw materials (C); and comparisons of length range – all raw materials (D).

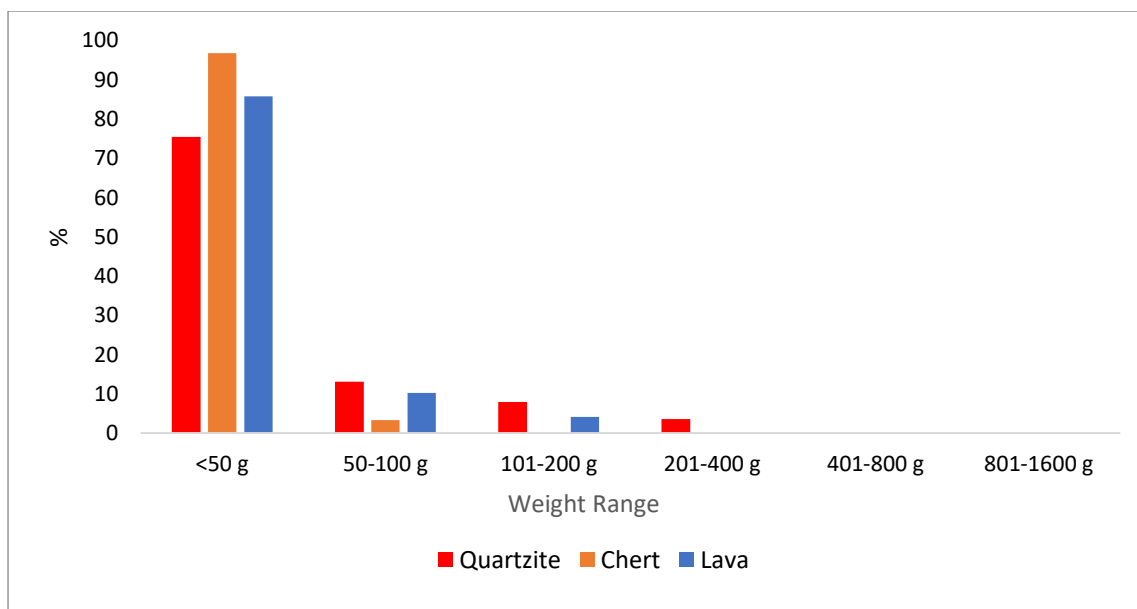


Figure 4. 4: Comparison of weight range of complete flakes per raw materials.

Table 4. 6: Table showing dimensions (mm and g) of technological categories in the experimental assemblage.

			Minimum	Maximum	Mean	Std dev
Small Flake	Total (n = 291)	Length	12	130	46.4	21.3
		Width	6	98	32.9	16.3
		Thickness	1	48	11.5	7.8
		Weight	0.1	317.8	27.5	45.3
	Lava (n = 47)	Length	16	93	46.6	19.7
		Width	9	70	35.2	14.4
		Thickness	3	30	12.2	5.9
		Weight	0.6	168	27	3.4
	Quartzite (n = 122)	Length	17	130	54.1	24.2
		Width	12	98	38.6	18.4
		Thickness	3	48	15.1	8.8
		Weight	0.8	317.8	45.1	60.5
	Chert (n = 122)	Length	12	82	38.5	14.9
		Width	6	62	26.4	11.7
		Thickness	1	29	7.6	5.2
		Weight	0.1	77.9	10.1	13.5
Core	Total (n = 18)	Length	40	144	73	24.3
		Width	32	111	57.7	21.8
		Thickness	14	81	36.2	15.8
		Weight	24.9	1480.5	241.8	323.5

Lava (n = 3)	Length	63	144	98	34
	Width	36	111	76	30.8
	Thickness	31	81	53.3	20.8
	Weight	107.1	1480.5	643.3	599.7
Quartzite (n = 8)	Length	55	93	78.9	13.6
	Width	42	89	62.6	15.2
	Thickness	36	49	43.1	4.6
	Weight	159.7	433.8	247.1	85.8
Chert (n = 7)	Length	40	83	58.5	16.1
	Width	32	79	46.5	15.3
	Thickness	14	39	23.6	8.6
	Weight	24.9	340.1	86.6	98

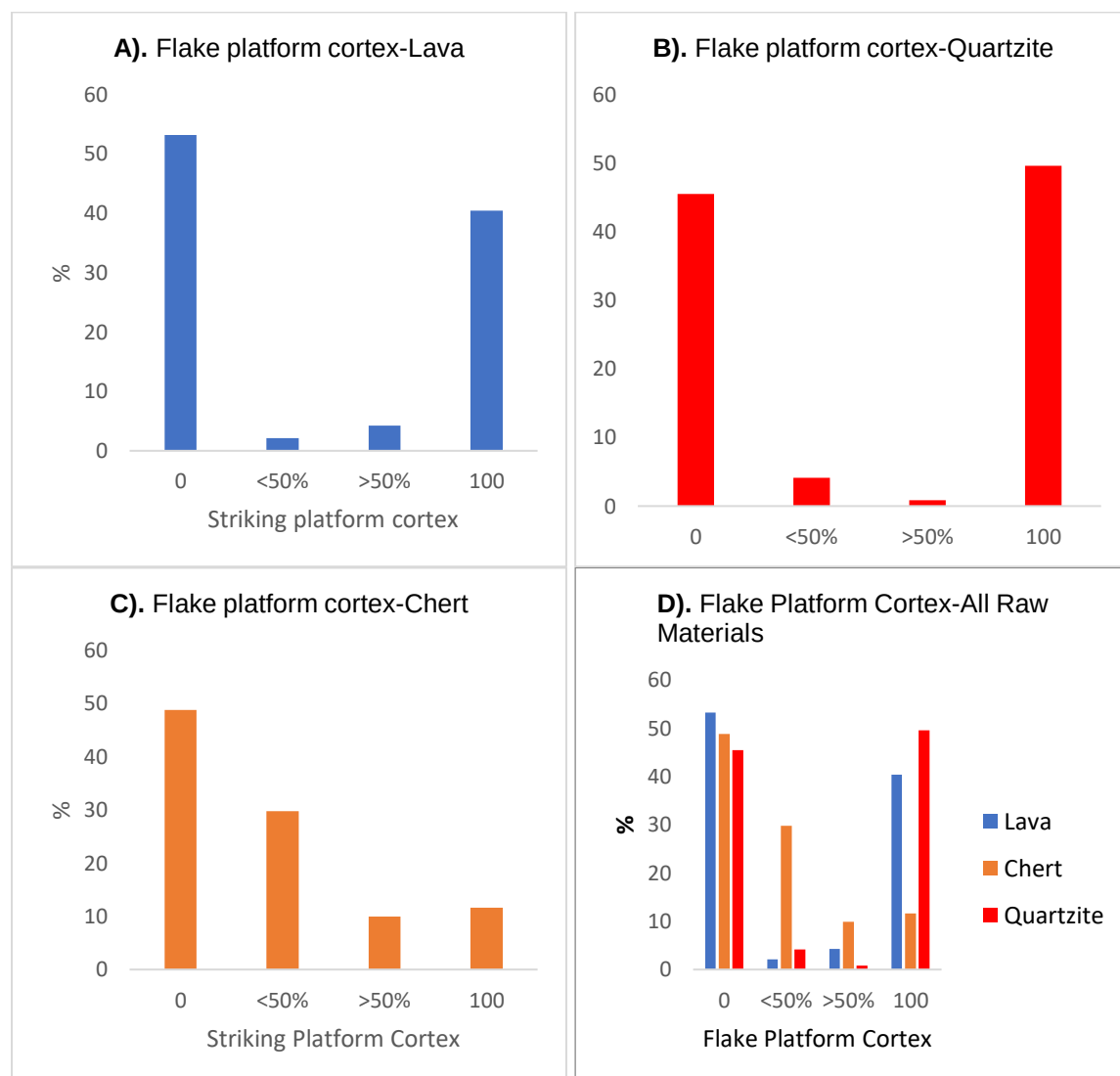


Figure 4. 5: A-D) Flake platform cortex coverage per raw materials. Figure 4.5D shows comparisons between the raw material types. Non-cortical platforms are highly represented.

Dorsal scars counts were grouped following de la Torre and Mora (2018), and hence these groups were compatible for comparisons. Most flakes were dominated by a pattern of 1-3 scars per flake, followed by 4-6 scars, whereas 7-9 scars were slightly represented (Figure 4.7). The thickness dimensions range from 1 to 30 mm thick, with flakes less than 10 mm being relatively significant than other dimensions (Figure 4.8).

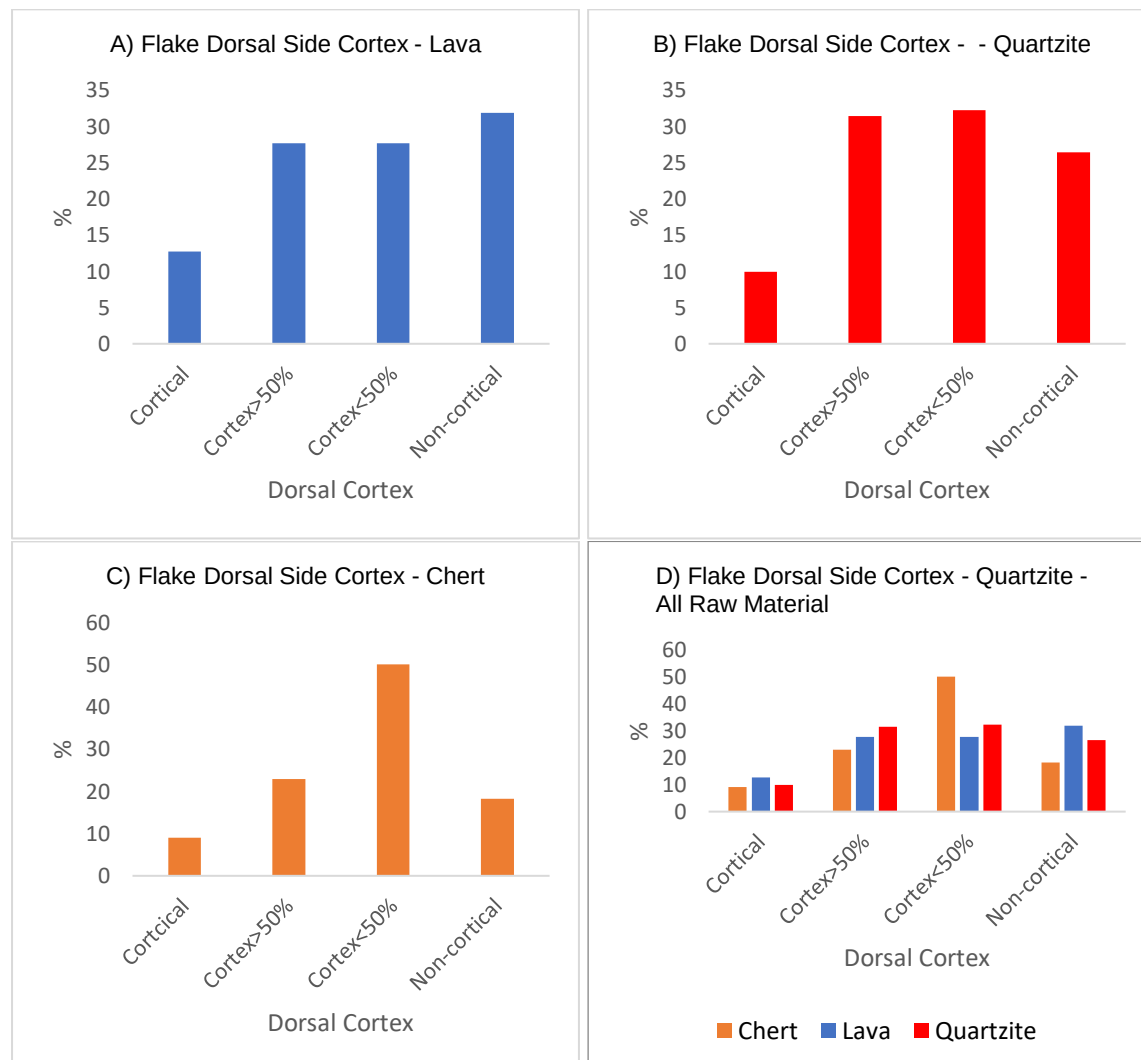


Figure 4. 6: A-D) Dorsal flake cortex of whole flake assemblage per raw material. Figure 4.6D shows comparisons of flake dorsal cortex; chert non-cortical dominant are the most conspicuous.

Further analysis of flakes involved Toth's flake types (Figure 4.9). As it can be shown in figure 4.9, there is high percentage of type V flakes within the flake assemblage. Nonetheless, there is significant variation of raw materials per flake type (Figure 4.9D).

In order to infer relative intensity of reduction within the experimental assemblages, this thesis uses Toth flake category system (Toth, 1982; Toth, 1985; Braun et al., 2008b). As shown in figure 4.9A, lava flakes were dominated with Toth's flake stage V, followed by stage III, while the rest remained slightly represented.

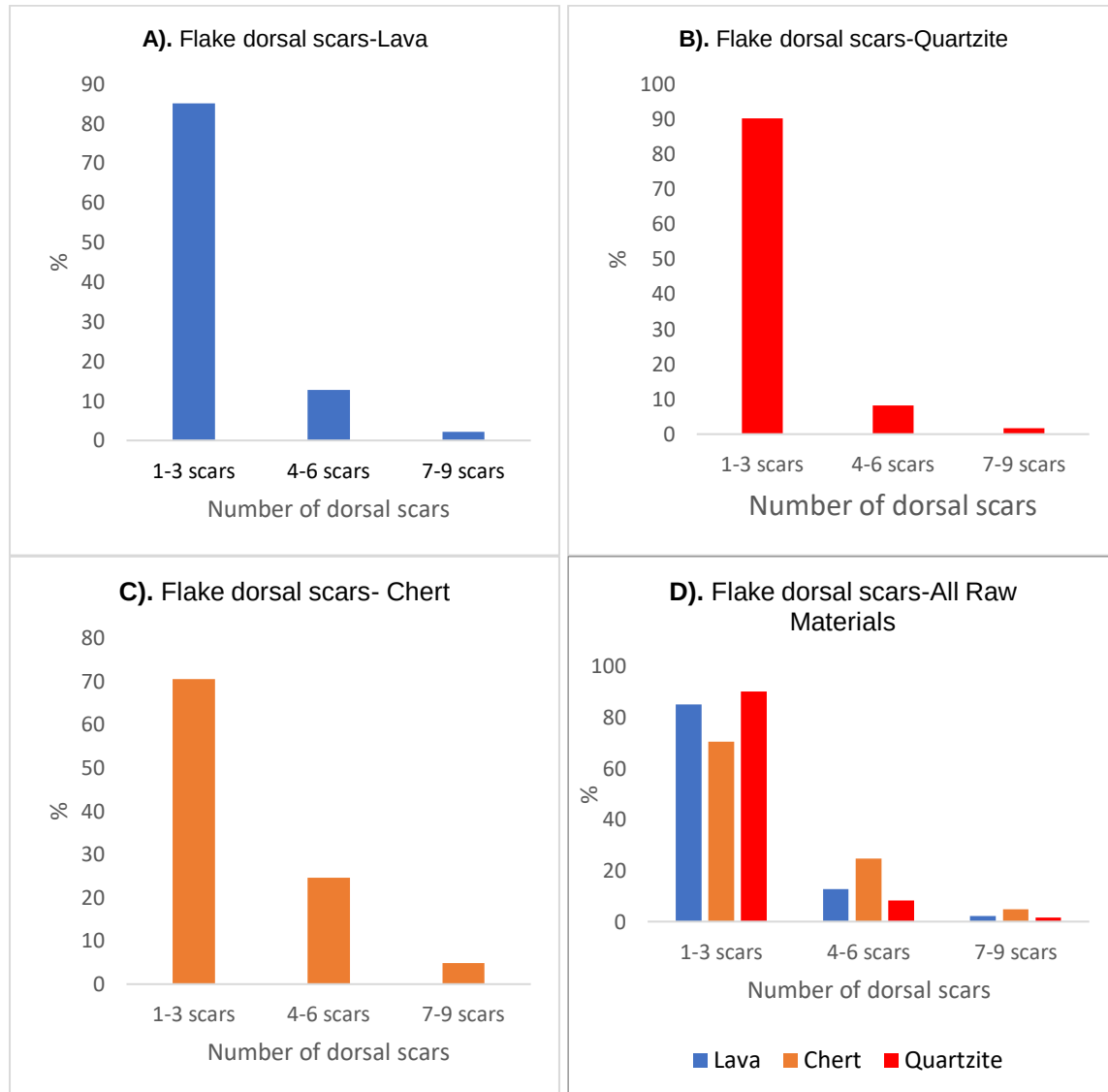


Figure 4. 7: A-D) Flake dorsal scars per raw materials. Figure 14D shows comparative patterns of dorsal scar, with high representation of scar ranges 1-3 scars.

Figure 4.9B, shows quartzite flakes dominated with stage V and II, followed by stage III and VI, whereas stage I and IV and marginally represented. This indicates that flake stages V and II were highly represented compared to early stages of flakes. In terms of chert, however, the analysis shows a slightly different result. Figure 4.9C shows that

chert yielded high frequency of stage V and VI, followed by stage II, I, and IV, whilst stage III slightly represented.

In general, there is high representation of stage V Toth's type flakes compared to other stages of reduction sequence. This model will be compared with archaeological flakes to test the level of reduction intensity within archaeological assemblages (see chapter 9).

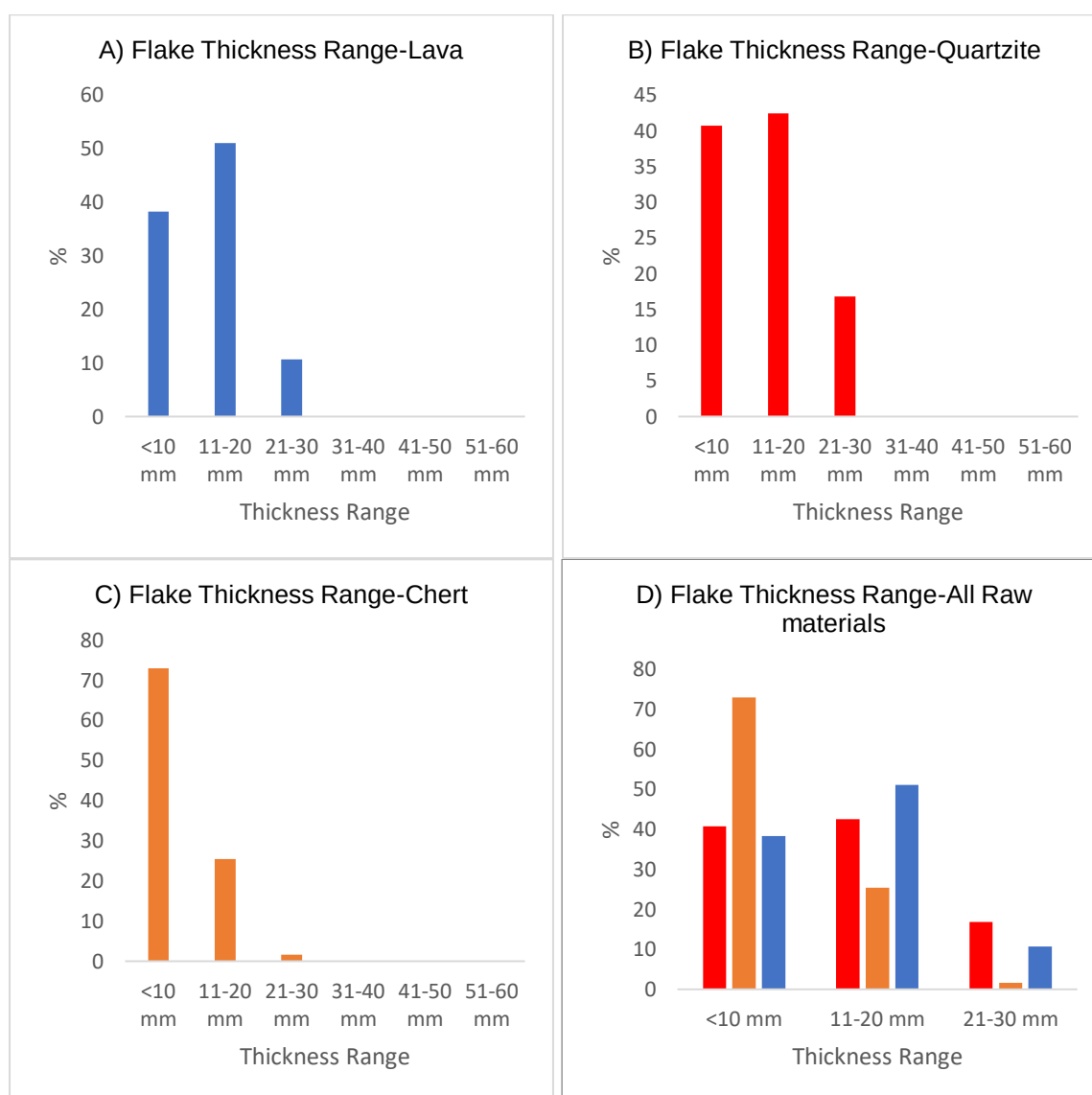


Figure 4. 8: A-D) Flake thickness ranges per individual raw materials. Figure 15D shows comparisons of length ranges.

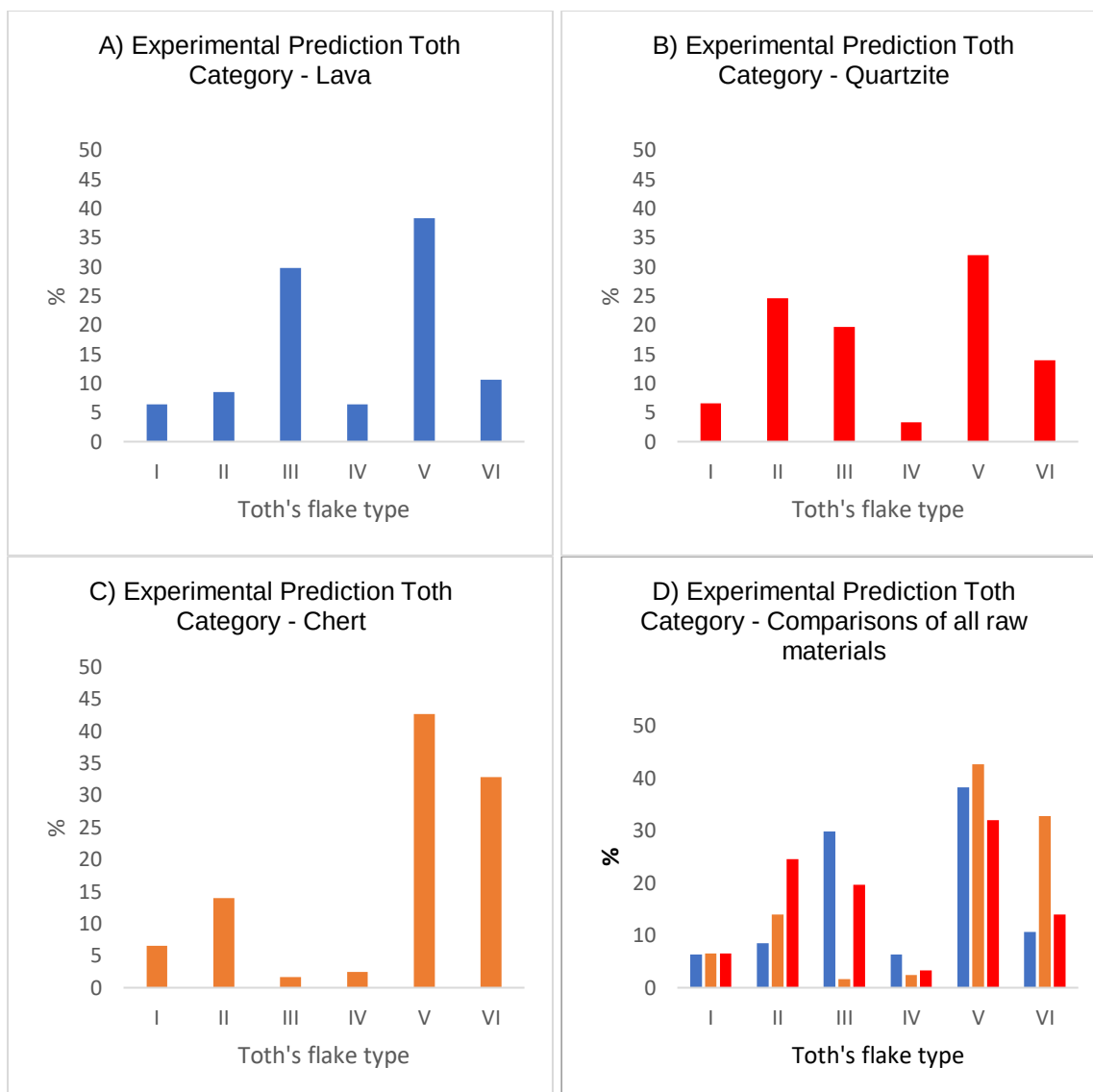


Figure 4. 9: A-D) Figures showing cortex on experimental flakes following Toth's (1982) flake types.

In addition to flakes and flake fragments, the experimental assemblage contains chunks ($n = 58$, 6.9%) with a total weight of over 1 kg (Table 4.4 and 4.5). Chunks are the least occurring category. They are mostly made of quartzite (654.72 g, 3.7%), followed by chert (380.9 g, 2.2%) and lava (13.1 g, 0.1%) (Table 4.4; Figure 4.10). Lava chunks are very rare ($n = 1$, 0.1%), therefore suggesting that lava yielded more technologically identifiable tool types than chert ($n = 25$, 3.0%) and quartzite ($n = 32$, 3.8%) (Table 4.5, Figure 4.10A).

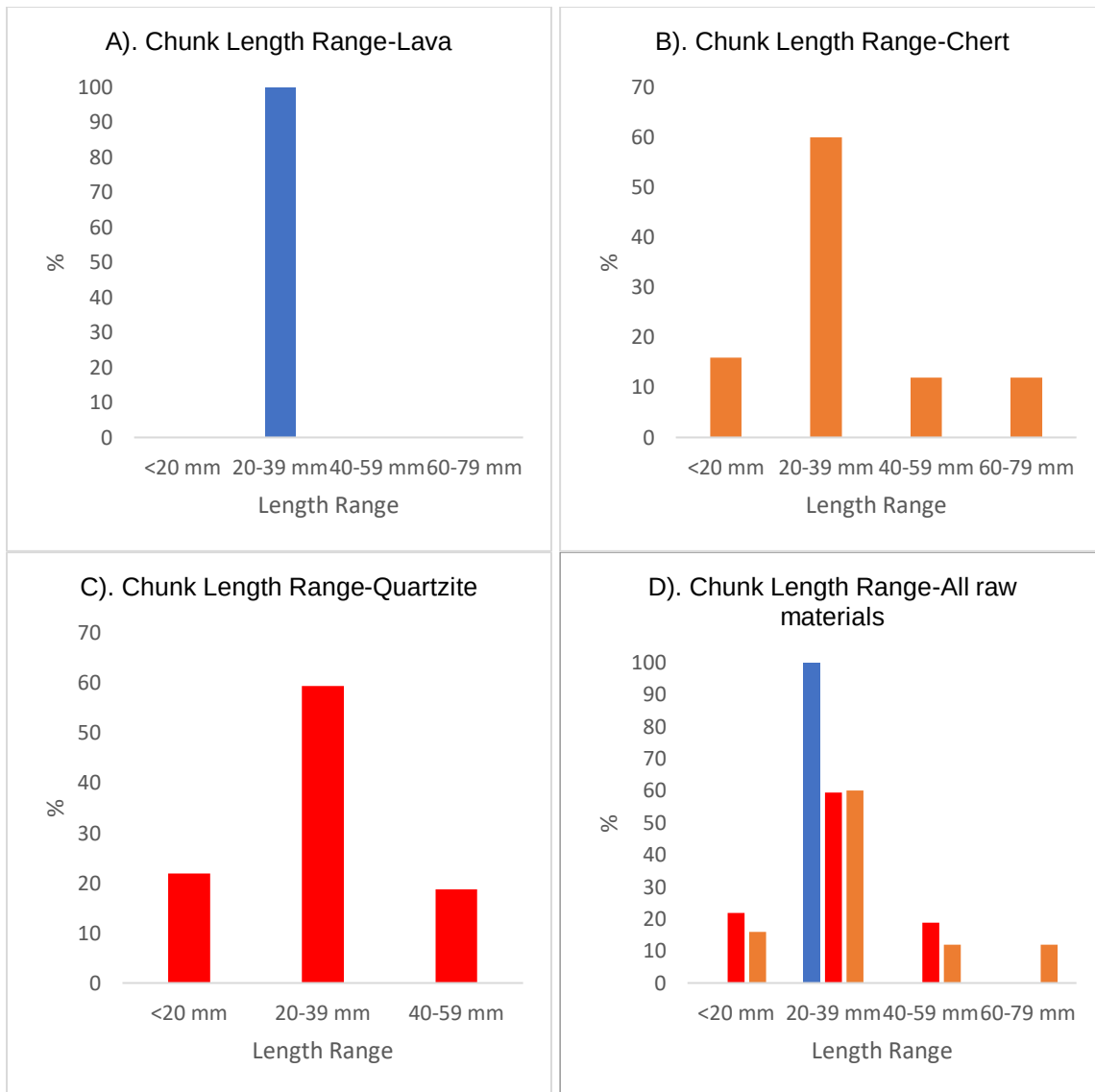


Figure 4. 10: A-D) Figures showing length range of chunks per raw materials in the experimental sample.

4.5.2 Flaked pieces

Cores ($n = 18$, ~4.3 kg, 24.7%) were analysed to understand the reduction intensity and the number of flakes removed from each individual core (Tables 4.3, 4.4, and 4.5). It can be seen from the data in Table 4.5 that chert ($n = 8$, 1%) and quartzite ($n = 7$, 0.8%) are the most abundant cores in the assemblage, followed by lava cores ($n = 3$, 0.4%). However, the results on the weight contribution reveal opposite, whereas chert

cores (0.6 kg, 3.9%) contribute minimal amount of weight compared to lava (n = 3; 1.9 kg, 10.9%) and quartzite (n = 7; 1.7 kg, 9.8%) cores (Tables 4.3-4.5).

Cores have an average length of 73 mm and weight of approximately 241.8 g (Table 4.6). The standard deviation (Table 4.6) shows a significant size variability amongst core assemblage. With a minimum length of 40 mm and maximum length of 144 mm (Table 4.6), there is substantial size variation pattern in the small debitage core assemblage. Core length class ranges from 40 - >100 mm – there is a clear difference in term of length per raw materials. Lava and quartzite material show an increase in frequency from small to large cores (Figure 4.11A-B). However, there is a slight difference in chert cores, which fluctuate in terms of frequency with an increasing length (Figure 4.11C).

More generally, figure 4.11D shows the comparison of core length ranges per raw materials, whereby there is a significant increase of number of cores with an increasing length. Most importantly, there is significant frequency of large core measuring >100 mm with lava (60%) being highly represented followed by quartzite (53.3%) and chert (52.9%). From the data in figure 4.11, it is apparent that there is a significant variation between small and large cores within experimental assemblage.

To examine core reduction intensity, the core scar counts, and cortex coverage were used (Figures 4.12 and 4.13). As shown in figure 4.12A, 33.3% of lava cores preserve six or fewer scars, whilst 66.7% of lava core preserve nine or more scars. Figure 4.12B shows 42.9% of quartzite core preserve three or fewer scars, 28.6% of quartzite core preserve six or fewer scars, and 28.6% of quartzite core preserve seven or more flake scars.

In addition, 25% of chert cores preserve three or fewer scars, 50% preserve six or fewer scars, and 25% preserve seven or more scars (Figure 4.12C). Interestingly, figure 4.12D shows that there is significant variation in number of scars per raw materials, with 66.7% of lava cores preserving nine or more scars, 50% of chert cores preserving six or few scars, whilst 42.9% of quartzite core preserving three or fewer scars. From this data, we can see that lava cores indicate high reduction intensity, followed by chert, while quartzite indicating low reduction intensity.

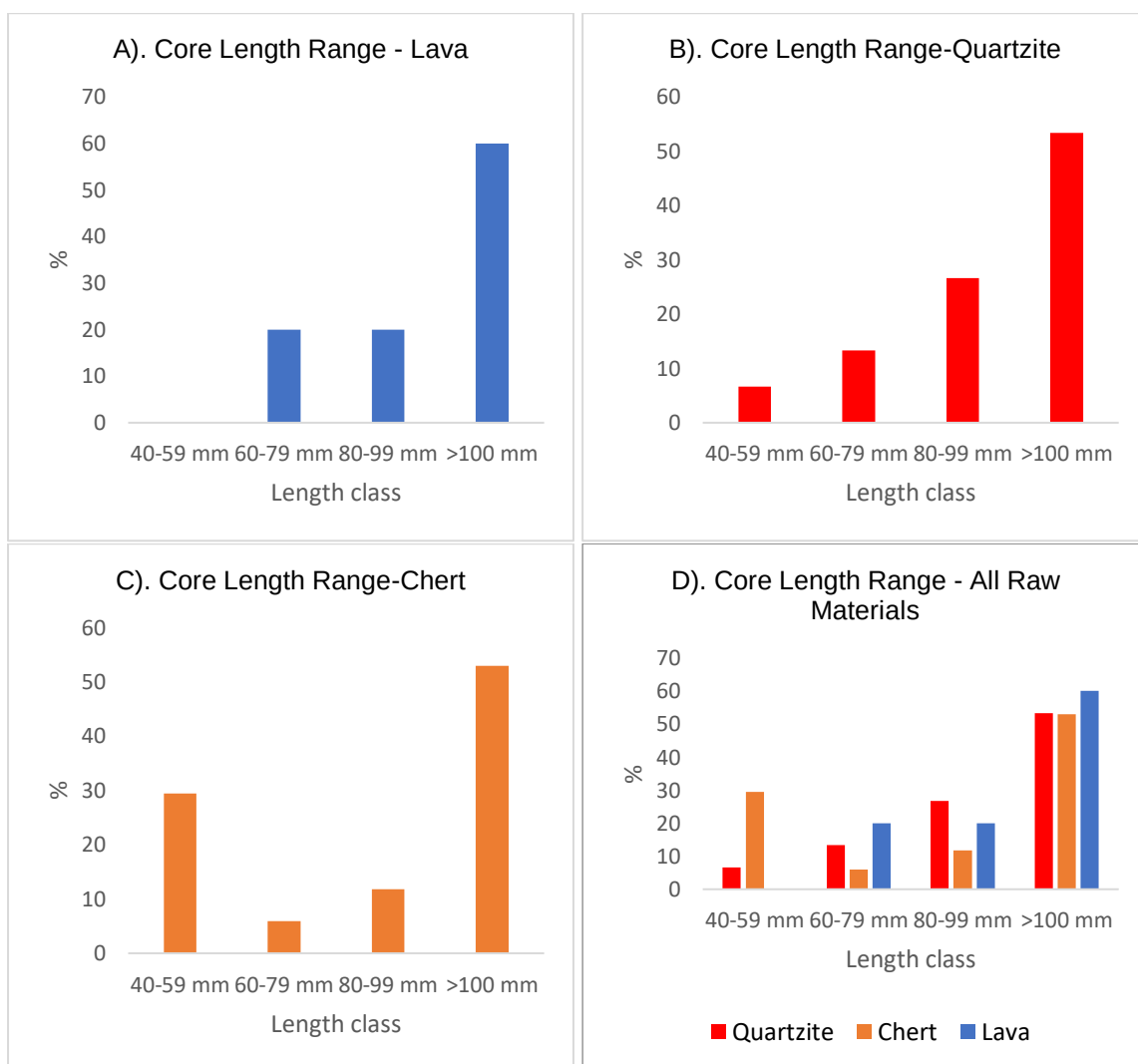


Figure 4. 11: A-D) Length classes of cores per each raw material. Figure 4.11D shows comparisons of length classes.

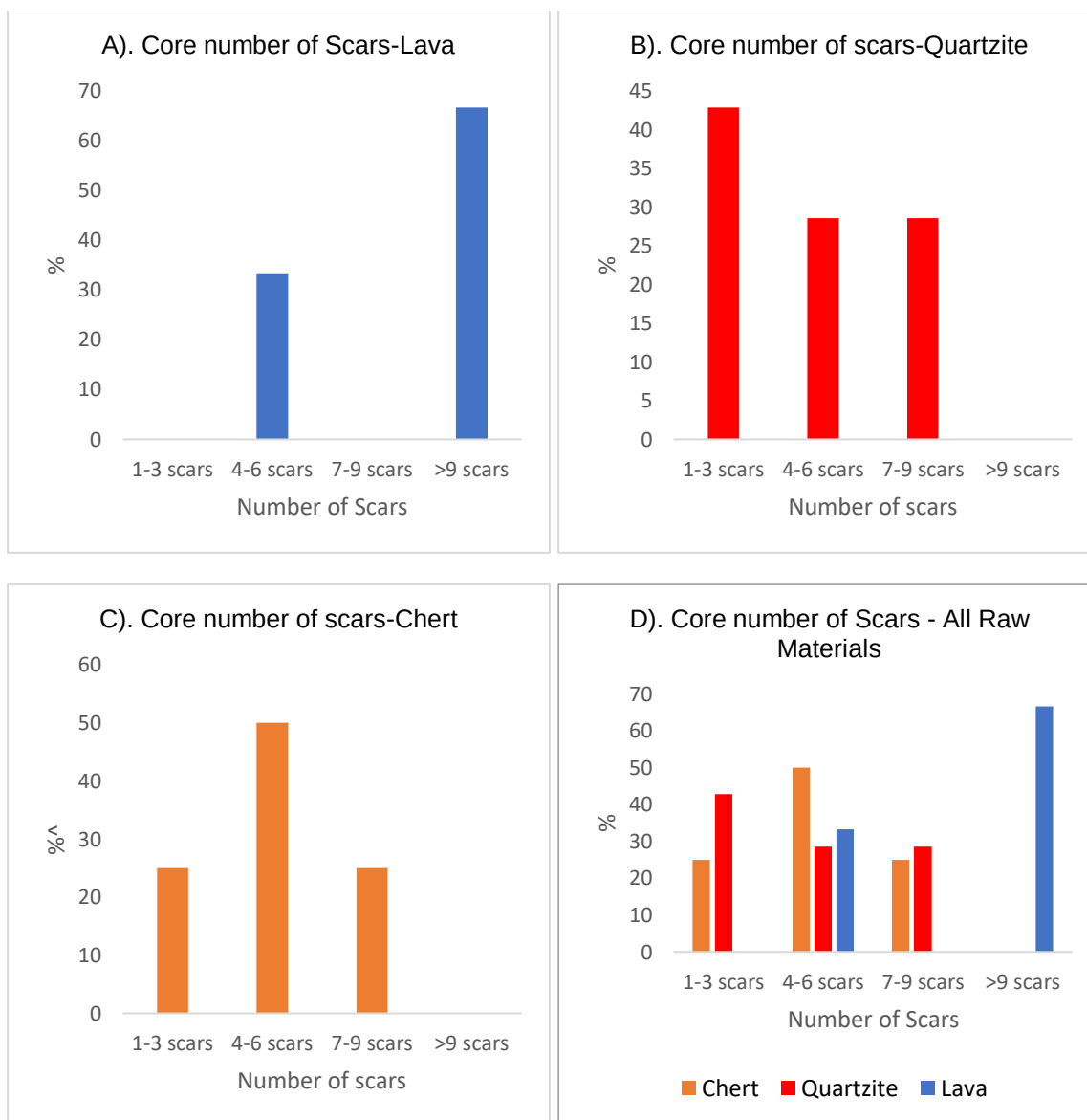


Figure 4. 12: A-D) Scar counts of cores per individual raw materials; 4.12D shows comparisons of number of scars of all raw materials, with lava as the most represented.

Further analysis of reduction intensity was undertaken by assessing the core cortex coverage. In terms of cortex coverage, 66.7% of lava cores are cortical dominant and 33.3% of them are non-cortical dominant (Figure 4.13A); quartzite cores indicate 85.7% are non-cortical dominant whilst 14.3% are non-cortical (Figure 4.13B). Chert, however, shows 25% of cores are cortical dominant and 75% of cores are non-cortical dominant (Figure 4.13C).

What is striking about the figure 4.13D is that it shows a pronounced variation in core cortex coverage per all raw materials, with 85.7% of quartzite cores dominated by non-cortical dominant, followed by 75% of chert cores, whilst 33.3% of lava core being marginally represented. The most interesting aspect of figure 4.13D is that 14.3% of quartzite cores are non-cortical whilst neither lava nor chert cores are represented (Figure 4.13D). Identification of quartzite cortex is challenging, even to experienced analysts. This is probably the reason for its high frequency.

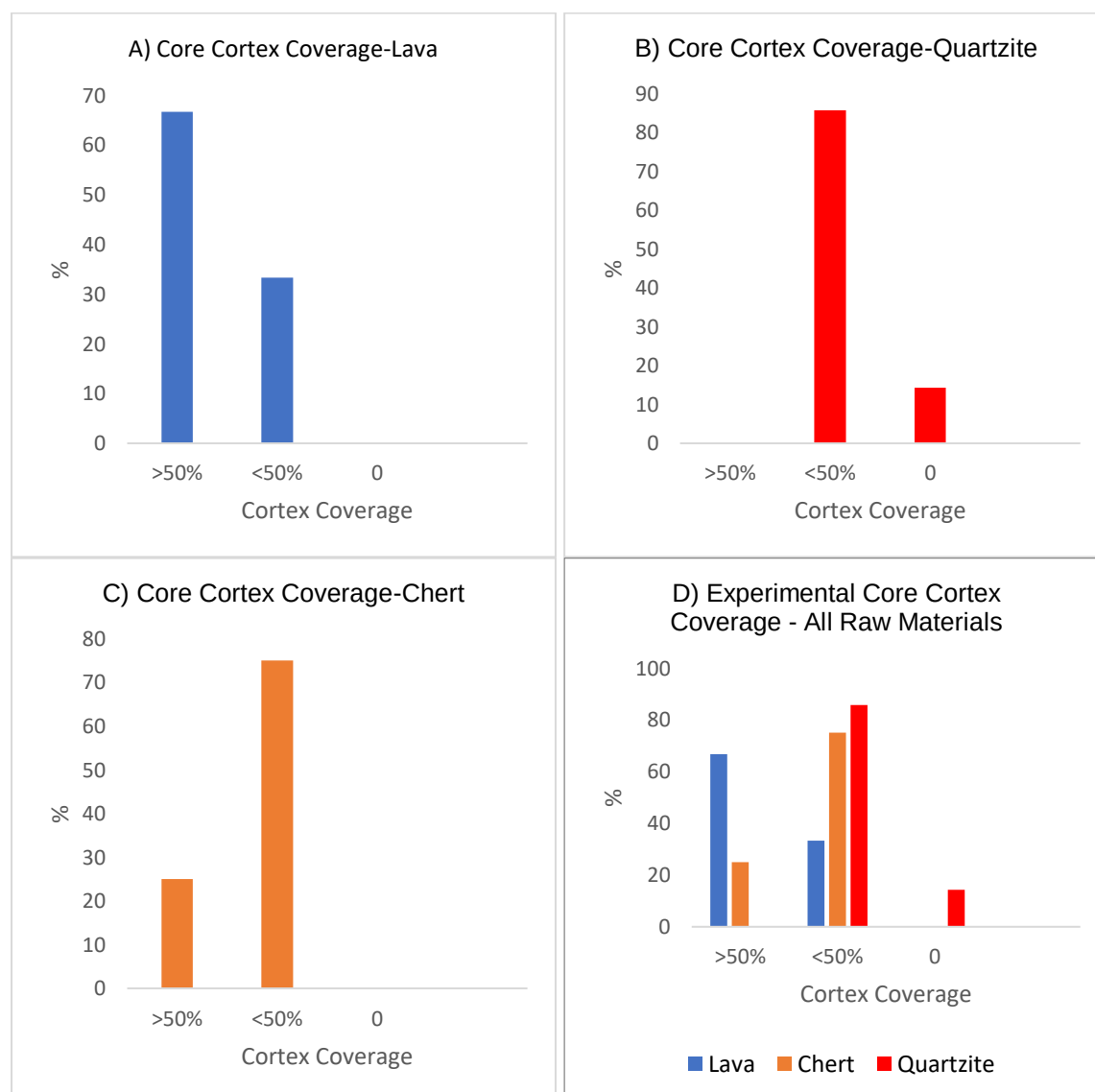


Figure 4. 13: A-D) Core cortex coverage per individual raw materials; Figure 4.13D show comparisons of core cortex of all raw materials, with non-cortical quartzite being the most conspicuous.

In addition to cortex coverage as a reduction intensity factor, weight of cores contributes 24.7% of the entire assemblage, with high frequency of lava (10.9%), followed by quartzite (9.8%), whereas chert (3.9%) was less represented (Table 4.4, Figure 4.15). With an average weight of 241.8 g and length range of 73 mm, there is a significant variation in core weight (Table 6; Figure 4.15), especially quartzite and chert cores (Figure 4.15B-C).

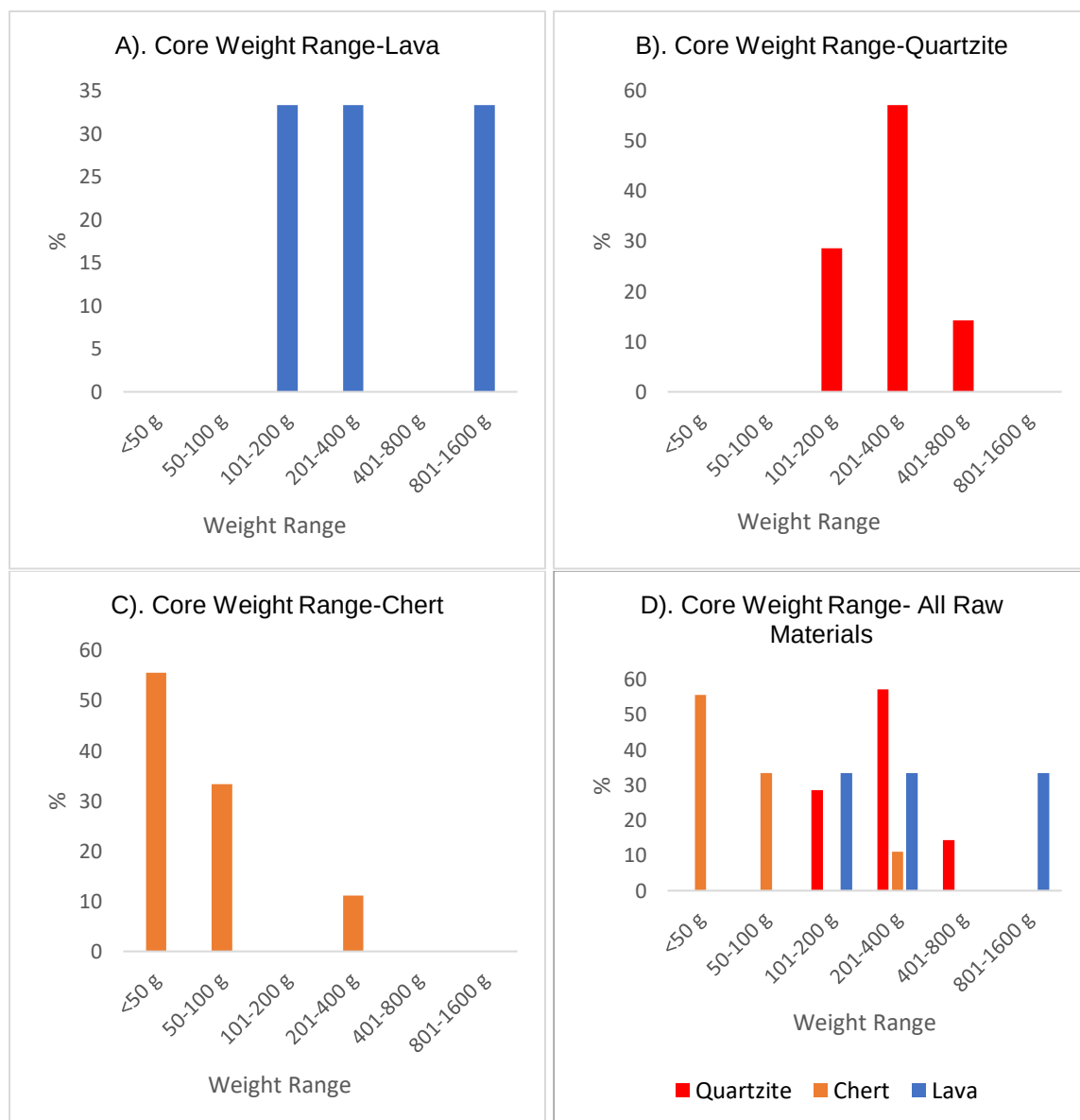


Figure 4. 14: A-D) Core weight range per raw materials (A-C); Core weight comparisons of all raw material (D).

4.6 Implications of experimental data to the current study

Having analysed the experimental lithic materials to test how different raw materials affect the levels of reduction, it is important to address how experimental results can aid in addressing research questions of this study.

Based on the data and interpretations presented above, the lithic analysis carried out in this study will treat each raw material separately. Furthermore, technological comparisons between experimental and archaeological data will generally be limited to comparisons of the same raw materials. Different technological attributes of cores and flakes will be compared based on raw materials. For instance, the flake lengths of the experimental and archaeological quartzite flakes from FC East, JK West, JK2, and WK site will be compared (see chapter 9).

Generally, inter-raw material comparisons will be restricted to cores and flakes, respectively. This will increase the precision of technological comparisons and help to answer the study's research questions, which aim to provide a thorough understanding of the technological capabilities of *Homo erectus* at Olduvai.

4.7 Conclusion

The aim of the experimental study was to better understand the way in which experimental materials manufactured may predict technological features expected to be found in archaeological assemblages. The results show comparisons of significant technological features that will be compared with archaeological materials. Cores were analysed to understand the reduction intensity. This was done through the analysis of scar counts and cortex coverage. Figure 4.12 shows that most cores 1-3 and 4-6 scars.

Generally, this indicates a low to medium reduction intensity. This attribute, among others, will be used to test the hypothesis of whether experimental results infer archaeological results. Moreover, complete flakes' attributes were analysed to predict the expected result of flake attributes within archaeological assemblages. It can, therefore, be concluded that the experimental assemblages provided crucial data that may aid in understanding archaeological assemblages and hominin raw material economy at Olduvai.

The next chapter explores the application of raw material survey data in understanding hominin raw material procurement strategies and selectivity on the Olduvai palaeolandscapes.

Chapter 5: Raw material economy of the Acheulean hominins at Olduvai

5.1 Introduction

This chapter reports on the raw material survey conducted by the author in two raw materials sources (namely, RMS1 and RMS2) and the analysis of associated conglomerates. The results from the analysis of conglomerates will be compared with archaeological assemblages. The analysed lithic assemblages represent a variety of raw materials reflecting volcanic lavas, metamorphic and sedimentary rocks, with the most predominant being metamorphic materials (table 6.6 in chapter 6, table 7.5 in chapter 7, and table 8.4 in chapter 8). This chapter involves a systematic analysis of sampled conglomerates which contain lava materials, but not metamorphic rocks. This is due to a number of reasons: firstly, at Olduvai raw materials were found from both primary (in site outcrops) and secondary (cobbles from drainages derived from primary sources) or tertiary (for example, hominins stone caches) sources (McHenry and de la Torre 2018: 1). This study focuses on secondary sources to determine the extent of foresight and planning that can be revealed by the transport of rocks by hominins. Among the hominin activities on the landscapes included intensity of raw materials transport (Stout et al 2005); sampling of the conglomerates that contained lava materials aimed at measuring the extents of hominins in planning and selection of rocks from the conglomerate and transport them to the sites. Most rounded blanks were accessed by hominins from the local stream channels whereas the angular blocks were likely acquired from the primary sources, predominantly Naibor Soit Hill (McHenry and de la Torre 2018). It is worth noting that metamorphic rocks were not

included in the raw material survey because they were mostly found from primary sources.

The first part describes the types of lithic raw materials discovered in Olduvai. The second portion examines the raw materials survey undertaken by the author while investigating the conglomerates, and the third and final section compares the raw material survey findings to those of the archaeological assemblages presented in chapters 6, 7, and 8.

5.2 Lithic Raw Materials at Olduvai

Researchers have studied the effects of lithic raw materials on the technological behaviour, home ranges and transport activities of hominins in eastern Africa (Hay, 1976; Jones, 1979, 1981; Stiles, 1979; Kyara, 1999; Ludwig, 1999; Semaw, 2000; Stout *et al.*, 2005; Goldman-Neuman and Hovers, 2009, 2012; McHenry and de la Torre, 2018). Further studies regarding the raw material economy shown by prehistoric toolmakers have been presented elsewhere (Binford, 1979; Shott, 1986; Kuhn, 1991; Andrefsky, 1994), and are fundamental in the understanding of the raw material economy and technological organisation of Pleistocene hominins. Based on such studies, this chapter presents a systematic assessment of the raw material economy of Acheulean hominins at Olduvai in Beds II, III, and IV.

An archaeological investigation of lithic raw material economies has two dimensions; firstly, the study of behaviour related to the management of stone artefact; and, second the analyses of patterns of raw material procurement and transport (Kuhn, 1995:124). In this study, cores, flakes, and retouched tools were analysed to understand the

degree to which their raw materials were obtained and reduced. Additionally, various attributes are used to measure the extent of reduction in different artefact categories.

Lithic raw material studies are essential for lithic analysis and for the understanding of hominin technological behaviour and raw material selectivity (Kuhn, 1992, 1995b; Stout et al., 2005). At Olduvai, outcrops in which raw materials were obtained were already exposed when Olduvai's Beds I and II and volcanic highlands were formed (Hay, 1976). McHenry and de la Torre (2018) mention that four large Pleistocene volcanoes that surround the Olduvai basin were potentially primary sources of lava raw materials (Figure 5.1A). Lemagrut volcano to the south provided basaltic to trachyandesitic lava; Satiman at the southeast provided undersaturated phonolites and phono-tephrites; Ngorongoro, to the east and southeast, provided basalt and trachyandesite; Olmoti, to the east, provided basaltic and trachytic lavas; and Engelosin, to the north, provided a distinctively green and fine-grained phonolite (McHenry and de la Torre, 2018). Palaeo-drainages from these volcanoes could have transported raw materials into the Olduvai basin (McHenry and de la Torre, 2018a). Hence, enabled availability of different types of lithic raw materials locally available for stone tool making by hominins.

As in many other Palaeolithic sites, researchers of the lower Palaeolithic technologies in eastern Africa have often focused on understanding raw material types, properties, sources, and preference (Hay, 1968, 1976; Stiles, Hay and O'Neil, 1974; Jones, 1979; Stiles, 1991; Kyara, 1999; Stout et al., 2005; McHenry and de la Torre, 2018), technological organisation (Bamforth, 1985, 1991; Shott, 1986; Dockall, 1997; Akoshima and Kanomata, 2015; Goldstein, 2021), and raw material transport

strategies from sources, particularly in Olduvai's Beds I and II (Kyara, 1999; Blumenschine et al., 2008; McHenry and de la Torre, 2018).

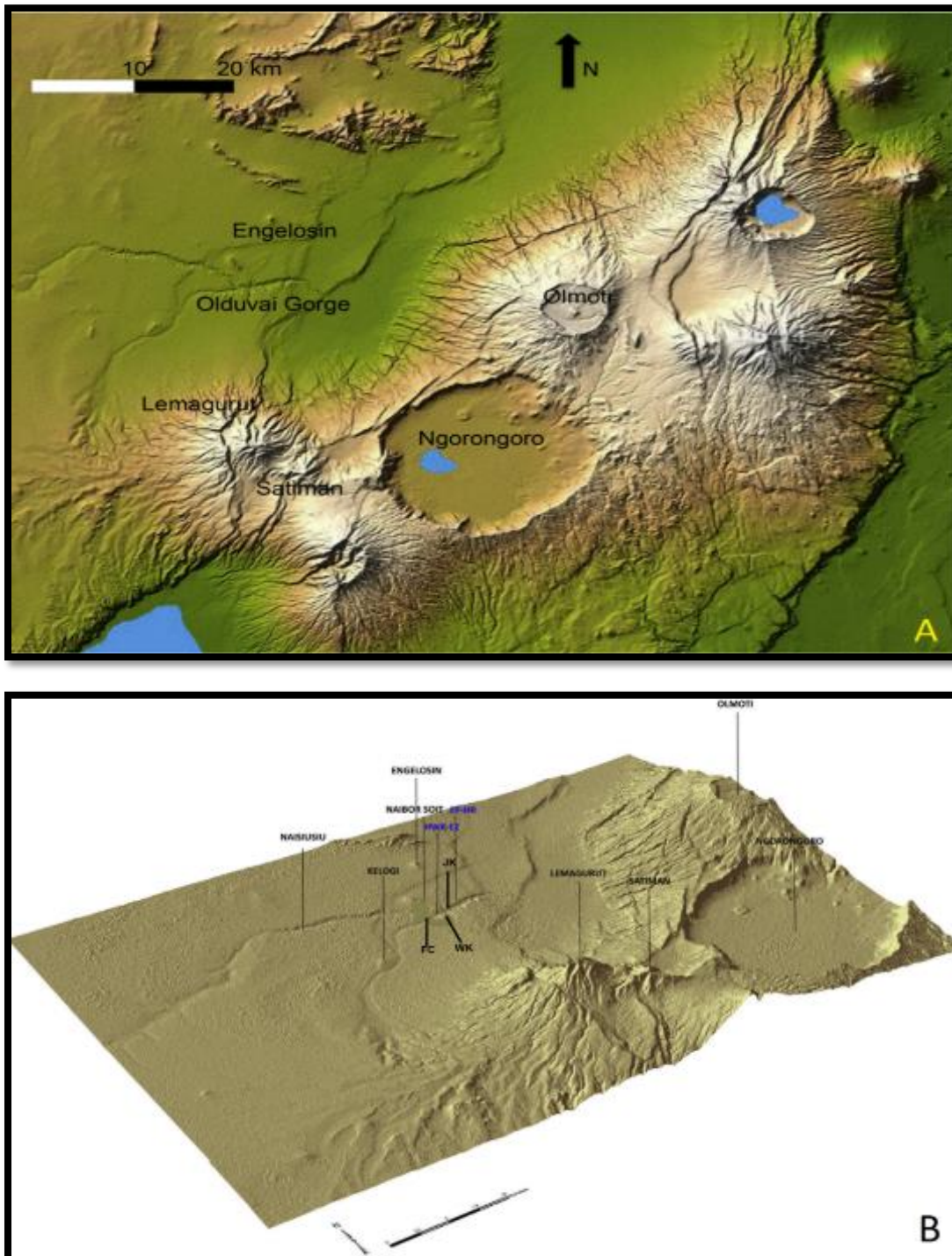


Figure 5. 1: Map of Olduvai showing position of the gorge and volcanoes that acted as primary source of volcanic raw materials A) and digital elevation model of the Olduvai basin with location of primary sources of raw materials and position of archaeological sites under study (B). Map adapted from McHenry and de la Torre (2018).

At Olduvai, raw material studies have been undertaken based on different perspectives. Hay (1976) conducted the geological study of the Olduvai basin, including the identification of raw material types and their sources. Hay's seminal work is important to this study due to: (1) It is one of the first works that laid down foundation for the studies of effects of raw materials for Olduvai stone tool production; (2) it contains map with sources of raw materials that were surveyed during fieldwork.

Moreover, Jones (1979, 1981) conducted experimental analysis by making handaxes using raw materials from the sources that were used by hominins, to determine the form of stone tools made from these raw materials. His work contributes to an understanding of Olduvai raw materials flaking properties and which rock types might have been preferential to hominins. Stiles (1991) explored the hominins transportation of artefact made from the sources to the sites to understand hominins capabilities of planning sequence of activities and site formation; Blumenschine et al. (2008) explored how the distance from sites to the sources of raw materials affected weight and size of detached pieces.

Moreover, McHenry and de la Torre (2018) conducted geochemical and petrographic analysis of raw materials to characterise rocks preferred by hominins for tool making. Their work is the most recent study that acts as a reference for identification of Olduvai raw material types and their properties. This work has been fundamental to the analysis of raw material samples collected from sources in which the analysis is presented below.

This chapter examines a sample of raw materials collected from penecontemporaneous conglomerates (in Beds II, III, and IV) that may have been used as local sources of raw materials by Acheulean hominins at Olduvai, and

examines raw material properties, and considers how distances from sources may have influenced raw material preferences, technological organisation and mobile toolkit designs of hominins from FC, JK, and WK.

At Olduvai, raw materials have been grouped into three main groups, namely: metamorphic rocks, igneous rocks, and sedimentary rocks.

5.2.1 Metamorphic rocks

At Olduvai, quartz, quartzites, granite, and gneisses are rock types under metamorphic rocks category; these rocks vary in lithology and mineral composition (Hay, 1976).

5.2.1.1 Quartzite

Quartzite is a multicrystalline metamorphic rock composed of quartz crystals (Figure 5.2A). It is very coarse-grained and commonly micaceous in Olduvai's northern and eastern regions, including Naibor Soit and highlands to the north of the gorge (Hay, 1976; Kyara, 1999; McHenry and de la Torre, 2018). The quartzite was available to hominins in the Naibor Soit inselberg, located at an approximately 5 km radius from most archaeological sites at Olduvai Gorge (Hay, 1976). This coarse-grained material occurs in slabs, from which tools can easily be produced. In addition, quartzite is versatile and could be used to make small tools such as flakes, scrapers and large tools like bifaces (Jones, 1981). Hay (1976) observed that quartzite from Naibor Soit was the chief raw material for bifaces at Acheulean sites in Beds II, III, and IV.

5.2.1.2 Quartz

Quartz is a monocrystalline semi-precious mineral (Figure 5.2B) and one of nature's most common minerals. Its colour ranges from translucent to transparent, milky or white. It has a non-metallic, light-coloured vitreous luster. Also, it has irregular fracture.

It is the hardest rock used for artifact production, ranging seventh on the Mohs' scale and capable of scratching glass (Kyara, 1999). At Olduvai, quartz and quartzite co-occur on the metamorphic outcrops within the Olduvai area, whereas the closest being Naibor Soit (Kyara, 1999; McHenry and de la Torre, 2018).

5.2.1.3 Gneiss

Gneiss is one of the metamorphic rocks in Olduvai; it is found in the western part of the gorge in the Kelogi inselbergs (Hay, 1976; McHenry and de la Torre, 2018a). Kelogi gneiss is coarse-grained rock with poor quality material for flaking (Figure 5.2G). At Olduvai, gneiss is ubiquitous in the Side Gorge, particularly in Bed II sites (Leakey, 1971; Hay, 1976; Kyara, 1999; McHenry and de la Torre, 2018a), in which the closest source being the Kelogi Hills that were proposed as the primary sources for gneiss raw material (Hay, 1976).

5.2.2 Lava

Lava materials at Olduvai have been grouped into several raw material types. It consists of basalt, phonolite, trachyte, trachyandesite, and lava from Sadiman. Sadiman lava was mainly available in the form of river cobbles from the stream channels flowing from the north of Sadiman (Hay, 1976: 183). The homogeneous nature of Sadiman lava made it the most selected lava for making choppers in Bed I and lower Bed II (Hay, 1976). Hay (1976) explains that the lava cobbles from Sadiman were most likely found within 2 km from most sites. Additionally, the Sadiman lava was mainly used for making heavy-duty tool such as choppers.

5.2.2.1 Basalt

Basalt is one of the volcanic lava types that originated from the nearby volcanic highlands in the region (Figure 5.2C) (Hay, 1976; McHenry and de la Torre, 2018). Basalt originates mostly from Lemagrut, a volcano located about 18 km south of Olduvai Gorge. Basalt is available as river-rounded cobbles and boulders; generally grey and pale black; it varies from medium to fine-grained. The size and nature of their occurrence made basalt and other lavas suitable for biface blanks (Jones, 1979).

5.2.2.2 Phonolite

Phonolite materials (Figure 5.2D) are found outcropping at the foot of Engelosin and occurs in tabular pieces. This material is dense and has weak foliation. Phonolite is fine-grained, brittle and easy to flake (Hay, 1976; Jones, 1979, 1981; McHenry and de la Torre, 2018). Although, Engelosin phonolite was not reported to occur on Bed I sites, it was found near the base of Bed II and became more abundant in later sequences in beds III-IV. Its abundant distribution increased in both Main and Side Gorges, and as far as Kelogi, approximately 18 km from the source (Hay, 1976: 184). In addition, phonolite was also found in Sadiman, particularly on the stream channels; Sadiman phonolite is chiefly porphyritic nephelinite and nepheline with dark greenish-gray colour (Hay 1976: 13).

5.2.2.3 Trachyandesite

Trachyandesite is a feldspathic extrusive rock that is composed of trachyte and andesite (Figure 5.2E) (Kyara, 1999). McHenry and de la Torre (2018) identified different groups of trachytes at Olduvai, whereas there are those with fine and coarse groundmass and phenocrysts. Most of the trachyandesite specimens contain some

phenocrysts, and major source of this rock type at Olduvai is Lemagrut (Hay, 1976; Kyara, 1999; McHenry and de la Torre, 2018).

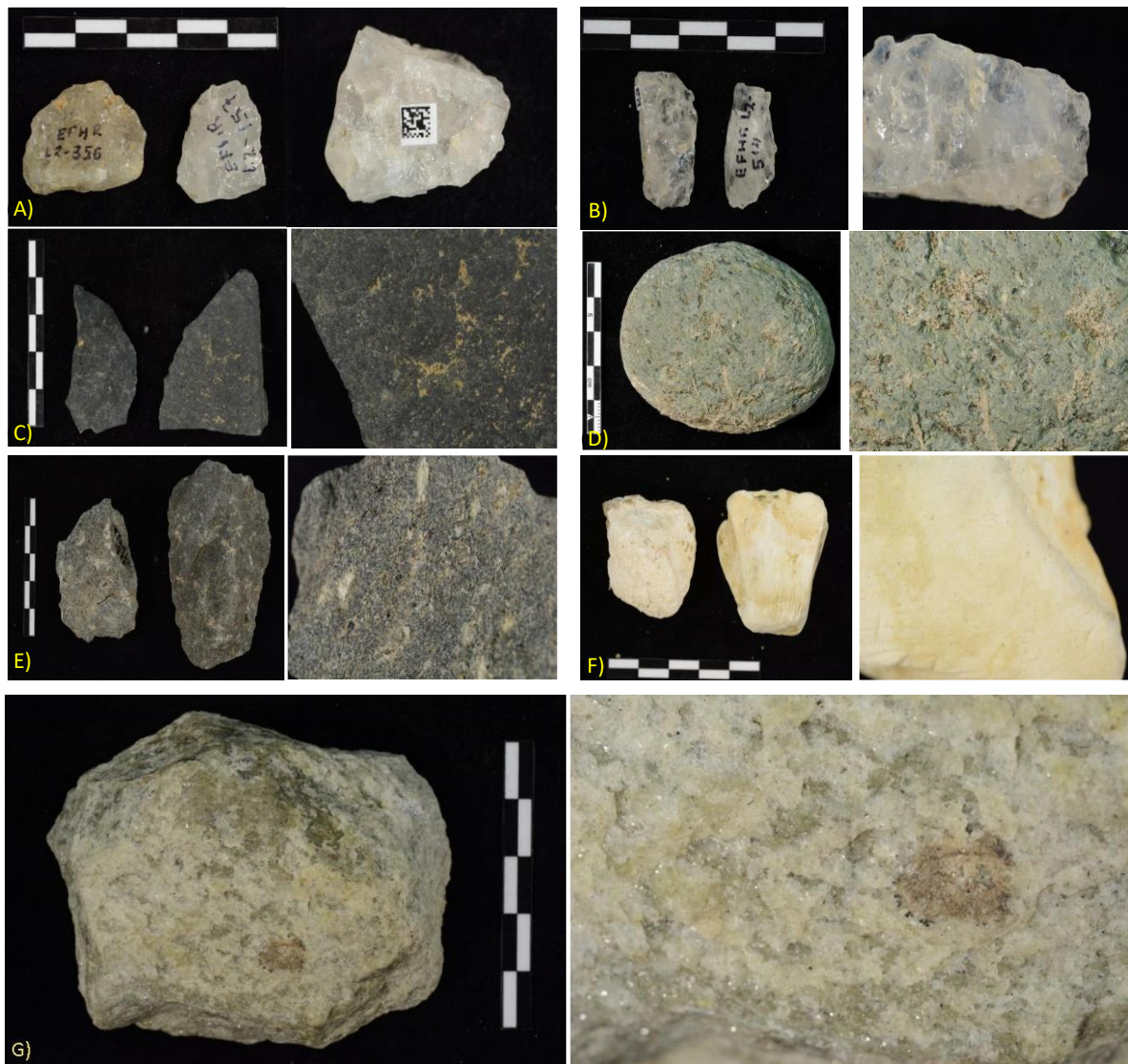


Figure 5. 2: Olduvai rock types (A-F): quartzite (A), quartz (B), basalt (C), phonolite (D), trachyte (E), chert (F), and gneiss (G) McHenry and de la Torre (2018).

5.2.3 Sedimentary rocks

5.2.3.1 Chert

Chert nodules are examples of sedimentary rocks that formed within the sediments of the Olduvai palaeolake during specific intervals; they are scattered within the lacustrine claystones of Bed II near RHC locality (McHenry and de la Torre, 2018).

Chert was formed in nodules of irregular shapes (Figure 5.2F). This material was formed through a precipitation of sodium-silicate minerals from the lake waters and changed chemically to form chert nodules (Hay, 1968; Stiles, Hay and O'Neil, 1974; Stiles, 1991; Kimura, 1997, p. 1, 1999). This strong and fine-grained material is frequently white and cloudy or milky, and sometimes yellowish-brown (Jones, 1981). It consists of microcrystalline quartz and bears a resemblance to flints in mechanical properties. At Olduvai, chert was formed in Beds I and II lake deposits, and it was mainly preferred for making flakes and other light-duty stone tools; most sites with chert materials were mainly located near the lake margins and were restricted only within 1 km from the local sources (Hay, 1976).

5.2.4 Lithic raw material procurement strategies at Olduvai

Research questions pursued in this chapter are: **What is the distance from raw material sources to the site? Did the raw materials sources reflect technological organisation of the *Homo erectus* groups?** The most relevant to the current study, moreover, are **What is the raw material economy of *Homo erectus* during Beds II, III and IV at Olduvai Gorge, and is there a relationship between technological capabilities and organisation and raw material?** Such questions can be addressed with the analysis of lithic raw materials collected from sources which presumably were used by hominins during prehistoric times.

5.3 Results

In February 2020, a raw material survey was undertaken at Olduvai Gorge. To gather information on the raw materials available for prehistoric hominins, a systematic survey of penecontemporaneous lithic raw materials sources was conducted to collect

a sample of raw materials that potentially were used to manufacture stone tools. During the survey, two sources were randomly selected and sampled; these conglomerates were selected because they were located within the same stratigraphy as the sites and abundance of cobbles, which were collected for raw materials analysis. Raw Material Source 1 (RMS1) and Raw Material Source 2 (RMS2) (Figure 5.3 and 5.4). Three raw material types were identified at RMS1 and RMS2: basalt, phonolite, and trachyte. The survey data are presented sequentially, allowing us to comprehend the raw material economy at Olduvai from Beds II, III, and IV.

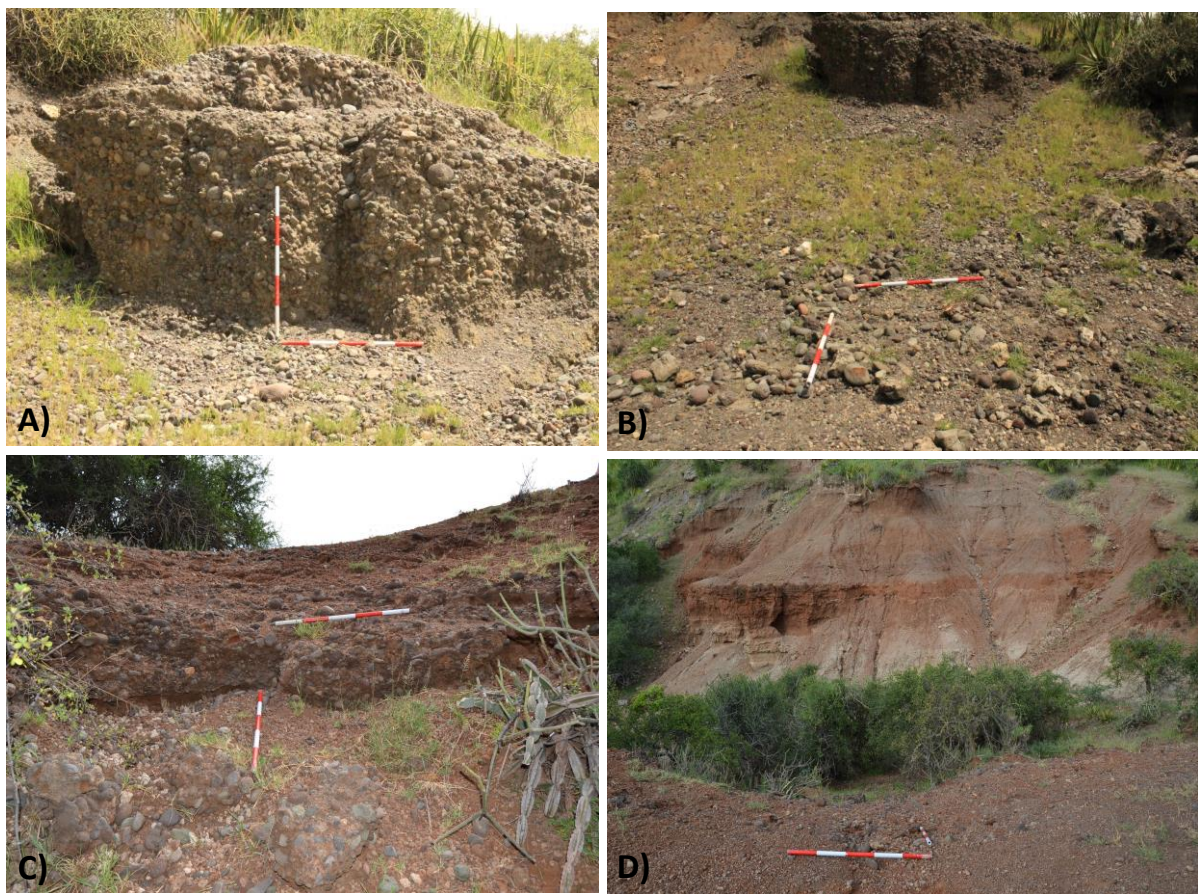


Figure 5. 3: Raw material outcrops where the samples were recovered. (A-B) RMS1 outcrop; (C-D) RMS2 outcrop.

5.3.1 The raw materials source: RMS1

The RMS1 was deposited within Bed II, and it was potentially a source of raw materials for FC East hominins. It is located at the south of the Olduvai confluence, just west of the Olduvai Museum (Figure 5.4). Three raw material types were collected from the outcrop, namely basalt, phonolite, and trachyte (Table 5.1, figure 5.5A). All these lava rocks might have originated from the volcanic highlands to the south and east, and were available to hominins as cobbles found in the stream channels draining from the highlands (Figure 5.1A-B) (McHenry and de la Torre, 2018).

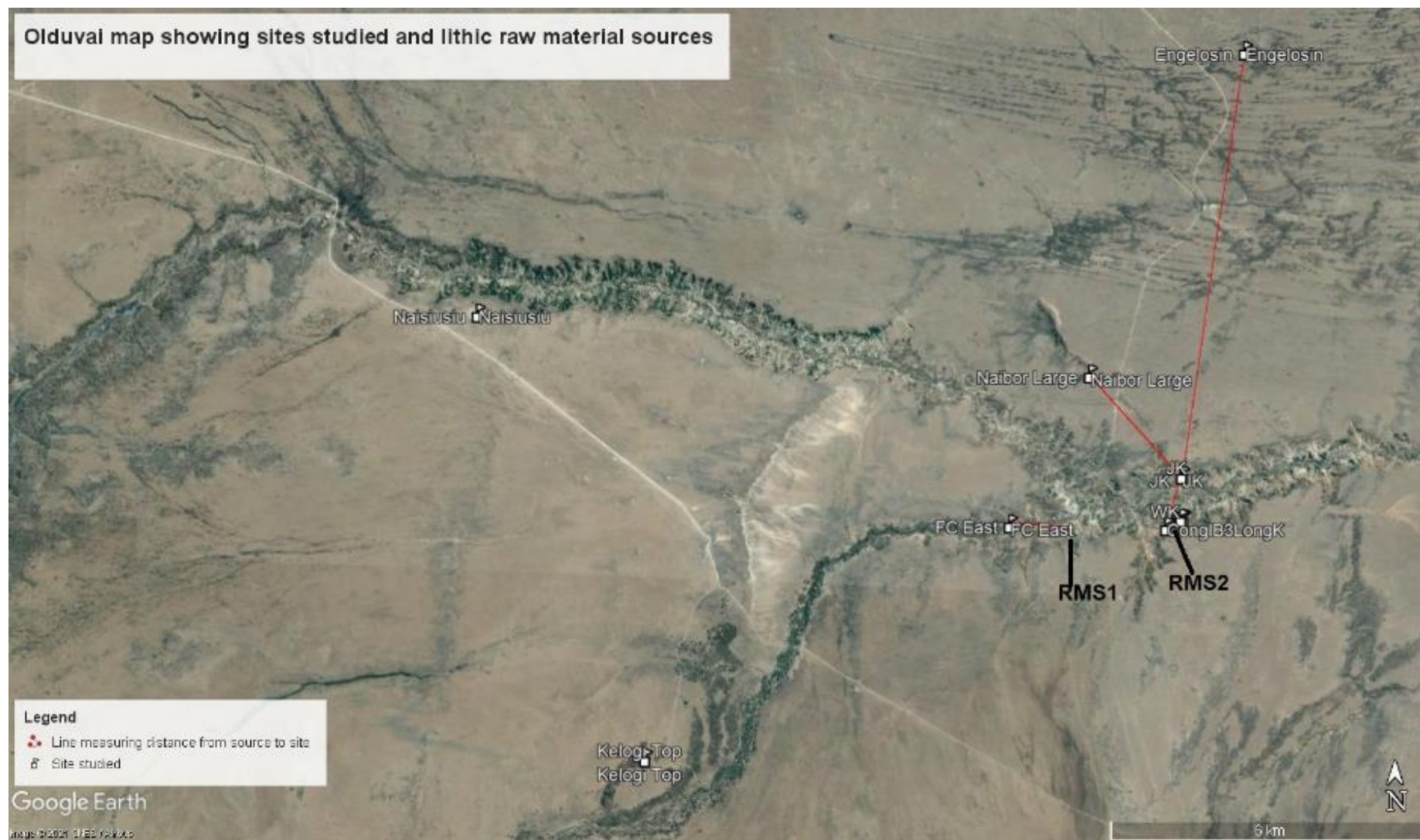


Figure 5. 4: Map showing Olduvai raw material sources and locations where samples were recovered (RMS1 and RMS2).

Table 5. 1: Table showing frequencies of rock type and weight in the RMS1 samples.

Rock type	Frequency		Weight
	n	%	grams
Basalt	65	65	59489
Phonolite	24	24	16343
Trachyte	11	11	11291
Total	100	100	87123



Figure 5. 5: A pile of cobble samples collected from raw material sources during raw material survey.

The cobbles are mostly sub-spheroid (35%; figure 5.6A-B) and fine-grained (Figure 5.6C-D) and hence good for knapping activities. Vesicular rocks are more common than coarse and fine rocks (Figure 5.6E). Basalt rocks are more vesicular, followed by trachyte, whereas phonolite is less frequently vesicular (Figure 5.6F). Phonolite cobbles are more angular than trachyte and basalt, making them more suitable for knapping activities (Figure 5.6B). Groundmass is fine-grained (Figure 5.6C), with trachyte being the most frequent, followed by basalt and phonolite (Figure 5.6D). Figure 5.6D shows preference of trachyte and basalt, whilst avoiding the use of phonolite; phonolite also appears to be coarse-grained than basalt and trachyte.

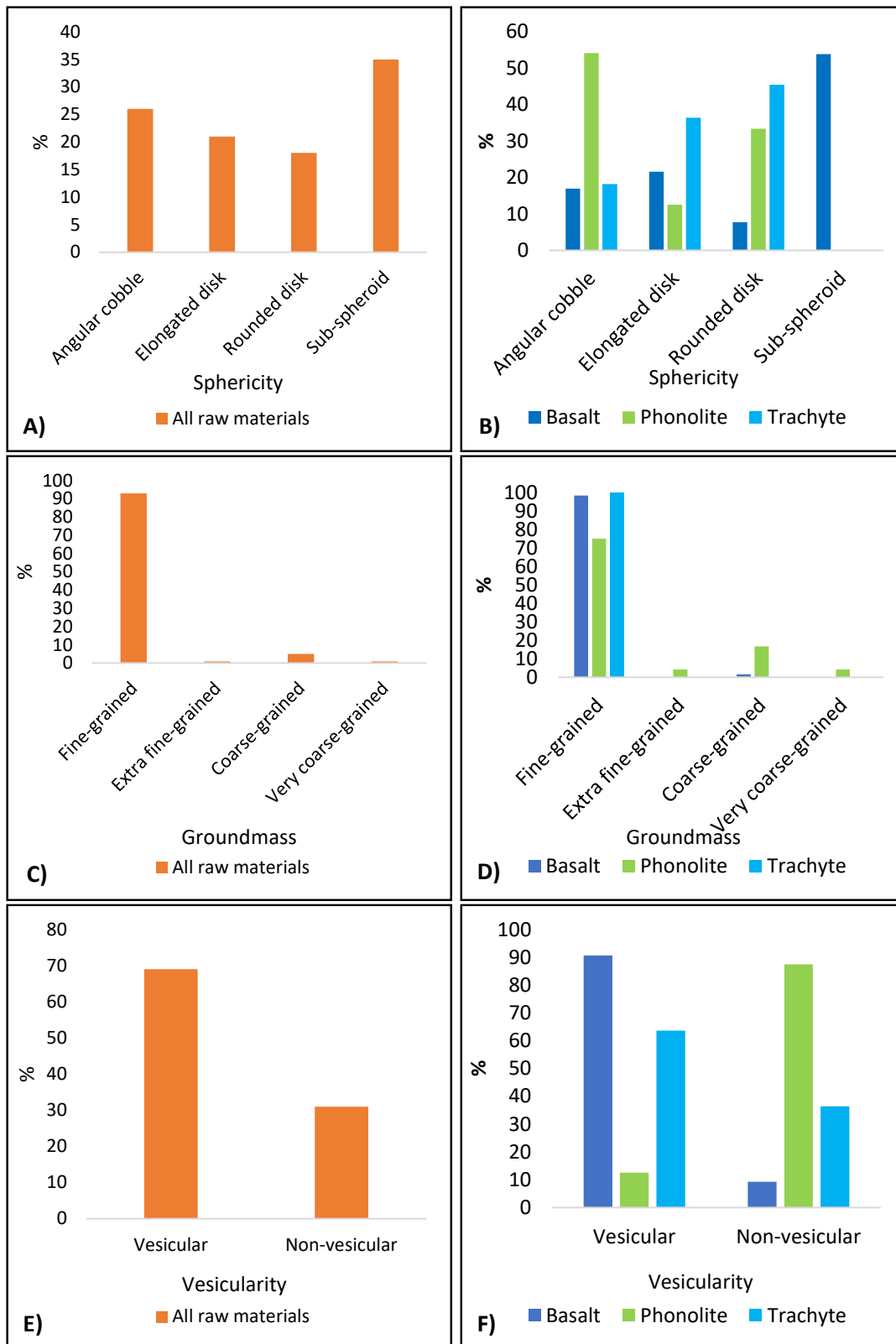


Figure 5. 6: Frequency distribution of various attributes by rock type in RMS1. (A-B) sphericity; (C-D) groundmass; and (E-F) vesicularity.

Basalts (n=65, 65%, >59kg) are the most frequent rock types and weigh in total more than phonolite (n=24, 24%, >16kg) and trachyte (n=11, 11%, >11kg) (Table 5.1).

Examination of length of individual cobbles shows that most cobbles are in the length range of 100-119 mm and 120-139 mm (Table 5.2; figure 5.7A). Within these length ranges, trachyte and phonolite were the most abundant rock types (Figure 5.7B). In terms of weight, it can be shown that most cobbles weigh between 801 and 1600 grams (Figure 5.7C). Within this weight range, basalt appears to be the most prevalent, followed by trachyte and phonolite (Figure 5.7D). In addition, basalts are, on average, larger than phonolite and trachyte (Table 5.3).

Trachytes occur as the less frequent cobbles in the RMS1 conglomerate (Table 5.1). Their average weight is greater than basalt and phonolite (Table 5.3). This is corroborated by the data on weight whereas cobbles weighing over 1600g being mostly trachyte followed by basalt and phonolite (Figure 5.7D).

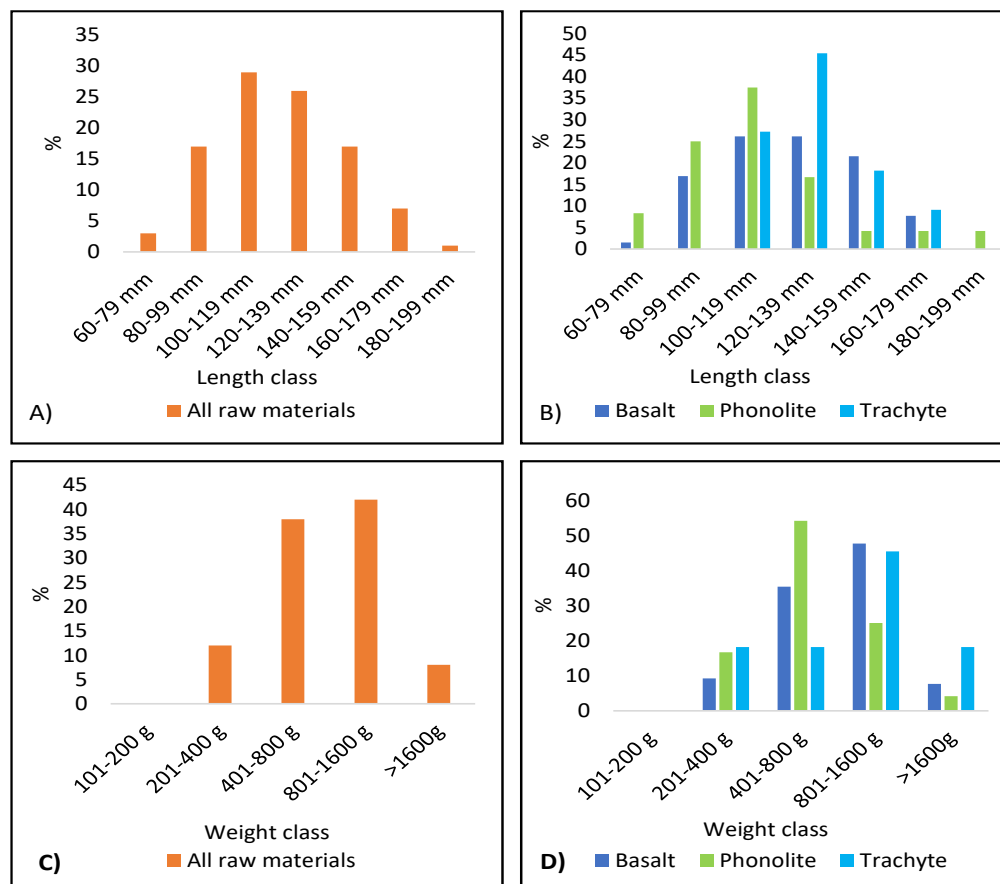


Figure 5. 7: Figure showing length (A-B) and weight (C-D) of the RMS1 cobble sample.

Table 5. 2: Table showing raw materials attributes in the RMS1 source.

		Raw Material						Grand Total	
		Basalt		Phonolite		Trachyte			
		n	%	n	%	n	%	n	%
Length classes	60-79 mm	1	2	2	8	0	0	3	3
	80-99 mm	11	17	6	25	0	0	17	17
	100-119 mm	17	26	9	38	3	27	29	29
	120-139 mm	17	26	4	17	5	45	26	26
	140-159 mm	14	22	1	4	2	18	17	17
	160-179 mm	5	8	1	4	1	9	7	7
	180-199 mm	0	0	1	4	0	0	1	1
	Total	65	100	24	100	11	100	100	100
Weight classes	101-200 g	0	0	0	0	0	0	0	0
	201-400 g	6	9	4	17	2	18	12	12
	401-800 g	23	35	13	54	2	18	38	38
	801-1600 g	31	48	6	25	5	45	42	42
	>1600g	5	8	1	4	2	18	8	8
	Total	65	100	24	100	11	100	100	100
Sphericity	Angular cobble	11	17	13	54	2	18	26	26
	Elongated disk	14	22	3	13	4	36	21	21
	Rounded disk	5	8	8	33	5	45	18	18
	Sub-spheroid	35	54	0	0	0	0	35	35
	Total	65	100	24	100	11	100	100	100
Groundmass	Fine-grained	64	98	18	75	11	100	93	93
	Extra fine-grained	0	0	1	4	0	0	1	1
	Coarse-grained	1	2	4	17	0	0	5	5
	Very coarse-grained	0	0	1	4	0	0	1	1
	Total	65	100	24	100	11	100	100	100
Vesicularity	Vesicular	59	91	3	13	7	64	69	69
	Non-vesicular	6	9	21	88	4	36	31	31
	Total	65	100	24	100	11	100	100	100

Table 5. 3: Descriptive statistics of metric features of cobble samples in the RMS1 conglomerate.

		Minimum	Maximum	Mean	Std. Dev.
Basalt	Length	75	175	123.3	24.1
	Width	60	153	91.7	18.5
	Thickness	35	114	63.2	13.7
	Weight	308	2686	915.2	478.1
Phonolite	Length	70	180	112.4	26.2
	Width	53	131	80.7	17.6
	Thickness	38	81	56.1	11.5
	Weight	204	2231	681	427.1
Trachyte	Length	102	170	131.5	18.8
	Width	60	118	90.7	18.8
	Thickness	30	88	61.3	20.5
	Weight	312	2168	1026.5	610.5

5.3.2 Comparative results: RMS1 cobbles and FC East assemblage

A comparison of geological samples and archaeological assemblages demonstrates the degree of raw material selectivity employed by the early Acheulean toolmakers at FC East.

5.3.2.1 Selection of rock type

Data on rock type from the archaeological sample were compared to those in the conglomerate (RMS1). Frequencies of raw materials in the archaeological sample corresponds with those in the source conglomerate (Figure 5.8). However, trachyte appears to be absent in the archaeological sample (Figure 5.8).

Examination of rock types represented within the RMS1, and FC East indicates that rock type contributed to the selection process and decision making when acquiring raw materials from the source. In addition, the distance from RMS1 conglomerate to

FC East is approximately 1.5 kilometres (Figure 5.4). This distance may have allowed hominins to walk and collect raw material from the source. This is corroborated by the evidence indicated in figure 5.8, which shows similarities in the presence of basalt and phonolite between RMS1 and FC East. Trachyte, however, does not seem to be represented in the archaeological assemblages (Figure 5.8). The absence may either be due to vesicularity of most trachyte cobbles as evidenced in figure 5.6F or other reasons such as its availability in the conglomerates. Figure 5.8 shows that trachyte is less abundant compared to basalt and phonolite materials.

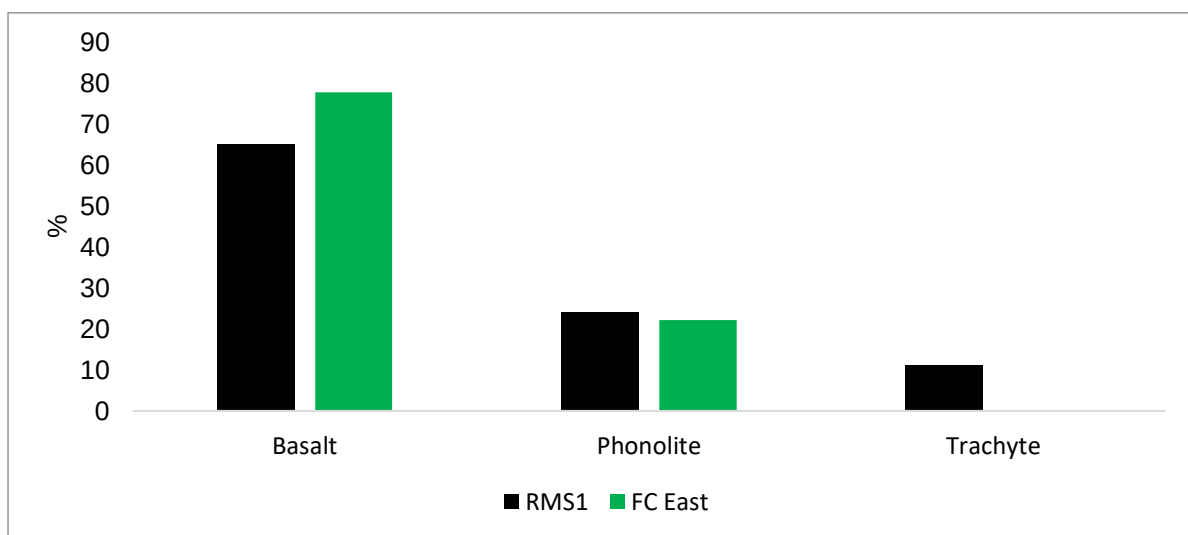


Figure 5. 8: Frequency of rock types between RMS1 and FC East assemblages.

5.3.2.2 Selection of raw material shape

Most cobbles from the sampled conglomerate appear to be sub-spheroid and angular with a few of them being elongated and rounded disks (Figure 5.6A-B). Angular and sub-spheroid cobbles tend to provide angles suitable for getting flakes from a cobble. Thus, it can be suggested that most cobble samples were suitable for toolmaking at FC East site.

5.3.2.3 Selection for cobble size

The size of cobble can play an important role in knapping strategies of prehistoric toolmakers. Different dimensions of cobbles were recorded from the RMS1 sample. Goldman-Neuman and Hovers (2012) used flakes that retained cortex on proximal and distal ends to approximate minimal knapped cobble size. This study used similar method to demonstrate the minimal cobble size selected by hominins.

Figure 5.9A shows conglomerate cobbles with a length range of 70 to 180 mm, while flakes in the FC East assemblage have a length range of 20 to 80 mm. Goldman-Neuman and Hovers (2012: 359) state that “flakes in the assemblage are not expected to directly mimic the sizes of the original clasts”. It is worth noting that the cobbles from RMS1 were large enough to allow toolmakers to produce flakes. As shown in figure 5.9B, the preferred flake sizes for both basalt and phonolite raw materials were within the length of cobbles. Although toolmakers produced flakes with length class of 20 to 80 mm, the cobble size could allow them to produce larger flakes of up to over 100mm in length (Figure 5.9A).

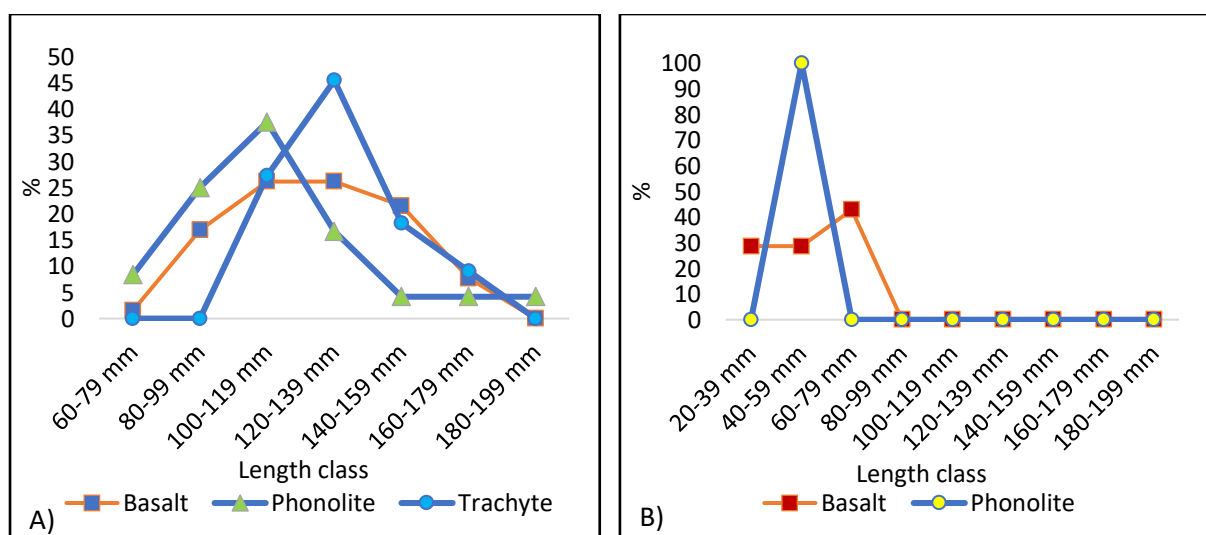


Figure 5. 9: Length distribution of rock types. (A) RMS1 sample; (B) whole flakes in the FC archaeological assemblage.

5.3.3 The raw material source: RMS2

The RMS2 was located within a Beds III conglomerate and was potentially a penecontemporaneous source of raw materials for JK West, JK2, and WK sites, respectively (Figures 5.3C-D, 5.4, and 5.5B). It is located south of JK site and just southwest of the WK site (Figure 5.4). RMS2 is situated about 500 meters from JK and 100 meters from WK sites (Figure 5.4). At RMS2, basalt, phonolite and trachyte raw materials were also collected (Table 5.4, figure 5.5B).

The cobbles in RMS2 are mostly angular and fine-grained (Figure 5.10A and C; table 5.5). The most common angular cobble is phonolite, followed by trachyte and basalt (Figure 5.10B). Despite being the least representative of angular cobbles, basalts appear to be the most prevalent in terms of grain size, followed by trachyte and phonolite (Figure 5.10D). In addition, some phonolite and trachyte cobbles are coarse-grained, with phonolite cobbles being the most prevalent than trachyte cobbles (Figure 5.10D).

Table 5. 4: Table showing rock type and weight frequencies in the RMS2 samples.

RMS2					
		Frequency		Weight	
		n	%	grams	%
Rock type	Basalt	54	54	45072	58
	Phonolite	17	17	12147	16
	Trachyte	29	29	20830	27
Total		100	100	78049	100

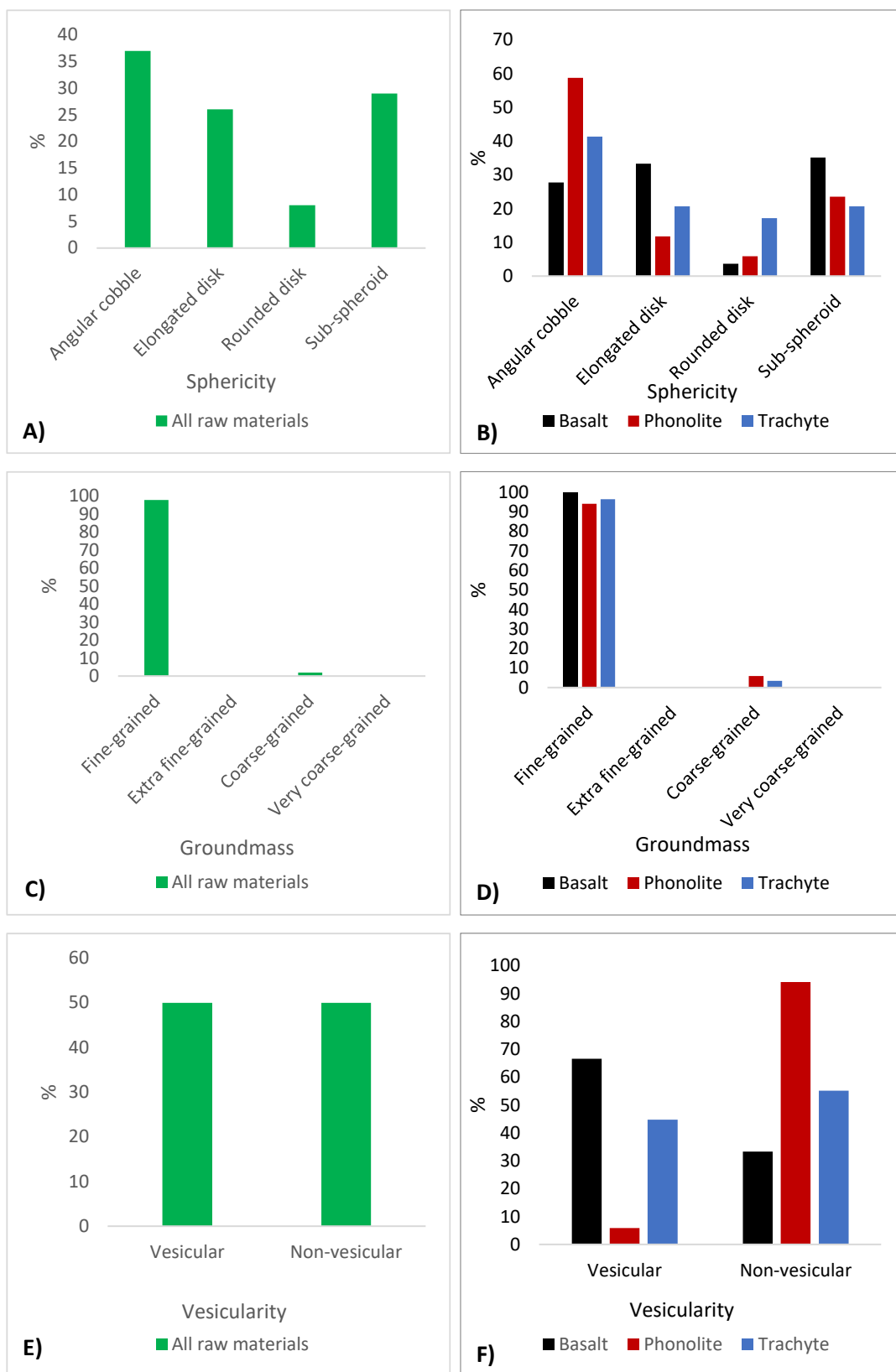


Figure 5. 10: Frequency distribution of various attributes by rock type in RMS2. (A-B) sphericity; (C-D) groundmass; and (E-F) vesicularity.

The vesicularity of rocks was also examined. When examining all cobbles samples, results shows that there is 50% of vesicular and 50% of homogeneous cobbles (Figure 5.10A). However, analysis of vesicularity per raw materials shows that most cobbles are homogeneous, with phonolite being the most prevalent, followed by trachyte, whereas basalt being the least represented (Figure 5.10D). In addition, vesicular cobbles appear be predominantly characterised by basalt, followed by trachyte, whereas phonolite being the least dominant (Figure 5.10F). Therefore, it is possible that hominins encountered more angular cobbles, particularly fine-grained and non-vesicular. This data will be compared to actual archaeological samples to determine similarities and differences. This will show whether these characteristics aided decision making when hominins chose cobbles for tool manufacture.

In terms of rock types, basalt (n=54, 54%) is the most common, followed by trachyte (n=29, 29%) and phonolite (n=17, 17%) (Figure 5.11; table 5.5). The majority of cobbles range in length from 100 to 119 mm, with phonolite being the most prevalent, followed by trachyte and basalt (Figure 5.12A-B; table 5.5). Trachyte, however, is the longest, with a maximum length of 196 mm, an average length of 116 mm, and a width of 86 mm (Table 5.6).

Furthermore, most cobbles weigh 401-800 grams, with phonolite being the most frequent, followed by trachyte and basalt (Figure 5.12C-D; table 5.5). Despite their low frequency, basalt and trachyte are heavier than phonolite; basalts have an average weight of 835 grams, followed by trachyte (718 grams), and phonolite (714.5 grams) (Figure 5.12D; Table 5.6). Thus, the RMS2 conglomerate may have provided hominins with long and suitable cobbles for making stone tools.

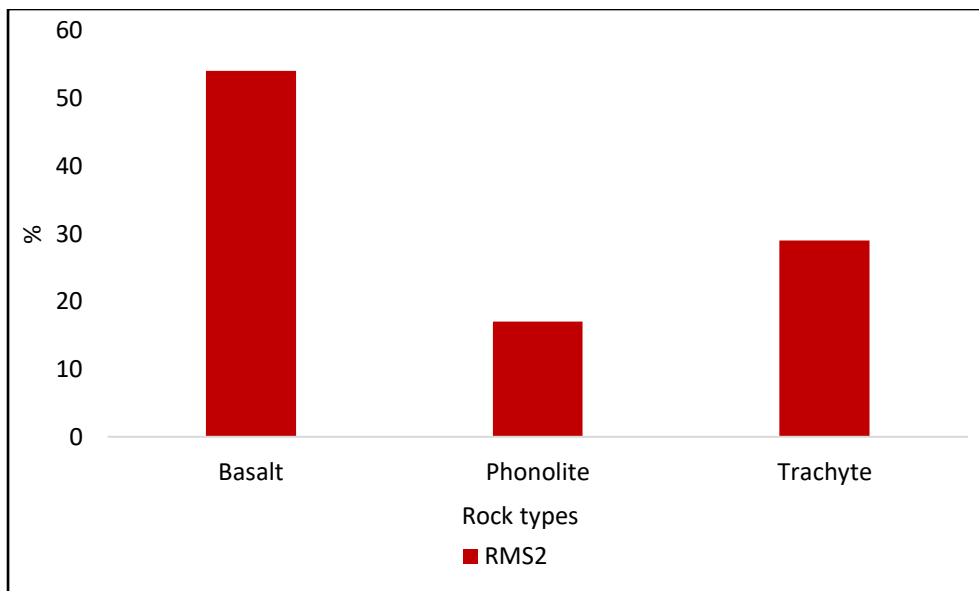


Figure 5. 11: Frequency of rock types in the RMS2 sample.

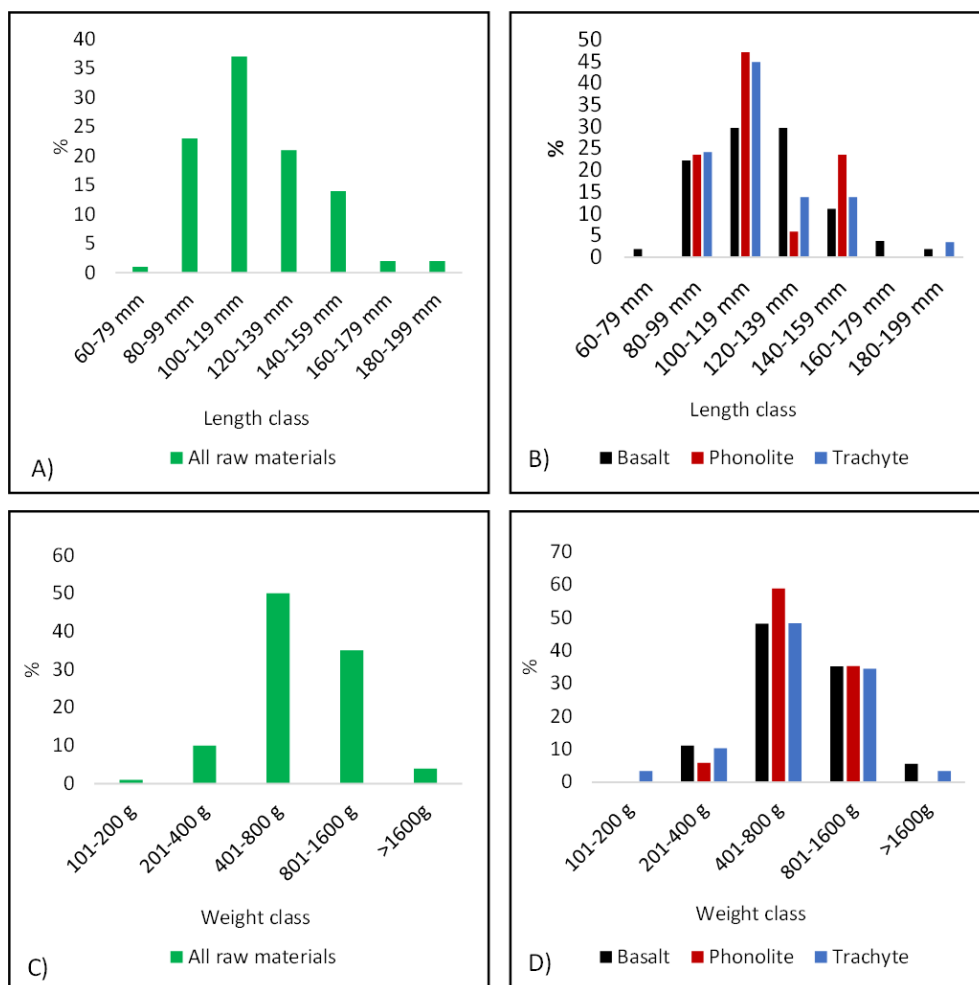


Figure 5. 12: Length and weight of the RMS2 cobble sample.

Table 5. 5: Raw material attributes in the RMS2 source.

		Raw Material						Grand Total	
		Basalt		Phonolite		Trachyte			
		n	%	n	%	n	%	n	%
Length classes	60-79 mm	1	2	0	0	0	0	1	1
	80-99 mm	12	22	4	24	7	24	23	23
	100-119 mm	16	30	8	47	13	45	37	37
	120-139 mm	16	30	1	6	4	14	21	21
	140-159 mm	6	11	4	24	4	14	14	14
	160-179 mm	2	4	0	0	0	0	2	2
	180-199 mm	1	2	0	0	1	3	2	2
	Total	54	100	17	100	29	100	100	100
Weight classes	101-200 g	0	0	0	0	1	3	1	1
	201-400 g	6	11	1	6	3	10	10	10
	401-800 g	26	48	10	59	14	48	50	50
	801-1600 g	19	35	6	35	10	34	35	35
	>1600g	3	6	0	0	1	3	4	4
	Total	54	100	17	100	29	100	100	100
Sphericity	Angular cobble	15	28	10	59	12	41	37	37
	Elongated disk	18	33	2	12	6	21	26	26
	Rounded disk	2	4	1	6	5	17	8	8
	Sub-spheroid	19	35	4	24	6	21	29	29
	Total	54	100	17	100	29	100	100	100
Groundmass	Fine-grained	54	100	16	94	28	97	98	98
	Extra fine-grained	0	0	0	0	0	0	0	0
	Coarse-grained	0	0	1	6	1	3	2	2
	Very coarse-grained	0	0	0	0	0	0	0	0
	Total	54	100	17	100	29	100	100	100
Vesicularity	Vesicular	36	67	1	6	13	45	50	50
	Non-vesicular	18	33	16	94	16	55	50	50
	Total	54	100	17	100	29	100	100	100

Table 5. 6: Descriptive statistics of metric features of cobble samples in the RSM2 conglomerate.

		Minimum	Maximum	Mean	Std. Dev.
Basalt	Length	65	195	119	25
	Width	37	123	86	16.7
	Thickness	28	100	59	15.2
	Weight	253.0	2936.0	835	484.9
Phonolite	Length	83	151	114.5	21.5
	Width	57	97	79.9	11.1
	Thickness	37	85	58.9	13.4
	Weight	387	1386	714.5	311.6
Trachyte	Length	86	196	116	23.5
	Width	58	122	86	15.9
	Thickness	26	76	56	12.8
	Weight	196	2060	718	370.1

5.3.3.1 Comparative results: RMS2 cobbles and JK West, JK2, and WK assemblages

Geological samples from RMS2 and archaeological assemblages from JK West, JK2, and WK were compared to demonstrate the degree of raw material selectivity employed by Acheulean toolmakers in Beds III and IV. The comparison focuses on the selection of rock type, rock morphology, size, groundmass, and vesicularity.

5.3.3.2 Selection of rock type

Frequency distribution of rock types from RMS2 corresponds with those from archaeological samples, whereas three rock types were used as main raw materials (Figure 5.13). Overall, basalt appears to be the most common rock type used by hominins across all sites, with phonolite and trachyte being slightly less common (Figure 5.13). Figure 5.13 shows that JK West hominins used basalt less frequently than the JK2 and WK. Furthermore, trachyte appears to be used more frequently in JK West than in JK2 and WK. Phonolite appears to be used with similar frequency across all sites (Figure 5.13). Thus, it can be said that hominins at JK West, JK2, and WK selected three lava rock types for stone tool manufacture. These rock types were used in different frequencies, probably due to their abundance, size, and weight that was required to be transported to the site and other traits such as rock shape.

5.3.3.3 Selection of rock morphology

The cobble shape facilitates the knapping of raw material. Data from raw materials from the conglomerate show that the majority of the cobbles were angular and sub-spheroid, providing suitable angles for knapping (Figure 5A-B; table 5.5). Elongated and rounded disks were less frequent cobbles (Figure 5.10A-B). Thus, it can be

argued that hominins at JK West, JK2, and WK encountered angular and sub-spheroid cobbles, which they may have used to make stone tools.

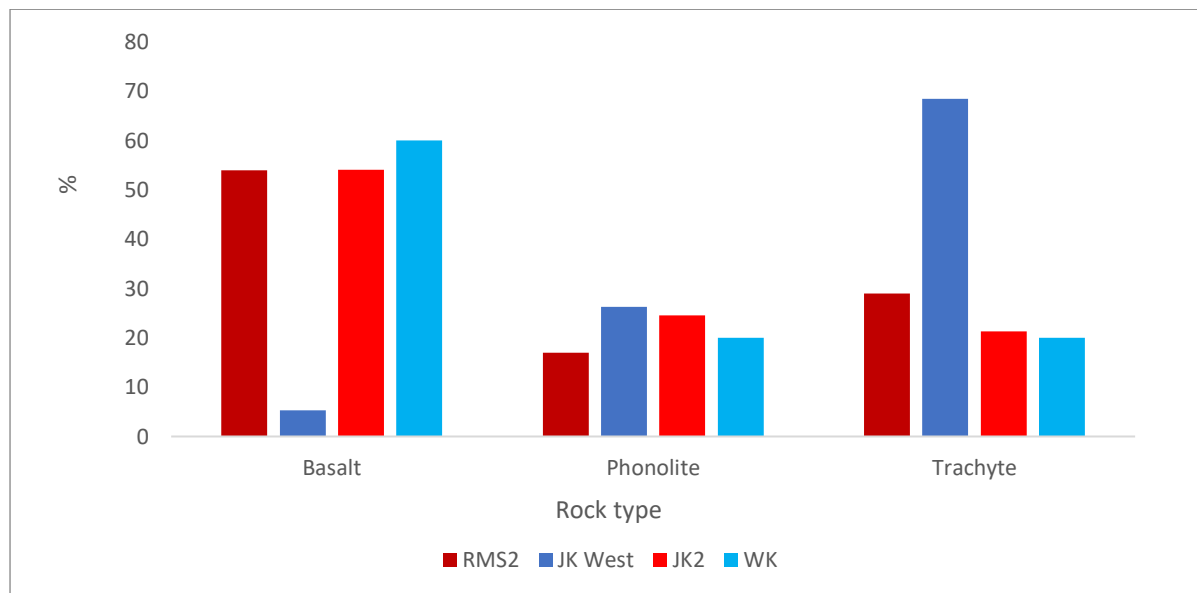


Figure 5. 13: Frequency of rock type between RMS2 cobbles and archaeological samples from JK, JK2, and WK sites.

5.3.3.4 Selection of rock size

Cobble sizes are important in stone tool making processes during prehistoric times. Different dimensions were recorded during the analysis. The length range of cobbles collected from the RMS2 conglomerate is shown in Table 5.5; cobble length ranges from 60 mm to 199 mm (Figure 5.14A). However, archaeological flakes come in a variety of lengths. JK West, for example, has flakes ranging in length from 20-39 mm (Figure 5.14B). JK2 flakes have length ranging from 20-39 mm to 100-119 mm (Figure 5.14C). Furthermore, the WK flakes have lengths ranging from 20-39 mm to 60-79 mm (Figure 5.14D). Thus, it could be interpreted that the sizes of cobbles were large enough to provide flake sizes obtained from the archaeological assemblages. Therefore, cobble size played a significant role in the selection of appropriate rock size for stone tool manufacture.

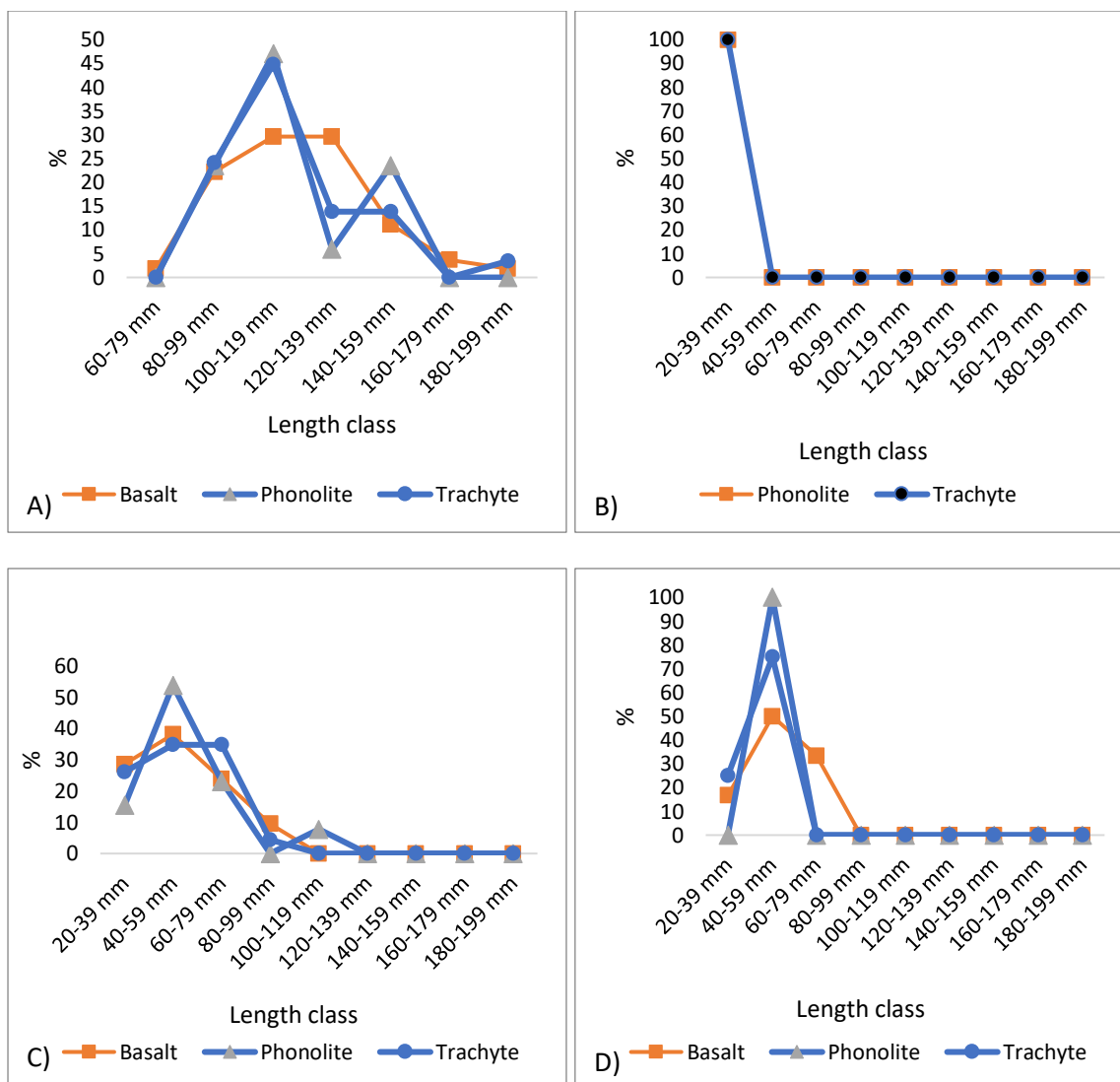


Figure 5. 14: Length distribution of rock types from RMS2 and archaeological flakes. (A) RMS2 cobbles; (B) JK West flake; (C) JK2 flakes; and (D) WK flakes.

5.3.3.5 Groundmass

The rock groundmass was examined by observing grain size and following the classification scheme developed by McHenry and de la Torre (2018). Groundmass was classified into four types based on grain size: fine-grained, extra-fine-grained, coarse-grained, and very coarse-grained. Figure 5.15A shows that the majority of the specimens have fine-grained groundmass, with the exception of JK West, which shows some specimens with coarse-grained groundmass (Figure 5.15A). Thus, it can

be argued that hominins at JK West, JK2, and WK preferred fine-grained cobbles for stone tool manufacture.

5.3.3.6 Vesicularity

During the analysis, the rock vesicularity was also examined. The vesicularity was measured on the levels: non vesicular and versus vesicular. Hominins may have avoided vesicular cobbles due to their bad quality for knapping activities. Schick and Toth (1993), for instance, argue that Koobi Fora toolmakers systematically avoided vesicular lavas and cobbles with weathering flaws. Figure 5.15B shows that most cobbles in the conglomerate, however, were non-vesicular. As a result, this archaeological evidence indicates that most hominins from JK West, JK2, and WK avoided vesicular cobbles in favour of homogeneous cobbles. This is due to high frequency of non-vesicular cobbles than vesicular cobbles (Figure 5.15B). Thus, it could be argued that JK West, JK2, and WK toolmakers were able to distinguish easily flaked materials suitable for the artefacts they intended to manufacture. Therefore, this could have helped them in planning the number of raw materials to be transported to sites.

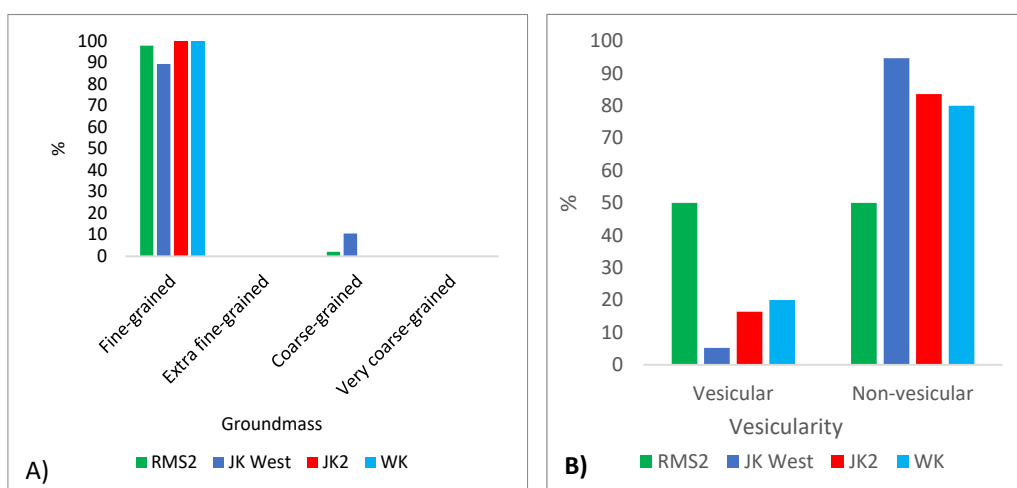


Figure 5. 15: Comparisons of raw material samples and archaeological materials from JK West, JK2, and WK. (A) Groundmass (B) Vesicularity.

5.4 Discussion and conclusion

The results from the cobble sample analysis and archaeological materials show that stone tool makers from these sites were able to locate, identify, and select raw materials with desirable characteristics. Data on rock type, sphericity, groundmass, and vesicularity all suggest a degree of raw material selectivity in these Acheulean sites of Olduvai.

Analyses from the two raw material sources and archaeological assemblages reveal that hominins in all sites preferred homogeneous and fine-grained rock for stone tool making. This is especially true for basalt rocks, which appear to be preferred in FC East. Also, phonolites were part of the rock types that were utilized (Figure 5.8). Similar results are observed in JK West, JK2, and WK sites (see chapters 7 and 8).

It is clear that hominins in JK West, JK2, and WK chose specific rock types for stone tool making. Hominins may have not picked up rocks at random during raw material acquisition; instead, they may have chosen them based on various qualities such as phenocrysts, size, and visual evaluation of cortex characteristics (Stout et al 2005). Thus, the frequency of basalt (figure 5.13) suggests intentional selection of that rock type by the hominins. Furthermore, the avoidance of coarse-grained cobbles and the selection of fine-grained groundmass (Figure 5.15) demonstrate that hominins were aware of the rock quality before collecting and transporting them to sites.

Goldman-Neuman and Hovers (2012: 361) mentions that one of the criteria that seemed to have guided Makaamitalu hominins was the “discrimination against impurities in the matrix (bands and vesicles)”. The data presented in this chapter demonstrate that Olduvai hominins were aware of the impurities in some rocks and avoided those vesicular rocks in favour of homogeneous rocks (Figure 5.15B).

Moreover, flake length distribution indicates that the cobbles size corresponds to the flake sizes that were analysed from the archaeological assemblages (Figure 5.14). Thus, the rock types transported from the conglomerate to the sites had to be of a certain size and other characteristics, such as sphericity which involved angular, elongated, rounded disk, and sub-spheroid cobbles; these were essential features in knapping. Goldman-Neuman and Hovers (2012) add that hominins assessed these properties by testing cobbles; this process was done at the source prior to their transport to a site.

Furthermore, it is worth noting that most cobbles analysed during the raw materials survey were lava cobbles. However, the most predominant raw materials observed in the archaeological assemblages was quartzite materials. As explained in the introduction section, metamorphic rocks were not included in the analysis and comparison because the raw material survey involved procurement of rocks from different sources, primarily secondary sources that were conglomerates that contained lava materials and lacked metamorphic rocks; metamorphic rocks' sources were predominantly primary sources such as Naibor Soit Hill.

Overall, the analysis reveals selectivity on all sites. The selectivity patterns inferred from all sites' lithic assemblage indicate familiarity with raw material properties and an understanding of their implications for knapping and later use of the artefacts (Goldman-Neuman and Hovers, 2012). In addition, all sites represent higher standards in the acquisition of raw materials for the manufacture of stone tools.

Further research will be required to better understand the rock properties of the cobbles examined. An experimental knapping of all collected cobbles to produce cores, flake, and flake fragments will be essential. These experimental artifacts will be

thoroughly analysed and compared to the archaeological artifacts. Therefore, this will provide us with a holistic understanding of the Acheulean hominins raw material economy at Olduvai throughout the sequence.

This chapter has described the methods used in the analysis of raw material sample, and it has been established that stone tool makers were able to locate, identify, and select raw materials with preferred characteristics. It has established a thorough understanding of the Olduvai raw material economy, which is crucial in understanding hominin technological capabilities. In the next chapter, the archaeological findings of an early Acheulean site (FC East) are analysed to understand the technological skills of early *Homo erectus* at Olduvai.

Chapter 6: FC East

6.1 Introduction

This chapter presents a technological analysis of a FC East lithic assemblage. The analysis is centered on a detailed examination of stone tools sample selected from an archaeological assemblage excavated by the Olduvai Geochronology and Archaeology Project (OGAP) during the 2014 fieldwork at Trench T30. The sample provided a comprehensive technological data obtained from cores, flakes, and retouched pieces. A database containing comprehensive technological information was created to aid gaining statistical results of the analysed stone artefacts. The technological results obtained are presented in this chapter and will be compared with the results from other sites in chapter 9.

6.2 FC East archaeological setting at Olduvai

The FC site complex is located on the north side of the Side Gorge, approximately 1.6 km from the junction where the Side Gorge joins the Main Gorge (Figure 6.1) (Leakey, 1971). Chronologically, the FC Bed II assemblages date between 1.6 – 1.5 Ma (McHenry et al. 2016; McHenry & Stanistreet 2018; McHenry & de la Torre 2018).

At FC, there are two localities, the FC West and FC East. The FC East is regarded as the main site. Leakey's excavations focused at FC West, although a trench was also excavated at FC. Further description on the Leakey's excavation at FC is presented below.

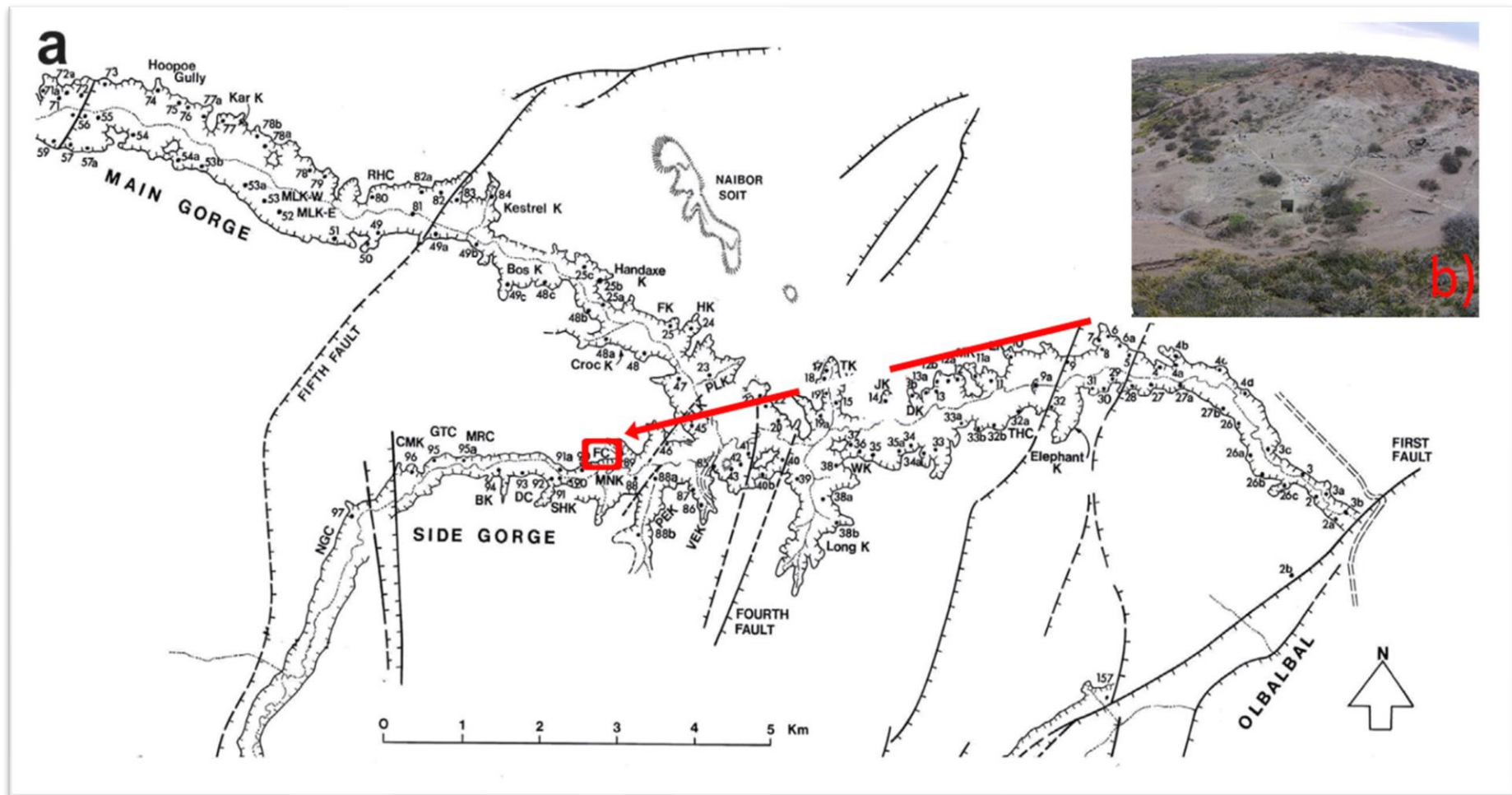


Figure 6. 1: Olduvai Map showing different localities a) and an aerial view of the FC landscape during the 2014 fieldwork season b) (Map adapted and redesigned from Hay (1976)). (b) adapted from de la Torre's 2014 unpublished report.

6.3 FC excavations by M.D. Leakey

In 1961, L.S.B. Leakey opened a trial trench at the FC site. The trench barely yielded stone and faunal remains, and hence it was abandoned (Leakey, 1971). Later in 1963, another trial trench was opened; it also appeared to be a disappointment, particularly in the section exposed; however, a small amount of cultural and faunal materials were recovered (Leakey, 1971: 156).

The preliminary work at FC was reported in Leakey (1971)'s monograph. The site is stratigraphically located in the Middle Member of Bed II of the Olduvai formations. These exposures of Bed II formations at FC have been known to be rich in artefact and faunal remains (Leakey, 1971).

The FC west is immediately upstream of FC proper (Leakey, 1971). It is located in middle Bed II; Bed II dates ~1.8–1.2 Ma (McHenry et al. 2016). At this site, M.D. Leakey opened up a trench at the base of Bed III and identified two main archaeological levels in middle of the Bed II. These are FC West Occupation Floor (OF), and FC West Reworked Tuff (RT), located just above the OF (Leakey, 1971; de la Torre and Mora, 2005b). According to M.D. Leakey those two levels belong to Developed Oldowan B (Leakey, 1971). Her work at the OF layer shows a large concentration of lithic artefacts and few fossil bones embedded on a clay surface (Leakey, 1971; de la Torre and Mora, 2005b).

Archaeologically, finds from the FC Reworked Tuff were dispersed throughout the deposit with no discernible concentration, though they were slightly more numerous at a height of 6 inches to 1 foot above the base than at any other level. The proportions of artefacts, fossil bones, and unmodified cobblestones are similar to those of the

underlying level, with faunal remains being unusually scarce in both contexts, despite the fact that the existing bones are well preserved (Leakey, 1971).

In 2005, de la Torre and Mora re-analysed the Leakey's collection from FC West Occupation Floor assemblage. Their analysis based more on aspects concerning technical productions than to the typological aspects that were applied by the Leakeys' analyses of Olduvai lithic materials (Leakey, 1971; de la Torre and Mora, 2005b).

In 2010, de la Torre (2014) and his team of the Olduvai Geochronology Archaeology Project (OGAP) set out grid systems for a renewed excavations at FC site, excavating at both FC proper (now named FC East) and at FC West. The focus of this study is one of the trenches dug in FC East, namely T30 (Figure 6.2). A detailed technological analysis focused on flakes, cores, and retouched pieces, sampling part of the large assemblage at this trench.

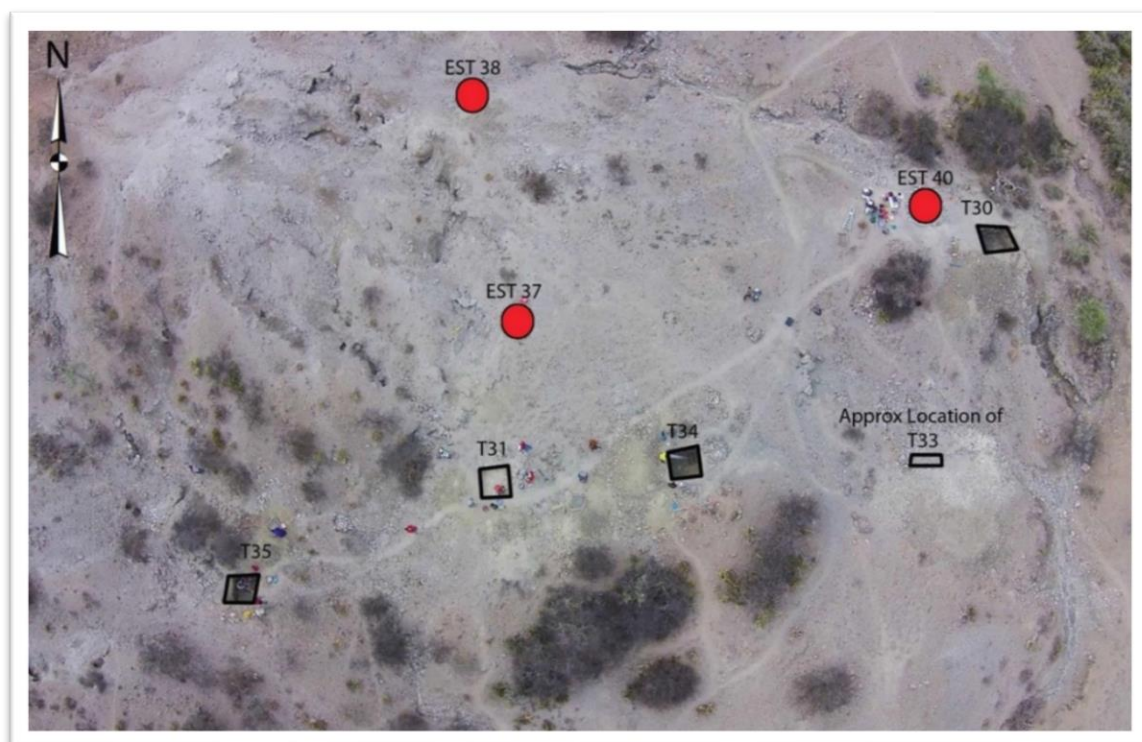


Figure 6. 2: FC East exposure from the 2014 excavations at the site. Photo courtesy by Ignacio de la Torre.

6.4 Taphonomic aspects of FC East assemblage

An analysis of taphonomic attributes of stone tools sample analysed from the FC East aids in the understanding of various post-depositional changes occurred to the assemblage. In this study, most flakes do not exhibit possession of pseudoretouch (n=78, 58%) on edges, whilst slightly less than half of the flake assemblage exhibit possession of pseudoretouch (n=57, 42%) (Table 6.1).

In terms of raw materials, most basalt flakes possess pseudoretouch (n=7, 64%), whilst a minimal number of flakes do not show possession of pseudoretouch (n=4, 36%). Quartzite flakes indicates that most of flakes do not possess pseudoretouch (n=74, 60%), followed by flakes that possess pseudoretouch (n=49, 40%). Phonolite flakes show that all flakes do not have pseudoretouch (n=2, 100%) on edges. However, one chert flake within the sample shows possession of pseudoretouch (n=1, 100%) (Table 6.1 and figure 6.3A).

Roundness of flake edges was also examined (Figure 6.3B). It was noted that a large number of flakes possess slight (n=81, 60%) rounding, whilst less than half of the flake sample possess moderate (n=54, 40%) rounding on the edges (Table 6.1). It is not clear if these results may suggest any water action that may have affected the stone tool composition of the FC East assemblage. Hence, it may be interpreted that roundness exhibited might be resulted from either weathering occurred at the site.

In terms of raw materials, within basalt flakes, most flakes possess slight (n=8, 73%) rounding, followed by moderate (n=3, 27%) whilst no heavy rounding recorded. Quartzite flakes analysis shows most flake possess slight (n=72, 59%) rounding, followed by moderate (n=51, 41%) rounding; also, no heavy rounding was found. One Chert flake recorded possesses slight (n=1, 100%) rounding. The phonolite flakes

show all flakes possess slight (n=2, 100%) rounding (Figure 6.3B). The overall result of rounding on flakes show that most flakes possess slight rounding followed by moderate rounding (Figure 6.3B).

Roundness was also examined on cores. It was found that most cores possess slight (n=23, 56%) rounding, followed by moderate (n=15, 37%) and a small number possess heavy (n=3, 7%) rounding (Figure 6.4). This data corroborates with the rounding observed within the flake sample analysed (Figure 6.3B).

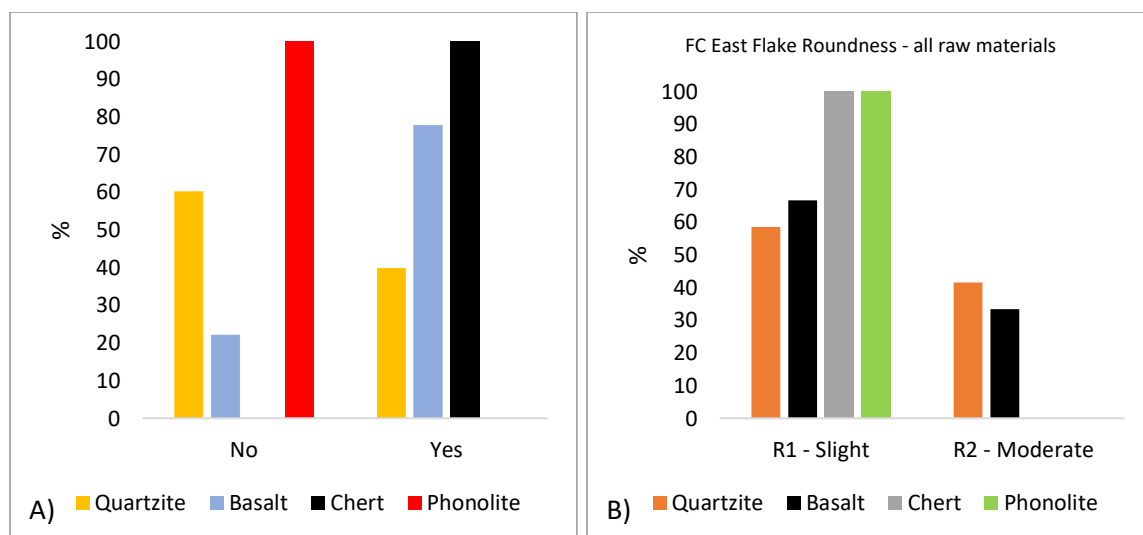


Figure 6. 3: FC East flake sample showing pseudoretouch (A) and roundness (B).

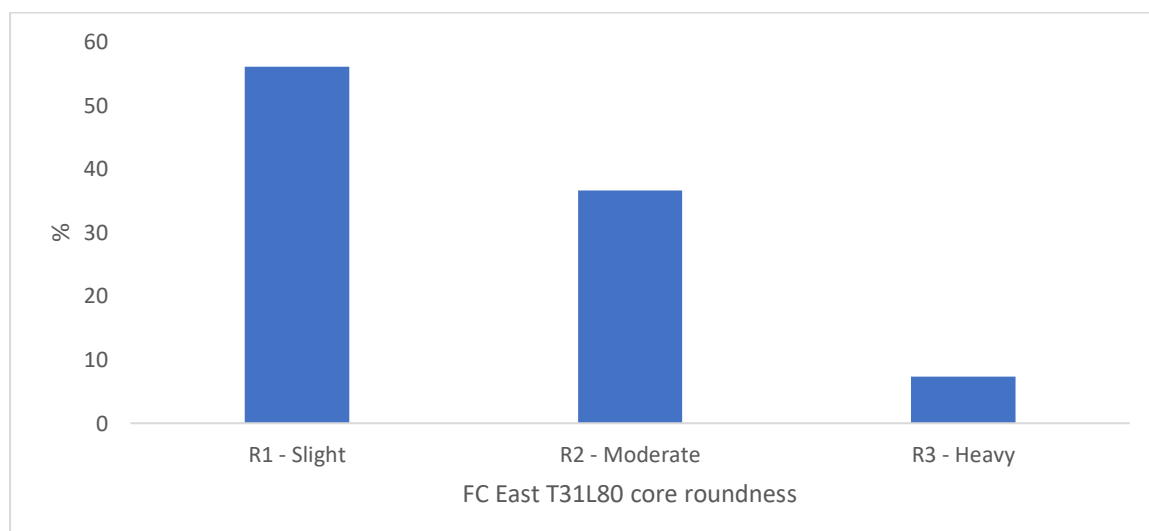


Figure 6. 4: Frequency of core roundness identified at FC East.

Table 6. 1: FC East flake pseudoretouch and roundness.

		Raw Material						Grand Total	
		Lava		Metamorphic		Sedimentary		n	%
		n	%	n	%	n	%		
Pseudoretouch	Yes	7	64	49	40	1	100	57	42
	No	4	36	74	60	0	0	78	58
	Total	11	100	123	100	1	100	135	100
Roundness	R1 - Slight	8	73	72	59	1	100	81	60
	R2 - Moderate	3	27	51	41	0	0	54	40
	Total	11	100	123	100	1	100	135	100

6.5 FC East, excavations by the OGAP team

The OGAP team excavated 5 trenches (T30, T31, T33, T34, and T35) in 2014 (de la Torre, 2014) in the stratigraphic interval between augitic medium sandstone and augitic coarse to medium sands with gravels (Tables 6.2, 6.3; figure 6.5). All trenches yielded archaeological materials except T33. The OGAP's excavations have uncovered a large collection of lithic artefacts and fossils at FC East. A sample of lithic artefacts from archaeological unit L80 in Trench T31 was analysed for this PhD study.

6.6 T31

Trench 31 measures 2 metres by 2 metres (Figure 6.5). This trench was excavated to about 1.7 metres deep, and yielded 5 archaeological horizons, which are T31L79, T31L80, T31L81, T31L82, and T31L84 (Table 6.2; Figures 6.6 and 6.7) (de la Torre, 2014). Specifically, this study analyses lithic materials from T31L80 (Table 6.2, Figure 6.6).

6.7 T31L80

According to de la Torre (2014), a sum of 3615 artefacts were unearthed from unit T31L80, with 2099 lithics and 1442 faunal remains (Table 6.3). These materials were found in dark yellow medium sands unit (Table 6.2 – 3, figures 6.6 and 6.9). Different archaeological materials were uncovered, predominantly lithic artefacts and fossils (Table 6.3, figure 6.10).

Table 6. 2: An overview of levels in each trench which yielded archaeological material at FC East site.

Trench Number	Level	Year Created	Lithology	Number of Lithics	Number of Fossils	Total Number of Artefacts	Max Thickness (cm) (Approx)
T30	T30L59	2014	Augitic medium sandstone	13	8	21	25
	T30L60	2014	Yellow medium sandstone	672	270	942	24
	T30L62	2014	Sandy Claystone	71	71	142	18
	T30L64	2014	Medium Clayey Sandstone	50	4	54	30
T31	T31L79	2014	Augitic medium sandstone	3	5	8	17
	T31L80	2014	Dark yellow medium sands	2099	1442	3541	19
	T31L81	2014	Fine silty pale yellow sands	6	25	31	13
	T31L82	2014	Cemented conglomerate with medium to coarse sands	33	58	91	23
	T31L84	2014	Conglomerate with sandy silt	64	3	67	9
T33	N/A	N/A	N/A	N/A	N/A	N/A	N/A
T34	T34L0	2014	N/A	0	7	7	N/A
	T34L89	2014	Yellow fine to medium sandstone	22	47	69	42
	T34L90	2014	Massive sandy silty clays	57	6	63	20
	T34L92	2014	Augitic medium to coarse sands with interlayered silt	139	5	144	20
T35	T35L0	2014	N/A	N/A	N/A	N/A	N/A
	T35L18	2014	Light yellow fine massive sands	4	3	7	12.5
	T35L20	2014	Augitic coarse sandstone	41	21	62	15
	T35L22	2014	Sandy Clays	25	16	41	15
	T35L24	2014	Augitic coarse to medium sands with gravels	37	1	38	13

Table 6. 3: Artefacts unearthed from FC East by the OGAP team.

Trench	Level	No. of findings	No. of Lithics	No. of Fossils	Lithostratigraphic Unit
T31	T31L79	8	3	5	Augitic medium sandstone
	T31L80	3615	2099	1442	Dark yellow medium sands
	T31L81	32	6	25	Fine silty pale-yellow sands
	T31L82	97	33	58	Cemented conglomerate with medium to coarse sands
	T31L84	71	64	3	Conglomerate with sandy silt
Total		3823	2205	1533	

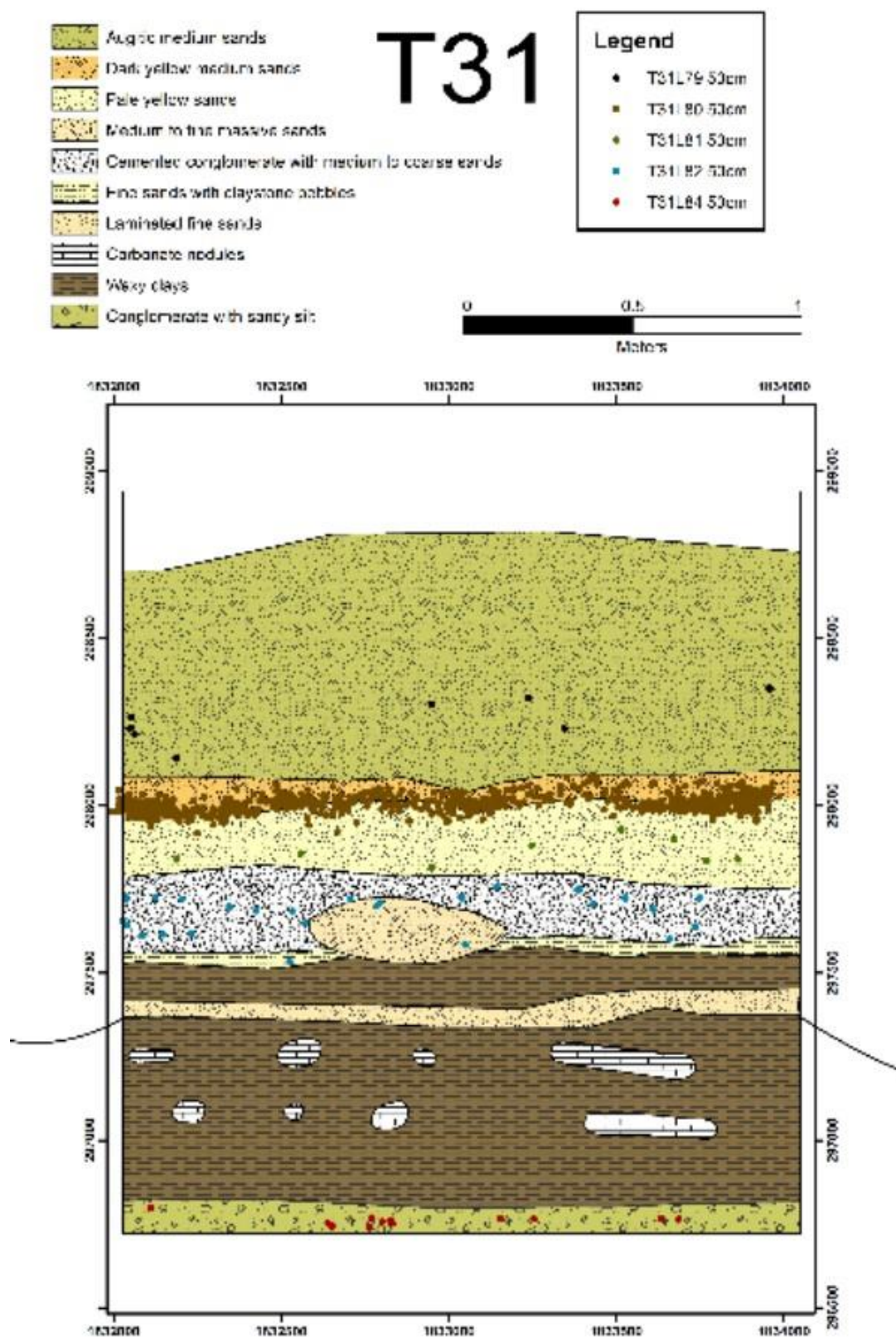


Figure 6. 6: Stratigraphy of T31 trench five archaeological horizons excavated by the OGAP team.



Figure 6. 7: FC East T31 trench. Photo courtesy by Ignacio de la Torre.

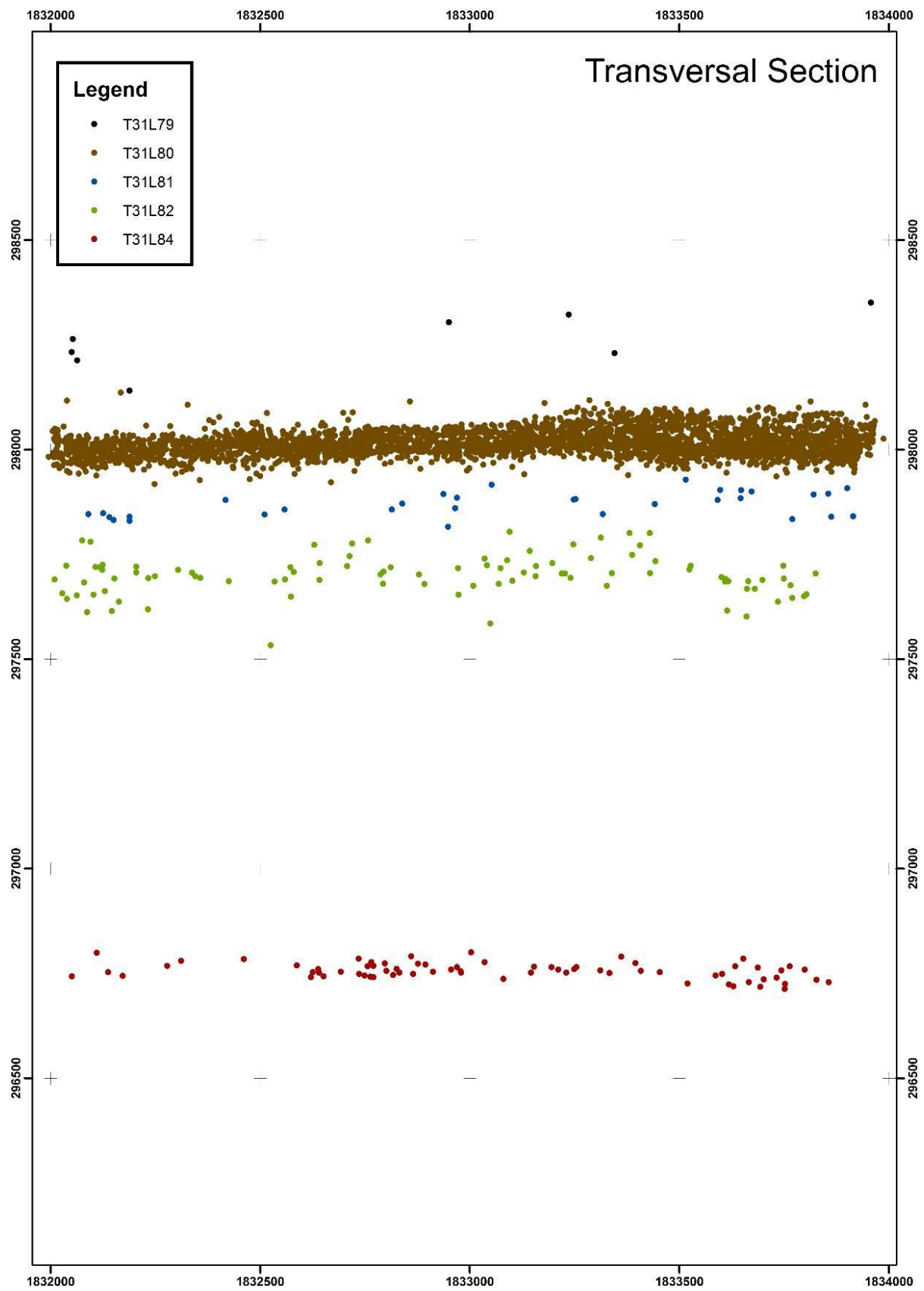


Figure 6. 8: Transversal section of all artefacts uncovered from trench T31.

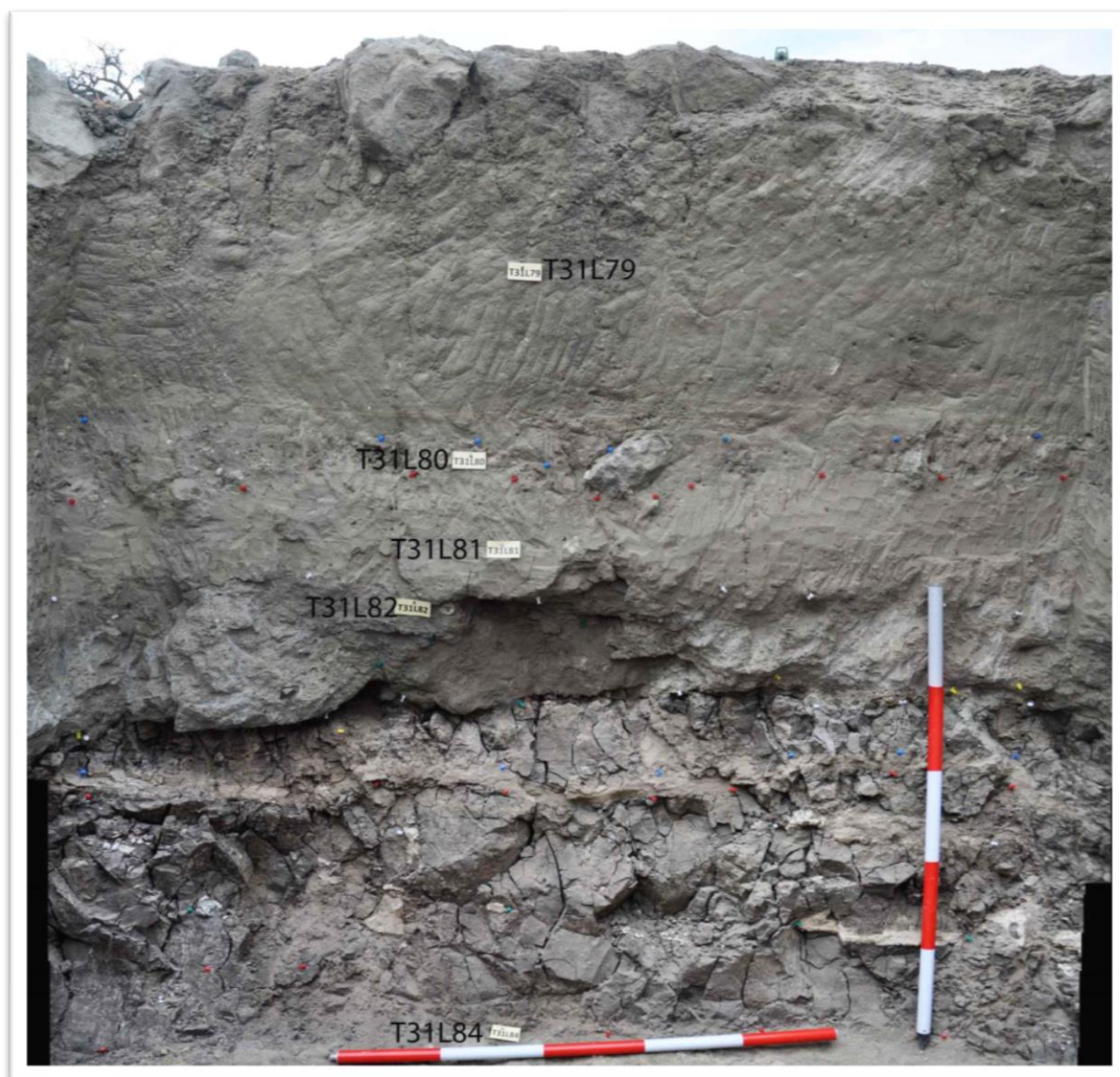


Figure 6. 9: Stratigraphic layers excavated at Trench 31, with the position of archaeological units.

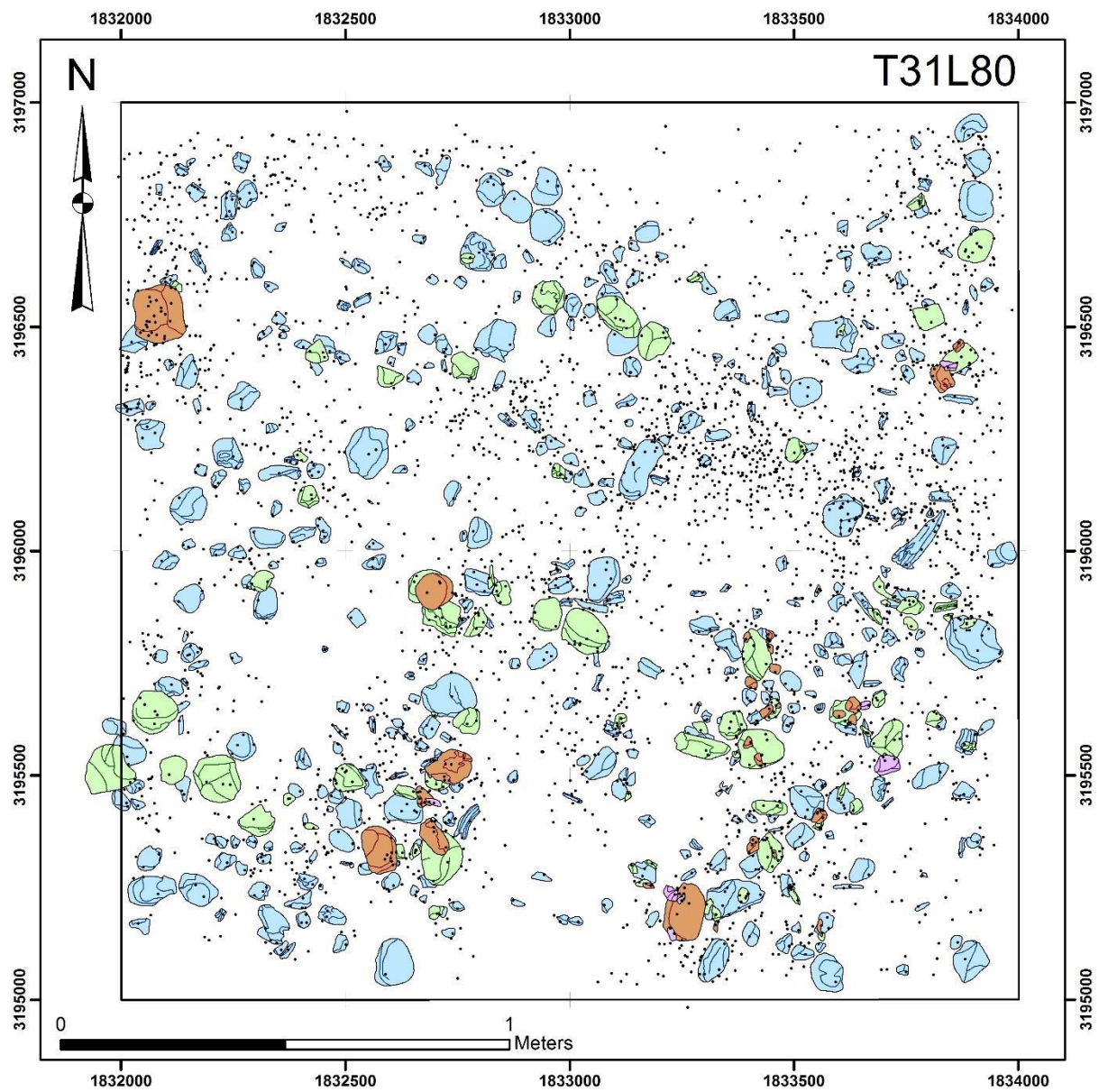


Figure 6. 10: Plan of archaeological materials uncovered in T31L80.

6.8 Lithic Analysis of FC East T31L80

6.8.1 Characteristics of the FC East lithic assemblage

A sample of flakes (n=135), flake fragments (n=375), cores (n=41), and retouched tools (n=18) was selected for technological analysis from the entire lithic assemblage (n=569) from T31L80. Selection of the materials aimed at sampling the most relevant categories from a technological point of view, and all raw materials represented in the assemblage (Table 6.5)

Detached pieces dominate the entire assemblage analysed sample (n=510, 90%), followed by flaked pieces (n=59, 10%) (Table 6.5). Although flaked pieces appear in low number, their weight contribution (12.4 kg, 78.7%) is significant compared to detached pieces (3.4 kg, 21.3%) (Figure 6.11C, Tables 6.4 and 6.5). In terms of raw materials composition, quartzite dominates statistically (n=546, 95.8%), followed by basalt (n=14, 2.5%), quartz (n=4, 0.7%), phonolite (n=3, 0.5%), trachyte (n=1, 0.2%), while chert is the least represented (n=1, 0.2%) (Table 6.6).

Statistically, the cores account for 7% (n=41) of the entire sample selected (Table 6.4, Figure 6.11A). In terms of weight, cores are heavier than other categories if are added together, having a total of over 12.1 kilograms (Table 6.4 and 6.5, Figure 6.11C). Moreover, amongst the transported raw materials, quartzite rocks are the most prevalent, weighing over 11 kg (Table 6.5).

Flakes account for 24% of the total sample and make the second largest group of the detached pieces after flake fragments (66%) (Figure 6.11A). In terms of weight, the entire flake sample totals over 2 kilograms, and flake fragments weigh slightly over 1 kilogram (Table 6.5).

Furthermore, retouched tools account 3% of the entire sample with a total weight of over 300 grams (Table 6.4 and 6.5, figure 6.11A). Within the retouched tools, quartzite rocks are the most prevalent raw material types utilised, followed by lava materials (Table 6.5).

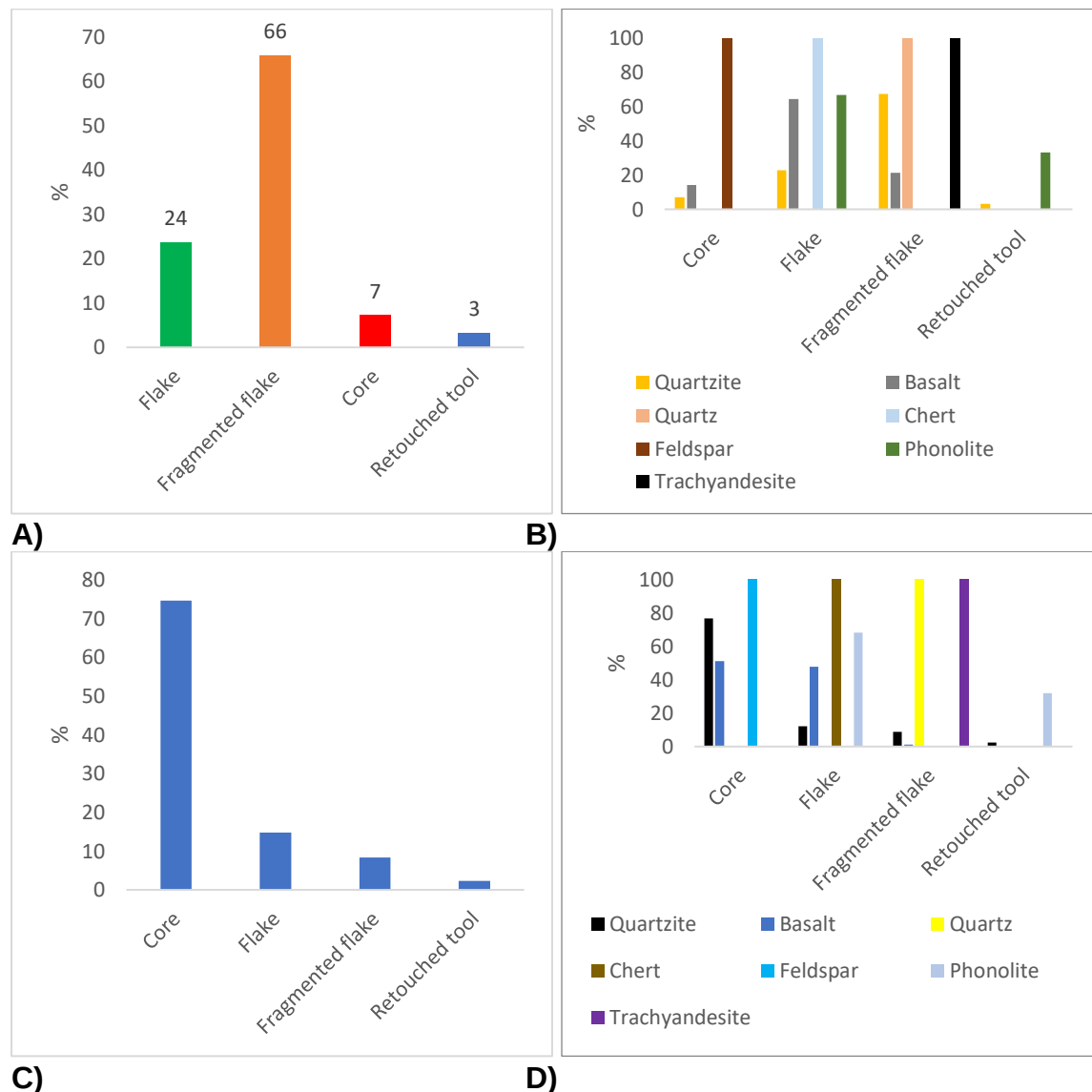


Figure 6. 11: A-B) Frequency of artefacts of the main lithic categories from T31L80 (A), and per raw materials (B). C-D) Relative frequencies of weight of FC East's main lithic technological categories (C), and raw materials (D).

Table 6. 4: Table showing relative frequency of artefacts and weight at FC East T31L80.

FC East T31L80					Total	
		Frequency		Weight		Frequency
		n	%	grams	%	n
Detached	Flake	135	24	2113	13.3	135
	Flake Fragment	375	66	1260	8.0	375
	Total Detached	510	90	3373	21.3	510
Flaked	Core	41	7	12114	76.4	41
	Retouched tool	18	3	360	2.3	18
	Total Flaked	59	10	12474	78.7	59
Grand Total		569	100	15847	100	569

Table 6. 5: Total weight of all lithic categories at FC East.

Technological Category		Lava (g)	Metamorphic (g)	Sedimentary (g)	Total (g)
Detached	Flake	411	1698	4	2113
	Flake Fragment	19	1241	0	1260
Flaked	Core	419	11695	0	12114
	Retouched tool	13	346	0	360
Total		862	14980	4	15847

6.8.2 Raw materials at FC East

The FC East assemblage contains raw materials from several prehistoric sources at Olduvai. These sources yielded different raw material groups that were locally available at Olduvai, and they include lava, metamorphic and sedimentary (Table 6.5). Within these groups, there are six rock types that were identified from the sample studied; they include basalt, quartzite, quartz, chert, phonolite, feldspar, and trachyandesite (Table 6.6). Analysis of the sample shows that metamorphic rocks are the most prevalent raw materials used at the site, contributing 94.3% of the weight of the sample studied (Table 6.6). Metamorphic rocks outweigh both lava (857.2 grams, 5.7%) and chert (4 grams, 0.03%).

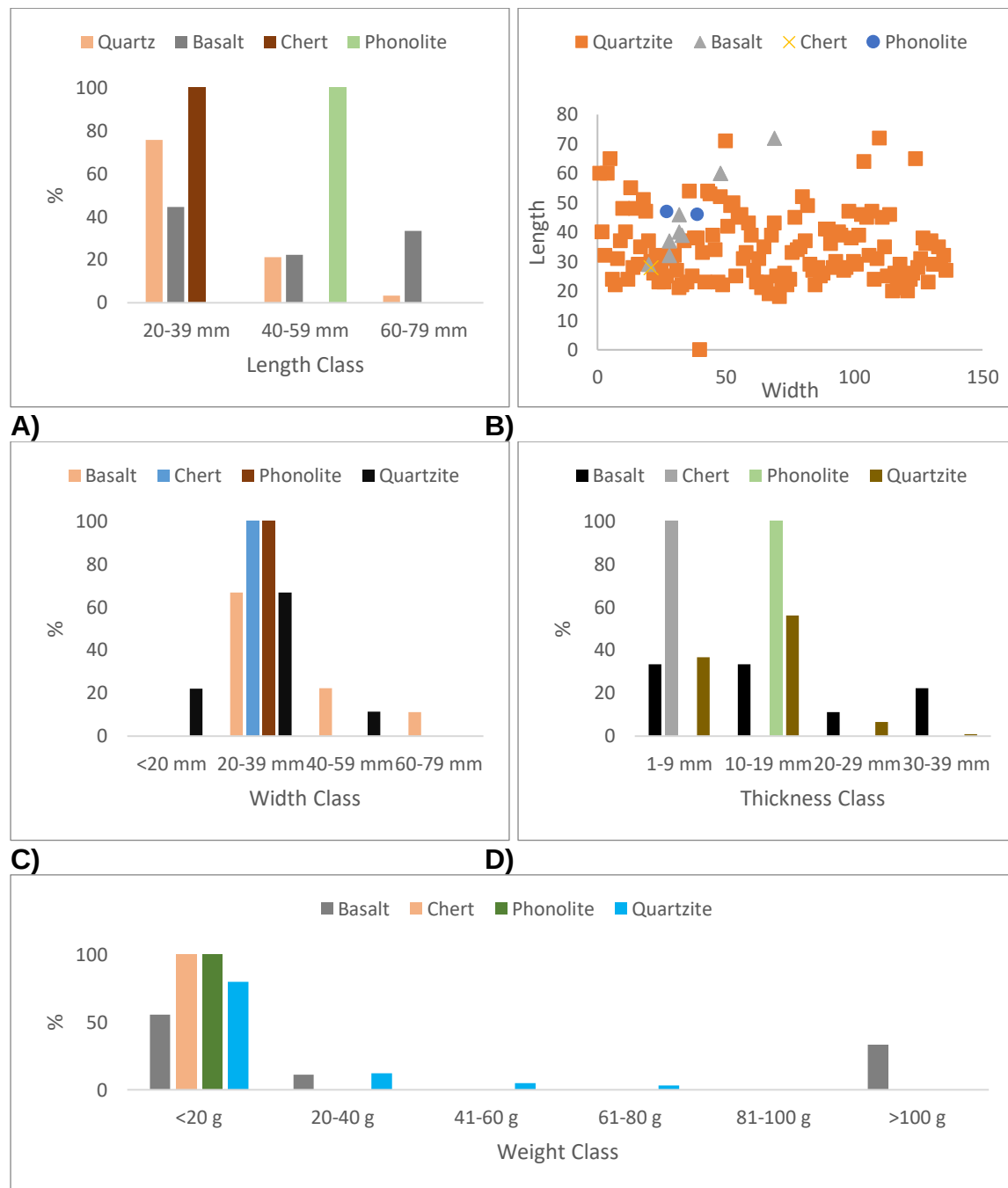
6.8.3 Flakes

Flakes (n=135, 24%) are the second most abundant artefacts within the detached pieces, after the flake fragments (n=375, 66%) (Table 6.4). Weighing a total of 2.11 kg, the flake sample is the second heaviest within the FC sample (Table 6.5). In absolute terms, the quartzite flakes (n=123) are more abundant than lava (n=11) and sedimentary (n=1) flakes (Table 6.6). The relative frequencies of flakes per raw materials show that lava (basalt and phonolite) are more frequent than quartzite flakes (quartzite) (Figure 6.11B).

In terms of raw materials, quartzite flakes (1.7 kg) dominate the detached pieces' group, followed by quartzite flake fragments (1.2 kg), by lava flakes (411 g), and lava flake fragments (19 g), whereas the chert flake (4 g) is the least presented (Table 6.5).

As it can be seen from the data in figure 6.12A, 6.13A-B and table 6.7, most flakes measure between 20-39 mm in length, with an average of 34.7 mm in length and 26.8

mm in width (see also table 6.8). In terms of raw materials, metamorphic flakes (76%) are more frequent than lava (36%) flakes (Figure 6.12A, table 6.7).



E) Figure 6. 12: A-B) Flake length class in the entire sample of FC East T31L80 per raw materials (A) and length-width (B). C-D) Flake width range per all raw materials (C) and thickness range per raw materials (D); and flake weight class per all raw materials (E).



A)



B)

Figure 6. 13: A-B) FC East flakes, ventral side (A) and dorsal side (B).

Moreover, figure 6.12C shows that most flakes measure between 20-39 mm in width (Figure 6.13A-B). This result is significant as it shows that flakes had almost similar length and width. Nevertheless, a substantial difference was recorded with flakes measuring up to 72 mm in length and some as small as 20 mm (Table 6.8). Figure 6.12D shows flake thickness, whereby most flakes measuring 1-9 mm and 10-19 mm in thickness. In addition, figure 6.12E shows flake weight class, with most flakes weighing <20 grams, with chert and phonolite flakes being the heaviest, followed by quartzite and then basalt.

Table 6. 6: FC East technological categories per individualised raw materials.

	Lava								Metamorphic								Sedimentary		Grand Total	
	Basalt		Trachyte		Phonolite		Total-Lava		Quartzite		Quartz		Feldspar		Total-Metamorphic		Chert			
	n	g	n	g	n	g	n	g	n	g	n	g	n	g	n	g	n	g	n	g
Flake	9	393.3	0	0	2	17.3	11	410.6	123	1689	0	0	0	0	123	1689	1	4	135	2099.6
Flake Frag	3	9.9	1	9.2	0	0	4	19.1	367	1237.5	4	17.2	0	0	371	1254.7	0	0	375	1273.8
Total Detached	12	403.2	1	9.2	2	17.3	15	429.7	490	2926.5	4	17.2	0	0	494	2943.7	1	4	510	3373.4
Core	2	419.4	0	0	0	0	2	419.4	39	10876.3	0	0	0	0	39	10876.3	0	0	41	11295.7
Retouched tool	0	0	0	0	1	8.1	1	8.1	17	351.5	0	0	0	0	17	351.5	0	0	18	359.6
Total Flaked	2	419.4	0	0	1	8.1	3	427.5	56	11227.8	0	0	0	0	56	11227.8	0	0	59	11655.3
Grand Total	14	822.6	1	9.2	3	25.4	18	857.2	546	14154.3	4	17.2	0	0	550	14171.5	1	4	569	15032.7
	Basalt		Trachyte		Phonolite		Total-Lava		Quartzite		Quartz		Feldspar		Total-Metamorphic		Chert		Grand Total	
	Frequency %	Weight %	Frequency %	Weight %	Frequency %	Weight %	Frequency %	Weight %	Frequency %	Weight %	Frequency %	Weight %	Frequency %	Weight %	Frequency %	Weight %	Frequency %	Weight %	Frequency %	Weight %
Flake	64.3	47.8	0	0	66.7	68.1	61.1	47.9	22.6	11.9	0	0	0	0	22.4	11.9	100	100	23.7	14
Flake Frag	21.4	1.2	100	100	0	0	22.2	2.2	67.3	8.8	100	100	0	0	67.5	8.9	0	0	65.9	8.5
Total Detached	85.7	49	100	100	66.7	68.1	83.3	50.1	89.9	20.7	100	100	0	0	89.8	20.8	100	100	89.6	22.4
Core	14.3	51	0	0	0	0	11.1	48.9	7	76.8	0	0	0	0	7.1	76.7	0	0	7.2	75.2
Retouched tool	0	0	0	0	33.3	31.9	5.6	0.9	3.1	2.5	0	0	0	0	3.1	2.5	0	0	3.2	2.4
Total Flaked	14.3	51	0	0	33.3	31.9	16.7	49.9	10.3	79.3	0	0	0	0	10.2	79.2	0	0	10.4	77.6
Grand Total	2.5	5.5	0.2	0.1	0.5	0.2	3.2	5.7	95.8	94.1	0.7	0.1	0	0	96.5	94.2	0.2	0.03	100	100

Table 6. 7: FC East T31L80 Flake Technological Attributes.

		Raw Material						Grand Total	
		Lava		Metamorphic		Sedimentary			
		n	%	n	%	n	%	n	%
Length Classes	<20 mm	0	0	0	0	0	0	0	0
	20-39 mm	4	36	93	76	1	100	98	73
	40-59 mm	4	36	26	21	0	0	30	22
	60-79 mm	3	27	4	3	0	0	7	5
	80-99 mm	0	0	0	0	0	0	0	0
	100-119 mm	0	0	0	0	0	0	0	0
	Total	11	100	123	100	1	100	135	100
Striking platform preparation	Non-faceted	5	45	16	13	0	0	21	16
	Unifaceted	5	45	103	84	1	100	109	81
	Bifaceted	0	0	4	3	0	0	4	3
	Multifaceted	1	9	0	0	0	0	1	1
	Total	11	100	123	100	1	100	135	100
Cortex dorsal side	Cortical	6	55	0	0	0	0	6	4
	Cortex >50%	2	18	10	8	1	100	13	10
	Cortex <50%	1	9	34	28	0	0	35	26
	Non-cortical	2	18	79	64	0	0	81	60
	Total	11	100	123	100	1	100	135	100
Toth's flakes	I	4	36	0	0	0	0	4	3
	II	1	9	9	7	0	0	10	7
	III	0	0	10	8	0	0	10	7
	IV	2	18	0	0	0	0	2	1
	V	2	18	34	28	1	100	37	27
	VI	2	18	70	57	0	0	72	53
	Total	11	100	123	100	1	100	135	100

With regards to the striking platform, most flakes are unifaceted (n=109, 81%), followed by cortical (non-faceted) (n=21, 16%), by bifaceted (n=4, 3%) and multifaceted (n=1, 1%) (Table 6.7, figure, 6.14A-B). In figure 6.14A-B and table 6.7, there is a clear overrepresentation of unifaceted flakes in both quartzite (84%) and lava (basalt) (45%) flakes. Overall, there were few flakes that show two or more removals on platforms (bifaceted: n=4, 3%; multifaceted: n=1, 1%) (Table 6.7, figure 6.14A-B).

Further analysis on cortex is presented in figure 6.14C-D, which show that there is an overrepresentation of Toth's flake types V and VI compared to other types (also, see table 6.7). It is interesting to see this remarkable difference in raw material representation between Toth's flake types V and VI. The overall larger proportion of flake types V and VI at the site suggests that the earlier stages of flakes, which would produce many cortical flakes, were underrepresented within the assemblage. Comparisons of Toth's flakes per raw materials shows that there is variation amongst types V and VI, with type V having overrepresentation of phonolite flakes, followed by quartzite and basalt (Figure 6.14D). With regards to Toth's type VI, there is overrepresentation of quartzite flake, followed by basalt flake (Figure 6.14D).

Further analysis of flake cortex involved analysis of dorsal cortex (Figure 6.15A-B). As it can be seen in figure 6.15A, there is a high percentage of non-cortical flakes, followed by <50% cortex and >50% cortex, whereas 100% cortex is the least represented. Nevertheless, there is a significant variation of dorsal cortex coverage per raw materials (Figure 6.15B). As can be seen in figure 6.15B, there is predominance of >50% dorsal cortex in phonolite and basalt, whereas quartzite is marginally represented. The presence of various cortex coverage within the flake

sample indicates that at FC East different stage of reduction occurred at the cores before flakes were detached. Regarding the number of dorsal scars on a flake, figure 6.15CA shows that most flakes are dominated by a pattern of 1-3 scars, followed by 4-6 scars, whereby 7-9 scars are least represented. The comparison of scars per raw materials shows that a 1-3 scar pattern is dominated by quartzite and basalt (Figure 6.15D). However, a 4-6 scar pattern shows a significant different whereby phonolite appears in higher frequency compared with quartzite. The 7-9 scar pattern is dominated by basalt flakes only (Figure 6.15D).

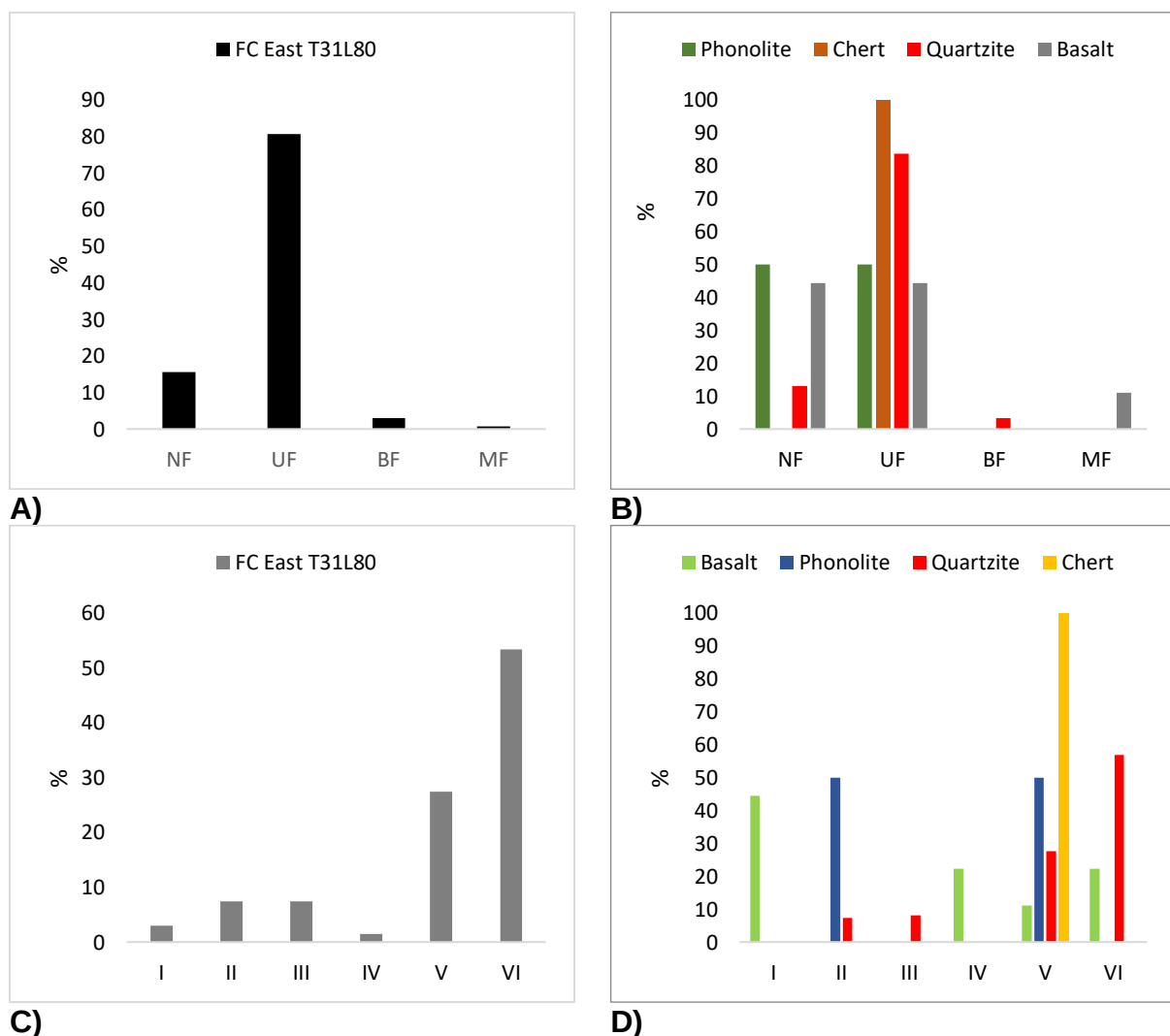


Figure 6. 14: Attributes of flakes in the FC East T31L80 assemblage (left) and raw materials (right). A-B) Percentage of flake's striking platform types in T31L80 (A) and per raw materials (B). C-D) Percentage of Toth's flake types in T31L80 (C) and percentage of frequency of Toth's flake types per raw materials (D).

Table 6. 8: FC East T31 L80 Min, Max, Mean, std. deviation.

			Minimum	Maximum	Mean	Std. Dev.
Whole flake	Total (n = 135)	Length	20.0	72.0	34.7	11.6
		Width	11.0	69.0	26.8	10.3
		Thickness	4.0	32.0	12.2	5.3
		Weight	1.1	112.9	15.8	20.6
	Lava (n = 11)	Length	29.0	72.0	46.2	13.1
		Width	20.0	69.0	36.7	13.7
		Thickness	6.0	32.0	15.1	9.1
		Weight	2.5	112.9	37.3	46.4
	Metamorphic (n = 123)	Length	20.0	71.0	33.8	11.0
		Width	11.0	54.0	25.9	9.5
		Thickness	4.0	31.0	11.9	4.9
		Weight	1.1	78.6	13.9	15.6
	Sedimentary (n = 1)	Length	28.0	28.0	28.0	0.0
		Width	21.0	21.0	21.0	0.0
		Thickness	9.0	9.0	9.0	0.0
		Weight	4.0	4.0	4.0	0.0
Flake Fragment	Total (n = 375)	Length	12.0	51.0	24.2	5.4
		Width	4.0	36.0	17.1	4.3
		Thickness	3.0	19.0	8.9	2.7
		Weight	0.8	18.0	4.4	2.9
	Lava (n = 2)	Length	23.0	27.0	25.0	2.8
		Width	17.0	22.0	19.5	3.5
		Thickness	7.0	11.0	9.0	2.8
		Weight	2.3	9.2	5.8	4.9
	Metamorphic (n = 373)	Length	12.0	51.0	24.2	5.4
		Width	4.0	36.0	17.1	4.4
		Thickness	3.0	19.0	8.9	2.7
		Weight	0.8	18.0	4.4	2.9
Core	Total (n = 41)	Length	42.0	127.0	60.6	32.4
		Width	18.0	118.0	50.9	26.5
		Thickness	12.0	106.0	40.0	24.8
		Weight	5.3	1766.4	275.5	405.0
	Lava (n = 2)	Length	63.0	80.0	71.5	12.0
		Width	54.0	67.0	60.5	9.2
		Thickness	24.0	54.0	39.0	21.2
		Weight	91.4	328.0	209.7	167.3
	Metamorphic (n = 39)	Length	22.0	127.0	60.0	33.1
		Width	18.0	118.0	50.4	27.1
		Thickness	12.0	106.0	40.5	25.2
		Weight	5.3	1766.4	278.9	414.4
Retouched tool	Total (n = 18)	Length	24.0	65.0	37.6	12.3
		Width	18.0	47.0	27.9	7.4
		Thickness	6.0	28.0	13.5	5.8
		Weight	4.6	79.2	20.0	20.3
	Lava (n = 2)	Length	26.0	34.0	30.0	5.7
		Width	25.0	25.0	25.0	0.0
		Thickness	6.0	12.0	9.0	4.2
		Weight	5.1	8.1	6.6	2.1
	Metamorphic (n = 16)	Length	24.0	65.0	38.6	12.7
		Width	18.0	47.0	28.3	7.8
		Thickness	8.0	28.0	14.1	5.8
		Weight	4.6	79.2	21.7	21.0

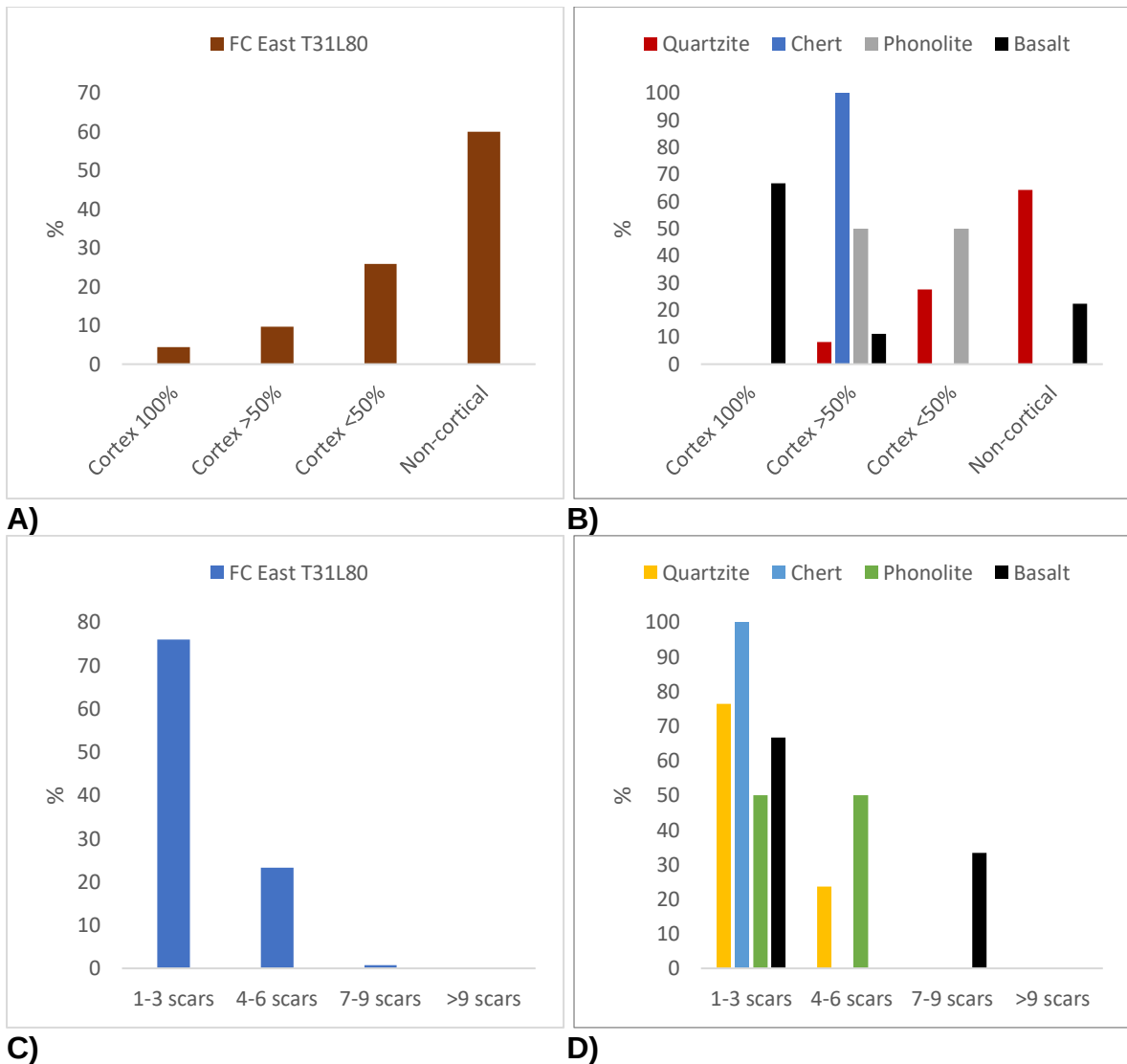


Figure 6. 15: A-B) FC East T31L80 flake dorsal cortex coverage(A) and raw materials (B). C-D) flake dorsal scar (C) and raw materials (D).

As shown in table 6.9, a total of over 10 m of cutting edge is present in flakes and retouched pieces, with an average of 76.9 mm and a standard deviation of 27.8 mm. In addition, table 6.9 shows that at this site there is a remarkable difference in cutting edge with maximum of 177mm and some flake with cutting edge as short as 34 mm.

Table 6. 9: FC East Cutting edge for flakes and retouched tools.

Cutting Edge	min	max	mean	std. deviation	Total length (mm)
Flake (n = 135)	34	177	76.9	27.8	10149
Retouched tool (n = 18)	52	140	85.2	29.2	1533

6.8.4 Cores

The analysed cores (n=41, 7%) (table 6.4) were all associated with the small debitage *chaîne opératoire*. Quartzite (n=39, 7%; total weight: 10.8 kg) are the most abundant cores in the sample, followed by lava cores (n=2, 11.1%; 419.4 g) (Table 6.6).

Core length classes range from 20-39 mm to 120-139 mm (Figure 6.16A and table 6.11). Most cores measure between 60 and 79 mm in length, followed by 80-99 mm; within the 60-79 mm, the most predominant raw material is basalt, followed by quartzite (Figure 6.16B). In addition, cores have an average length of 60.6 mm and weight of 275.5 g (Table 6.8). In addition, the standard deviation, in table 6.8, shows significant variability within the core sample. Cores have a minimum length of 42 mm and maximum length of 127 mm (Table 6.8), thus, there is a significant size difference within the core sample from the site.

Core size variations were also considered per raw material, which showed quartzite cores are larger in size than those of basalt (Figure 6.16C-D). There is low frequency of large cores with dimensions ranging from 100 mm and above, with quartzite being the only raw material represented (Figure 6.16B).

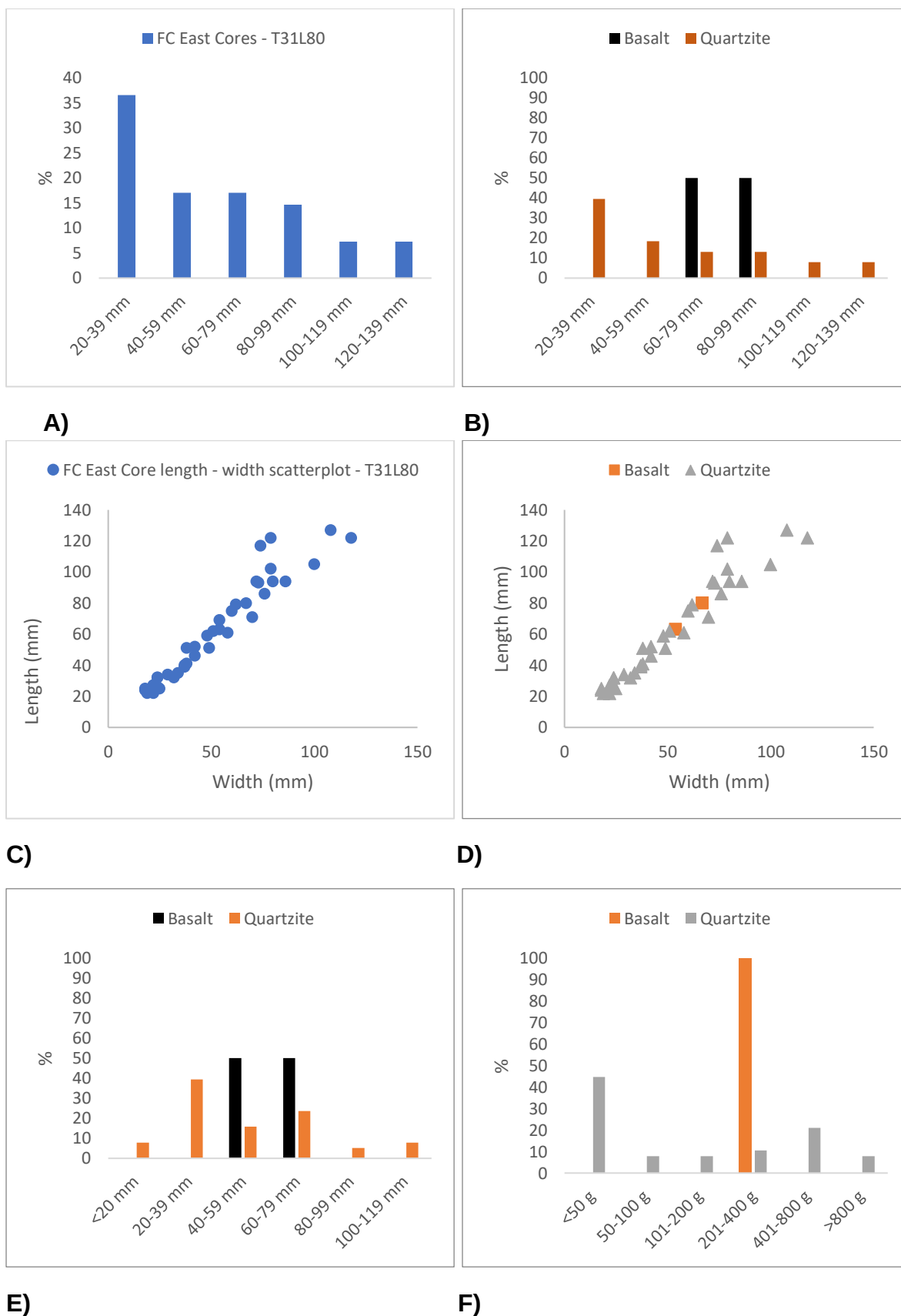


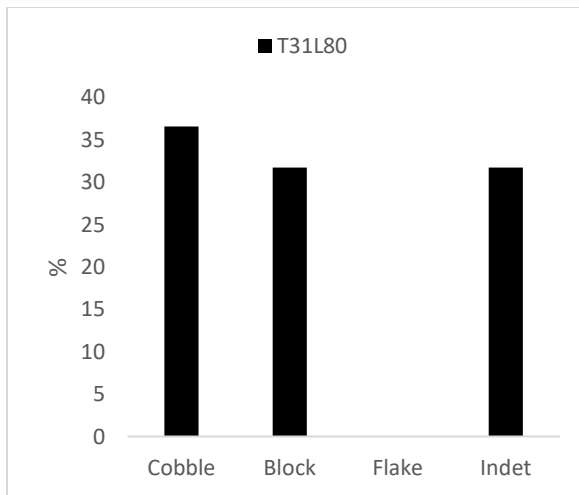
Figure 6. 16: A-B) FC East T31L80 length ranges of cores A) and raw materials (B). C-D) Core length-width scatterplot (C) and raw materials (D). E-F) Core width range per raw materials (C) and cores weight range per raw materials (D).

Figure 6.16E shows that most cores have width ranging between 40-59 mm and 60-79 mm, with basalt cores being the most predominant in these size patterns. In addition, and as can be seen in figure 6.16F, there is significant variation in weight patterns, with most cores being less than 50 grams and some cores being between 200-400 grams, and some exceeding 400 grams. There is decrease in frequency of cores with an increasing weight and size (Figure 6.162F).

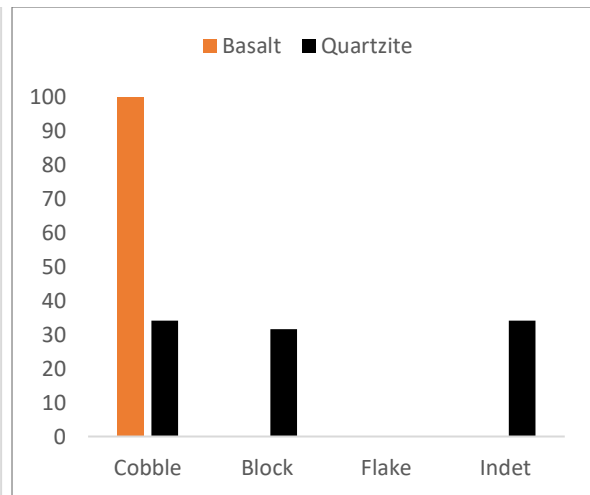
Figure 6.17A-B and table 6.10 show that there is predominance of cobble blanks (n=30, 37%), followed by block (n=26, 32%) and indeterminate (n=26, 32%). Figure 6.17B shows overrepresentation of basalt cobbles. The Olduvai core blanks are mainly linked with the sources such as river sources for lava cobble blanks, and Naibor Soit hillslopes for quartzite tabular blocks, which were the most widely exploited raw material blanks than cobbles.

Cores preserving <50% cortex are the most abundant within the core sample (Figure 6.17C-D and Table 6.10). The second most predominant cores are non-cortical, with quartzite being the only raw material to have no cortex preserved (Figure 6.17D and table 6.10). In addition, figure 6.17D shows predominance of basalt cores that preserve most of the cortex (>50%).

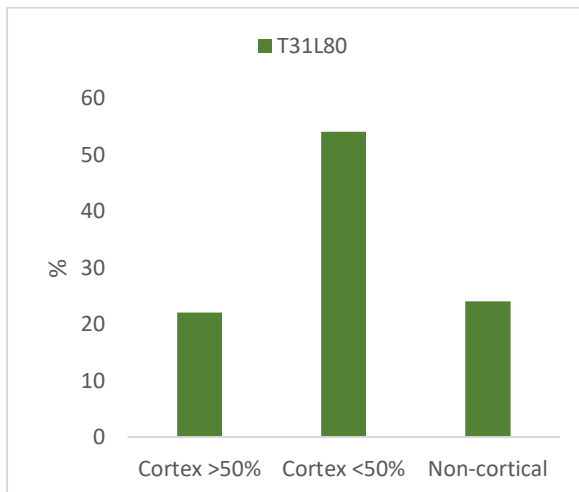
As shown in figure 6.17E and Table 6.10, most cores preserve six or fewer scars. Table 6.10 shows 29% of cores preserve three or fewer scars, with lava (50%) being the most prevalent of this group with only a few scars, followed by metamorphic (28%) (Figure 6.17F and table 6.10). Figure 6.17F shows that 8% of quartzite cores preserve nine or more scars. In general, this data suggests that quartzite cores underwent higher reduction intensity, followed by basalt (Figure 6.17F and table 6.10).



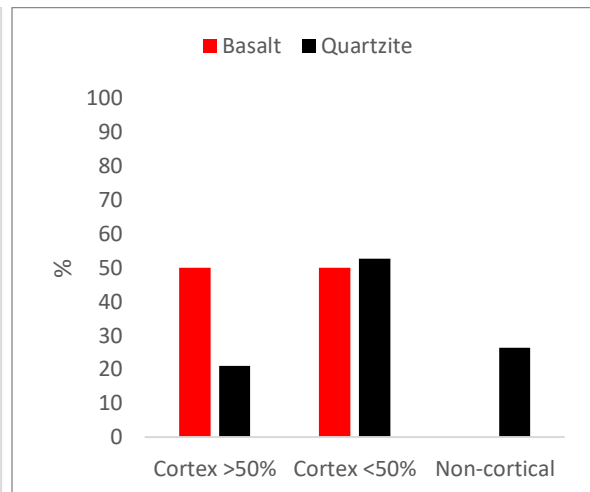
A)



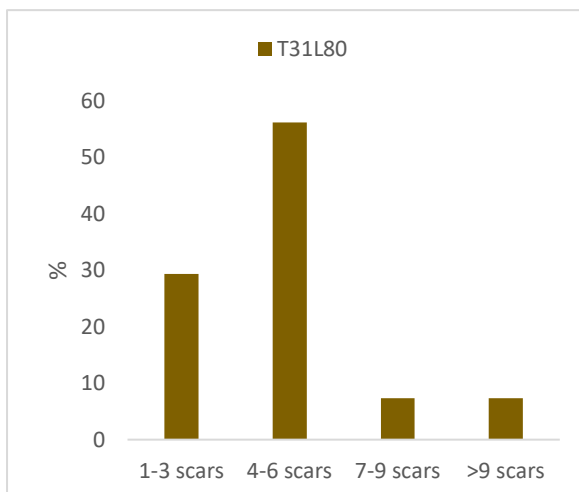
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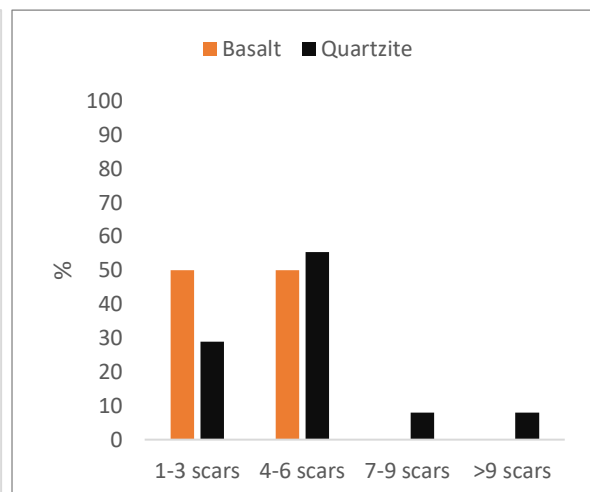
C)



D)



E)



F)

Figure 6. 17: Technological attributes of cores in the entire sample (left) and raw materials (right). A-B) Core blanks. C-D) Cortex coverage. E-F) Number of flake scars.

Table 6. 10: Attributes of the core sample at FC East T31L80.

		Raw Material				Grand Total	
		Lava		Metamorphic		n	%
		n	%	n	%		
Length class	20-39 mm	0	0	15	38	15	37
	40-59 mm	0	0	7	18	7	17
	60-79 mm	1	50	6	15	7	17
	80-99 mm	1	50	5	13	6	15
	>100 mm	0	0	6	15	6	15
	Total	2	5	39	95	41	100
Cortex	Cortex >50%	1	50	8	21	9	22
	Cortex <50%	1	50	21	54	22	54
	Non-cortical	0	0	10	26	10	24
	Total	2	5	39	95	41	100
Blank	Cobble	2	100	13	33	15	37
	Block	0	0	13	33	13	32
	Flake	0	0	0	0	0	0
	Indet	0	0	13	33	13	32
	Total	2	5	39	95	41	100
Number of scars	1-3 scars	1	50	11	28	12	29
	4-6 scars	1	50	22	56	23	56
	7-9 scars	0	0	3	8	3	7
	>9 scars	0	0	3	8	3	7
	Total	2	5	39	95	41	100

6.8.4.1 Core Exploitation Systems

Three major exploitation systems are described at FC East (Table 6.11 and figure 6.18). The exploitation strategies identified comprise of unifacial, bifacial and multifacial (Table 6.11). The Chi-square test results show significant variation in the raw material groups represented in each reduction type ($X^2 (2) = 26.865, p < .001$) (Appendix 6.1). Moreover, there is significant differences between raw materials in unifacial reduction, with lava being more common than metamorphic; similar results are also observed in bifacial reduction strategy, whereas bifacial lavas are more frequent than metamorphic bifacial cores (Figure 6.18, Appendix 6.1).

As with the multifacial reduction strategy, there is complete absence of lava cores within the sample studied (Table 6.11 and figure 6.18). The explanation of an absence of lava multifacial cores is not straightforward; it can be suggested that lava core blanks (cobbles) might have lacked potential angles to reduce core multifacially; hence, it seems that hominins utilised lava cobbles strictly following unifacial and bifacial reduction strategies.

Table 6. 11: FC East core knapping systems per raw material groups.

	Raw material				Total	
	Lava		Metamorphic		n	%
	n	%	n	%		
Unifacial	1	50	13	33	14	34
Bifacial	1	50	17	44	18	44
Multifacial	0	0	9	23	9	22
Total	2	5	39	95	41	100

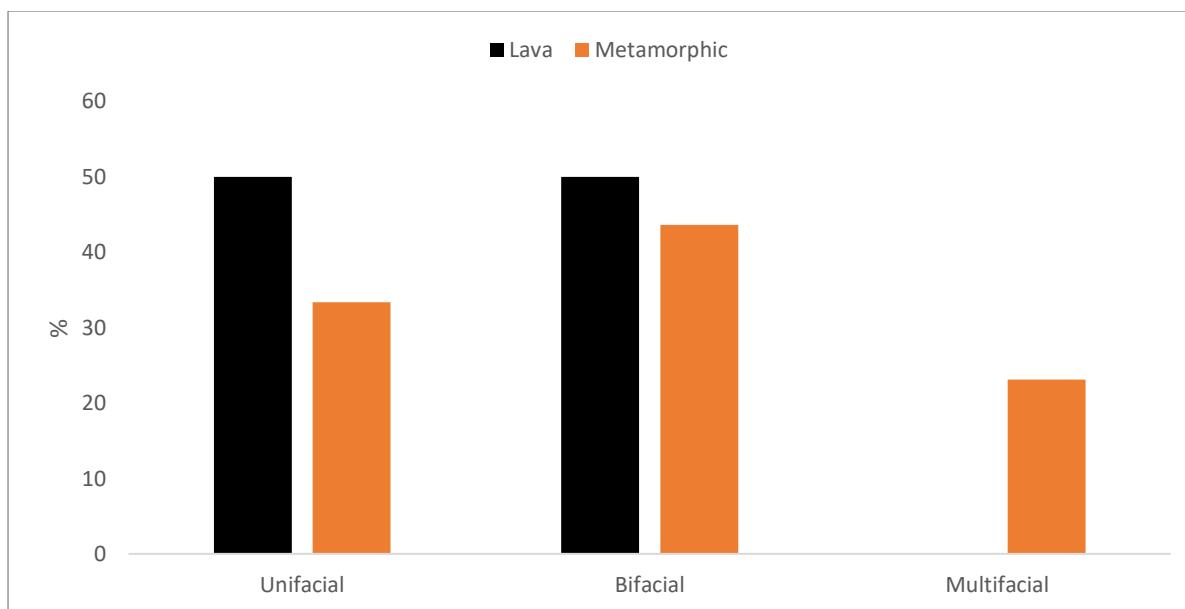


Figure 6. 18: FC East T32L80 core exploitation systems per raw materials.

6.8.4.2 Unifacial core exploitation strategy

The unifacially exploited cores (n=14, 34%) consist of five knapping schemes (Tables 6.12 and 6.13). Specifically, table 6.12 shows that unifacial exploitation systems are **USP2**, Unifacial simple partial exploitation (n=1, 3%) of metamorphic materials; **UAU1**: Unidirectional abrupt unifacial exploitation in one knapping surface of lava (n=1, 50%) and one of quartzite (n=1, 3%). In addition, table 5.13 shows that **UAU2**: Unidirectional abrupt unifacial exploitation in two independent knapping surfaces of metamorphic (n=1, 3%); **UAUT**: Unifacial abrupt unidirectional total exploitation of metamorphic (n=5, 13%); and **UABI**: Unifacial abrupt bidirectional exploitation of metamorphic (n=1, 3%). Whilst the **USP2** exploit the core using a simple angle between the striking platform and flaking surface, the **UAU1**, **UAU2**, **UAUT**, and **UABI** use an abrupt angle between the knapping platform and flaking surface (Tables 6.12 and 6.13).

In terms of size, most unifacial cores are between 20-39 mm and 120-139 mm long (Figure 6.19A-B). As can be seen in figure 6.19B, lava raw materials appear to be prevalent than metamorphic raw materials. Metamorphic materials, however, are

widely used than lava materials, making them appear in different length classes (Figure 6.19B).

Table 6. 12: Flaking scheme in the FC East core assemblage by raw materials.

	Raw material				Total	
	Lava		Metamorphic		n	%
	n	%	n	%		
TC	0	0	4	10	4	10
USP2	0	0	1	3	1	2
BSP	0	0	1	3	1	2
UAU1	1	50	1	3	2	5
UAU2	0	0	1	3	1	2
UAUT	0	0	5	13	5	12
UAB1	0	0	1	3	1	2
BALP	1	50	8	21	9	22
BALT	0	0	4	10	4	10
DISC	0	0	4	10	4	10
MLT	0	0	9	23	9	22
Total	2	5	39	95	41	100

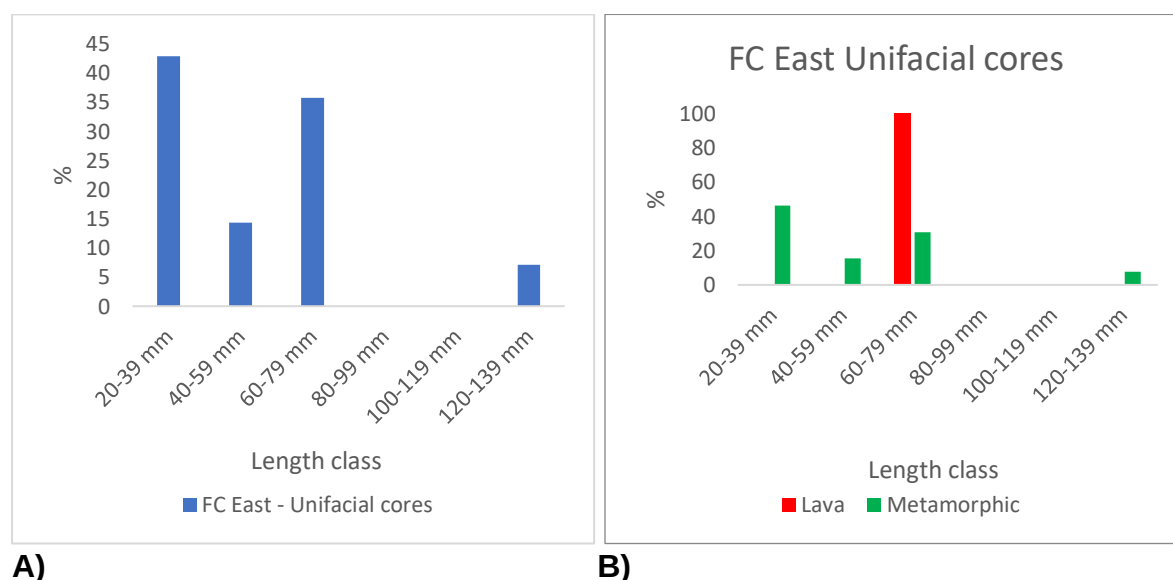
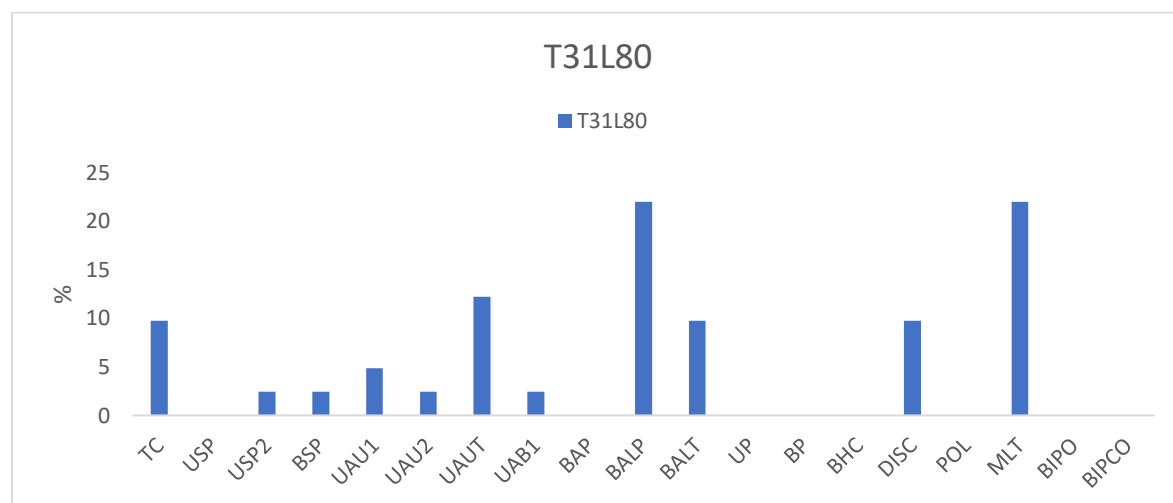
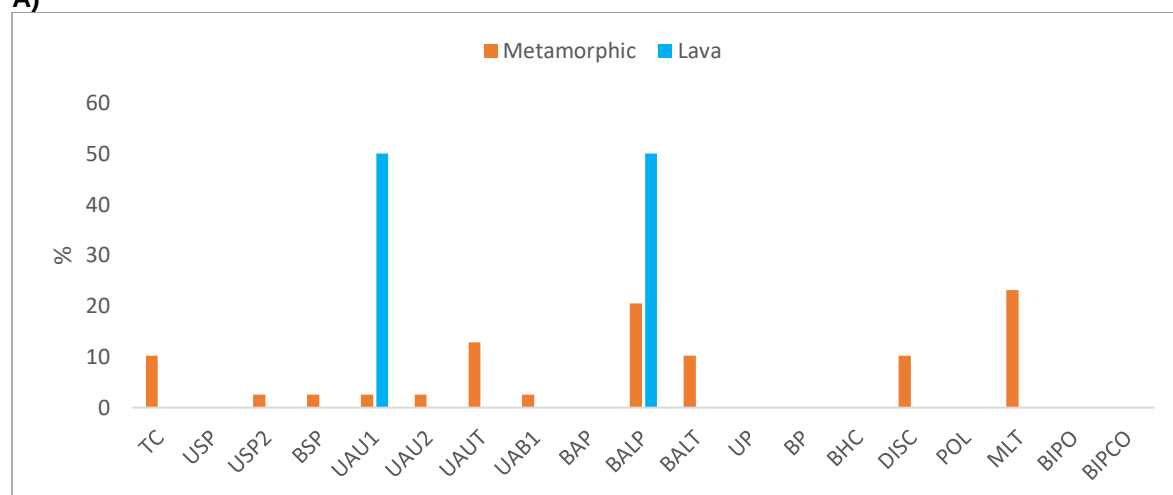


Figure 6. 19: A-B) FC East unifacial cores length class. A) Length class all raw materials B) length class per raw material group.

Figure 6.20B shows that **UAU1** (50%) of lava being the most predominant than metamorphic (3%). The **UAU1** flaking technique is characterised by short series of removals and limited to one knapping surface. The adjusted residual results show that there is significant overrepresentation of lava cores in **UAU1** exploitation strategy (Appendix 6.2). Most unifacially exploited cores were made of metamorphic cores, except with the **UAU1** which is predominated by lava raw materials (Figure 6.20B). The chi-squared result shows a statistically significant difference ($\chi^2 (10) = 131.517$, $p < .001$), with adjusted residuals showing predominance of lava raw materials in the UAU1 (Appendix 6.2).



A)



B)

Figure 6. 20: A-B) FC East core exploitation systems at FC East T31L80 (A) and per raw materials (B).

6.8.4.3 Bifacial core exploitation strategy

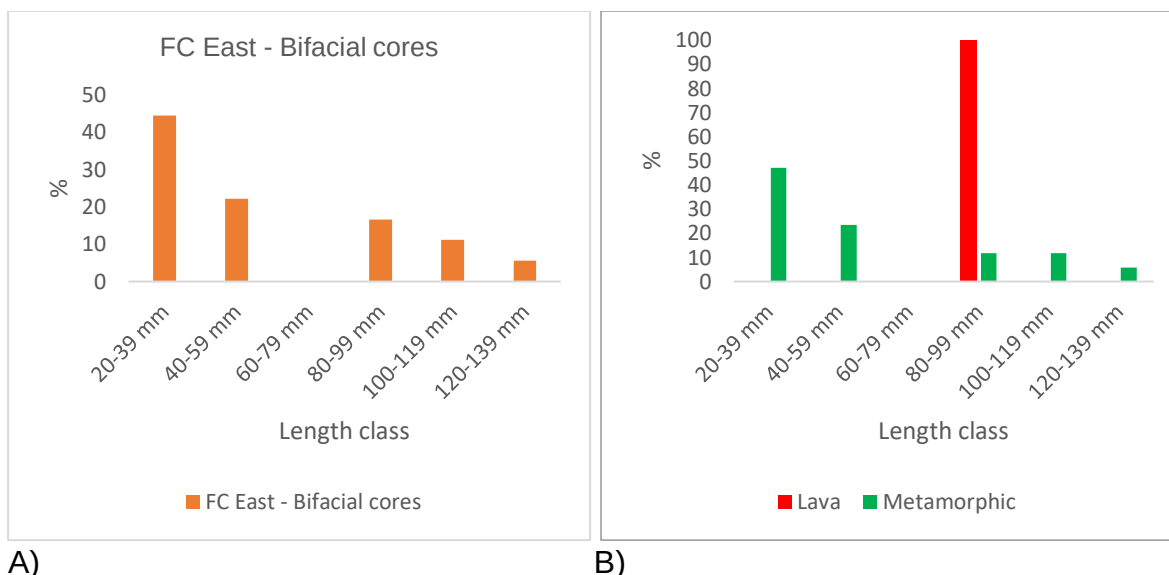
Bifacial cores (n=18, 44%) are the most prominent within the core sample (Table 6.11), with three reduction types being identified. **BSP**: Bifacial simple partial exploitation (n=1, 3%), comprising only metamorphic materials; **BALP**: bifacial alternating partial exploitation of lava (n=1, 50%) and eight (21%) of metamorphic materials; and **BALT**: bifacial alternating total exploitation of metamorphic materials (n=4, 10%) (Table 6.12).

Frequency data was produced to identify the most significant exploitation strategy within the bifacial scheme. Overall, **BALP** (n=9, 22%) appears to be the most predominant scheme within the entire core sample (Table 6.12). Within this strategy, a core is flaked partially on one surface and rotated to flake an adjacent surface using flake scars of the other knapping surface.

BALT (n=4, 10% of the entire core sample) is the second most prevalent exploitation strategy, where the entire circumference of a core is exploited bifacially by rotating the core as in the **BALP** method (Table 6.12).

In terms of size, most bifacial cores measure between 20-39 mm and 120-139 mm in length (Figure 6.21A). Within the bifacial cores, metamorphic rocks were the most widely exploited than lava; this is supported by the presence of different length classes. Lava rocks, however, appear to be the most predominant than metamorphic rocks within the 80-99 mm length class (Figure 6.21B).

Statistically, the chi-square test results show a significant difference across bifacially exploited cores ($\chi^2 (10) = 131.517, p < .001$), with adjusted residuals showing predominance of lava within the **BALP** cores, predominance of metamorphic within the **BALT** cores, and predominance of metamorphic within the **BSP** cores (Appendix 6.2).



A) B) *Figure 6. 21: A-B) FC East bifacial cores length class. A) Length class of all bifacial cores B) Length class of all bifacial cores per raw material group*

6.8.4.4 Multifacial core exploitation strategy

The multifacial exploited cores (n=9, 22%) only appear in metamorphic rocks (table 6.11). These cores show multiple flaking platforms with no clear organisation of flaking of flakes. Often these cores are highly exploited, whilst retaining only little characteristics indicating original blank; they mostly possess less than fifty percent of cortex coverage due to the intensity of exploitation. In terms of reduction intensity, most of them possess 4-6 scar and a few possess over nine scars (>9 scars) (Figure 6.22A). In terms of their size, most multifacial cores are predominated by 80-99 mm long, followed by 60-79 mm (Figure 6.22B). This suggests that the most predominant and widely exploited raw material was used to produce different sizes of flakes, ranging from 20-39 mm to over 100 mm long.

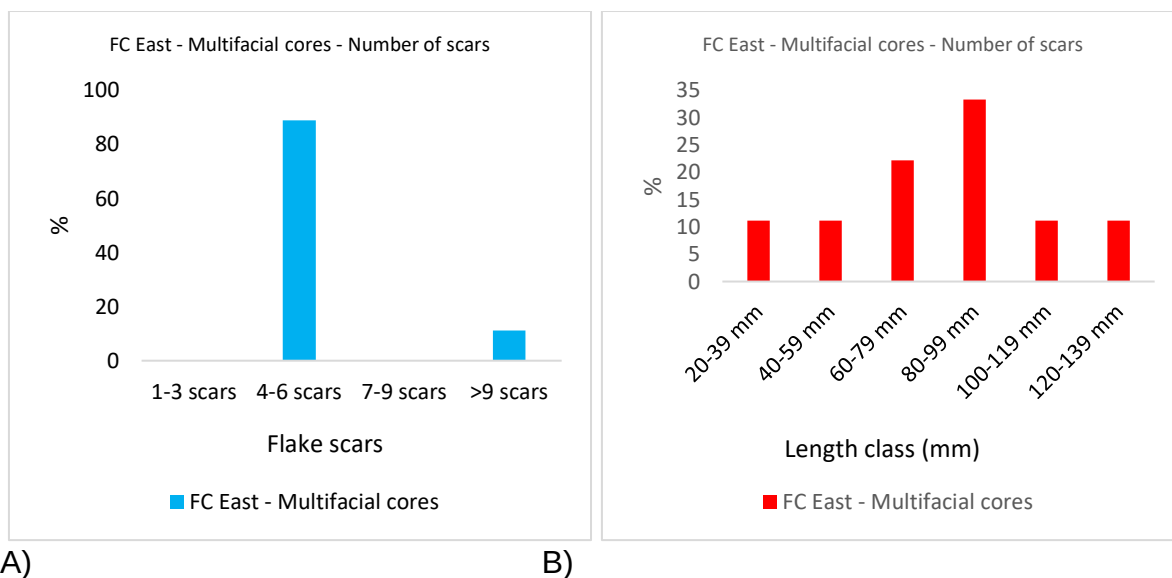


Figure 6. 22: A-B) FC East multifacial cores. Length class of all multifacial cores B) Flake scars of all multifacial cores.

6.8.4.5 Discoid core exploitation strategy

Discoid exploited cores (n=4, 10%) are made only in metamorphic materials (Table 6.12). In terms of size, most discoids are smaller in size with length ranging from 20-39 mm to 40-59 mm (Figure 6.23A). In addition, most discoids possess 4-6 scars, followed by 7-9 scars (Figure 6.23B).

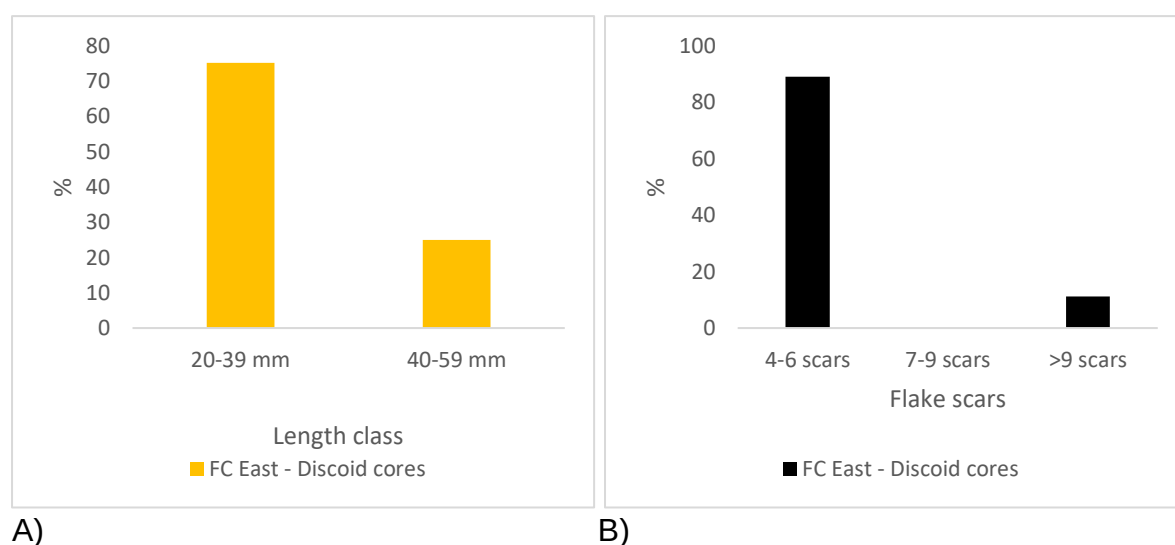


Figure 6. 23: A-B) FC East discoid cores. A) Length class of discoid cores B) Number of flake scars on discoid cores.

6.8.4.6 Test core exploitation strategy

Test core (n=4, 10%) are predominated by metamorphic materials (Table 6.12 and figure 6.20B). It should be noted that **TC** involves detachment of 1 or 2 removals that are randomly distributed. FC East provides evidence that hominins did not only exploit cores using different exploitation strategies, but they also tested some core blanks before utilising them. Coincidentally, the test cores raw materials appear to be metamorphic (n= 4), which is the most utilised raw materials in the entire core sample, followed by lava materials (n= 2).

Therefore, it can be suggested that hominins tested metamorphic materials and found them suitable for further reduction stages. This fact, coupled with the overrepresentation of metamorphic raw materials amongst most exploitation strategies may also suggest that hominins were preferentially selecting tabular blocks and other blank types for knapping activities (Table 6.13).

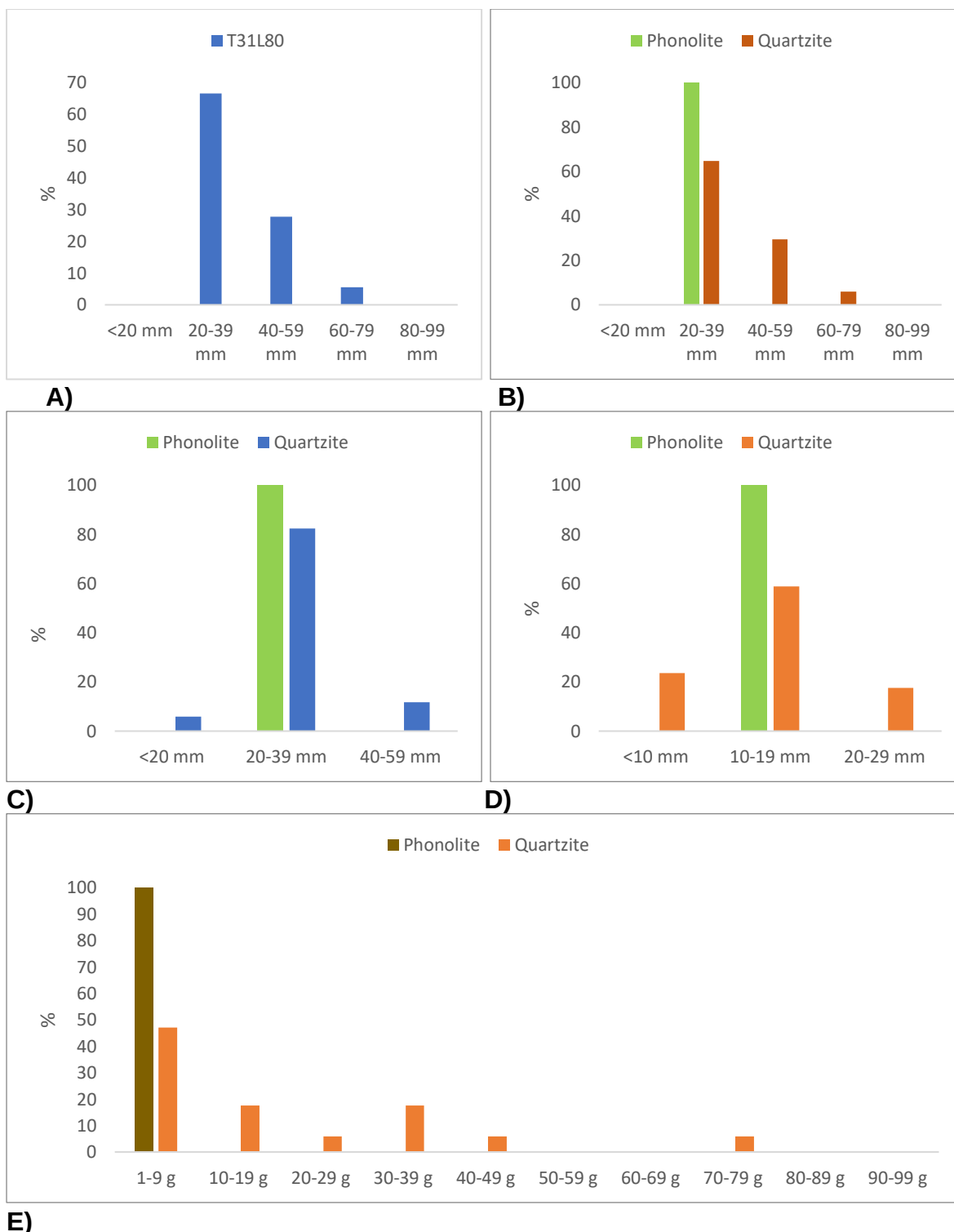
Table 6. 13: FC East core blanks.

Core blank										
	Block		Cobble		Flake		Indet		Total	
	n	%	n	%	n	%	n	%	n	%
TC	4	11.4%	4	10.5%	2	100.0%			10	11.4%
BSP	3	8.6%	4	10.5%			1	7.7%	8	9.1%
UAU1	3	8.6%	2	5.3%					5	5.7%
UAU2			4	10.5%			1	7.7%	5	5.7%
UAB1	3	8.6%							3	3.4%
BALP	2	5.7%	3	7.9%					5	5.7%
BALT									0	0.0%
BP	1	2.9%							1	1.1%
BHC			1	2.6%					1	1.1%
DISC	4	11.4%	6	15.8%			2	15.4%	12	13.6%
POL	2	5.7%	2	5.3%					4	4.5%
MLT	13	37.1%	12	31.6%			9	69.2%	34	38.6%
BIPO									0	0.0%
BIPCO									0	0.0%
Total	35	39.8%	38	43.2%	2	2.3%	13	14.8%	88	100.0%

6.8.5 Retouched pieces

Retouched pieces (n=18) total 3% of the sampled assemblage at FC East and sum up a total weight of 360 grams (Tables 6.4 and 6.5; figure 6.11). As shown in figure 6.24A and B and table 6.14, most retouched tools are 20-39 mm in length, with an average of 37.6 mm (Table 6.8, figure 6.25). Figure 6.24B shows that most retouched pieces measure 20-39 mm in length, with phonolite being the most prevalent lava than quartzite. It is worth noting that phonolite is mostly fine-grained and hence suitable material for retouching. Moreover, figure 6.24C show that retouched tools are between 20-39 mm wide and 10-19 mm thick; lava materials appear more frequently than quartzite raw materials (Figure 6.24C-D). In terms of weight, most retouched pieces weigh between 1-9 grams (Figure 6.24E). In fact, a good example of pieces that seem to have been modified intentionally are those seen in figure 6.25. All these retouched pieces shown were retouched from complete flakes, while other items were retouched from indeterminate blanks.

In terms of raw materials, the most prevalent raw material is quartzite (n=17, 3.1%), followed by lava (n=1, 5.6%) (Table 6.6). Metamorphic retouched pieces are the longest, with an average length of 38.6 mm, followed by lava retouched tools, with an average of 30 mm (Table 6.8). Overall, the retouched pieces have an average weight of 20 g and a width of 27.9 mm (Table 6.8). It should, however, be noted that there is a significant variation in length and weight, with some retouched pieces measuring 65 mm in length and other pieces as short as 24 mm in length (Table 6.8). Likewise, there is a significant weight difference, with some retouched pieces weighing as heavy as 79.2 g while some as light as 4.6 g (Table 6.8).



E) Figure 6. 24: Dimensions and metric of retouched tools. A-B) Length of retouched tools per (A) and per raw materials (B). C-D) Width per raw materials (C) and thickness per raw materials (D). E) Retouched tools weight ranges per raw materials.

The Chi-Square test results ($\chi^2 (2) = 42.424, p < .001$), support the significant difference in length, with the adjusted residuals showing overrepresentation of

metamorphic retouched pieces ranging 60-79 mm in length when compared to lava retouched pieces (Appendix 6.3).

Three retouched tool types were identified: denticulates (n=8, 44%), notches (n=5, 28%), and sidescrapers (n=4, 22%) (Table 6.14).



A)



B)

Figure 6. 25: A-B) FC East retouched pieces. A) Dorsal side of retouched pieces B) Ventral side of retouched pieces.

In addition, denticulates appear in larger number within the metamorphic (n=7) materials than in lava (n=1) (Table 6.14). In addition, notches (n=4) are more common in metamorphic than the lavas (n=1) (Table 6.14). Sidescrapers (n=4) retouched pieces only appear in metamorphic materials. Indeterminate (n=4) retouched piece was also recorded, and it was retouched from quartzite materials (Table 6.14).

Regarding dorsal cortex on the retouched tools, non-cortical retouched tools dominate (n=12, 67%) the sample, followed by those with <50% cortex (n=4, 22%), and those with >50% cortex (n=2, 11%) (Table 6.14). Within the non-cortical retouched tools, metamorphic (n=11) appear more frequently than lava (n=1) retouched tools. In addition, retouched tool with <50% cortex are all manufactured from metamorphic (n=4) raw materials (Table 6.14). A Chi-Square test was conducted to determine dorsal cortex coverage representation per raw materials. The Chi-Square test results ($X^2 (2) = 62.605, p < .001$), show non-cortical retouched tools are more frequent within metamorphic than lava retouched pieces (See appendix 6.4). In addition, the adjusted residuals show retouched pieces with >50% cortex are dominated by lavas over quartzite, while retouched pieces with <50% cortex appear more frequently within metamorphic than lava materials (Appendix 6.4).

Table 6. 14: FC East retouched tools attributes.

		Raw Material				Grand Total	
		Lava		Metamorphic		n	%
		n	%	n	%		
Length class	20-39 mm	2	100	10	63	12	67
	40-59 mm	0	0	5	31	5	28
	60-79 mm	0	0	1	6	1	6
	Total	2	11	16	89	18	100
Cortex dorsal side	Cortex >50%	1	50	1	6	2	11
	Cortex <50%	0	0	4	25	4	22
	Non-cortical	1	50	11	69	12	67
	Total	2	11	16	89	18	100
Retouch Type	Denticulate	1	50	7	44	8	44
	Notch	1	50	4	25	5	28
	Point	0	0	0	0	0	0
	Sidescraper	0	0	4	25	4	22
	Indet	0	0	1	6	1	6
	Total	2	11	16	89	18	100

6.8.6 Technological strategies at FC East

Within the core sample, there is a predominance of flake scar patterns ranging between 1-3 scars and 4-6 scars per core (Figure 6.17E-F; Table 6.10). The most prevalent reduction pattern is 4-6 scars per core, suggesting that the reduction intensity at the site was mostly medium rather than low intensity (Table 6.10, figure 6.17A-B).

Further analysis of reduction intensity focused on core cortex. As shown in figure 6.17C-D, there is predominance of cores preserving <50% cortex coverage, suggesting that cores were not fully exploited to their exhaustion stage. This observation is consistent with the evidence of Toth's flake types, whereby the analysis shows predominance of types V and VI (Figure 6.14C-D). Moreover, figures 6.14A-B show predominance of unifaceted striking platform on most flakes, a pattern that indicate hominins removed cortex on cores before detaching a flake.

The analysis of core length shows that most cores were ranging 20-39 mm and 40-59 mm in length (Figure 6.16A and 6.26A-B; Table 6.10). This suggests that hominins used small to medium cores in manufacturing flakes. This result is consistent with the results of flake length, whereby most flakes are ranging between 20-39 mm and 40-59 mm, followed by 60-79 (Table 6.7; figure 6.12A).

Furthermore, the analysis of core knapping accidents shows that over half of the cores shows step scars (n=22, 54%) knapping accidents (Table 6.15). Most of these accidents are observed in the quartzite (n=21, 54%) cores, a raw material that is susceptible to causing accidents due to nature of the rock texture, which is mostly coarse-grained (McHenry and de la Torre, 2018). It should, however, be noted that

these accidents may not be directly related to knappers' knapping skills, and they may be partly related to the nature of the rock utilised.



A)



B)

Figure 6. 26: A-B) FC East cores analysed in this study.

Table 6. 15: FC East core knapping accidents.

Core Knapping accident	Raw Material				Grand Total	
	Lava		Metamorphic		n	%
	n	%	n	%		
Step scar	1	50	21	54	22	54
Fracture	1	50	1	3	2	5
N/A	0	0	17	44	17	41
Total	2	5	39	95	41	100

Table 6. 16: Frequency of lithic technological categories uncovered from T31L80 by OGAP team in 2014.

Technological Category	Count	%
Core (BN1G)	97	5
Retouched tool (BN2G)	32	2
Natural rock (BNA)	81	4
Hammerstone (BNE)	22	1
Flake (BP)	252	12
Shatter (BP2G)	350	17
Fragmented flake (BPF)	1130	54
Chunk (BPI)	123	6
Grand total	2087	100

6.9 Conclusion

The FC East sample analysed from T31L80 presents over 15 kg of utilized stones attributed to small debitage *chaîne opératoire*, which consists of small, medium and few large-sized cores, small flake, fragmented flakes, and retouched tools. It is suggested that the raw materials used to manufacture different lithic categories were obtained from the local sources located nearby the site and were procured to the site

for the aim of producing stone tools. Metamorphic rocks were the most preferred raw materials at the site.

A total of 569 stone tools were sampled and analysed (Table 6.4). The sample analysed shows a single reduction sequence observed at FC East assemblage, which is mostly characterised by a smalldebitage *chaîne opératoire*. There were no large cutting tools from the original assemblage that was excavated by the OGAP team at FC East (Table 6.16). Thus, it can be suggested that the smalldebitage *chaîne opératoire* is characterised by medium reduction intensity, which depended upon raw material blanks, particularly tabular blocks from sources located nearby the site, predominantly Naibor Soit Hills. Analysis of flaking methods indicates expedient flaking with the exception of the discoid cores, and a flake production geared towards low to medium reduction intensity.

This chapter has presented a technological analysis of FC East stone tools. It has demonstrated that the assemblage was characterized by a medium reduction intensity. This suggests that early Acheulean hominins at FC East preferred simple and less complex technology, as attested by the sample studied. The next chapter presents a detailed technological analysis of JK assemblage and provides an overview of archaeological evidence that demonstrate hominin technological behaviour at JK.

Chapter 7: Juma's Korongo Site

7.1 Introduction

This chapter presents a technological analysis of the Juma's Korongo (JK) stone tool assemblages. The analysis is based on a comprehensive examination of samples of lithic materials recovered from JK by M.R. Kleindienst and M.D. Leakey between 1961-62 and 1969 and 1971, respectively. This thesis' analysis has generated a database containing an array of technological information specific to the JK site. An extensive technological analysis and systematic description of Acheulean stone artefacts from Bed III was carried out and the results will be presented here in Part I and Part II. These data will also be compared in chapter 9.

7.2 JK Archaeological setting at Olduvai

The JK site, one of the first of those identified and excavated in Olduvai during the 1931-32 expedition (Leakey, Arthur and Hans, 1931; Leakey, 1951), is located on the north side of the Gorge, approximately 2.5 km downstream from the junction of the Main and the Side Gorges (Figure 7.1) (Leakey, Arthur and Hans, 1931; Leakey, 1951; Kleindienst, 1973; Leakey and Roe, 1994).

In 1931, L.S.B. Leakey carried out a preliminary investigation at the site and found lithic tools which he regarded as part of the transition from Chellean to the Acheulean industry (Leakey, Arthur and Hans, 1931). He also called the site an occupation site in an archaeological context (Pante, 2010). The initial work at JK was then reported in detail in 1951's report on the evolution of the handaxe culture at Olduvai (Leakey, 1951).

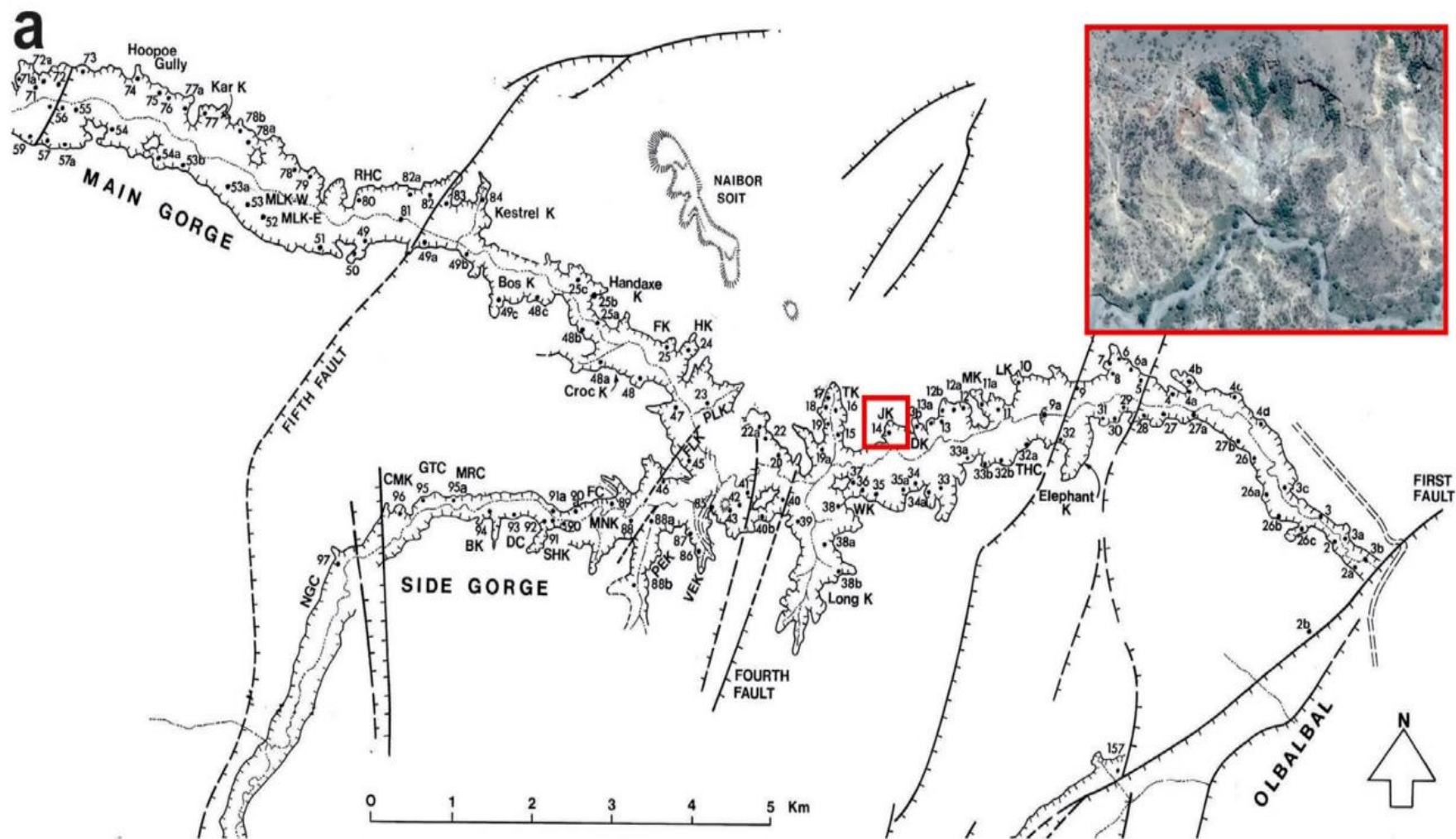


Figure 7. 1: Map showing location of JK site at Olduvai Gorge (adapted from Yravedra et al. (2020)).

Stratigraphically, the site is located within Bed III (Kleindienst, 1973; Hay, 1976; Leakey and Roe, 1994). The JK deposits are positioned 10-15 m below the rim of the Gorge; they were formed by three head branches of a side gully which joins to form a stream that joins the Olduvai river to the south (Pante, 2010). In the original publication on the geology of Olduvai (Hay, 1976), a chronology of Bed III was estimated at around 1.15 to 0.80 Ma. However, the most recent dates put Bed III at 1.14 ± 0.05 Ma (Deino et al., 2020). Thus, the age of the JK site would be around this period.

In 1961-62, Kleindienst was invited by Drs. L.S.B and M. D Leakey to conduct further excavation at JK (Kleindienst, 1973). The work lasted from October 1961 through February 1962. Since L. Leakey had uncertainties about whether Kleindienst was excavating the site he initially excavated, Kleindienst renamed the site JK2 (Kleindienst, 1973; Pante, 2010). However, the terms JK and JK2 simply represent the same site; thus, this thesis uses the original name, JK.

Additionally, the use of JK and JK2 are used to distinguish assemblages excavated by M.D. Leakey and Kleindienst, respectively. Therefore, in this study, the sample assemblage excavated by M.D. Leakey is referred to as JK and JK2 for the sample excavated by Kleindienst. Additionally, it should be noted that both M.D. Leakey and Kleindienst added terms “JK East and JK West” or “JK2 East and JK2 West” to distinguish the excavation undertaken at either the eastern side or western side of the JK gully. In this chapter, these terms will be used accordingly.

According to Leakey and Roe (1994), Kleindienst’s work focused at two localities; JK West and JK East, both positioned in Bed III. Leakey and Roe (1994) state that JK East yielded lithic industry with small tools and choppers but missing bifaces, and JK

West yielded bifacial stone tools, hominid remains and some faunal materials (Leahey and Roe, 1994). Kleindienst only published a paper on the interpretation of the geological background (Kleindienst, 1973, Leahey and Roe 1994).

Kleindienst 1962's excavations planned to focus at JK2 West but the work was extended to JK2 East, about 100 m away, to elucidate the geologic setting (Pante, 2010). Both JK2 East and West were interpreted to have been found in fluvial or deltaic environments. Excavations at JK2 West had to be extended to JK2 East in order to clarify the stratigraphic relationships of the two sides of the ravine (Kleindienst, 1973). In JK2 West two trenches were opened, trench A and B. In JK2 East, a total of 10 trenches were excavated, of which 8 were geological trenches (Kleindienst, 1973; Yravedra *et al.*, 2020). Kleindienst found that JK2 is the only site within Bed III yielding a high concentration of cultural remains (Kleindienst, 1973: 148). Kleindienst excavated three fossil-bearing trenches which are trenches A and B, located in JK West where L. Leahey discovered cultural remains in 1931-32, and trench 8 which was found at JK East. In the previous sections, a description of the JK site excavations has been provided in order to clarify the localities excavated by M.D. Leahey and M.R. Kleindienst, yet it is now interesting to describe which trenches were excavated and the kinds of archaeological materials uncovered from each one.

7.2.1 Trench A, JK2 West (Figures 7.2 and 7.4)

Trench A in JK2 West yielded numerous fossil bones and teeth which were associated with lithic artefacts (handaxes) found in coarse sand in contact with silty clay (Figures 7.2 and 7.4) (Kleindienst, 1973; Pante, 2010; Yravedra *et al.*, 2020). Kleindienst (1973) suggested that the size and abundance of these faunal and lithic materials were evidence that transportation may have occurred at JK2. The upper part of the

coarse sand layer (bed 6) contained larger materials, alongside with crocodile teeth and fish remains; also, large vertebrate fossils such as elephant vertebrae and several artefacts appeared close to the base of the sand, nearer to the contact with silty clay (bed 7). The finds seen in the section to lie on the foreset bedding planes (Kleindienst 1973). As a result, these finds can be regarded as deposited naturally, and the finds deposited on the same horizontal level have not been deposited at the same time. In addition, one cleaver and other small artefacts were uncovered from the bottom of the sand, north-eastern side of the trench (Kleindienst, 1973).

The coarse sand narrows and grades into medium and fine sand in Trench B (Figure 7.3), in which handaxes, cleaver (of Acheulean type), small artefacts and fossil bones were concentrated at the basal part (Kleindienst, 1973). The parts of artefact concentration have a linear northeast-southwest configuration (Figure 7.4). Kleindienst (1973) adds that the outer two coincide with depressions underlying clay surface that indicate transportation and deposition by water; Kleindienst mentions that this evidence suggests a probable geological context in trenches A and B.

7.2.2 Trench B, JK2 West (Figure 7.4)

In trench B, handaxes, cleavers, small artefacts and fossil bones were recovered from the basal layers of coarse sand and grit overlying grey silty clay. Remains from trench B indicated a scattered distribution. The sediments below coarse sand/silty clay contact, some pebbles, artefacts and faunal remains were found scattered through the bed above lower red silty clay. Rock types used in stone tool production are the same as those in Trench 8. Further description of artefacts found in Trench B is given below, in the section of excavation by Kleindienst at JK2 site.

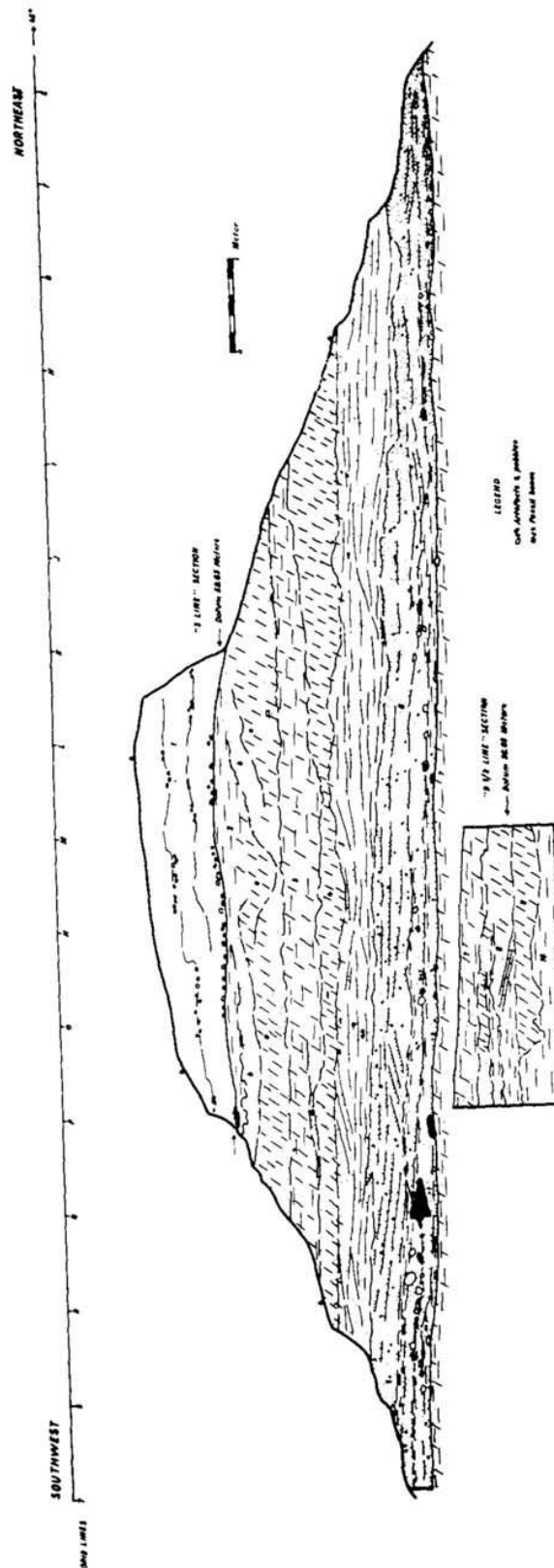


FIG. 10.

Figure 7. 2: An image of stratigraphic section of JK2's Trench A. This image was reproduced from Kleindienst (1973)'s figure 10.

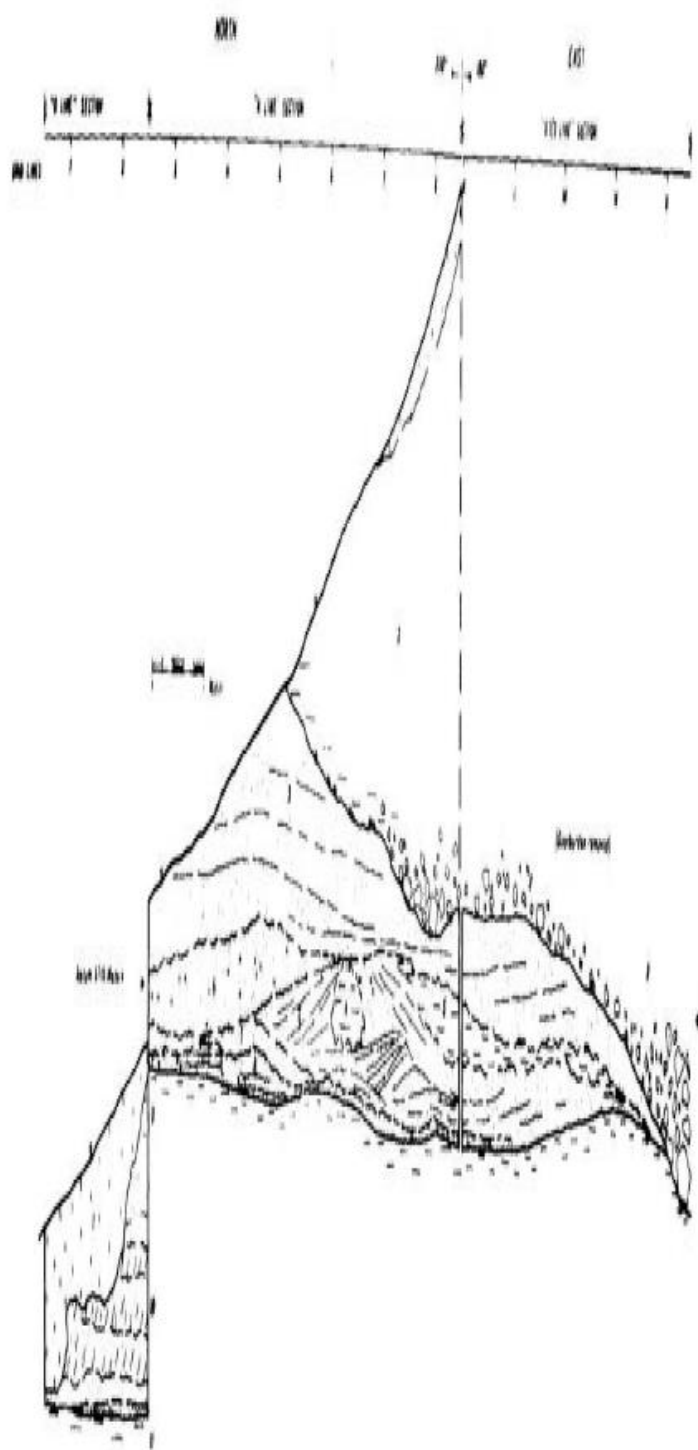


Figure 7. 3: An image of stratigraphic section from JK2 Trench B, excavated by M.R. Kleindienst in 1973 (Kleindienst, 1973).

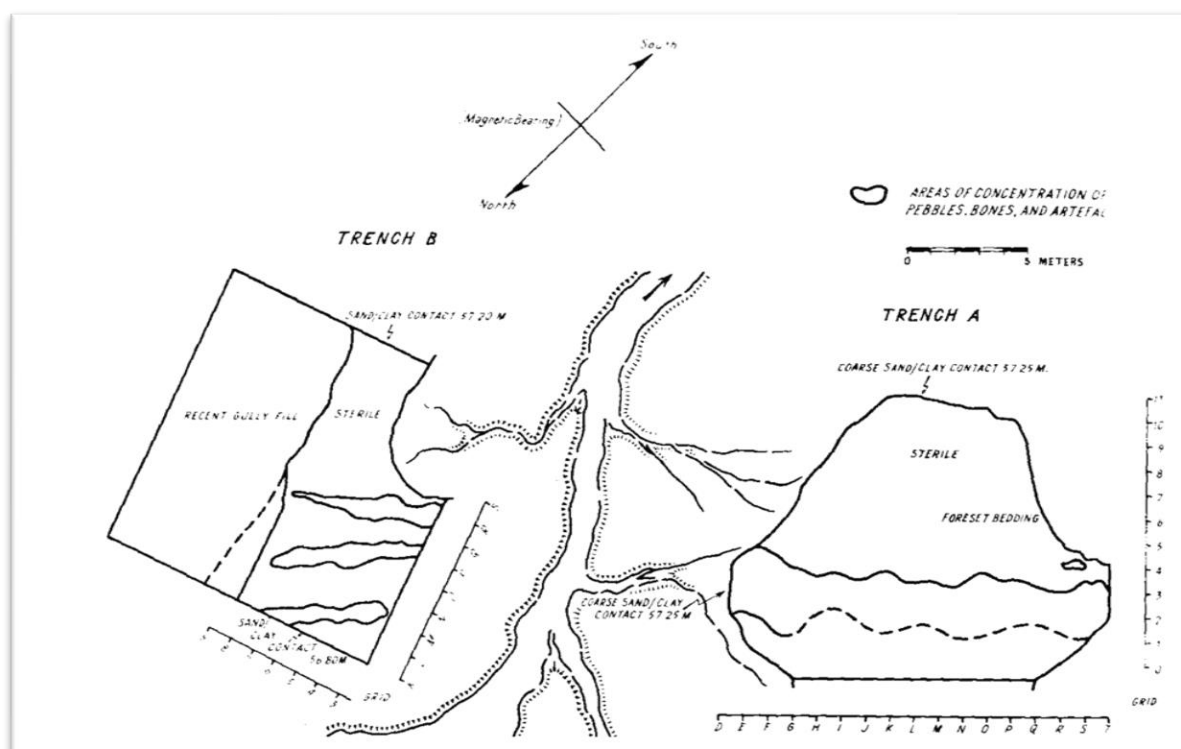


Figure 7. 4: Image showing excavations by Kleindienst at trenches A and B (Image adapted from Kleindienst (1973)).

7.2.3 Trench 8

At trench 8, Kleindienst defines two archaeological occurrences, in which lithic artefacts and bones were uncovered. The first being the lower part of the coarse sand that presents a high concentration of fossils and lithic artefacts, and the second being the upper part of the coarse sand that presented the scattered distribution of fossils and artefacts (Kleindienst, 1973, Pante, 2010). A concentration of materials designated as lower archaeological occurrence was discovered immediately overlying a coarse sand/silty clay, where the base of the coarse sand found level-bedded within the top of the clay. The clay contained artifact together with parts of hippopotami skeletons, bovid, equid and suid fossil remains, in which all were interpreted by Kleindienst as streamside butchery site (Kleindienst, 1973; Yravedra et al., 2020). Nevertheless, Leakey (1994: 15) highlights that Kleindienst never undertook a detailed study of these artefact assemblages. Hence, this thesis takes part to re-

examine a sample of JK lithic materials in detail and present the technological organisation at JK.

7.3 JK West and JK2, excavations by M. Kleindienst

7.3.1 Trench A, JK West (Figure 7.5)

Lithic artefact and fossil remains were found at trench A (Figure 7.5). These remains were found scattered throughout grey-brown silts. The frequency and size of the fossils and artefacts increased at the gradational contact with fine sand and continued down to the gradational contact with the coarser sand. Elephant vertebrae and artefacts were also found at the base of the coarse sand, where sand interfingers with silt clay (Kleindienst, 1973). Kleindienst (1973: 183) explains that the type and frequency of comminuted bone, occurrence of debitage from stone working of different size ranges, shows that the remains are human occupational area debris such as those found on earlier undisturbed sites at Olduvai.

Pante (2010: 99) assents that finds in the silty, clayey beds, and fine sands may represent remains of prolonged human occupation in an undisturbed context. Kleindienst (1973) adds that a few of bones and artefacts are abraded, but most of them are in pristine condition, indicating that they may not have been transported from a great distance. Moreover, the geologic environment, another aggrading situation, possibly indicate that finds found in the silty and clayed beds, and fine sands, represent the finds of continuous human occupation, in undisturbed context. However, Kleindienst (1973: 183) regards the finds from these beds as redeposited occupation debris that have undergone little transport and are probably a representative of the materials from a living site nearby the JK site.

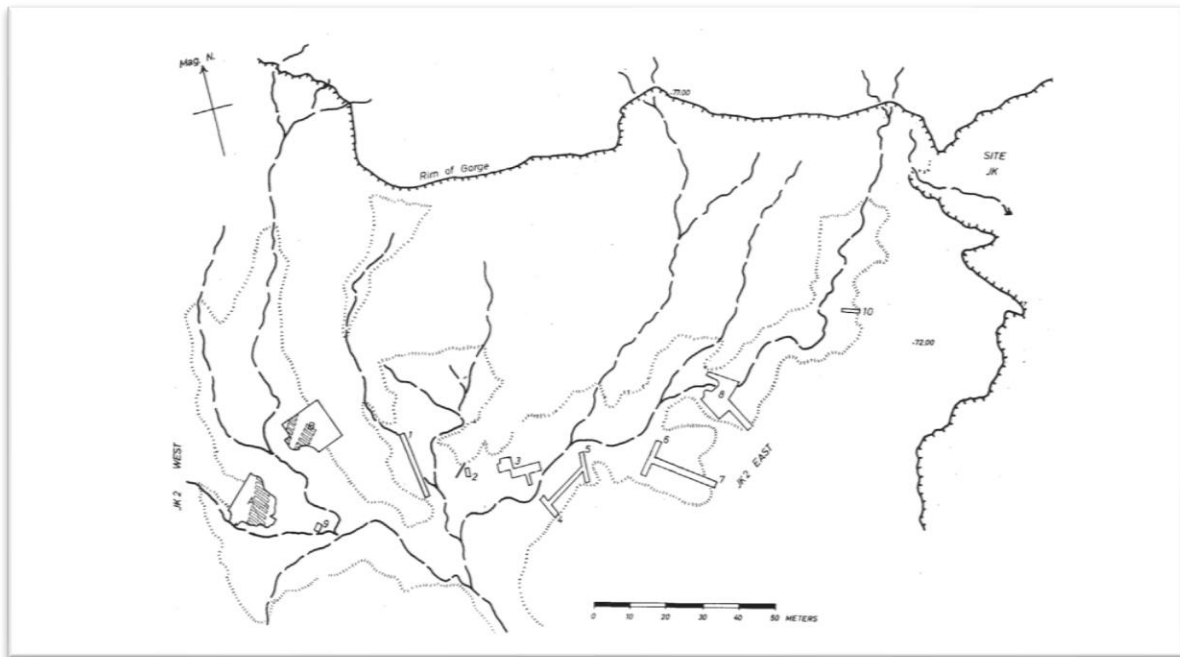


Figure 7. 5: Image showing a plan of excavations from different trenches at JK2. Image adapted from Kleindienst (1973)).

7.3.2 Trench B, JK West (Figure 7.5)

In this trench, lithic artefacts such as handaxes, cleavers, fossil bones, and small artefacts were found concentrated in the basal layers of coarse sand and grit overlying grey silt clay (Pante, 2010; Yravedra et al., 2020). Kleindienst (1973) described three areas of concentration that have linear northeast-southeast alignment (see figure 7.4). She adds that the outer two areas that coincide with depressions under the clay surface that indicate transport and deposition caused by water. This evidence suggests a probable geological context in trench A and B. Additionally, the sediment underlying the coarse sand/silty clay, a scatter of pebbles, some artefacts and fossils were found through beds overlying lower red silty clay. Moreover, a preliminary count of artefacts from JK2 West shows that rocks used in trench B are the same as those used in trench A; also, a rare pieces of vein quartz, pegmatite, green metaquartzite, and dark coloured quartzites and chert (of unknown source) were counted.

Fossil remains of various form were also found. Hippopotamus bones were the most abundant, succeeded by bovid remains and equid. B. Mohl determined more fossil remains from JK2 West, which are as follows:

Primate	Cercopithecidae teeth and phalange Hominidae(?) femur fragment, tibia fragment (H. 34), <i>Homo</i> sp. (See Leakey, 1971a: 234)
Lagomorpha	Bones, scarce
Rodentia	Bones, teeth, scarce
Carnivora	1 Hyaenid mandible, Felid tibia, scapula Small carnivores, bone fragment and teeth
Proboscidea	Various bones, 1 mandible
Perissodactyla	Equidae bones and teeth Rhinocerotidae bones and teeth
Artiodactyla	Suidae bones and teeth, including giant forms Hippopotamus bones and teeth Bovidae bones, teeth, and horn cores Plus, many fish bones and crocodile teeth, fragments of tortoise carapace snake vertebrae, and a few bird bones.

Kleindienst (1973) explains that the artefact density and accompanying faunal materials are not evenly distributed in Bed III sediments; the density varies, with the highest in the Lower Archaeological Occurrence, in trench 8. This may suggest a reflection of stoneworking remains in the gravel bar, from a possible occupational site; Kleindienst (1973) adds that this is similar to densities found on other occupational

floors in Bed II such as TK Lower floor (Kleindienst, 1973). Kleindienst (1973) adds that natural forces can scatter or concentrate coarse materials; at JK2 West evidence shows dispersal in finer beds and concentration in Trench B. The most interesting part is that most densities of artefacts are scattered in the deposits. These remains presented a scattered distribution with no clusters (Yravedra et al., 2020).

7.3.3 Trench 8, JK East (Figures 7.4 and 7.5).

Two separate archaeological occurrences are described in trench 8 (Figure 7.4). The upper archaeological occurrence (UAO), where scattered bones and artefacts were found in the upper coarse sand. The lower archaeological occurrence (LAO) was found immediately overlying coarse sand/silty clay contact in which the base of coarse sand was level-bedded and within the top of the clay. Within clay, lithic artefacts were found together with two partial hippopotamus skeletons and other fossil remains of suids, equids, and bovids. The fossils and artefacts from LAO appear to have been contemporaneous across the bedding contact, and the environment continued aggrading (i.e sandbar or stream bank) (Pante 2010: 100). Kleindienst interpreted it as a streamside butchery site. In these deposits, no handaxes were recovered and most lithic artefacts were manufactured from lava and quartzite cobbles (Kleindienst, 1973; Pante, 2010; Yravedra et al., 2020).

7.4 JK West, excavations by M. D. Leakey

In 1969 and 1970, M.D. Leakey conducted further excavations at JK; all of her excavations were undertaken at JK West (Leakey and Roe, 1994). The site yielded fauna and artefact remains, which were recovered from the sandy filling of a river channel that cuts through the JK area and orientated about southwest to northeast (Leakey and Roe, 1994). The material remains differed in physical condition, with

some fresh and some heavily rolled, which Leakey and Roe (1994) state that they were not in primary context.

Further excavations were undertaken in 1971 to search for further parts of OH 34, which was represented by a femur and part of the tibia shaft found by Kleindienst in 1962 (Day, 1971). Leakey's excavations at JK West uncovered a series of pits and associated furrows dug into pink siltstone above the coarser fluvial sediments that contained artefacts (Leakey and Roe, 1994: 15).

At JK West gully, M.D. Leakey recorded an exposed section in 8 trenches as follows, in order from top to bottom:

- a) recent hillwash;
- b) Tuff IVB;
- c) grey siltstone;
- d) 9.5 m of clay and sandstone;
- e) 0.4 m of pink siltstone with pits;
- f) 0.2 m of sandy clay;
- g) 0.5 m of ferruginous sand which intertwines with the level below;
- h) 0.7 m of coarse grey sand (the lowermost part of the channel);
- i) 1 m of clay locally cut into by the channel; and
- j) Tuff IID at the top of Bed II.

Moreover, the stratigraphic levels at JK West were divided into the following four artefact bearing levels which contained archaeological materials as follows:

- a) lowest artefact bearing level, coarse sand, the basal filling of the channel and grey in colour,

- b) fine-grained sand with clay lenses, red in colour and interfingers with grey sand,
- c) pink siltstone with pits, and
- d) clay above the pink siltstone, which is the highest level (Leahey and Roe, 1994: 17).

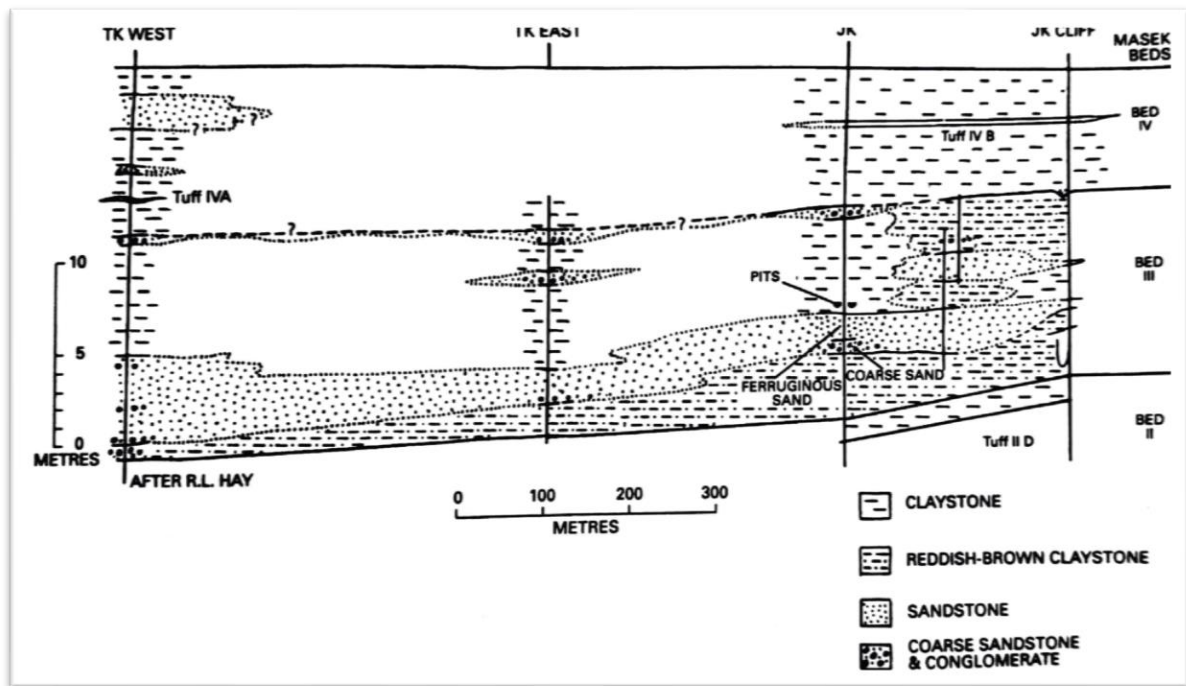


Figure 7. 6: Stratigraphic section of Beds III and IV from west to east along the main drainage channels in TK and JK sites. Image adapted from Hay (1976).

Given the fact that the JK provides lithic materials attributed to Acheulean hominins (Leahey, Arthur and Hans, 1931; Leahey, 1951; Kleindienst, 1973; Leahey and Roe, 1994), it provides a good sample that can contribute several answers to the current research questions under study. What, if any, were the hominin technological capabilities at JK site? Is there a stasis of technological change at JK? What is the raw material economy of *Homo erectus* at JK? Is there a relationship between technological capabilities and the organisation of raw material? How did raw material availability affect reduction intensity and mobile toolkit of *Homo erectus* at JK? What

were the palaeogeographical and ecological contexts of JK? What is the technological organisation of *Homo erectus* at JK? Some of these research questions will be addressed in this chapter and will contribute to the overarching research questions which aim to increase the understanding of Acheulean hominin technological strategies at Olduvai.

7.5 Part I: JK West

7.5.1 Introduction

This part investigates and presents the analysis of JK West lithic sample derived from the M.D. Leakeys assemblage (Table 7.1) (Leakey and Roe, 1994), which is housed at Laetoli lab in the Olduvai's Leakey camp. The characteristics of the lithic sample are described in this part. Following this, a brief description of raw material used in the manufacture of lithic assemblages is presented. This is followed with the detailed description of each technological category including flakes, cores, and flake fragments. Each technological category was analysed by identifying different attributes examined including length, width, thickness, weight, and reduction intensity. Finally, all flaked and detached pieces are discussed in detail to present the technological strategies exhibited at JK West during lower Pleistocene times at Olduvai.

7.5.2 Characteristics of the JK West lithic assemblage

At JK West, the lithic assemblage analysed comes from two archaeological units, JK Grey Sand and JK Ferruginous Sand levels (Table 7.2). The largest sample is JK Grey Sand, and most artefacts were obtained from Trench III, located on the eastern side of the JK West gully (Leakey and Roe, 1994: 17). The JK Ferruginous Sand level, stratigraphically located above in the JK sequence, is a smaller assemblage and was recorded from trenches II to VI (Leakey and Roe, 1994). With regards to the two archaeological levels under investigation, the Leakeys recovered a total number of 5416 stone tools during their excavations at JK (Table 7.1).

Table 7. 1: Table showing the Leakey's assemblage (Leakey and Roe 1994) at JK West.

		JK Lower Coarse grey sand		JK Ferruginous Sand		Grand Total	
		Frequency		Frequency			
	Leakey Tool Category	n	%	n	%	n	%
Tools	Tools	81	2.3	61	2.8	142	2.5%
	Utilised material	81	2.3	54	2.5	135	2.4%
	Debitage	3341	95.3	2075	94.7	5416	95.1%
		3503	99.9	2190	100.0	5693	100.0%
	Bifaces	12	14.8	13	21.3	25	17.6%
	Choppers	7	8.6	9	14.8	16	11.3%
	Polyhedrons	3	3.7	0	0	3	2.1%
	Discoids	3	3.7	6	9.8	9	6.3%
	Spheroids/subspheroids	20	24.7	14	23.0	34	23.9%
	Scrapers, heavy-duty	2	2.5	2	3.3	4	2.8%
	Scrapers, light-duty	24	29.6	11	18.0	35	24.6%
	Awls	0	0	2	3.3	2	1.4%
	Burin	1	1.2	0	0.0	1	0.7%
	Laterally trimmed flakes	2	2.5	1	1.6	3	2.1%
	Outils ecailles	7	8.6	1	1.6	8	5.6%
	Punches	0	0	2	3.3	2	1.4%
Utilised material		81	99.9	61	100.0	142	100.0%
	Pitted anvils/hammerstones	2	2.6	11	20.4	13	10%
	Cobbles	10	12.3	0	0.0	10	7%
	Light-duty flakes	69	85.1	20	37.0	89	66%
	Hammerstones	0	0	3	5.6	3	2%
	Cobbles and blocks	0	0	20	37.0	20	15%
Debitage		81	100.0	54	100.0	135	100%
	Whole flakes	253	7.6	127	6.1	380	7%
	Broken flakes	1568	46.9	1117	53.8	2685	50%
	Core fragments	1519	45.5	821	39.6	2340	43%
	Core	1	0.0	10	0.5	11	0%
Total		3341	100.0	2075	100.0	5416	100%

The current study samples the two archaeological levels, JK Grey Sand (n = 277) and JK Ferruginous Sand (n = 198) (Table 7.3), focusing on stone tool categories (flakes, flake fragments, cores and retouched tools) suitable for a technological analysis and the reconstruction raw material economy.

There is a slight difference between the number of cores identified in this study and the ones identified in Leakey's assemblage; this study has more cores than the Leakey's (Table 7.1 and Table 7.3). This is likely to occur because some of the artefacts that were classified by M.D. Leakey as polyhedrons, spheroids, discoids, and choppers, were considered here as cores (Table 7.3).

Regarding the sum of weight transported from raw material sources to JK West, the sample represents over 25 kilograms, including both archaeological levels analysed (Table 7.2). Over 17 kilograms of the 25 kilograms sampled at JK West correspond to the knapping of metamorphic rocks, with only a little over 8 kilograms of lavas in the analysed sample (Table 7.4). Cores count for 19% of the entire sampled assemblage but represent the largest group in terms of weight (more than flakes, flake fragments and retouched tools if all added together) (Table 7.3 and 7.4). This suggests that hominins at JK transported raw materials from sources to the site for knapping activities, in which the most transported rock types were metamorphic rocks (Table 7.4). Flakes count 43% of the total assemblage and make the largest group of the detached pieces in terms of weight, weighing over 2 kilograms, followed by flake fragments which count 17% of the sample studied, weighing over 500 grams (Table 7.3 and 7.4).

Table 7. 2: JK technological groups per archaeological unit and general raw material.

Archaeological unit	Detached						Flaked						Total	
	Lava		Metamorphic		Sedimentary		Lava		Metamorphic		Sedimentary			
	n	g	n	g	n	g	n	g	n	g	n	g	n	g
JK Ferruginous Sand	14	86	64	643	0	0	32	7318	88	9913	0	0	198	17960
JK Grey Sand	4	27	202	1895	1	7	9	755	61	4758	0	0	277	7442
Grand Total	18	113	266	2538	1	7	41	8073	149	14671	0	0	475	25402

Table 7. 3: Technological categories per archaeological unit in the JK assemblage.

		JK West Grey Sand				JK West Ferruginous Sand				Total			
		Frequency		Weight		Frequency		Weight		Frequency		Weight	
		n	%	Sum	%	n	%	Sum	%	n	%	Sum	%
Detached	Flake	153	55%	1581	21%	49	25%	549	3%	202	43%	2130	8%
	Flake Frag	54	19%	348	5%	29	15%	181	1%	83	17%	529	2%
	Total Detached	207	75%	1929	26%	78	39%	730	4%	285	60%	2659	10%
Flaked	Core	29	10%	4980	67%	59	30%	16266	91%	88	19%	21246	84%
	Retouched tool	41	15%	533	7%	61	31%	965	5%	102	21%	1498	6%
	Total Flaked	70	25%	5513	74%	120	61%	17231	96%	190	40%	22744	90%
Grand Total		277	100.0	7,442	100.0	198	100	17,961	100.0	475	100.0	25,403	100.0

Table 7. 4: Total weight of all lithic categories at JK.

		Technological Category	Lava (g)	Metamorphic (g)	Sedimentary (g)	Total (g)
Detached		Flake	67	2056	7	2130
		Flake Fragments	47	482	0	529
Flaked		Cores	7578	13668	0	21246
		Retouched tool	495	1003	0	1498
Total			8187	17209	7	25403

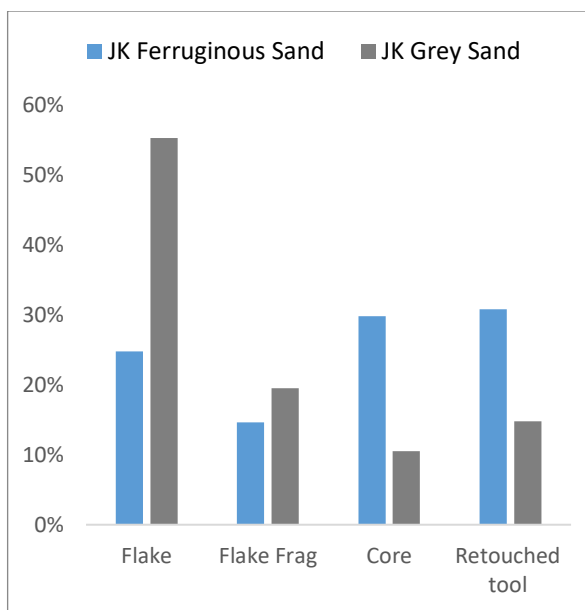
7.5.3 Raw Materials

This assemblage consists of raw materials from different sources at Olduvai, which include basalt, trachyte, phonolite, chert, quartzite, quartz, gneiss (Table 7.4). The analysis shows that the most predominant raw material used at JK West is quartzite; it contributes 67.7% of the weight of the sample studied (Table 7.5). It is double the weight of lava (8198 grams) and sedimentary (7 grams) materials altogether (Table 7.5).

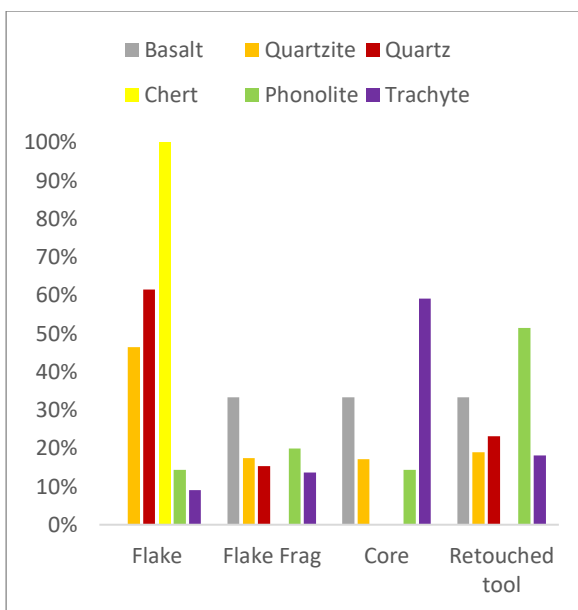
7.5.4 Flakes

Flakes (n = 202) are the most abundant lithic category (representing 43% of the entire sample) within detached pieces (Table 7.3). Weighing 2.13 kg, flake sample is the second heaviest within the JK West sample groups (Tables 7.3 and 7.4). In absolute terms, metamorphic flakes (n = 194) are much more abundant than lava (n=7), and sedimentary (n=1) flakes (Table 7.5). In terms of their distribution per archaeological unit, flakes from JK West Grey Sand make up 55% of the entire JK West sample, whereas in the JK West Ferruginous Sand they make up 25% of the total sample (Figure 7.7A and Table 7.3). When comparing the relative frequencies of flakes per raw material, metamorphic flakes (quartz and quartzite) have relatively higher percentages than lava flakes (basalt, phonolite and trachyte) (Figure 7.7B).

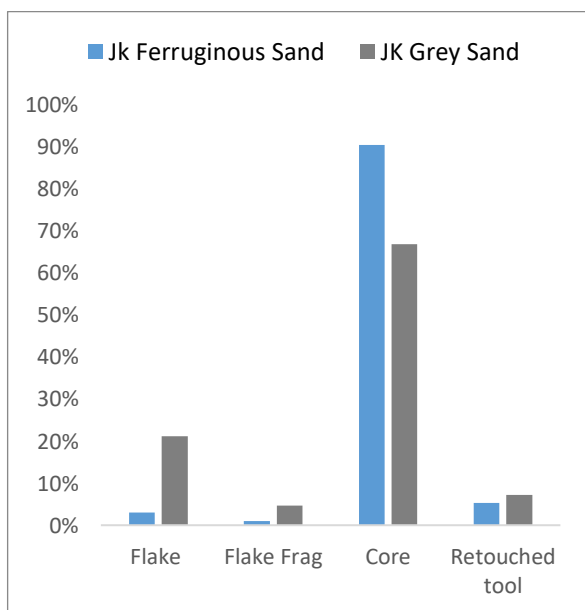
Figure 7.8A-B shows that flakes lengths measure between 20 and 40 mm, with an average of 31.8 in length and 23.6 mm in width (also see Table 7.6, Figures 7.9 and 7.10). However, there is a substantial difference within the flake assemblage, whereby some flakes measuring up to 70 mm in length and some as small as 16 mm (Table 7.7).



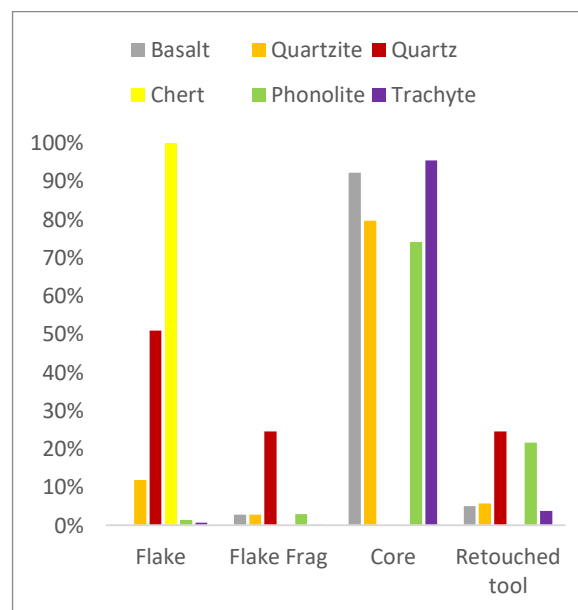
A)



B)

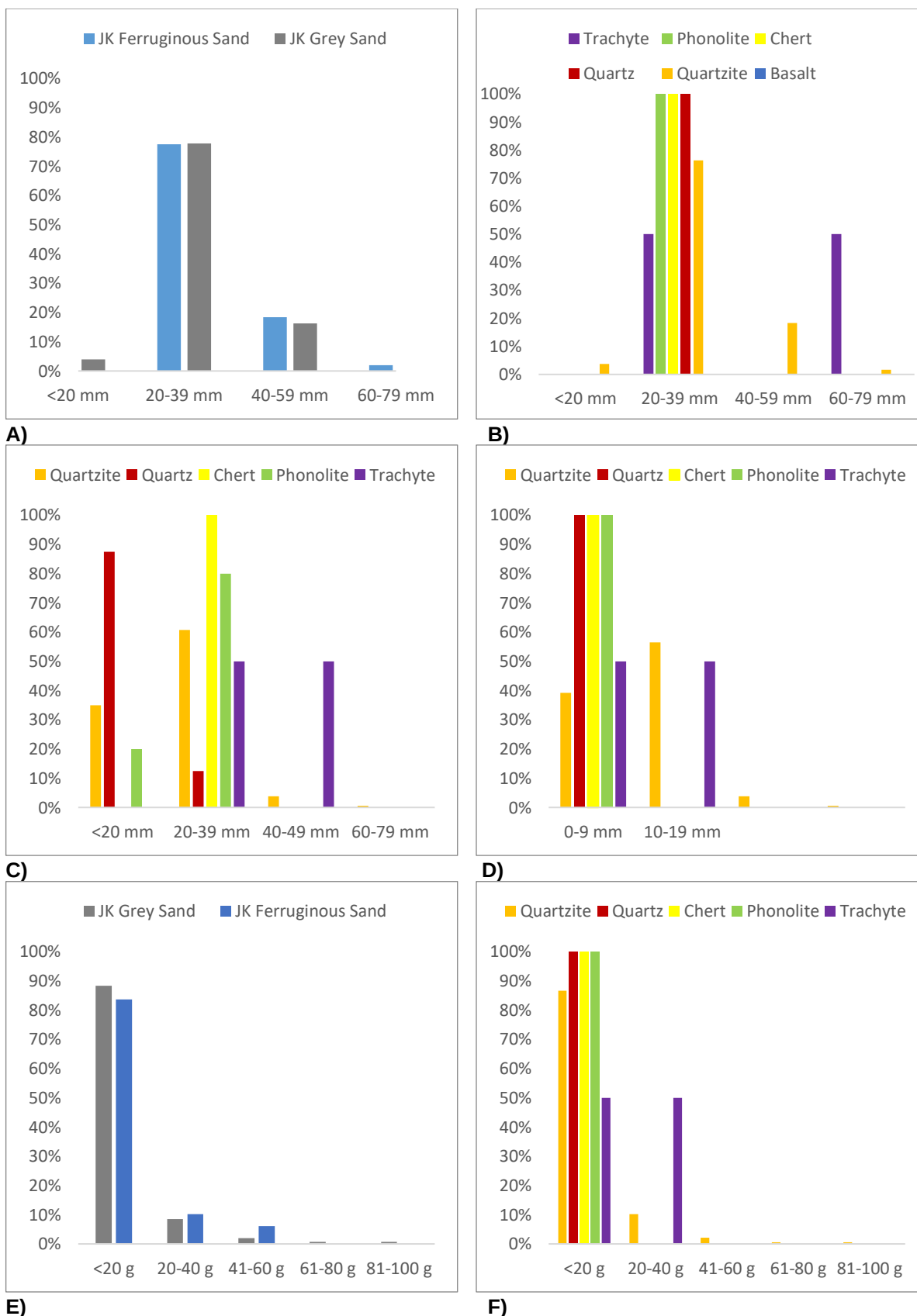


C)



D)

Figure 7. 7: A – B) Number of JK West artefacts per archaeological unit (A) and raw material (B). C-D Relative frequency of weight of JK artefact per archaeological unit (C) and raw material (D).



E) F) Figure 7. 8: A-B) Flake Length ranges in the entire JK assemblage per archaeological unit (A) and raw material (B). C-D) Flake width range – all raw materials (C) and flake thickness range – all raw materials (D). E-F) Flake weight class per archaeological unit (E) and raw materials (F), based on artefact frequency.

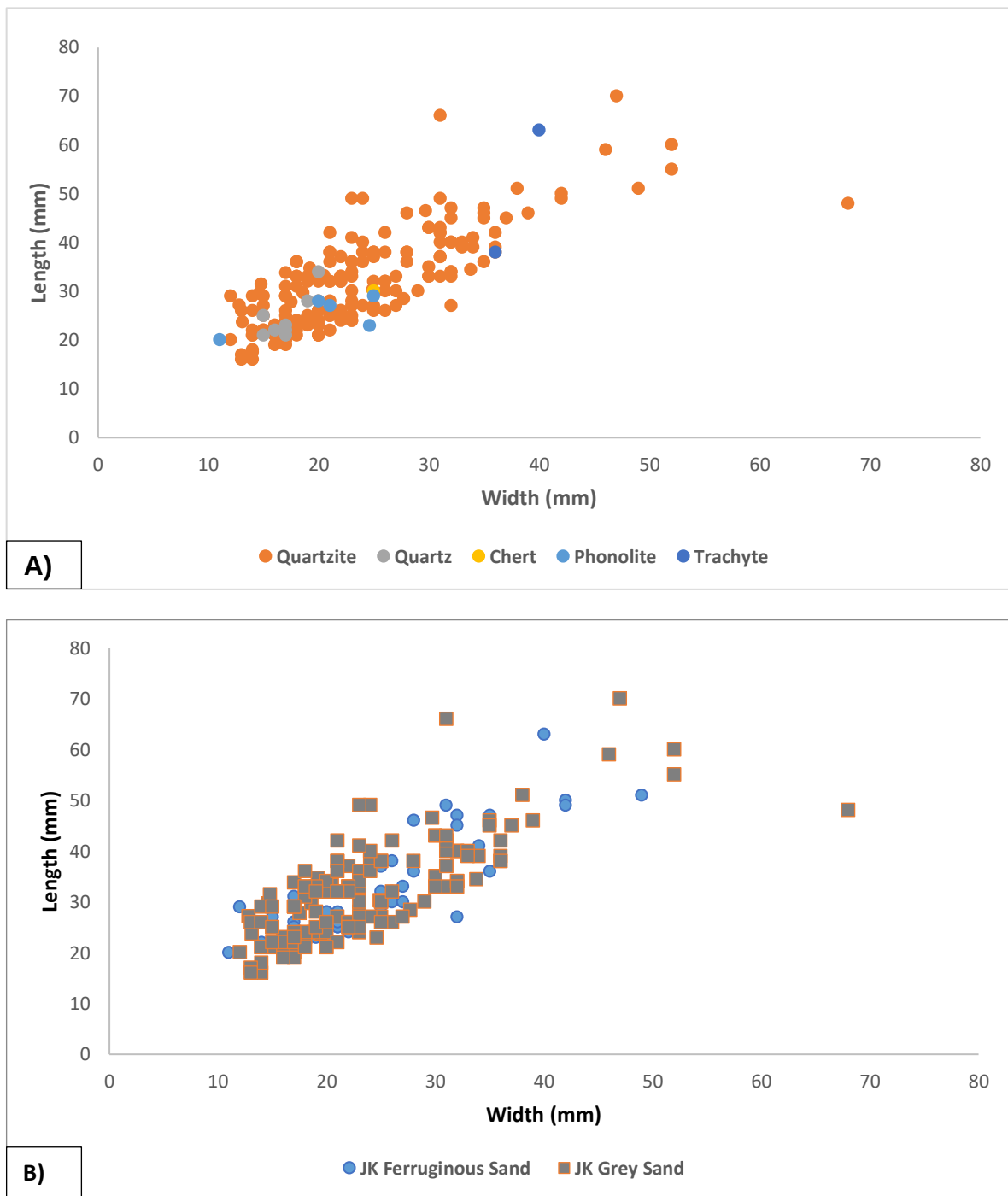


Table 7. 5: JK West's technological categories per individualised raw material.

	Lava								Metamorphic								Grand Total	
	Basalt		Trachyte		Phonolite		Total-Lava		Quartzite		Quartz		Total-Metamorphic		Chert			
	n	g	n	g	n	g	n	g	n	g	n	g	n	g	n	g	n	g
Flake	0	0	2	51	5	16	7	67	186	2029	8	27	194	2056	1	7	202	2130
Flake Frag	1	4	3	11	7	32	11	47	70	469	2	13	72	482	0	0	83	529
Total Detached	1	4	5	62	12	48	18	114	256	2498	10	40	266	2538	1	7	285	2659
Core	1	131	13	6624	5	823	19	7578	69	13668	0	0	69	13668	0	0	88	21246
Retouched tool	1	7	4	258	18	241	23	506	76	979	3	13	79	992	0	0	102	1498
Total Flaked	2	138	17	6882	23	1064	42	8084	145	14647	3	13	148	14660	0	0	190	22744
Grand Total	3	142	22	6944	35	1112	60	8198	401	17145	13	53	414	17198	1	7	475	25403
	Basalt		Trachyte		Phonolite		Total-Lava		Quartzite		Quartz		Total-Metamorphic		Chert		Grand Total	
	Freq %	Wt %	Freq %	Wt %	Freq %	Wt %	Freq %	Wt %	Freq %	Wt %	Freq %	Wt %	Freq %	Wt %	Freq %	Wt %	Freq %	Wt %

Flake	0	0	9.1	0.7	14.3	1.4	11.7	0.8	46.4	11.8	61.5	50.9	46.9	12	100	100	42.5	8.4
Flake Frag	33.3	2.8	13.6	0.2	20	2.9	18.3	0.6	17.5	2.7	15.4	24.5	17.4	2.8	0	0	17.5	2.1
Total Detached	33.3	2.8	22.7	0.9	34.3	4.3	30	1.4	63.8	14.6	76.9	75.5	64.3	14.8	100	100	60	10.5
Core	33.3	92.3	59.1	95.4	14.3	74	31.7	92.4	17.2	79.7	0	0	16.7	79.5	0	0	18.5	83.6
Retouched tool	33.3	4.9	18.2	3.7	51.4	21.7	38.3	6.2	19	5.7	23.1	24.5	19.1	5.8	0	0	21.5	5.9
Total Flaked	66.7	97.2	77.3	99.1	65.7	95.7	70	98.6	36.2	85.4	23.1	24.5	35.7	85.2	0	0	40	89.5
Grand Total	0.6	0.6	4.6	27.3	7.4	4.4	12.6	32.3	84.4	67.5	2.7	0.2	87.2	67.7	0.2	0	100	100

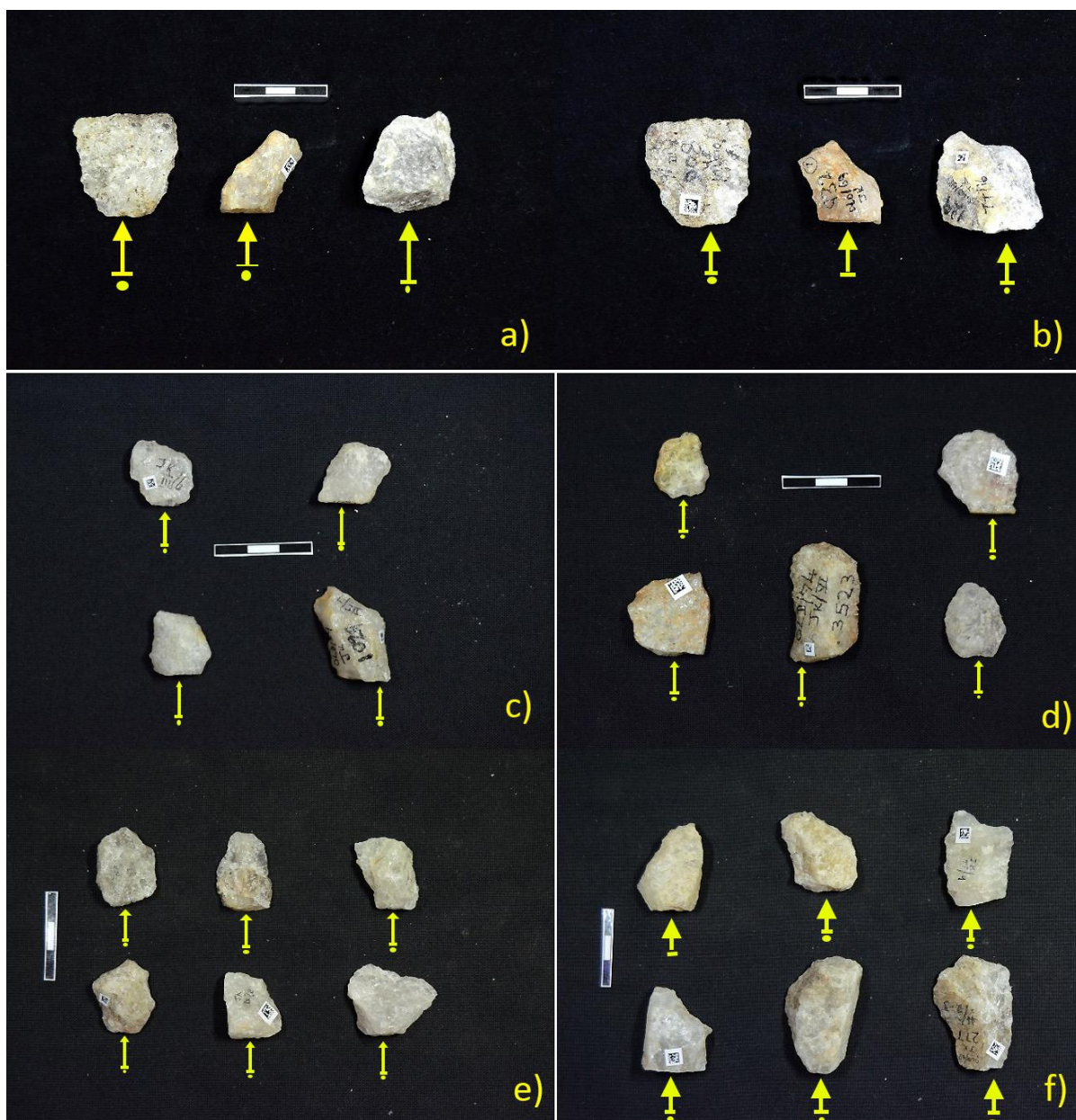


Figure 7. 10: A-F) JK West freehand regular flakes. A) Ventral side B) Dorsal side C-F) Dorsal sides.

Table 7. 6: Technological attributes of whole flakes at JK West.

		Raw Material						Archaeological Unit				Grand Total	
		Lava		Metamorphic		Sedimentary		JK Grey Sand		JK Ferr. Sand			
		n	%	n	%	n	%	n	%	n	%	n	%
Length Classes	<20 mm	0	0%	7	4%	0	0%	6	4%	1	2%	7	3%
	20-39 mm	6	86%	150	77%	1	100%	119	78%	38	78%	15	78%
	40-59 mm	0	0%	34	18%	0	0%	25	16%	9	18%	34	17%
	60-79 mm	1	14%	3	2%	0	0	3	2%	1	2%	4	2%
	80-99 mm	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	Total	7	3.5%	194	96%	1	0%	153	76%	49	24%	20	100%
Striking platform preparation	Non-faceted	0	0%	37	0.2	0	0%	33	22%	4	8%	37	18%
	Unifaceted	6	86%	148	76%	1	100%	114	75%	41	84%	15	77%
	Bifaceted	1	14%	6	3%	0	0%	5	3%	2	4%	7	3%
	Multifaceted	0	0%	3	2%	0	0%	1	1%	2	4%	3	1%
	Total	7	3%	194	96%	1	0%	153	76%	49	24%	20	100%
Cortex dorsal side	Cortical Cortex	0	0%	3	2%	0	0	3	2%	0	0%	3	1%
	>50% Cortex	1	14%	40	21%	0	0	31	20%	10	20%	41	20%
	<50% Cortex	2	29%	53	27%	1	1	41	27%	15	31%	56	28%

Toth's flakes	Non-cortical	4	57%	98	51%	0	0	78	51%	24	49%	10	2	50%
	Total	7	3%	194	96%	1	0%	153	76%	49	24%	20	2	100%
	I	0	0%	3	2%	0	0%	3	2%	0	0%	3	3	1%
	II	0	0%	11	6%	0	0%	10	7%	1	2%	11	11	5%
	III	0	0%	14	7%	0	0%	12	8%	2	4%	14	14	7%
	IV	0	0%	0	0%	0	0%	0	0%	0	0%	0	0	0%
	V	3	43%	80	41%	1	100%	60	39%	24	49%	84	84	42%
	VI	4	57%	86	44%	0	0%	68	44%	22	45%	90	90	45%
	Total	7	3%	194	96%	1	0%	153	76%	49	24%	20	2	100%

Table 7. 7: Dimensions (mm and g) of all JK West technological categories.

			Minimum	Maximum	Mean	Std. deviation
Whole flake	Total (n = 202)	Length	16.0	70.0	31.8	9.8
		Width	11.0	68.0	23.6	8.5
		Thickness	4.0	33.0	10.8	4.2
		Weight	1.0	90.0	10.5	11.7
	Lava (n = 7)	Length	20.0	63.0	32.6	14.6
		Width	11.0	40.0	25.4	6.9
		Thickness	4.0	16.0	7.7	4.1
		Weight	2.0	40.0	9.6	13.8
	Metamorphic (n = 194)	Length	16.0	70.0	31.8	9.6
		Width	12.0	68.0	23.6	8.5
		Thickness	4.0	33.0	10.9	4.2
		Weight	1.0	90.0	10.6	11.7
	Chert/Sedimentary (n = 1)	Length	30.0	30.0	30.0	.
		Width	25.0	25.0	25.0	.
		Thickness	9.0	9.0	9.0	.
		Weight	7.0	7.0	7.0	.
Flake Fragment	Total (n = 83)	Length	12.5	43.3	27.2	7.5
		Width	9.8	35.0	19.4	5.7
		Thickness	3.0	24.3	10.7	3.7
		Weight	1.0	24.0	6.4	5.1

Core	Lava (n = 11)	Length	12.5	43.3	27.2	7.6
		Width	9.8	35.0	19.3	5.8
		Thickness	3.0	24.3	10.6	3.7
		Weight	1.0	24.0	6.3	5.2
	Metamorphic (n = 72)	Length	12.5	43.3	27.3	7.6
		Width	9.8	35.0	19.4	5.8
		Thickness	3.0	24.3	10.8	3.7
		Weight	1.0	24.0	6.5	5.1
	Chert (n = 0)	Length	.	.	.	.
		Width	.	.	.	.
		Thickness	.	.	.	.
		Weight	.	.	.	.
	Total (n = 88)	Length	25.0	193.0	66.4	25.8
		Width	23.0	121.0	53.0	18.4
		Thickness	10.0	85.0	40.8	14.6
		Weight	17.0	2919.0	241.4	341.6
	Lava (n = 19)	Length	25.0	193.0	67.4	25.6
		Width	23.0	121.0	53.7	18.3
		Thickness	10.0	85.0	41.2	14.6
		Weight	17.0	2919.0	248.3	345.6
	Metamorphic (n = 69)	Length	25.0	193.0	66.6	26.0
		Width	23.0	121.0	53.4	18.4
		Thickness	10.0	85.0	41.1	14.5
		Weight	17.0	2919.0	246.0	344.2

Retouched tool	Chert (n = 0)	Length	.	.	.	.
		Width	.	.	.	.
		Thickness	.	.	.	.
		Weight	.	.	.	.
			.	.	.	.
	Total (n = 102)	Length	21.0	90.0	36.0	13.3
		Width	13.0	63.0	26.0	9.6
		Thickness	3.0	24.0	12.0	4.2
		Weight	2.0	94.0	14.7	17.7
	Lava (n = 22)	Length	17.0	90.0	36.5	13.4
		Width	13.0	63.0	36.5	9.6
		Thickness	3.0	24.0	11.6	4.2
		Weight	2.0	94.0	14.9	17.8
	Metamorphic (n = 80)	Length	21.0	90.0	36.3	13.3
		Width	13.0	63.0	26.0	9.6
		Thickness	2.0	24.0	12.0	4.2
		Weight	2.0	94.0	14.7	17.7
	Chert (n = 0)	Length	.	.	.	.
		Width	.	.	.	.
		Thickness	.	.	.	.
		Weight	.	.	.	.
			.	.	.	.

With regards to the striking platform, most flakes are unifaceted (77%), followed by cortical (18%); there is a very small sample of bifaceted (3%) and multifaceted (1%) (Table 7.6). Figure 7.11A and table 7.6 show that there is an overrepresentation of unifaceted flakes in the upper level, JK Ferruginous sand if compared with the lower level, JK Grey Sand.

Additional analysis of cortex is shown in figure 7.11C-D, and Table 7.6. It is shown that fully cortical flakes (Type I) make up 1% only, compared to fully non-cortical flakes (Type VI) which make up to 45% in this technological category (Table 7.6). There is a slight overrepresentation of Toth's types V and VI within JK Ferruginous Sand as opposed to JK Grey Sand (Table 7.6 and figure 7.11A). Furthermore, in terms of raw material comparisons, there are significant variations of Toth's types V and VI (Figure 7.11B). The JK West flakes produced a total of 14 m of cutting edges, with an average of 71.2 mm and a standard deviation of 24.7 mm (Table 7.8).

Table 7. 8: Cutting edge for flakes and retouched tools.

Cutting Edge	min	max	mean	std. deviation	Total length (mm)
Flake (n = 202)	29.0	175.0	71.2	24.7	14155
Retouched tool (n = 102)	50.0	210.0	78.2	30.2	2502

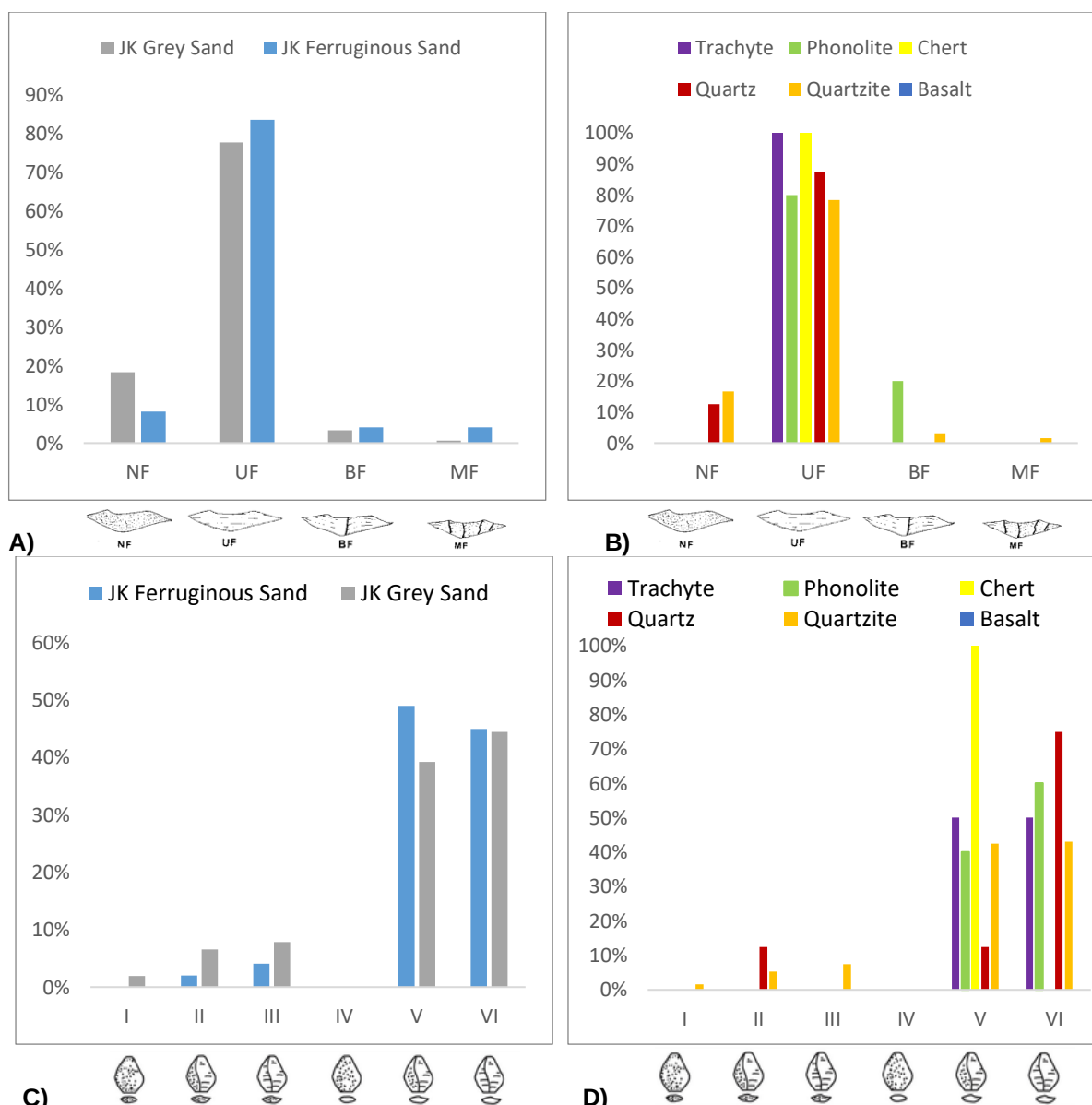


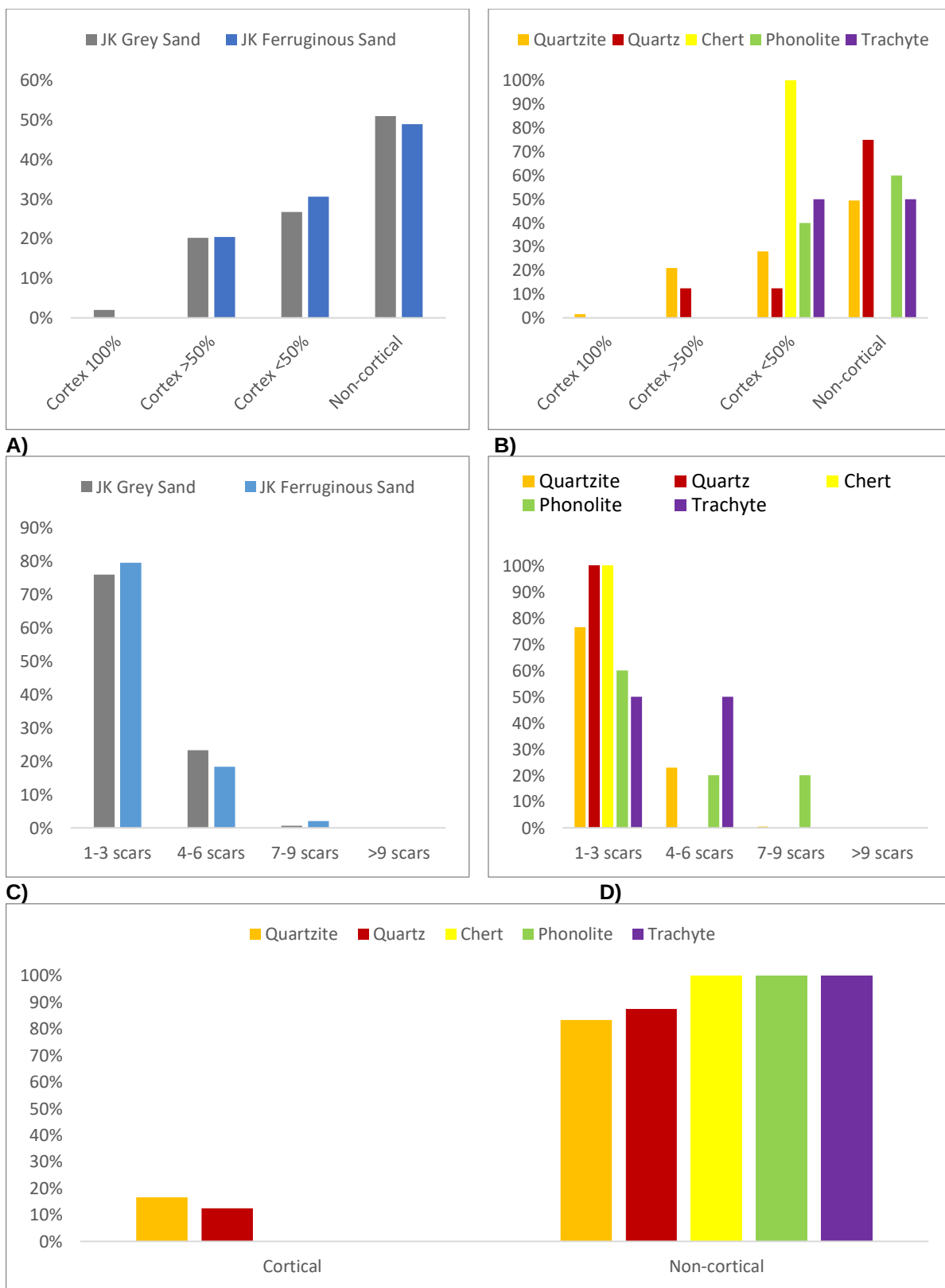
Figure 7. 11: Attributes of flakes in the JK West assemblage per archaeological unit (left) and raw material (right). A-B) Percentage of cortex on flakes following Toth's (1982) flake types. C-D) Types of striking platform (NF: non-faceted; UF: unifaceted; BF; bifaceted; MF multifaceted).

JK West flakes dorsal cortex are predominantly non-cortical (n = 102; 50%), the most abundant being flakes made of metamorphic rocks (n = 98; 51%) (Table 7.6). It should be noted that these results correspond with the Toth's flake types, in which Toth's type VI (45%) are the most abundant, followed by Toth's type V (42%) (Table 7.6; Figure 7.11D). Further results are shown in figure 7.12A. Figure 7.12A shows that there is a predominance of non-cortical flakes in both archaeological units, with the

Toth's flake types V and VI being most abundantly recorded in JK West Ferruginous Sand.

JK West flakes dorsal sides preserve few scars. As shown in figure 7.12C-D, flakes preserving fewer scars (1-3 scars) are almost similar in JK West Grey Sand (76%) and Ferruginous Sand (80%) units. Specifically, flake with 1-3 scars (76%) are the most predominant within the flake sample, followed by flake with 4-6 scars (22%), and 7-9 scars (1%) and >9 scars, respectively (Figure 7.13). In terms of raw materials, metamorphic rocks are predominantly preserving fewer scars, whereas lavas such as phonolite and trachyte preserve 4-6 and 7-9 scars, respectively (Figure 7.12D).

In terms of flake striking platform cortex, most flake striking platforms are non-cortical, followed by cortical (Figure 7.12E).



E) Figure 7. 12: A-B) Flake dorsal cortex in the entire JK assemblage per archaeological unit (A) and raw material (B). C-D) Flake dorsal scar per archaeological unit (C) and raw materials (D). E) Flake platform cortex per raw materials.

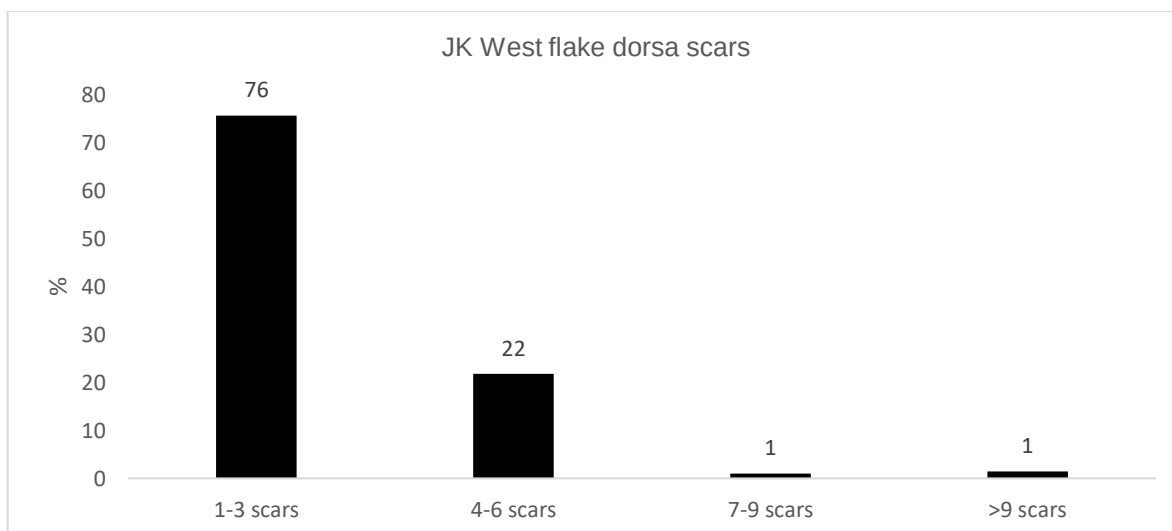
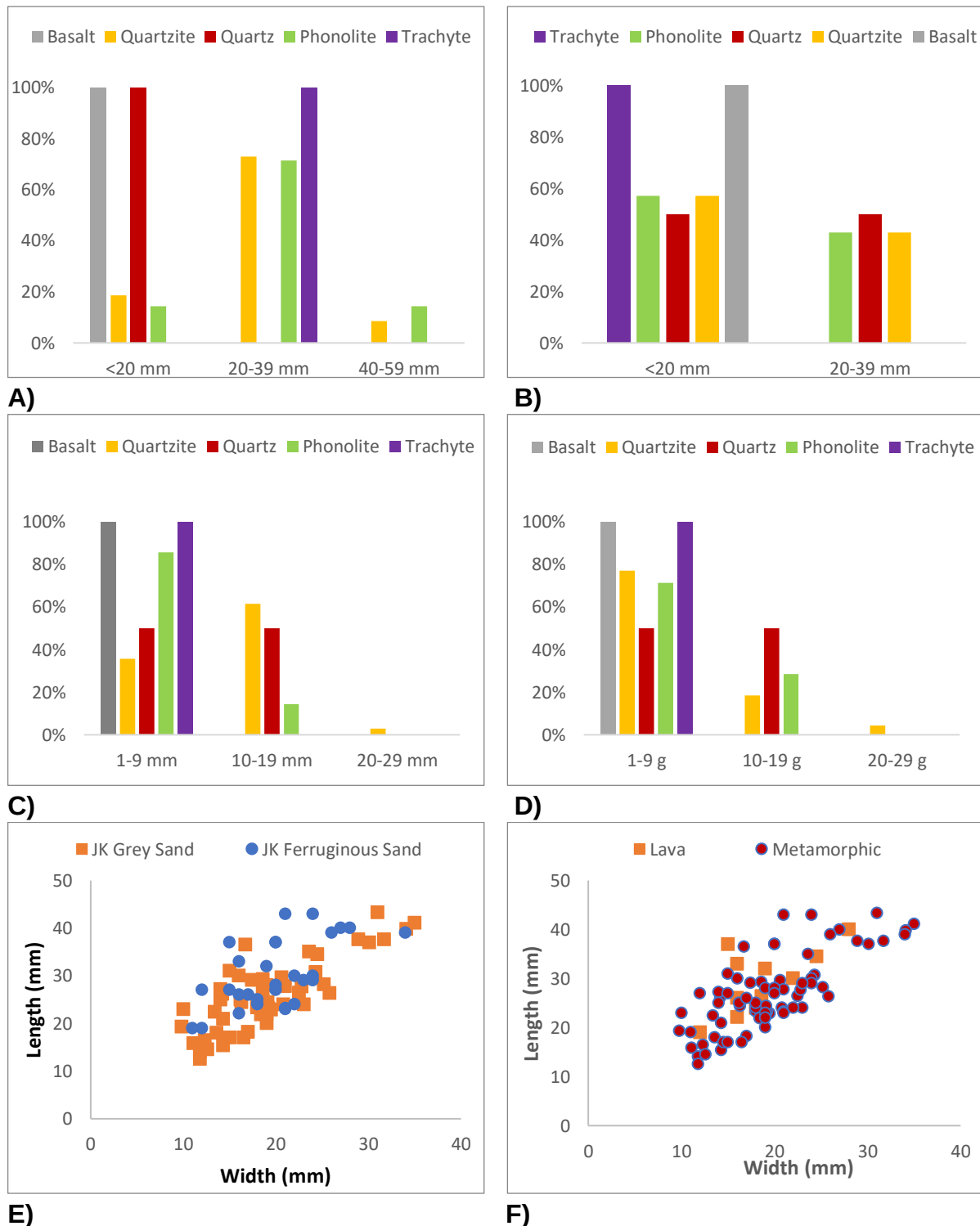


Figure 7. 13: JK West flake scars per all raw materials.

7.5.5 Fragmented flakes

Flake fragments (n = 83) contribute 17% to the analysed sample (Table 7.3). Figure 7.14A-B shows that most flake fragments measure between 20 and 39 mm in length and width, with an average of 27.2 and 19.4 mm, respectively (also see Table 7.7 and 7.15A-E). However, there is a slight variation with the flake fragment sample, with some flake fragments measuring 43.3 mm in length and others as small as 12.5 mm in length (Table 7.7). In terms of width, most flake fragments measure under 20 mm width, followed by 20-39 mm (Figure 7.14B). In addition, most flake fragments are between 1 and 9 mm thick, followed by 10-19 mm thick, whereas 20-29 mm being the least represented (Figure 7.14C). In terms of weight, most flake fragments are relatively light, with a mean of 6.4 g; nonetheless, there is a significant difference within the sample, with flake fragments weighing up to 24 g, whereas others are as small as 1 g (Table 7.7). Lava flake fragments are the lightest (n = 11; 47 g) as opposed to metamorphic flake fragments (n = 72; 482 g), whereas the JK Grey Sand being the most abundant (Table 7.5; Figure 7.14D). Moreover, figure 7.14E-F shows flake fragment length-width scatterplot, with JK West flake fragments Grey Sand being

wider and longer than JK West Ferruginous Sand (Figure 7.14E). In terms of raw materials, metamorphic flake fragments are longer and wider than lava flake fragments (Figure 7.14F).



E) **F)**
Figure 7. 14: A-D) Dimensions of flake fragments per raw materials. A) Length (mm). B) Width (mm). C) Thickness (mm). D) Weight (g). Scatterplots showing length and width per archaeological unit E) and per raw material F).

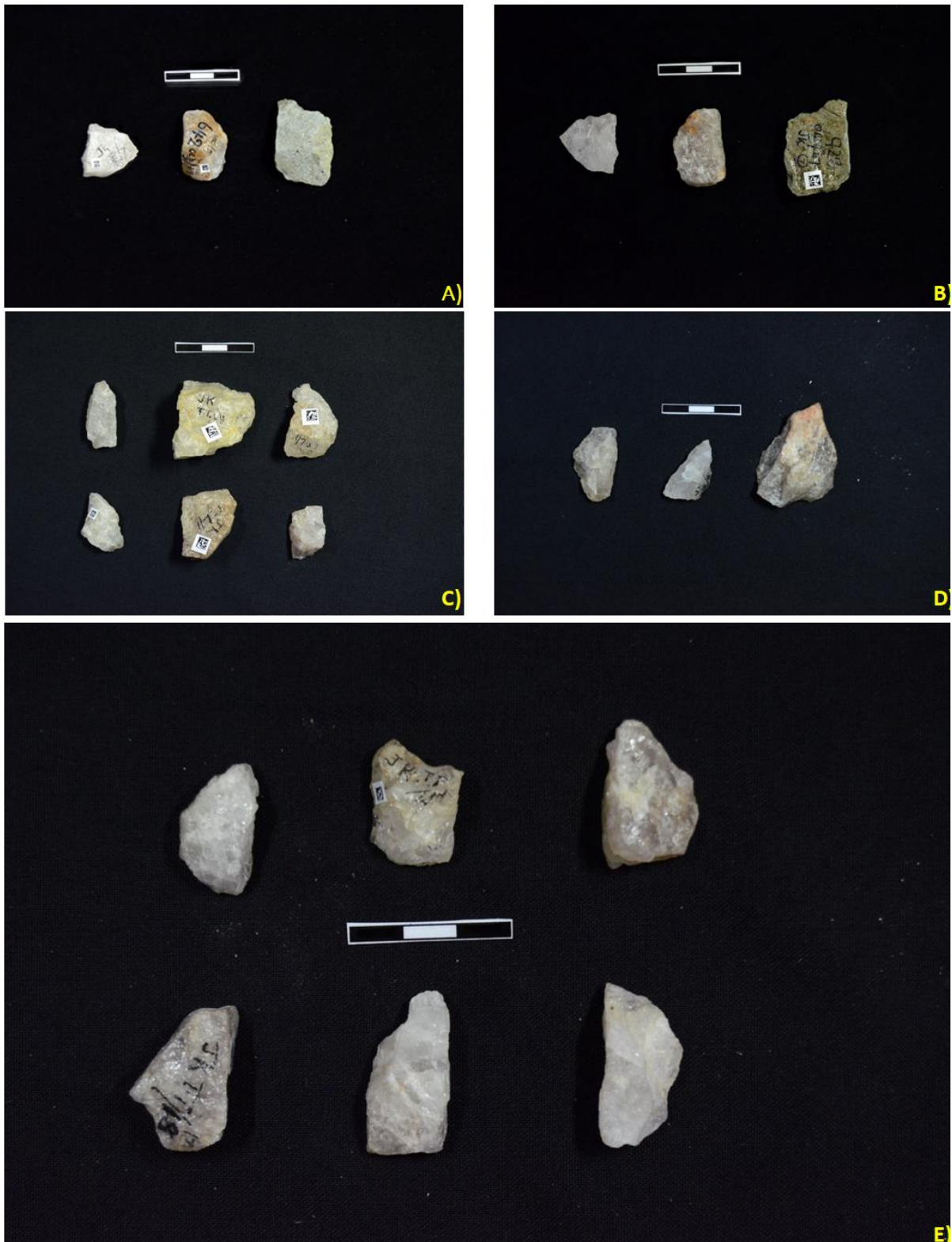


Figure 7. 15: Examples of JK flake fragments made of lava and metamorphic raw materials from JK (Bed III) site. A) Dorsal side. B) Ventral side. C) Shot taken from dorsal side. D) Freehand regular fragmented flakes. E) Freehand regular fragmented flakes (Scale = 3 cm).

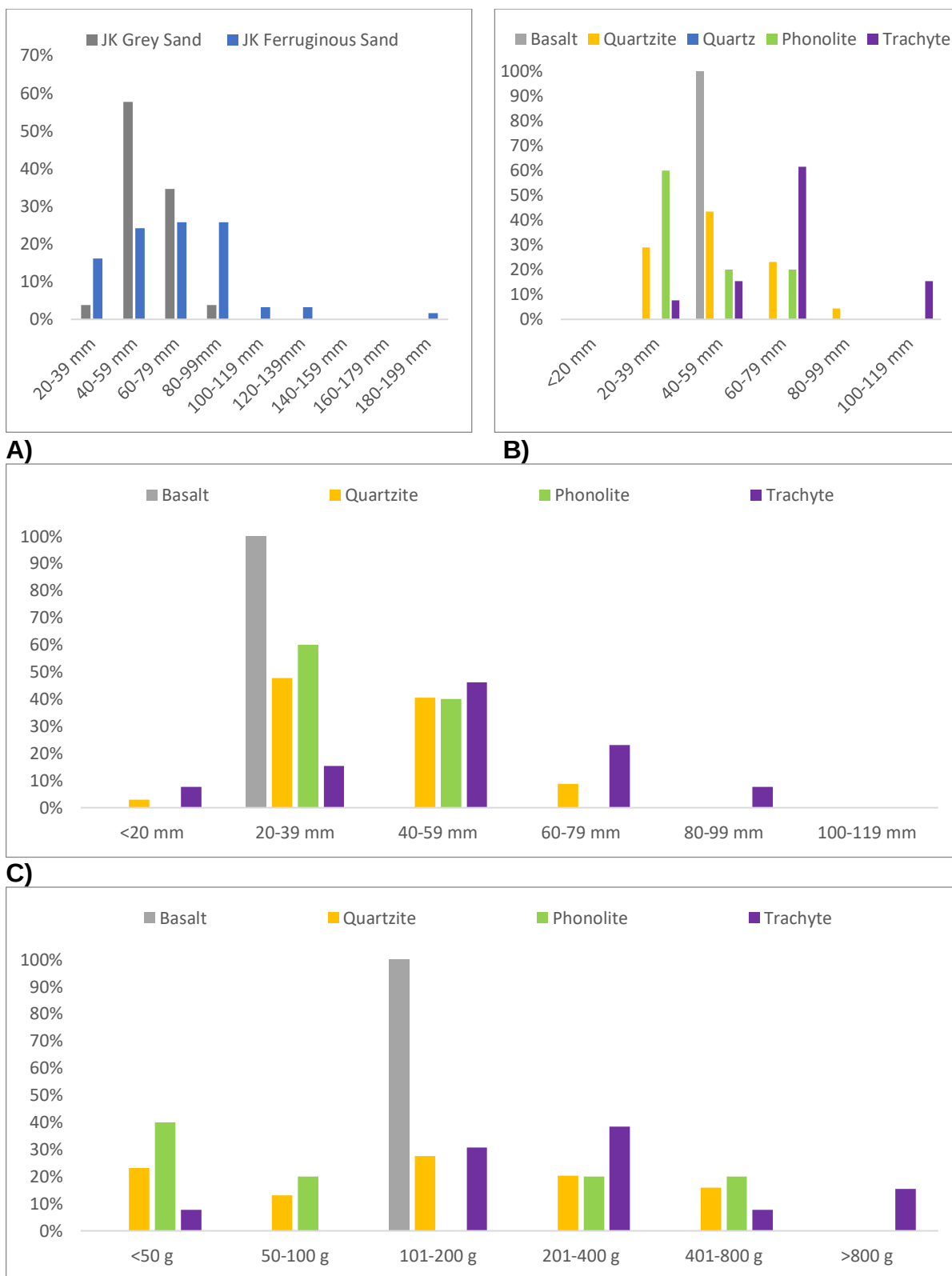
7.5.6 Cores

The JK core assemblage (n = 88, 19%) amount to over 21 kg of raw materials at the site (Table 7.3). Metamorphic cores (n = 69), all of them in quartzite, are the predominant in the core assemblage, followed distantly by lava cores (n = 19). Among the lava cores, trachyte predominates (n = 13), whilst phonolite (n = 5) and basalt (n = 1) are infrequent (Table 7.5). In terms of weight distribution, quartzite is the heaviest group (13.7 kg), followed by trachyte (6.6 kg), phonolite (823 g) and basalt (131 g) (Table 7.5).

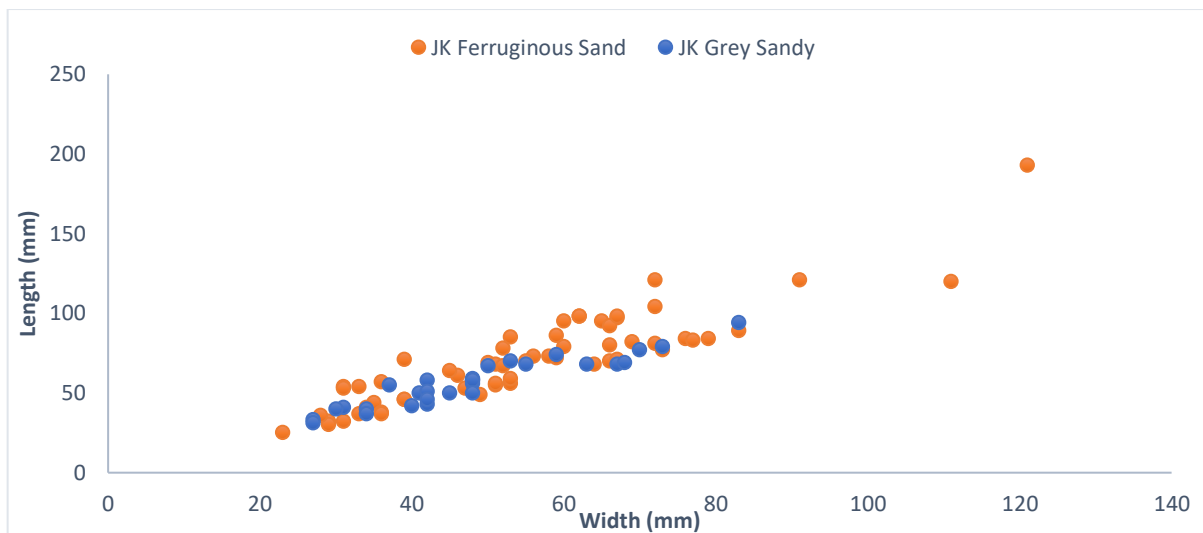
Among cores, there is an average length of 66.4 mm and 241 g of weight (Table 7.7). It should be noted that there is substantial size variation within the core sample; the largest cores reach a length of 193 mm, whereas the small size cores measure 25 mm in length (Table 7.7).

Core size differences at JK West are revealed when comparing raw materials (Figure 7.16A-B). It is evident that lava cores are slightly larger in size than metamorphic cores, with an average of 67.4 mm (lava) as opposed to 66.6 mm (quartzite); (Table 7.7). The majority of lava cores are found in between 40-59 mm and 60-79 mm length classes (Figure 7.16A; Figure 7.17A-B; Table 7.9). Similarly, lava cores appear to be heavier than metamorphic cores, with most of them being in the 101-200 g and 201-400 g weight classes, while a small number of metamorphic cores is represented in 50-100 g, 101-200 g, 201-400 g and 401-800 g (Figure 7.16C and Table 7.9).

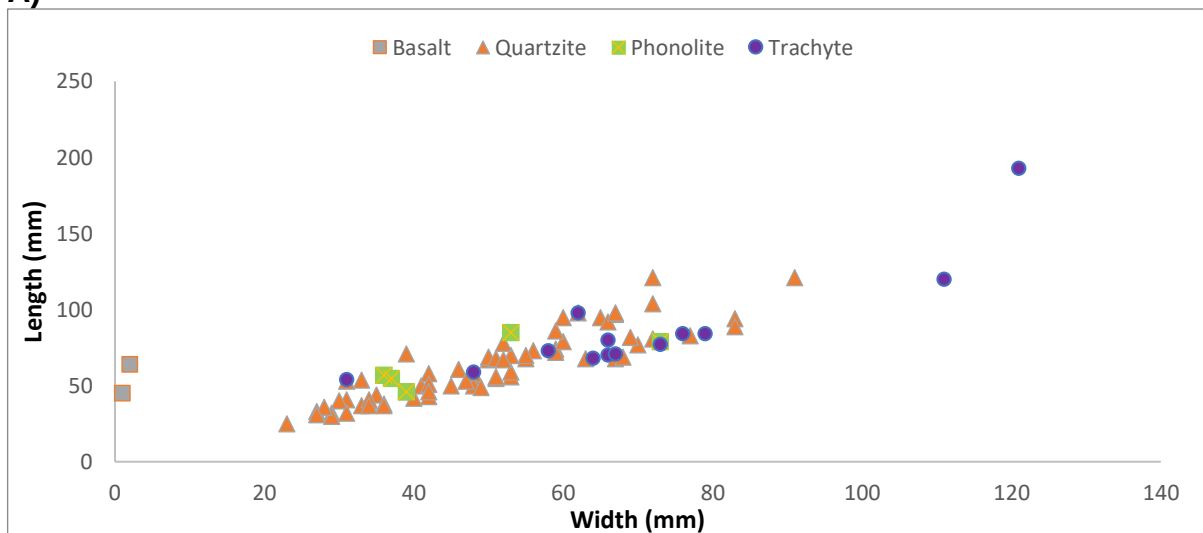
While 33% of the cores preserve most of the cortex covering cortex >50%, only 3.4% are non-cortical, whereas cores preserving cortex <50% being the most abundant within the assemblage (Table 7.9; Figure 7.18A-B). Figure 7.18B shows that most lava cores preserve less than 50% cortex (see more detail in Table 7.9).



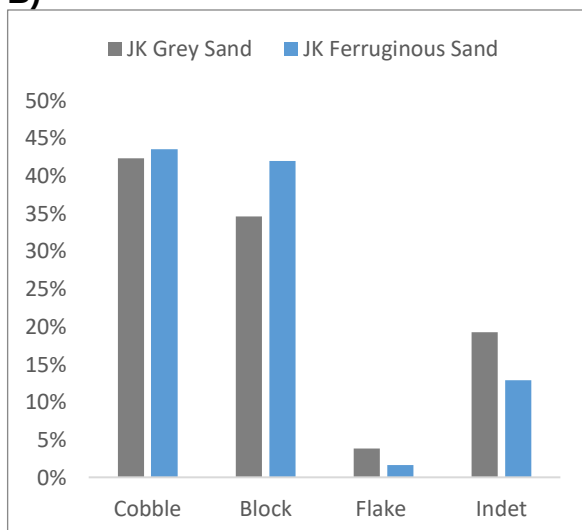
D) Figure 7. 16: Dimensional attributes of cores per archaeological unit (A) and raw material (B-D). A) Length range. B) Width range. C) Thickness range. D) Weight class.



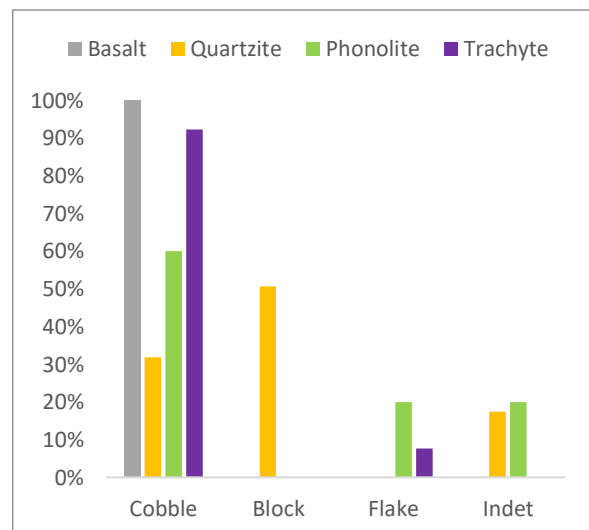
A)



B)



C)



D)

Figure 7. 17: Dimensions and blanks of cores in the JK A-D. Length and Width (mm) per archaeological unit (A) and Length and width per raw material (B). Core blanks per archaeological unit (C) and per raw material (D).

Table 7. 9: Attributes of the core assemblage at JK West.

		Archaeological unit				Raw Material				Grand Total	
		JK Grey Sand		JK Ferruginous Sand		Lava		Metamorphic		n	%
		n	%	n	%	n	%	n	%		
Length class	<20 mm	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	20-39 mm	3	10.3%	8	13.6%	0	0.0%	11	15.9%	22	12.5%
	40-59 mm	16	55.2%	14	23.7%	5	26.3%	25	36.2%	60	34.1%
	60-79 mm	9	31.0%	16	27.1%	7	36.8%	18	26.1%	50	28.4%
	80-99 mm	1	3.4%	16	27.1%	5	26.3%	12	17.4%	34	19.3%
	>100 mm	0	0.0%	5	8.5%	2	10.5%	3	4.3%	10	5.7%
	Total	29	16.5%	59	33.5%	19	10.8%	69	39.2%	176	100.0%
Weight class	<50 g	6	20.7%	13	22.0%	3	15.8%	16	23.2%	38	21.6%
	50-100 g	6	20.7%	4	6.8%	1	5.3%	9	13.0%	20	11.4%
	101-200 g	8	27.6%	16	27.1%	5	26.3%	19	27.5%	48	27.3%
	201-400 g	6	20.7%	14	23.7%	6	31.6%	14	20.3%	40	22.7%
	401-800	3	10.3%	10	16.9%	2	10.5%	11	15.9%	26	14.8%
	>800 g	0	0.0%	2	3.4%	2	10.5%	0	0.0%	4	2.3%
	Total	29	16.5%	59	33.5%	19	10.8%	69	39.2%	176	100.0%
Cortex	Cortex >50%	3	10.3%	26	44.1%	8	42.1%	21	30.4%	58	33.0%
	Cortex <50%	25	86.2%	31	52.5%	8	42.1%	48	69.6%	112	63.6%
	Non-cortical	1	3.4%	2	3.4%	3	15.8%	0	0.0%	6	3.4%
	Total	29	16.5%	59	33.5%	19	10.8%	69	39.2%	176	100.0%
Blank	Cobble	12	41.4%	26	44.1%	16	84.2%	22	31.9%	76	43.2%
	Block	10	34.5%	25	42.4%	0	0.0%	35	50.7%	70	39.8%
	Flake	1	3.4%	1	1.7%	2	10.5%	0	0.0%	4	2.3%
	Indet	6	20.7%	7	11.9%	1	5.3%	12	17.4%	26	14.8%
	Total	29	16.5%	59	33.5%	19	10.8%	69	39.2%	176	100.0%
Number of scars	1-3 scars	4	13.8%	17	28.8%	5	26.3%	16	23.2%	42	23.9%
	4-6 scars	12	41.4%	18	30.5%	4	21.1%	26	37.7%	60	34.1%
	7-9 scars	9	31.0%	11	18.6%	4	21.1%	16	23.2%	40	22.7%
	>9 scars	4	13.8%	13	22.0%	6	31.6%	11	15.9%	34	19.3%
	Total	29	16.5%	59	33.5%	19	10.8%	69	39.2%	176	100.0%

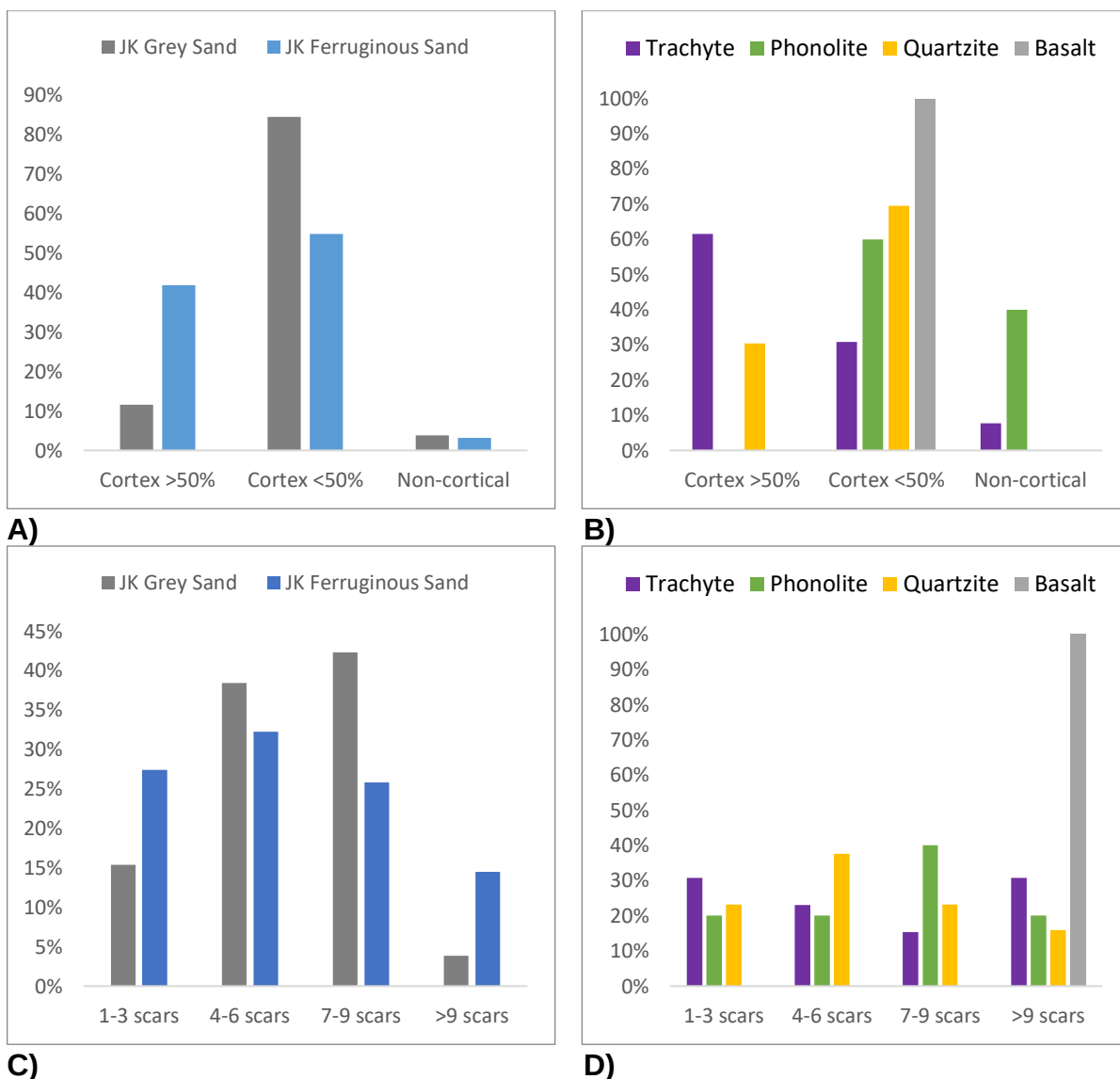


Figure 7. 18: Core attributes per archaeological unit (left) and raw materials (right). A-B) Length interval. C-D) Cortex coverage. E-F) Number of previous scars.

The core reduction intensity was examined by counting the number of flake scars preserved on core flaking surfaces, and core size. As can be seen in Table 7.9, 34.1% of cores preserve 4-6 flake scars, followed by 23.9% of cores preserve 3 or fewer flake scars. Only 22.7% of cores preserve 7-9 flake scars and just about 19.3% preserve 9 or more flake scars (Table 7.9).

There is a predominance of cobble blanks (43.2%) over block (39.8%) and flake blanks (2.3%) (see Table 7.9 and 7.10). Most cobble blanks are lavas (84.2%), while

all block blanks (50.7%) are metamorphic rocks (Table 7.9 and Figure 7.17D). At Olduvai, core blank correlations are generally associated with raw material sources, such as river streams for lava materials and hillslopes for quartz and quartzite materials (McHenry and de la Torre, 2018a; de la Torre and Mora, 2018a).

7.5.6.1 Core Exploitation Systems

All these cores were produced using a freehand knapping method. Multifacial (n=38, 43%) is the most predominant flaking scheme at JK West, with metamorphic (n=33, 38%) raw material being the most prevalent than lava (n=5, 6%) materials (Table 7.10; figure 7.19). In addition, the bifacial (n=29, 33%) is the second most prevalent flaking scheme, with metamorphic (n=20, 23%) being the most predominant raw material than lava (n=9, 10%) (see table 7.10). The least predominant flaking scheme is unifacial (n=21, 24%), with metamorphic (n=16, 18%) being the most predominant raw material than lava (n=5, 6%) materials (Table 7.10).

Table 7. 10: JK West core knapping systems per raw material groups.

	Raw material				Total	
	Lava		Metamorphic		n	%
	n	%	n	%		
Unifacial	5	6	16	18	21	24
Bifacial	9	10	20	23	29	33
Multifacial	5	6	33	38	38	43
Total	19	22	69	78	88	100

Different blanks were selected by hominins during core reduction process. Table 7.11 shows that the most prevalent blank was cobble (n=38, 43.2%), followed by block (n=35, 39.8%), indeterminate (n=13, 14.8%), and flake (n=2, 2.3%). It can be argued that hominin selected lava cobbles and metamorphic block from the sources for core reductions.

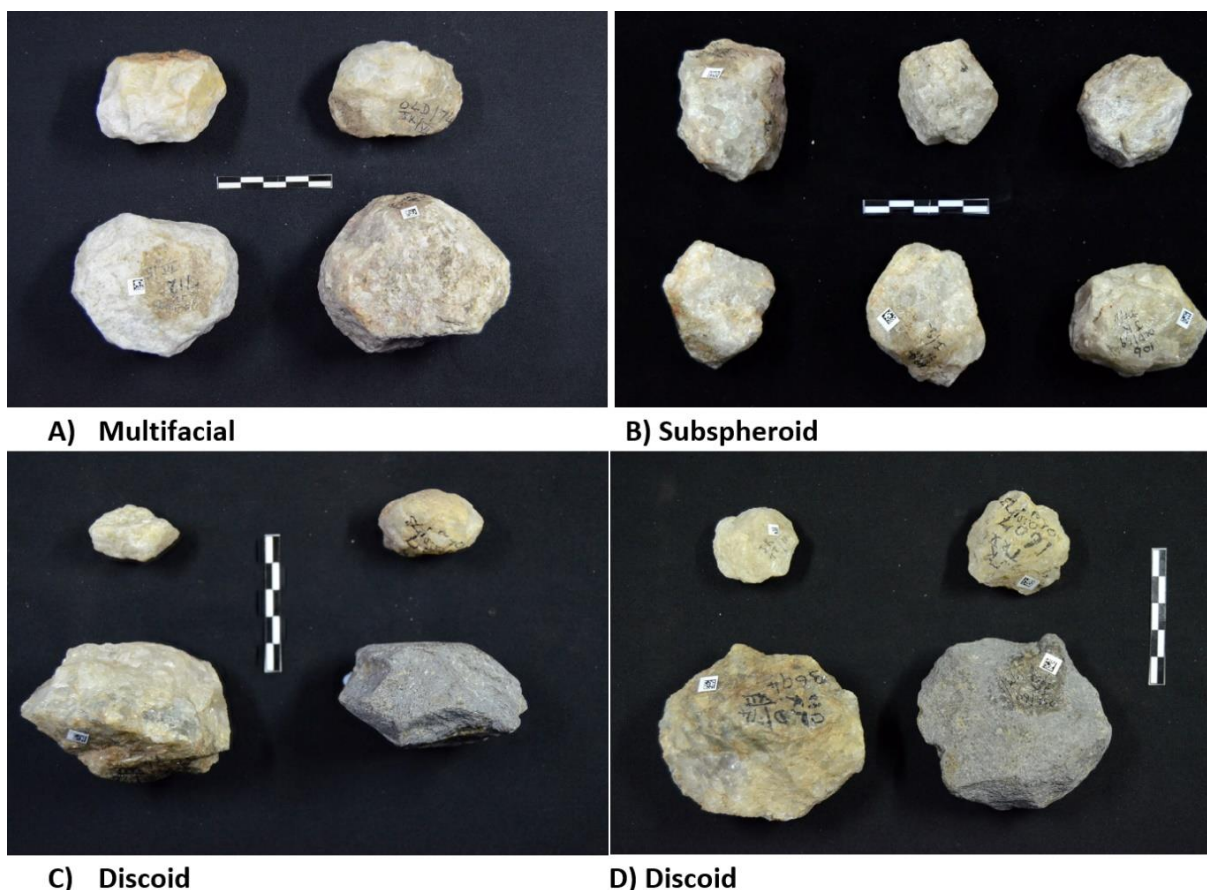


Figure 7. 19: JK West core exploitation systems. A) Multifacial B) Subspheroid C-D) Discoids.

Core reduction process has employed various flaking techniques that determine different levels of reductions. The most prevalent technique is multifacial (n=34, 38.6%), followed by discoids (n=12, 13.6%), testcores (n=10, 11.4%), BSP (n=8, 9.1%), UAU1 (n=5, 5.7%), UAU2 (n=5, 5.7%), BALP (n= 5, 5.7%), POL (n=4, 4.5%), UAB1 (n=3, 3.4%), BP (n=1, 1.1%), and BHC (n=1, 1.1%) (Table 7.12).

The prevalence of multifacial technique indicates a higher reduction intensity of cores at JK West (Table 7.12; figure 7.20A). In terms of reduction level per archaeological unit, JK West Grey Sand multifacial cores appear to be the most predominant over JK West Ferruginous Sand multifacial cores (Table 7.12; figure 7.20B). The flaking scheme shown in table 7.12 agrees with the argument of high reduction intensity at JK West, with multifacial (38.6%), and discoids (13.6%), both are suggesting that the

high reduction sequence at JK West was prevalent. However, there are some indicators of short-term flaking sequences which are due to the presence of BSP, UAU1, and UAU2 (Table 7.12).

Moreover, the high reduction intensity level is supported by core cortex and number of flake scars. As shown in figure 7.18A most cores are non-cortical dominant, with JK West Grey Sand being the most prevalent, followed by JK West Ferruginous Sand. In terms of raw materials, non-cortical dominant cores are predominated by basalt, followed by quartzite, phonolite, while trachyte being the least prevalent (Figure 7.18B).

Furthermore, the frequency of core number of scars supports the high reduction intensity, with most cores possessing 4-6 scars and 7-9 scars (Figure 7.18C). As shown in figure 7.18D cores possessing over nine scars are predominated by basalt raw material, followed by trachyte, phonolite, and quartzite. This suggests that hominins at JK West selected cobbles that were subjected to higher reduction level than quartzite blocks.

Table 7. 11: Flaking schemes of the JK West core assemblage per blank.

	Core blank									
	Block		Cobble		Flake		Indet		Total	
	n	%	n	%	n	%	n	%	n	%
TC	4	11.4%	4	10.5%	2	100.0%			10	11.4%
USP									0	0.0%
BSP	3	8.6%	4	10.5%			1	7.7%	8	9.1%
UAU1	3	8.6%	2	5.3%					5	5.7%
UAU2			4	10.5%			1	7.7%	5	5.7%
UAUT									0	0.0%
UAB1	3	8.6%							3	3.4%
BAP									0	0.0%
BALP	2	5.7%	3	7.9%					5	5.7%
BALT									0	0.0%
UP									0	0.0%
BP	1	2.9%							1	1.1%
BHC			1	2.6%					1	1.1%
DISC	4	11.4%	6	15.8%			2	15.4%	12	13.6%
POL	2	5.7%	2	5.3%					4	4.5%
MLT	13	37.1%	12	31.6%			9	69.2%	34	38.6%
BIPO									0	0.0%
BIPCO									0	0.0%
Total	35	39.8%	38	43.2%	2	2.3%	13	14.8%	88	100.0%

TC: Test core. **USP:** Unifacial simple partial exploitation. **BSP:** Bifacial simple partial exploitation. **UAU1:** Unidirectional abrupt unifacial exploitation on one knapping surface. **UAU2:** Unidirectional abrupt unifacial exploitation on two independent knapping surfaces. **UABI:** Unifacial abrupt bidirectional exploitation. **BAP:** Bifacial abrupt partial exploitation. **BALP:** Bifacial alternating partial exploitation. **BALT:** Bifacial alternating total exploitation. **BP:** Bifacial peripheral. **BHC:** Bifacial hierarchical centripetal. **DISC:** Discoid. **POL:** Polyhedron. **MLT:** Multifacial

Table 7. 12: Flaking schemes in the JK West core assemblage by raw materials and archaeological unit.

	Lava		Raw material		Sedimentary		Archaeological unit		JKW Ferruginous Sand		Total	
			Metamorphic				JKW Grey Sand					
	n	%	n	%	n	%	n	%	n	%	n	%
TC	5	26.3%	5	7.2%	0	0.0	2	7.7%	8	12.9%	10	11.4%
USP	0	0.0%	0	0.0%	0	0.0					0	0.0%
BSP	3	15.8%	5	7.2%	0	0.0			8	12.9%	8	9.1%
UAU1	1	5.3%	4	5.8%	0	0.0	3	11.5%	2	3.2%	5	5.7%
UAU2	1	5.3%	4	5.8%	0	0.0			5	8.1%	5	5.7%
UAUT	0	0.0%	0	0.0%	0	0.0					0	0.0%
UAB1	0	0.0%	3	4.3%	0	0.0			3	4.8%	3	3.4%
BAP	0	0.0%	0	0.0%	0	0.0					0	0.0%
BALP	2	10.5%	3	4.3%	0	0.0	1	3.8%	4	6.5%	5	5.7%
BALT	0	0.0%	0	0.0%	0	0.0					0	0.0%
UP	0	0.0%	0	0.0%	0	0.0					0	0.0%
BP	0	0.0%	1	1.4%	0	0.0			1	1.6%	1	1.1%
BHC	1	5.3%	0	0.0%	0	0.0			1	1.6%	1	1.1%
DISC	1	5.3%	11	15.9%	0	0.0	3	11.5%	9	14.5%	12	13.6%
POL	1	5.3%	3	4.3%	0	0.0	3	11.5%	1	1.6%	4	4.5%
MLT	4	21.1%	30	43.5%	0	0.0	14	53.8%	20	32.3%	34	38.6%
BIPO	0	0.0%	0	0.0%	0	0.0					0	0.0%
BIPCO	0	0.0%	0	0.0%	0	0.0					0	0.0%
Total	19	21.6%	69	78.4%	0	0.0	26	29.5%	62	70.5%	88	100.0%

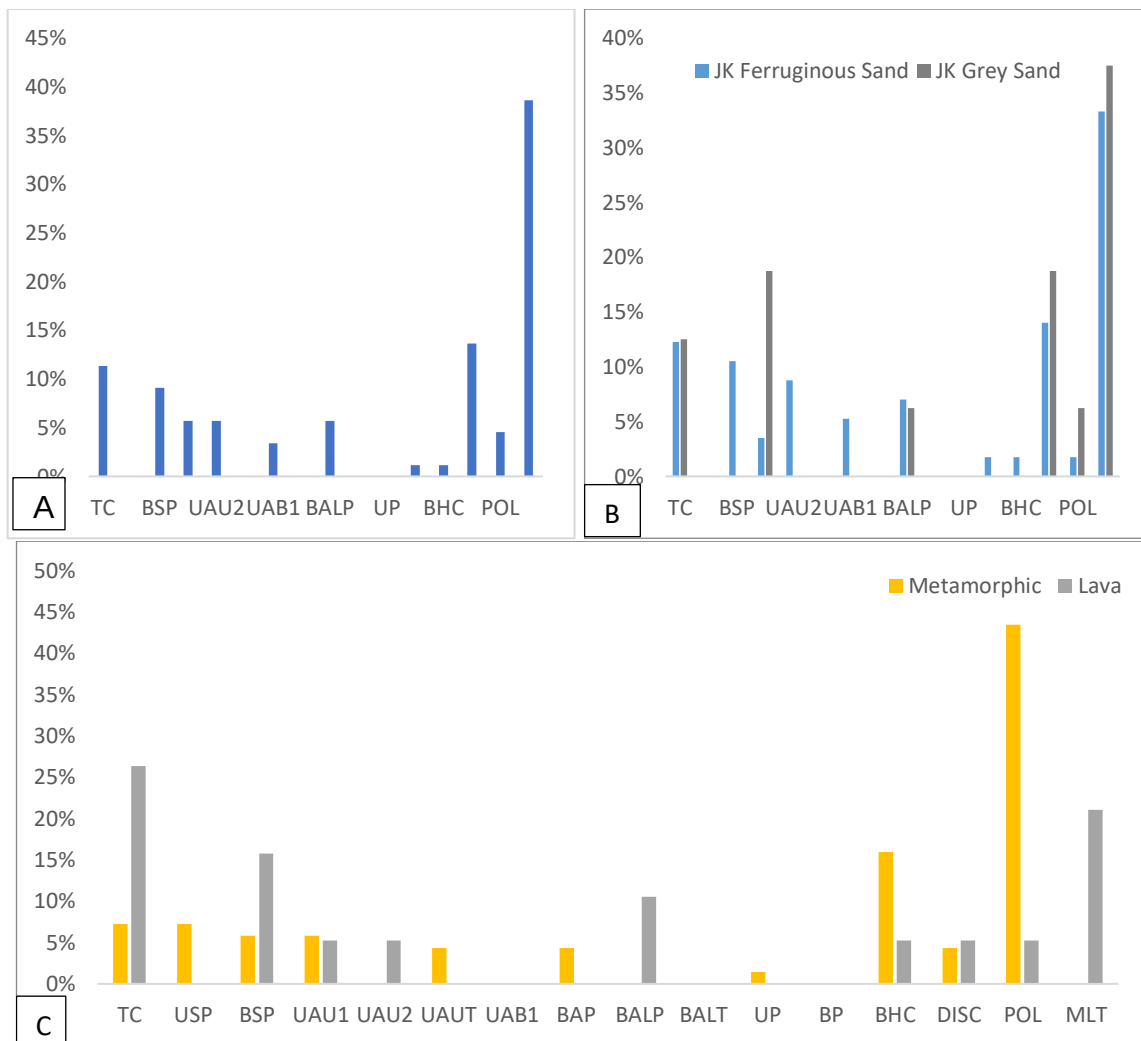


Figure 7. 20: JK West freehand flaking techniques. A-C) Relative frequencies of the whole core assemblage (A), per archaeological unit (B), and per raw material (C).

Core knapping accidents at JK West were also examined. The most prevalent knapping accident is step scars, which count 98.9% of the core assemblage (Table 7.13). de la Torre and Mora (2018) argue that step scars normally lead to the abandonment of flaking surfaces, rotation of the blank in the quest for a suitable flaking surface and sometimes the discard of the cores. Core step scars are more abundant in JK Ferruginous Sand ($n = 57$) than in JK Grey Sand ($n = 29$) unit (Table 7.13). In terms of raw material, metamorphic rocks ($n = 69$) show a higher number of cores with step scars when compared to lava cores ($n = 19$) (Table 7.13).

Table 7. 13: Table showing JK West core knapping accidents identified in this study.

Core Knapping accident	Archaeological unit				Raw Material				Grand Total	
	JK Grey Sand		JK Ferruginous Sand		Lava		Metamorphic		n	%
	n	%	n	%	n	%	n	%		
Step scars	29	100.0%	57	96.6%	19	100.0%	69	100.0%	174	98.9%
N/A	0	0.0%	2	3.4%	0	0.0%	0	0.0%	2	1.1%
Total	29	16.5%	59	33.5%	19	10.8%	69	39.2%	176	100.0%

7.5.7 Retouched Pieces

Retouched artefacts (n=102) from the small debitage reduction sequence contribute 21% of the sampled assemblage at JK West (Table 7.3), with the total weight of 1.5 kg of the assemblage (Table 7.4). Figure 7.21A and B and 7.22 show that most retouched tools are 20-39 mm in length, with an average of 36 mm (slightly longer than that of the flakes) (Tables 7.7 and 7.14-15). In terms of archaeological unit, JK West Grey Sand retouched pieces measuring 20-39 mm are more frequent than JK West Ferruginous Sand retouched pieces (Figure 7.21A). However, JK West Ferruginous Sand retouched pieces measuring 40-59 mm are more frequent than JK West Grey Sand (Figure 7.21A; Table 7.14).

Lava retouched tools are the longest, with an average length of 36.5 mm, followed by metamorphic retouched tools, with an average of 36.3 mm (Table 7.7; figure 7.21B). Retouched tools have an average weight of 14.7 g and a width of 26 mm (Table 7.7). There is a distinct variation in length and weight, with some retouched tools measuring 90 mm in length and others as short as 21 mm in length (Table 7.7). Similarly, there is variation in weight, with some retouched tools weighing as heavy as 94 g while some as light as 2 g (Table 7.7).

Most retouched pieces measure 20-39 mm in width, with an average width of 26 mm (Table 7.7; figure 7.21C). Lava retouched pieces are on average wider (36.5 mm) than metamorphic (26 mm) retouched pieces (Table 7.7). In terms of thickness, most retouched pieces measure 10-19 mm in thickness (Figure 7.21D). Average thickness of all retouched pieces measure 12 mm, with metamorphic retouched pieces measuring average of 12 mm in thickness and lava measuring an average of 11.6 mm in thickness (Table 7.7).

Table 7. 14: Retouched tools at the JK West assemblage per archaeological unit.

		Archaeological unit				Grand Total	
		JK Grey Sand		JK Ferruginous Sand			
		n	%	n	%	n	%
Length class	20-39 mm	29	71	38	62	67	66
	40-59 mm	10	24	19	31	29	28
	60-79 mm	2	5	3	5	5	5
	80-99 mm	0	0	1	2	1	1
	Total	41	40	61	60	102	100
Cortex dorsal side	Cortex >50%	4	10	8	13	12	12
	Cortex <50%	5	12	13	21	18	18
	Non-cortical	32	78	40	66	72	71
	Total	41	40	61	60	102	100
Retouch Type	Denticulate	15	37	12	20	27	26
	Notch	17	41	49	80	66	65
	Point	1	2	0	0	1	1
	Sidescraper	8	20	0	0	8	8
	Total	41	40	61	60	102	100

Table 7. 15: Retouched tools at the JK West assemblage per raw material group.

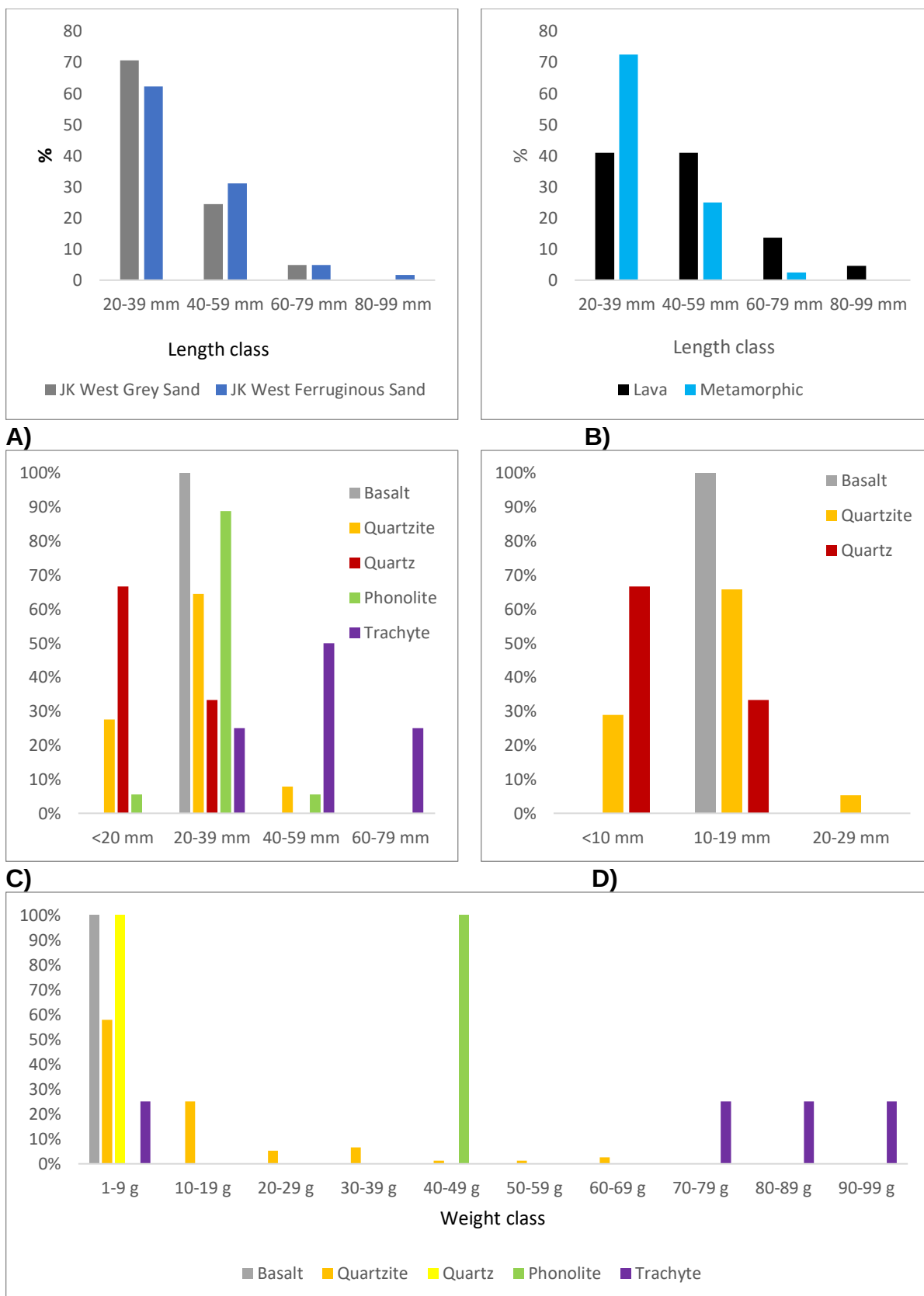
		Raw Material				Grand Total	
		Lava		Metamorphic			
		n	%	n	%	n	%
Length class	20-39 mm	9	41	58	73	67	66
	40-59 mm	9	41	20	25	29	28
	60-79 mm	3	14	2	3	5	5
	80-99 mm	1	5	0	0	1	1
	Total	22	22	80	78	102	100
Cortex dorsal side	Cortex >50%	2	9	10	13	12	12
	Cortex <50%	4	18	14	18	18	18
	Non-cortical	16	73	56	70	72	71
	Total	22	22	80	78	102	100
Retouch Type	Denticulate	6	27	21	26	27	26
	Notch	15	68	51	64	66	65
	Point	1	5	0	0	1	1
	Sidescraper	0	0	8	10	8	8
	Total	22	22	80	78	102	100

Regarding retouched pieces weight, most retouched pieces weigh between 1 and 9 grams (Figure 7.21E). The heaviest retouched piece weighs 94 grams with an average weight of 14.7 grams. Lava retouched pieces are on average heavier (14.9 grams) than metamorphic retouched pieces (14.7 grams) (Table 7.7). Figure 7.21E shows most of heavier retouched pieces are retouched from lava materials, particularly phonolites and trachytes.

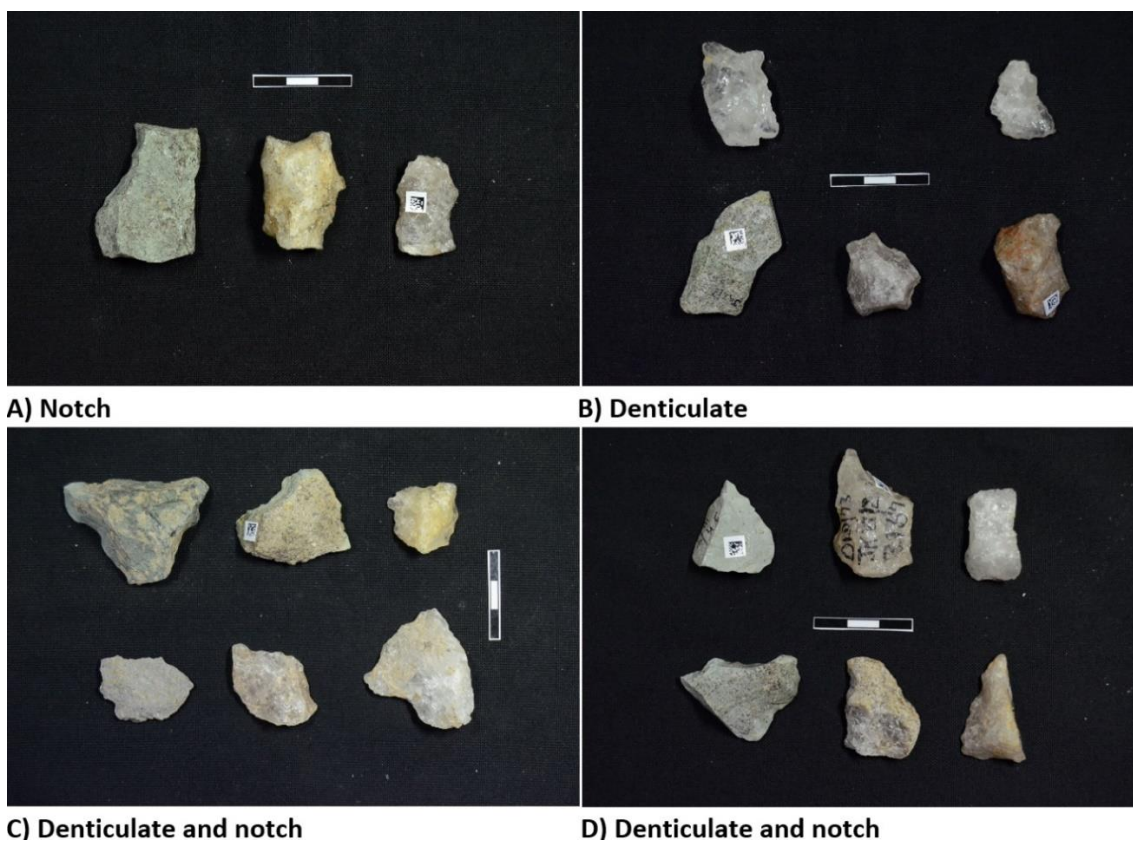
In terms of cortex coverage, most retouched pieces are non-cortical (n=71, 71%), followed by non-cortical dominant (n=18, 18%), whereas cortical dominant (n=12, 12%) being the least predominant (Table 7.14).

Regarding tool types, denticulates, notch, sidescrapers, and point are recorded (26%, 65%, 8%, 1%, respectively) (Table 7.14). In terms of raw materials, notches (n=66, 65%) are the most predominant, with lava (68%) materials being the most frequent than metamorphic (64%) (Table 7.15; Figure 7.23).

Denticulates (n=27, 26%) are the second-most predominant retouch type, with lava (27%) being the most prevalent than metamorphic (26%) (Table 7.15; figures 7.22 and 7.23). Sidescrapers (n=8, 8%) and points (n=1, 1%) are the least represented retouch types (Table 7.15). As shown in table 7.15, sidescrapers only appear within metamorphic (n=8, 10%) materials, whereas points (n=1, 5%) appears in lava materials (also see figure 7.23).



E) Figure 7. 21: Dimensions and metric of retouched tools. A-D) Length of retouched tool per archaeological unit (A) and per raw material (B). C-D) Width pre raw material (C) and thickness per raw material (D). F) Retouched tools weight classes per raw material.



A) Notch **B) Denticulate**
C) Denticulate and notch **D) Denticulate and notch**
 Figure 7. 22: Retouched pieces. A) Notches; B) Denticulates; and C-D) Denticulates and notches.

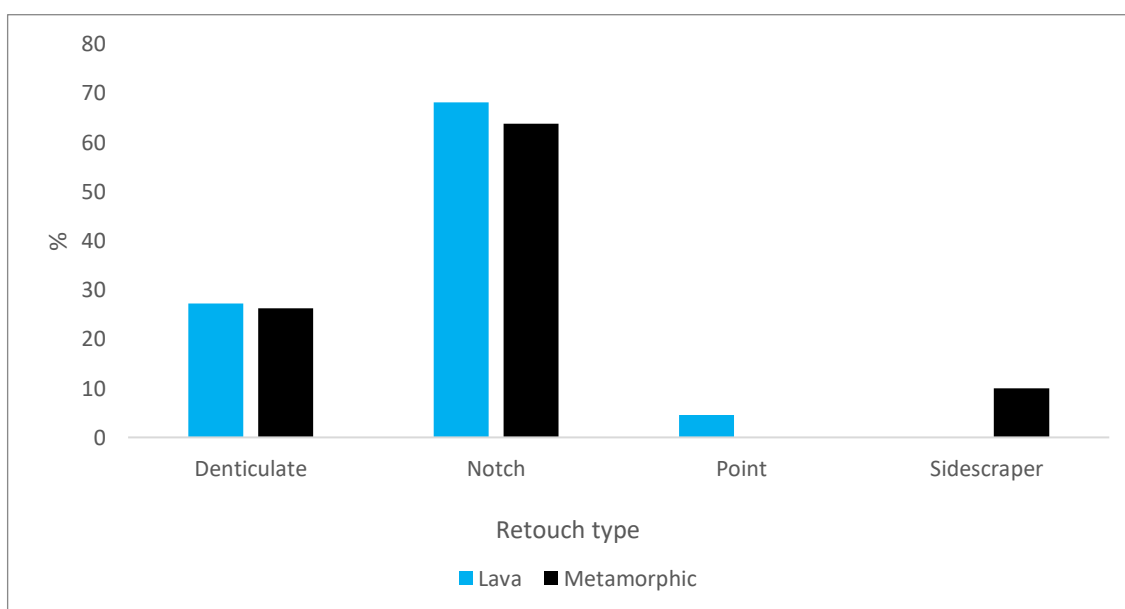


Figure 7. 23: JK West retouched pieces' types per raw material group.

7.5.8 Technological Strategies at JK West

The assemblage sampled at JK West accounts for 25,403 grams which were used in the production of flakes, cores, flake fragments, and retouched tools (Tables 7.4-5).

As shown in figure 7.16A, most core sizes range between 20-39 mm and 180-199 mm in length. The most prevalent length class is 40-59mm, followed by 60-79 mm in length (Figure 7.16A). Likewise, core width class is predominated by 40-59 mm and 60-79 mm with, suggesting JK West hominins selected medium-sized blanks for exploitation. However, most cores thickness class range between 20-39 mm and 40-59 mm in thickness. Most of the cores weighed between 101-200 grams and 201-400 grams (Figure 7.16D). It is worth noting that JK West hominins selected blanks with varied weights depending on the requirement at the time. Hence, the assemblage sampled contain varied weight and length sizes (Figure 7.16).

Furthermore, most of the core blanks were cobbles, followed by blocks (Figure 7.17C-D). Most cobbles were predominantly basalts, followed by trachytes, and phonolite; quartzites were the least represented among cobbles. It can be suggested that hominins selected cobble blanks from different raw material types, preferably basalt. However, they preferentially selected quartzite blocks whenever possible (Figure 7.17D).

There is a good number of cores that allow the understanding of knapping techniques at JK West. The exploitation techniques utilised at JK West show a prevalence of an intense reduction method, particularly with the predominance of multifacial cores and a high percentage of cores with cortex less than 50%, all indicating extended exploitation of cores at the site (Tables 7.9, 7.10, and 7.12; figure 7.18). Moreover, the excess of flake scars ranging from 4-6 scars (34.1%) and 7-9 scars (22.7%)

support this explanation (Table 7.9; figure 7.18). It should be noted that most of the knapping products obtained from cores were relatively small, with dimensions ranging from 2-3 centimetres (average flake length 31.8 mm). This suggests that JK West hominins' goal was to produce small flakes and could also potentially explain why most retouched tools in this assemblage are notches (65%), followed by denticulates (26%) (Table 7.14; figure 7.22 and 7.23), both indicative of cursory retouching.

With regards to flakes, there is a predominance of Toth's flake types V and VI (Table 7.6 and figure 7.11C-D). This indicates that during the reduction processes, the toolmakers at JK West were producing flakes from cores that have undergone high reduction intensity. On the other hand, the majority of flakes striking platform facets were unifaceted (Figure 7.11A-B), suggesting that hominins preferred clearing cortex on cores that could enable a successful blow to detach a flake, but did not conduct extensive preparation of platforms.

7.6 Part II: JK2

7.6.1 Characteristics of the JK2 lithic Collection

This section presents the analysis of JK2 lithic sample excavated by M.R. Kleindienst (1973) in 1961-62 at JK site (Table 7.16). Kleindienst's work began at JK and extended to JK2, identifying several archaeological units in different trenches (Kleindienst, 1973). Most of the lithic artefacts were obtained from JK2's Coarse Sand (C.S.D) and the rest came from the Fine Sand (F.SD) layer (see details Tables 7.16, 7.17, & 7.18).

Kleindienst (1973) explains that the Coarse Sand (C.S.D) unit has a higher concentration of artefacts than Fine Sand (F.SD) unit. This pattern is similar to observations by Leakey in JK, in which the Coarse Sand unit yielded more artefacts than the Ferruginous Sand unit (Leakey and Roe, 1994). JK2's Fine Sand unit is stratigraphically younger than JK2's Coarse Sand unit (Kleindienst, 1973).

Following the Kleindienst's recovery of the JK2 lithic assemblage, no detailed technological studies were conducted to understand the technological skills of the JK2's hominins at Olduvai. Leakey and Roe (1994) have attempted to mention the lithic assemblage recovered by Kleindienst, but they did not attempt to conduct a full analysis.

Table 7. 16: Kleindienst's assemblage from JK East site (recounts adapted from Kleindienst, 1973: 181).

Artefact Class	Tr.10 Bed IV Base	Tr. 8 Bed III							
		Fine Sand	U.A.O/F.S.D	L.A.O/C.S.D		Total	%	%	S/R
			Sand	Clay					
Large, Edged Tools									
Handaxe	1								
Knife	1								
Total Number	2								
Heavy Duty Tools									
Chopper	1			16	3	19	35.2		1
Core scraper			1	3	2	5	9.3		
Polyhedral				11		11	20.4		
Spheroid	2		7	19		19	35.1		
Total Number	3		8	49	5	54		13.2	1
Small Tools									
Scraper			3	85	6	91	52		
Protoburin			1	36	2	38	21.7		
Borer			3	10	1	11	6.3		
Discoïd				8	2	10	5.7		
Biface			2	14		14	8		
Other				11		11	6.3		
Total Number			9	164	11	175		42.9	
Modified Tools									
Unifacial			6	48	3	51	79.7		
Bifacial				13		13	20.3		
Total Number			6	61	3	64		15.7	
Utilised Tools									
Flake edge			2	34	4	38	33.1		

Chunk/slub edge			1	43	2	45	39.1	
Anvil			1	4		4	3.5	
Hammerstone				13	2	15	13	
(Core)			-1	-13		-13	11.3	
Total Number			5	107	8	115		28.2
Total Number	5		28	381	27	408		1
Cores								
Radial Trimming								
Biconical		1	6	108	3	111		
Partial working			1	7	1	8		
Total Number		1	7	115	5	119		59.8
Multidirectional Trimming								
Formless			1	57	3	60		
Tri-directed				5		5		
Partial working	1		3	15		15		
Total Number	1		4	77	3	80		40.2
Total Number	1	1	11	192	7	199		
Debris								
Flakes	4	1	17	196	11	207	6.6	3
Chips and Chunks	13	7	309	2728	189	2917	93.4	
Total Number	17	8	326	2924	200	3124		3
TOTAL AGGREGATE	23	9	365	3497	234	3731		4

The JK2 sample studied here includes a total of 1235 stone tools excavated from two stratigraphic units (JK2 Coarse Sand Unit and Fine Sand Unit) and weighs 80 kg (Table 7.17) and was analysed in the National Museum of Tanzania (NMT)'s laboratory in Dar es salaam. The sample is dominated by detached pieces (n = 789, 64%), followed by flaked pieces (n = 446, 36%) (Table 7.18). However, there is variation in the relative frequencies per archaeological unit, with a higher percentage of detached pieces in the Fine Sand Unit compared to the Coarse Sand Unit (see table 7.18 and figure 7.24A).

Detached pieces are essentially dominated by quartzite (n = 1008) (Table 7.20). This dominance is emphasised in terms of weight contribution of metamorphic artefacts (see table 7.19). Weighing over 55-kilogram, flaked artefacts contribute most of the overall weight to the sample analysed (69%), followed by detached artefacts (31%) (Table 7.20). As shown in table 7.17, the total weight of metamorphic flaked artefacts (28.5 kg) is slightly higher than the overall weight of lava flaked artefacts altogether.

7.6.2 Raw Materials

The JK2 sample contains artefacts manufactured from Olduvai's two major raw material groups, lava and metamorphic respectively (Table 7.17). These groups include rock types such as basalt, trachyte, trachyandesite, phonolite, quartz, quartzite, and feldspar (Hay, 1976; Kyara, 1999; McHenry and de la Torre, 2018a).

Quartzite is the most represented raw material (n = 1008; 82%), followed numerically by basalt (n = 90; 7%), trachyte (n = 60; 5%), phonolite (n = 59; 5%), trachybasalt (n = 13; 1%), quartz (n = 4; 0%), and feldspar (n = 1; 0%) (Table 7.20).

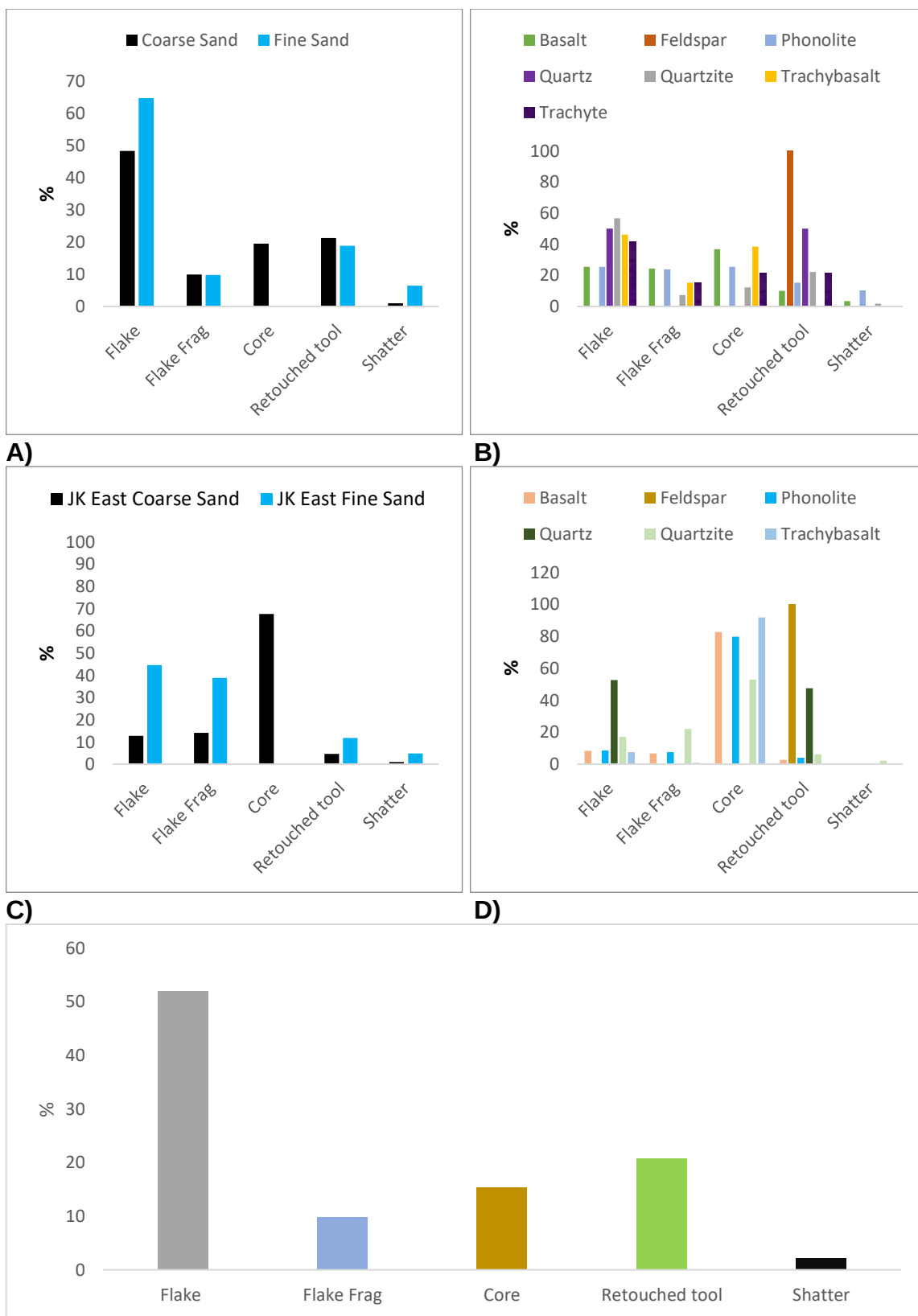
In terms of weight, quartzite artefacts make the largest contribution of weight within the sample (48.4 kg; 60%), followed by basalt (17.2 kg; 21%), phonolite (6.5 kg; 8%), trachyte (5.6 kg; 7%), trachybasalt (2.7 kg; 3%), feldspar (25 g; 0%), and lastly quartz (19 g; 0%) (Table 7.20).

Table 7. 17: Weight of main technological groups per archaeological unit and general raw material in the JK2 analysed sample.

Archaeological unit	Detached						Flaked						Total	
	Lava		Metamorphic		Sedimentary		Lava		Metamorphic		Sedimentary			
	n	g	n	g	n	g	n	g	n	g	n	g	n	g
JK East Fine Sand	28	827	187	3391	0	0	3	21	47	537	0	0	265	4776
JK East Coarse Sand	96	4577	475	16462	0	0	95	26556	301	28007	0	0	967	75602
Grand Total	124	5404	662	19853	0	0	98	26577	348	28544	0	0	1232	80378

Table 7. 18: JK2 lithic assemblage sample, including all lithic artefacts from the two archaeological units (Coarse Sand and Fine Sand).

		JK2 Coarse Sand				JK2 Fine Sand				Total			
		Frequency		Weight		Frequency		Weight		Frequency		Weight	
		n	%	g	%	n	%	g	%	n	%	g	%
Detached	Flake	469	82	9638	46	172	80	2133	51	641	81	11771	47
	Flake Frag	96	17	10644	51	26	12	1855	44	122	15	12499	49
	Shatter	9	2	757	4	17	8	230	5	26	3	987	4
	Total Detached	574	59	21039	28	215	81	4218	88	789	64	25257	31
Flaked	Core	190	48	51121	94	0	0	0	0	190	15	51121	64
	Retouched tool	206	52	3442	6	50	100	558	100	256	21	4000	5
	Total Flaked	396	41	54563	72	50	19	558	12	446	36	55121	69
Grand Total		970	100.0	75,602	100.0	265	100	4,776	100.0	1235	100.0	80,378	100



E) Figure 7. 24: A-B) Relative frequency artefacts per archaeological unit (A) and raw material (B) in the JK2 sampled assemblage. C-D) Relative Frequency of weight per archaeological unit (C) and raw material (D) in the whole JK2 sample studied. E) Percentage of JK2 lithic technological categories.

7.6.3 Flakes

Flakes (n=641) are the most prevalent lithic category within the JK2 sample assemblage, representing 81% of the entire sample (Table 7.18). Weighing 11.7 kg, flake sample is the third heaviest within the JK2 sample (Table 7.19). In absolute terms, quartzite flakes (n=570) are much more abundant than lava flakes altogether (Table 7.20).

In terms of flake sample distribution per archaeological unit, flakes from JK2 FSD are more frequent than flakes from JK2 CSD (Figure 7.24A). In absolute terms, however, flakes from JK2 CSD (n=469) are much higher in number than JK2 FSD (n=172) (Table 7.18). Metamorphic flakes (quartzite and quartz) contribute a relatively higher frequency than lava flakes (basalt, trachyte and phonolites (Figure 7.24B).

Figure 7.25A shows that most flakes measure 20-39 mm in length, with JK2 fine sand flakes being the most frequent than JK2 coarse sand flakes (also see table 7.22 and figure 7.26-27 and 7.28). Table 7.21 shows an average flake length is 34.7 mm in length and 26 mm in width, whereas 13 mm thickness. In addition, there is significant difference in flake dimension whereas some flakes measure up to 101 mm in length while others measure as small as 20 mm in length (Table 7.21). In terms of width, most flakes measure <20 mm in width, and thickness between 10-19 mm (Figure 7.25C-D). In terms of weight, most flakes weigh less than 20 grams, with JK2 fine sand flakes being more frequent than JK2 coarse sand flakes (Figure 7.25A). In terms of raw materials, quartz and quartzite are the most predominant raw materials within the most prevalent weight class (<20 grams) (Figure 7.25F).

Table 7. 19: Total weight of all lithic categories at JK2.

Technological Category		Lava (g)	Metamorphic (g)	Total (g)
Detached	Flake	3535	8236	11771
	Flake Fragments	1840	10659	12499
	Shatter	29	958	987
Flaked	Cores	25505	25616	51121
	Retouched tool	1072	2928	4000
Total		31981	48397	80378

Table 7. 20: JK2 technological categories per individualised raw material.

Lava										Metamorphic							
Basalt		Trachyte		Trachybasalt		Phonolite		Quartzite		Quartz		Feldspar		Grand Total			
n	g	n	g	n	g	n	g	n	g	n	g	n	g	n	g		
Flake	23	1425	25	1326	6	203	15	559	570	8248	2	10	0	0	641	11771	
Flake																	
Fragment	22	1130	9	201	2	22	14	487	75	10659	0	0	0	0	122	12499	
Shatter	3	11	0	0	0	0	6	18	17	958	0	0	0	0	26	987	
Total																	
Detached	48	2566	34	1527	8	225	35	1064	662	19865	2	10	0	0	789	25257	
Core	33	14188	13	3683	5	2474	15	5160	124	25616	0	0	0	0	190	51121	
Retouched tool	9	439	13	350	0	0	9	258	222	2919	2	9	1	25	256	4000	
Total Flaked	42	14627	26	4033	5	2474	24	5418	346	28535	2	9	1	25	446	55121	
Grand Total	90	17193	60	5560	13	2699	59	6482	1008	48400	4	19	1	25	1235	80378	
Basalt		Trachyte		Trachybasalt		Phonolite		Quartzite		Quartz		Feldspar		Frequency		Weight	
Frequency	Weight	Frequency	Weight	Frequency	Weight	Frequency	Weight	Frequency	Weight	Frequency	Weight	Frequency	Weight	Frequency	Weight	Frequency	Weight
%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Flake	26	8	42	24	46	8	25	9	57	17	50	53	0	0	52	15	
Flake																	
Fragment	24	7	15	4	15	1	24	8	7	22	0	0	0	0	10	16	
Shatter	3	0	0	0	0	0	10	0	2	2	0	0	0	0	2	1	
Total Detached	53	15	57	27	62	8	59	16	66	41	50	53	0	0	64	31	
Core	37	83	22	66	38	92	25	80	12	53	0	0	0	0	15	64	
Retouched tool	10	3	22	6	0	0	15	4	22	6	50	47	100	100	21	5	
Total Flaked	47	85	43	73	38	92	41	84	34	59	50	47	100	100	36	69	
Grand Total	7	21	5	7	1	3	5	8	82	60	0	0	0	0	100	100	

Table 7. 21: Table showing JK2 Min, Max, Mean, std. deviation.

			Minimum	Maximum	Mean	Std. deviation
Whole flake	Total (n = 641)	Length	20.0	101.0	34.7	12.8
		Width	10.0	70.0	26.0	9.4
		Thickness	4.0	84.0	13.0	6.2
		Weight	1.0	260.0	18.4	25.7
	Lava (n = 70)	Length	22.0	101.0	52.2	16.3
		Width	16.0	70.0	38.4	11.5
		Thickness	4.0	84.0	18.0	11.5
		Weight	1.0	260.0	50.5	51.3
	Metamorphic (n = 571)	Length	20.0	78.0	32.6	10.4
		Width	10.0	55.0	24.6	7.9
		Thickness	5.0	37.0	12.5	4.8
		Weight	1.0	115.0	14.4	16.7
Flake Fragment	Total (n = 55)	Length	21.0	57.0	31.9	7.6
		Width	15.0	39.0	23.7	5.3
		Thickness	5.0	23.0	11.4	3.8
		Weight	2.0	47.0	9.5	7.5
	Lava (n = 10)	Length	21.0	49.0	34.5	9.0
		Width	16.0	39.0	24.7	6.6
		Thickness	5.0	15.0	8.9	3.0
		Weight	2.0	20.0	8.3	6.3
	Metamorphic (n = 45)	Length	21.0	57.0	31.2	7.2
		Width	15.0	38.0	23.5	5.0
		Thickness	6.0	23.0	12.0	3.8
		Weight	2.0	47.0	9.8	7.8
Core	Total (n = 190)	Length	30.0	181.0	70.8	24.1
		Width	21.0	114.0	55.5	18.7
		Thickness	14.0	92.0	40.8	14.2
		Weight	16.0	2128.0	269.0	282.0
	Lava (n = 66)	Length	54.0	181.0	85.8	21.9
		Width	37.0	114.0	66.9	16.8
		Thickness	16.0	83.0	47.4	12.7
		Weight	57.0	2128.0	386.4	312.0
	Metamorphic (n = 124)	Length	30.0	132.0	62.9	21.5
		Width	21.0	110.0	49.5	16.7
		Thickness	14.0	92.0	37.2	13.9
		Weight	16.0	2000.0	206.6	243.9
Retouched tool	Total (n = 256)	Length	21.0	70.0	33.8	9.2
		Width	13.0	54.0	24.9	6.7
		Thickness	5.0	38.0	12.2	4.3
		Weight	1.0	129.0	13.0	12.9
	Lava (n = 32)	Length	21.0	91.0	48.0	17.5
		Width	11.0	74.0	34.3	13.5
		Thickness	4.0	30.0	12.7	5.7
		Weight	1.0	191.0	33.5	39.5
	Metamorphic (n = 224)	Length	21.0	70.0	33.8	9.2
		Width	13.0	54.0	24.9	6.7
		Thickness	5.0	38.0	12.2	4.3
		Weight	1.0	129.0	13.0	12.9

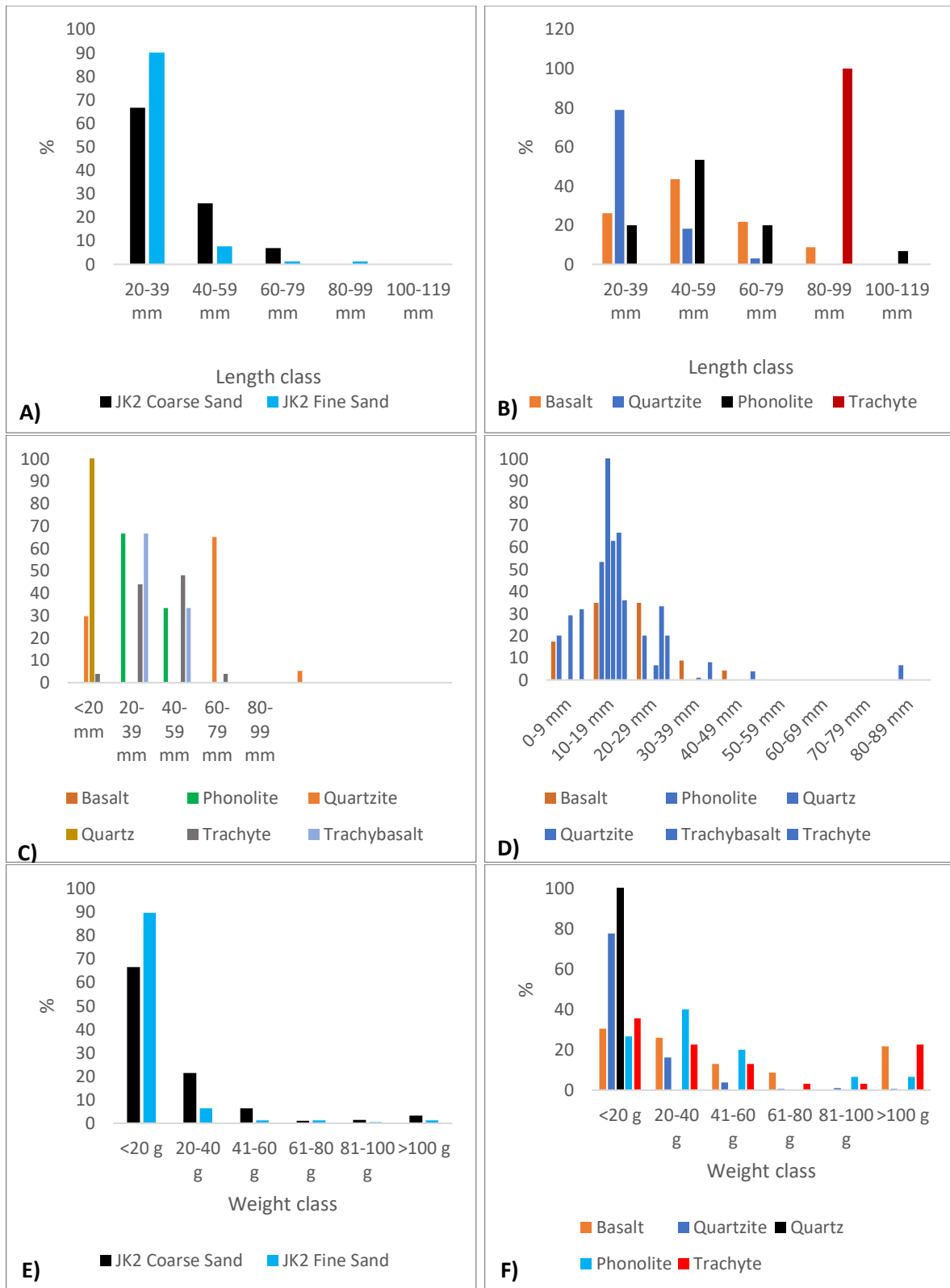


Figure 7. 25: JK2 flakes dimensions. A) Length per archaeological unit; B) Length per raw material; C) Width per raw material; D) Thickness per raw material; E) Weight per archaeological unit; and F) Weight per raw material.



A) Dorsal Face



B) Ventral Face

Figure 7. 26: A-B) JK2 Small Flakes Dorsal face (A) and Ventral Face (B).



A) Dorsal Face



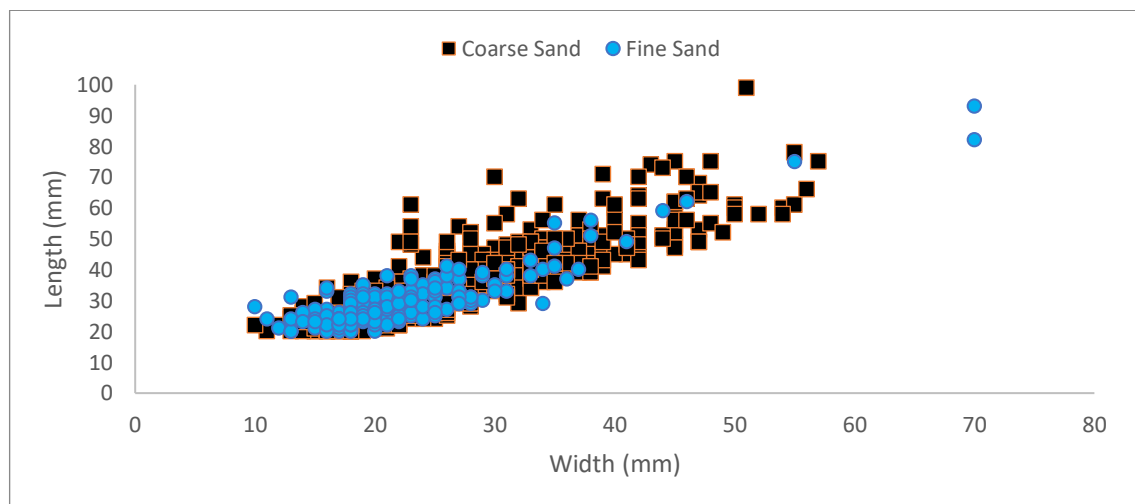
B) Ventral Face

Figure 7. 27: A-B) JK2 Small Flakes Dorsal Face (A) and Ventral Face (B).

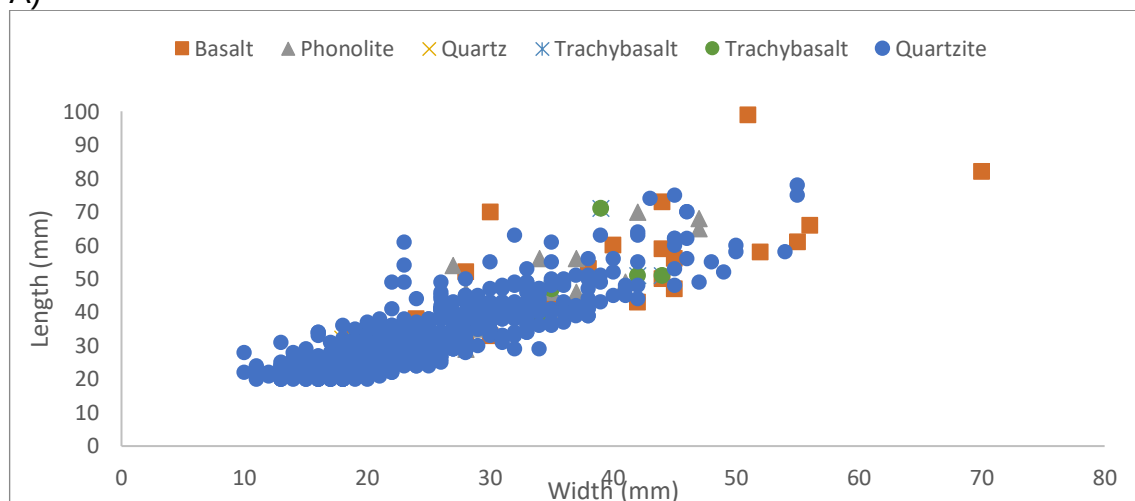
As shown in table 7.20, there is a clear preference for quartzite flakes ($n=571$) in the assemblage, over trachyte ($n=25$), basalt ($n=23$), phonolite ($n=15$), and trachybasalt ($n=6$). Whole flakes striking platform are mainly unifaceted (81%; Table 7.22; Figure 7.29A-B). Table 7.22 shows that most dorsal surfaces are non-cortical (35%), followed by non-cortical dominant surfaces (30%). In addition, there is predominance of Toth's type V flakes (Table 7.22; figure 7.29C-D).

There is an underrepresentation of fully cortical flakes (Toth's type I) ($n = 22$; 3%) and flakes with the entire dorsal side covered by cortex (Toth's type IV) ($n = 16$; 2%) (Table 7.22; figure 7.29D). Toth's flake type I is associated with the cortex removal during artefact manufacture; Toth's flake type IV is associated with clearance of striking platforms in cores that are still in the early stages of reduction (Table 7.22; figure

7.29C-D). In fact, the majority of flakes show presence of platform preparation by the knapper; most of them are non-cortical (Toth's type V, $n = 326$; 51% and Toth's type VI, $n = 191$; 30%) (Table 7.22; figure 7.29D). This suggests that the cores were being reduced with multiple preparation of the platforms with non-cortical surfaces being used as striking platforms by the knappers. The overrepresentation of Toth's types V and VI may suggest a presence of high degree of reduction at the site (Figure 7.29A-B), although the presence of all stages of flake reduction at the site suggest that all stages of the reduction sequence were taking place on site (Table 7.22).



A)



B)

Figure 7. 28: A-B) JK2 flake Length-Width scatterplots of all flakes studied per archaeological unit (A) and raw materials (B).

Table 7. 22: JK2 flake technological attributes.

		Raw Material				Archaeological Unit				Grand Total	
		Lava		Metamorphic		Coarse Sand		Fine Sand			
		n	%	n	%	n	%	n	%	n	%
Length Classes	<20 mm	0	0	0	0	0	0	0	0	0	0
	20-39 mm	17	24	451	79	313	67	155	90	468	73
	40-59 mm	32	46	103	18	122	26	13	8	135	21
	60-79 mm	17	24	17	3	32	7	2	1	34	5
	80-99 mm	3	4	0	0	1	0	2	1	3	0
	100-119 mm	1	1	0	0	1	0	0	0	1	0
	Total	70	100	571	100	469	100	172	100	641	100
Striking platform preparation	Non-faceted	22	31	89	16	76	16	35	20	111	17
	Unifaceted	48	69	469	82	383	82	134	78	517	81
	Bifaceted	0	0	13	2	10	2	3	2	13	2
	Multifaceted	0	0	0	0	0	0	0	0	0	0
	Total	70	100	571	100	469	100	172	100	641	100
Cortex dorsal side	Cortical	19	27	19.00	3	30	6	8	5	38	6
	Cortex >50%	20	29	168.00	29	150	32	38	22	188	29
	Cortex <50%	19	27	173.00	30	140	30	52	30	192	30
	Non-cortical	12	17	211.00	37	149	32	74	43	223	35
	Total	70	100	571.00	100	469	100	172	100	641	100
Toth's flakes	I	13	19	9	2	17	4	5	3	22	3
	II	9	13	47	8	41	9	15	9	56	9
	III	1	1	29	5	19	4	11	6	30	5
	IV	6	9	10	2	13	3	3	2	16	2
	V	30	43	296	52	252	54	74	43	326	51
	VI	11	16	180	32	127	27	64	37	191	30
	Total	70	100	571	100	469	100	172	100	641	100

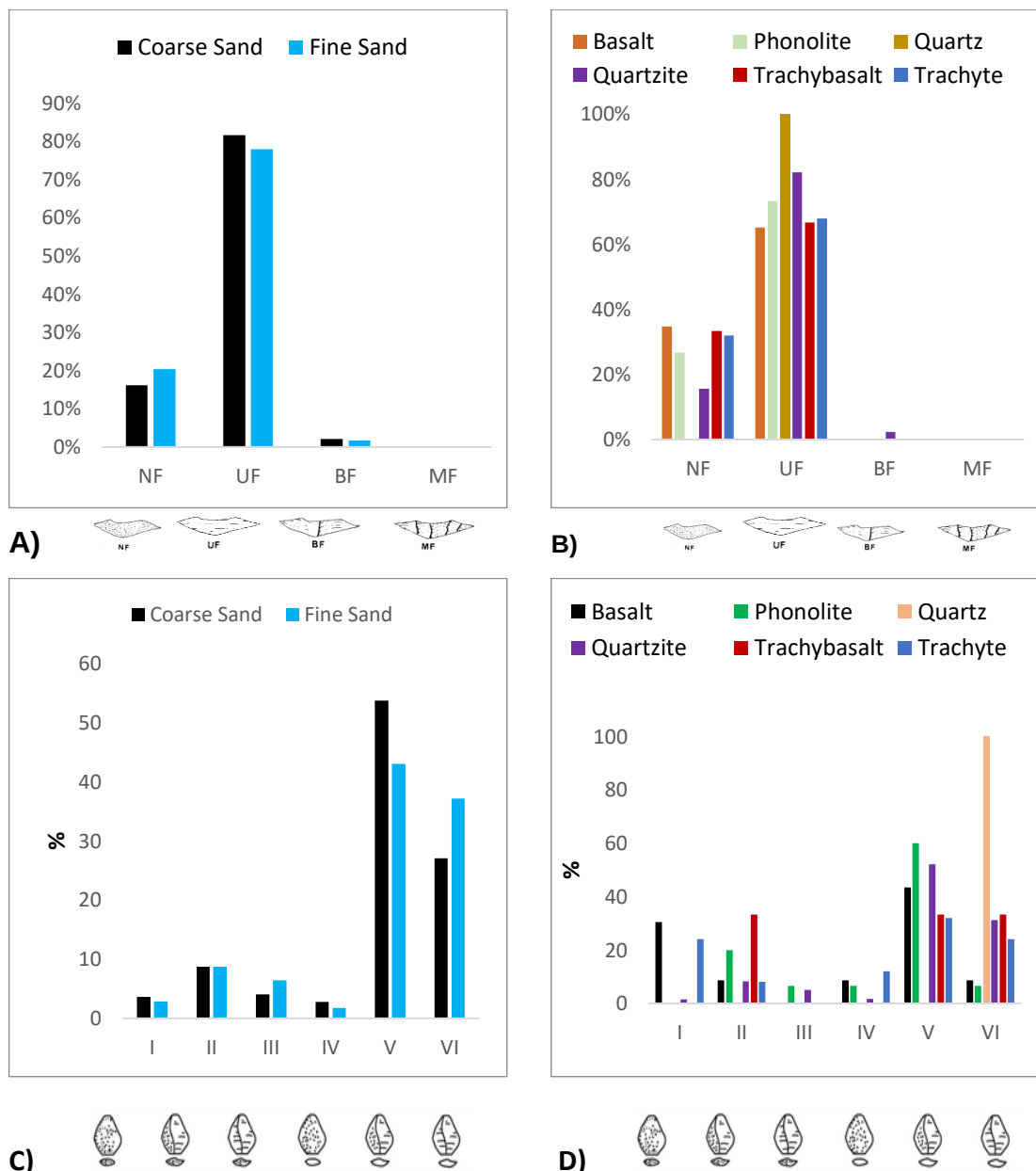


Figure 7. 29: JK2 flake platform facets per archaeological unit A), all raw materials B).

This degree of accuracy and competency in manufacturing flakes is supported by the overrepresentation of flakes (n=378; 59%) with no identifiable knapping accidents, with only about 40.6% (n=260) having step scars and 0.5% (n=3) with plunging termination (Figure 7.30; table 7.23).

In terms of dorsal cortex, most flakes are non-cortical, with JK2 coarse sand flakes being the most frequent than JK2 fine sand (Figure 7.31A-B). In terms of raw material, non-cortical flakes are predominated by quartz and quartzite materials (Figure 7.31B).

From the flake sample studied at this site, a total of 1370 dorsal scars extractions were identified, with an average of 2.1 per flake (Table 7.24). However, some flakes provided up to 6 dorsal flake extractions (Figure 7.31D).

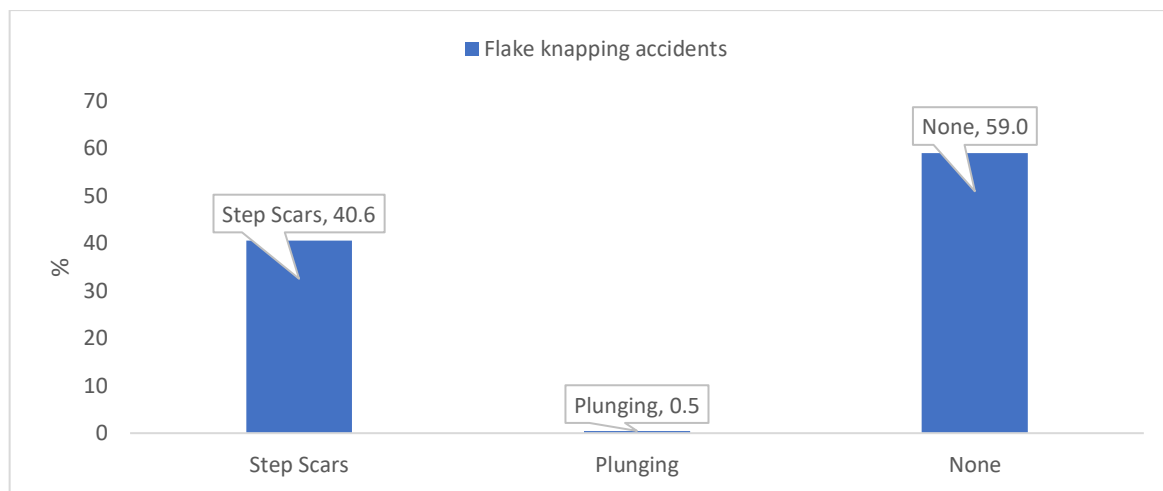


Figure 7. 30: Figure showing the JK2 Flake knapping accidents.

Table 7. 23: JK2 Flake knapping accidents.

Knapping accidents	n	%
Step Scars	260	40.6
Plunging	3	0.5
None	378	59.0
Total	641	100.0

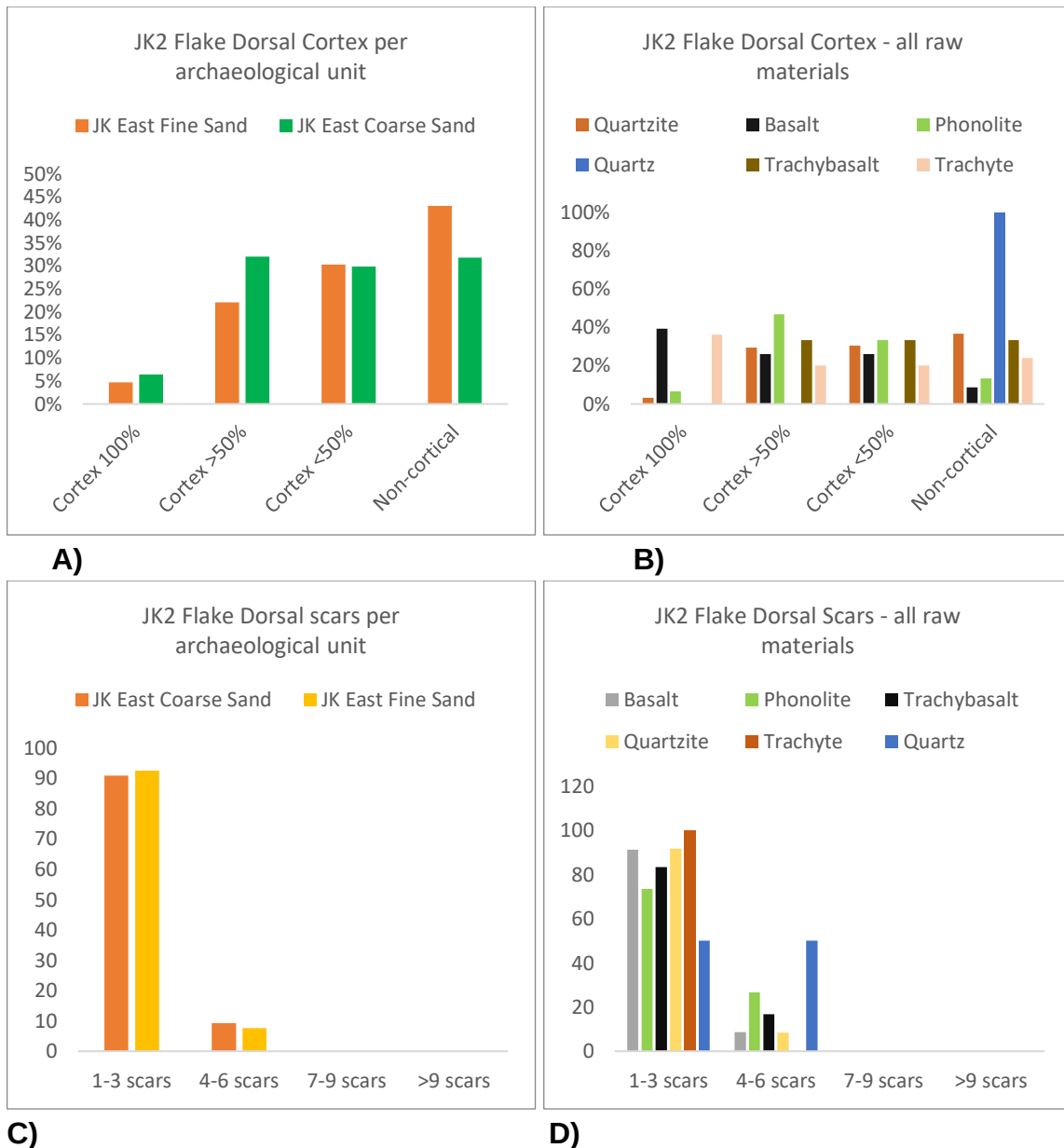


Figure 7. 31:A-D) JK2 Dorsal Cortex and scars. A) Dorsal cortex per archaeological Unit. B) Dorsal cortex per raw material. C) Dorsal scar per archaeological unit. D) Dorsal scar per raw material.

The JK2 flake sample produced a total of 50 m of cutting edges, with an average of 80.2 mm and a standard deviation of 31 mm (Table 7.25). With a maximum of 230 mm long cutting edge and minimum of 25 mm long cutting edge, the JK2 hominins intended to produce as many flakes with cutting edges as possible.

Table 7. 24: Flake dorsal scar extraction directions at JK2 Site.

Flake dorsal scar extraction direction	n	%
OPD	127	9
LP	288	21
OPI	117	9
TI	132	10
ODI	80	6
LD	190	14
ODD	90	7
TD	147	11
Indet	199	15
Total	1370	100

Table 7. 25: Flake and retouched pieces cutting edge.

JK2					
Cutting Edge	min	max	mean	std.deviation	Total length (mm)
Flake	25.0	230.0	80.2	31.0	50059
Retouched tool	17.0	230.0	78.5	29.3	19967

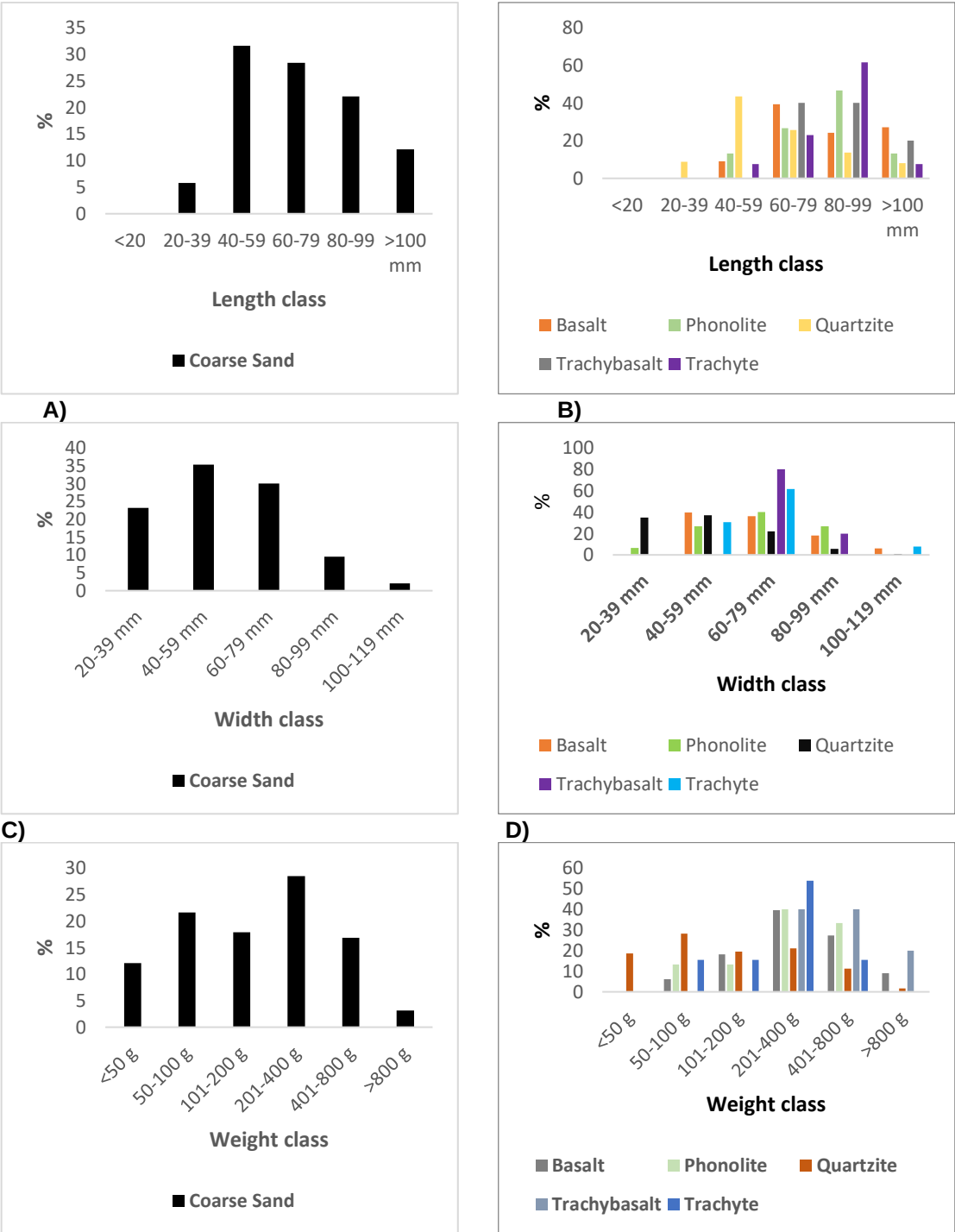
7.6.4 Cores

All the JK2 cores (n=190, 51 kg) analysed here are associated with the small debitage *chaîne opératoire*, and no LCT production cores were observed in the collection in Dar es Salaam; The core sample amounts over 51 kg of raw materials transported to the site (Table 7.19). As shown in table 7.20, quartzite cores (n=124) are most abundant, whereas lava cores are represented in much smaller quantities; basalt cores (n=33, 14.2 kg) are more abundant than phonolite (n=15, 5.2 kg) cores, while trachyte (n=13, 3.6 kg), trachybasalt (n=5, ~2.5 kg) cores are only marginally represented (Table 7.20). With an average length of 70.8 mm and weight of 269 g, there is a slight variation in core dimensions (Table 7.20). In the core sample, 31.6% range between 40-59 mm in length (Table 7.26), with metamorphic cores being the largest and heaviest (Tables 7.19 and 7.20).

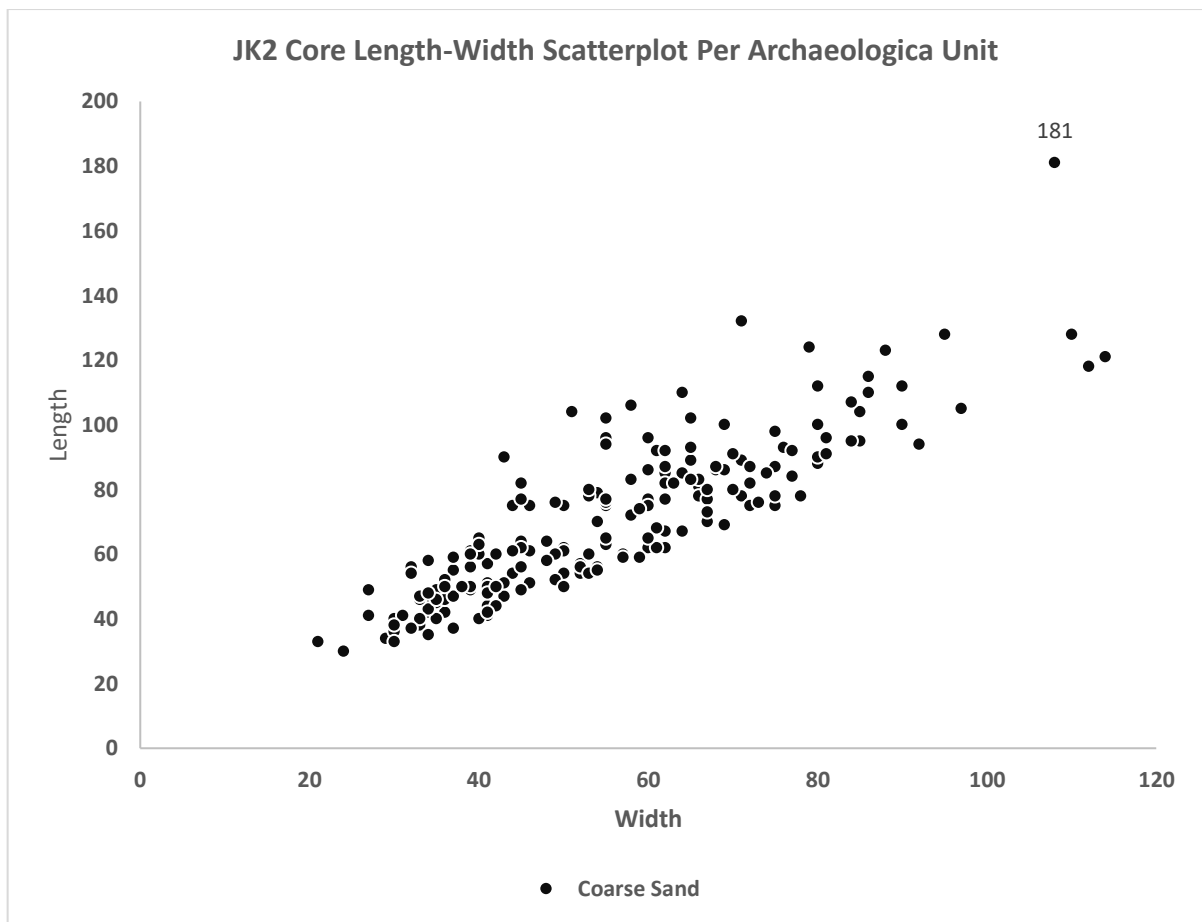
Core average length ranges between 30 mm and 70 mm (Table 7.21), although there is great variation within the sample, with a core as large as 181 mm and as small as 30 mm in length (Table 7.21). In terms of size, it is evident that lava cores are larger than metamorphic cores (Figure 7.32B). Most lava cores are between 60-79 mm and 80-99 mm length range, while metamorphic cores are between 40-59 mm and 60—79 mm (Table 7.27; Figures 7.32B and 7.33B).

Correspondingly, lava cores appear to be heavier than metamorphic cores, with most of them being in the 201-400 g and 401-800 g weight classes, while a small number of metamorphic cores is overrepresented in <50 g, 50-100 g, and 101-200 g respectively (Figure 7.32).

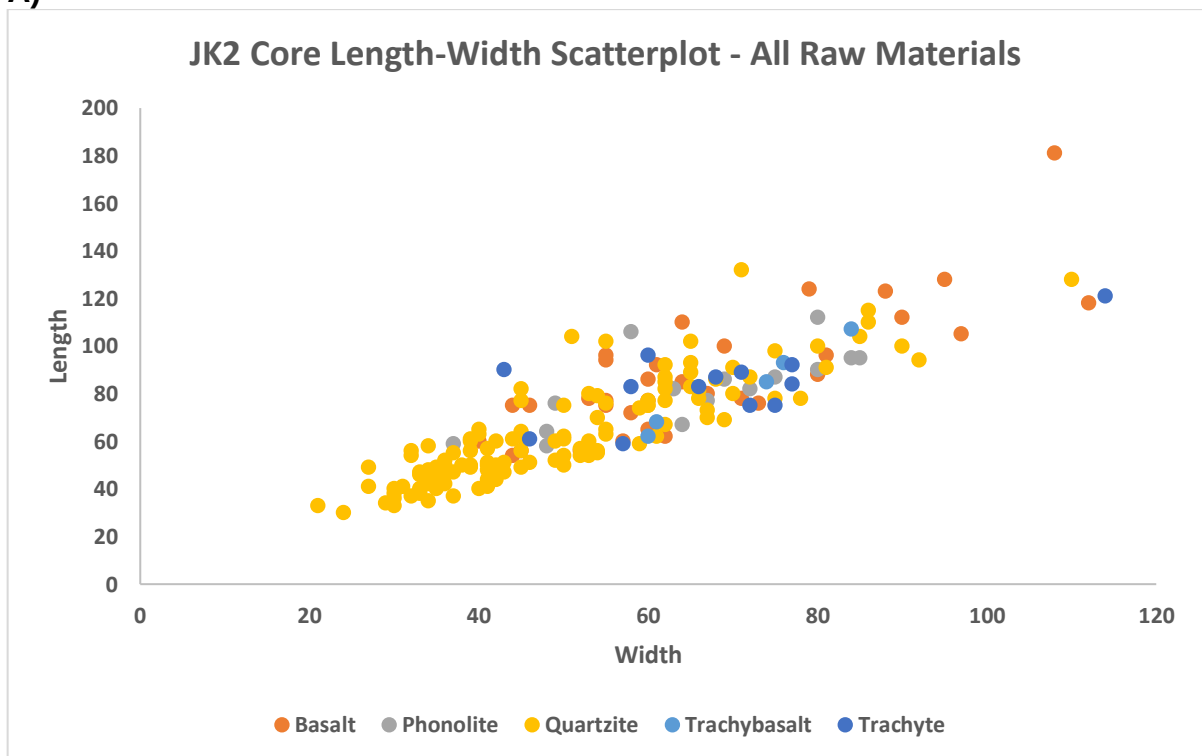
Identical proportion of the cores (n=85, 44.7%) were manufactured from tabular blocks and from rounded cobbles (n=85, 44.7%), with a very small number of cores (n=4, 1.1%) being produced on flake blanks (Table 7.26).



E) F) Figure 7. 32: JK2 core length per archaeological unit (A) and raw materials (B).



A)



B)

Figure 7. 33: JK2 core length-width scatterplots per archaeological unit (A) and raw material (B).

It should be noted, however, that a substantial number of cores (n=18, 9.5%) have been worked to the stage where describing the original blank used was not achievable (Table 7.26 and Figure 7.34C). Most cobble blanks are associated with lava and block blanks with metamorphic rocks.

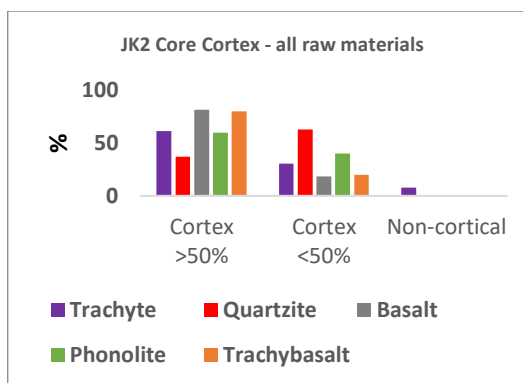
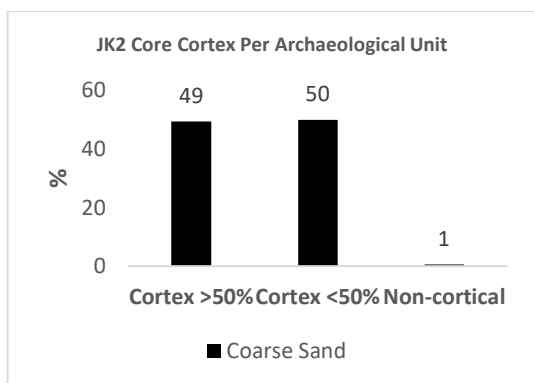
Cortex is visible on 99.5% of the core assemblage, although non-cortical dominant is the most prevalent (n = 95, 50%) (Table 7.26). This is followed by cortical dominant (94, 49.5%). The core cortex can be used as a proxy to assess the level of core exploitation and, overall, it can be seen from figure 7.34A-B that the majority of cores possess less than 50% cortex coverage, while some cores possess more than 50% cortex coverage, with a very small number regarded as fully non-cortical (Table 7.26 and Figure 7.34A).

Remaining cortex is particularly evident in lava cores, which as shown in figure 7.34B, are mostly cortical dominant. This evidence suggests that the cores were not heavily reduced, an observation further supported by the number of scars count on cores, whereby majority of cores possess between 1-3 scars and 4-6 scars of flake extractions (Table 7.26 and Figure 7.34E-F).

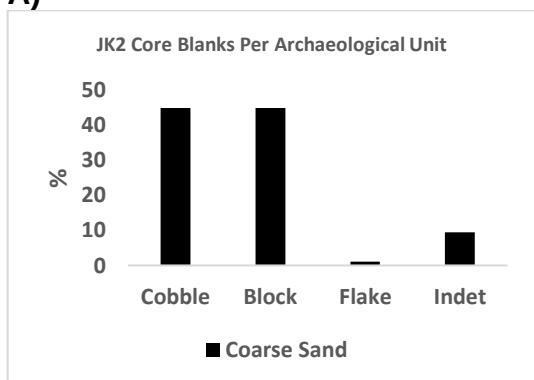
Reduction intensity of cores can also be identified via the number of flake scar counts preserved on cores. As shown in Table 7.26, 97.4% of cores preserve nine or fewer flake scars, and only about 2.6% have more than nine flake scars. Figure 7.34F shows the reduction intensity in terms of raw materials, with predominance of 1-3 scars in lava cores, 4-6 scars in metamorphic (particularly quartzite) cores, and 7-9 scars also in lava (especially trachybasalt).

Table 7. 26: Table showing JK2 Core attributes per archaeological unit and raw material.

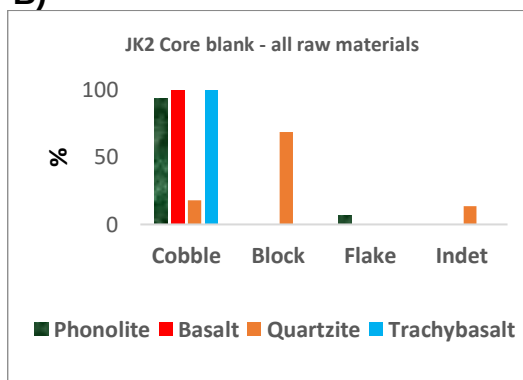
		Archaeological unit				Raw Material				Grand Total	
		Coarse Sand		Fine Sand		Lava		Metamorphic		n	%
		n	%	n	%	n	%	n	%		
Length class	20-39 mm	11	5.8	0	0.0	0	0.0	11	8.9	22	5.8
	40-59 mm	60	31.6	0	0.0	6	9.1	54	43.5	120	31.6
	60-79 mm	54	28.4	0	0.0	22	33.3	32	25.8	108	28.4
	80-99 mm	42	22.1	0	0.0	25	37.9	17	13.7	84	22.1
	>100 mm	23	12.1	0	0.0	13	19.7	10	8.1	46	12.1
	Total	190.00	50.0	0.00	0.0	66.00	17.4	124.00	32.6	190.00	100.0
	<50 g	23	12.1	0	0.0	0	0.0	23	18.5	46	12.1
Weight class	50-100 g	41	21.6	0	0.0	6	9.1	35	28.2	82	21.6
	101-200 g	34	17.9	0	0.0	10	15.2	24	19.4	68	17.9
	201-400 g	54	28.4	0	0.0	28	42.4	26	21.0	108	28.4
	401-800	32	16.8	0	0.0	18	27.3	14	11.3	64	16.8
	>800 g	6	3.2	0	0.0	4	6.1	2	1.6	12	3.2
	Total	190.00	50.0	0.00	0.0	66.00	17.4	124.00	32.6	190.00	100.0
	Cortex >50%	94	49.5	0	0.0	48	72.7	46	37.1	188	49.5
Cortex	Cortex <50%	95	50.0	0	0.0	17	25.8	78	62.9	190	50.0
	Non-cortical	1	0.5	0	0.0	1	1.5	0	0.0	2	0.5
	Total	190.00	50.0	0.00	0.0	66.00	17.4	124.00	32.6	190.00	100.0
Blank	Cobble	85	44.7	0	0.0	63	95.5	22	17.7	170	44.7
	Block	85	44.7	0	0.0	0	0.0	85	68.5	170	44.7
	Flake	2	1.1	0	0.0	2	3.0	0	0.0	4	1.1
	Indet	18	9.5	0	0.0	1	1.5	17	13.7	36	9.5
	Total	190.00	50.0	0.00	0.0	66.00	17.4	124.00	32.6	190.00	100.0
	1-3 scars	84	44.2	0	0.0	40	60.6	44	35.5	168	44.2
	4-6 scars	80	42.1	0	0.0	16	24.2	64	51.6	160	42.1
Number of scars	7-9 scars	21	11.1	0	0.0	7	10.6	14	11.3	42	11.1
	>9 scars	5	2.6	0	0.0	3	4.5	2	1.6	10	2.6
	Total	190.00	50.0	0.00	0.0	66.00	17.4	124.00	32.6	190.00	100.0



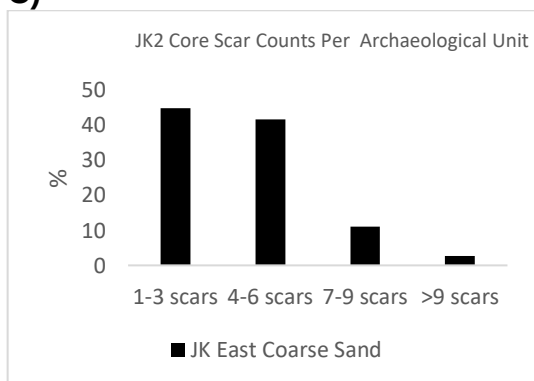
A)



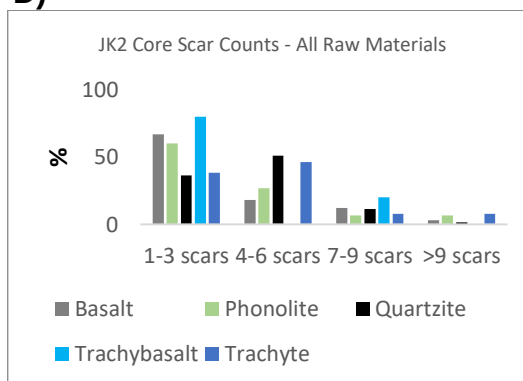
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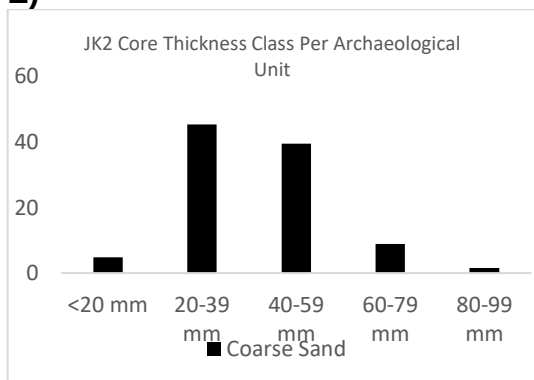
C)



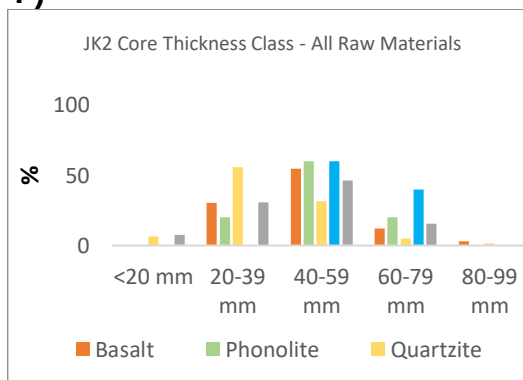
D)



E)



F)



G)

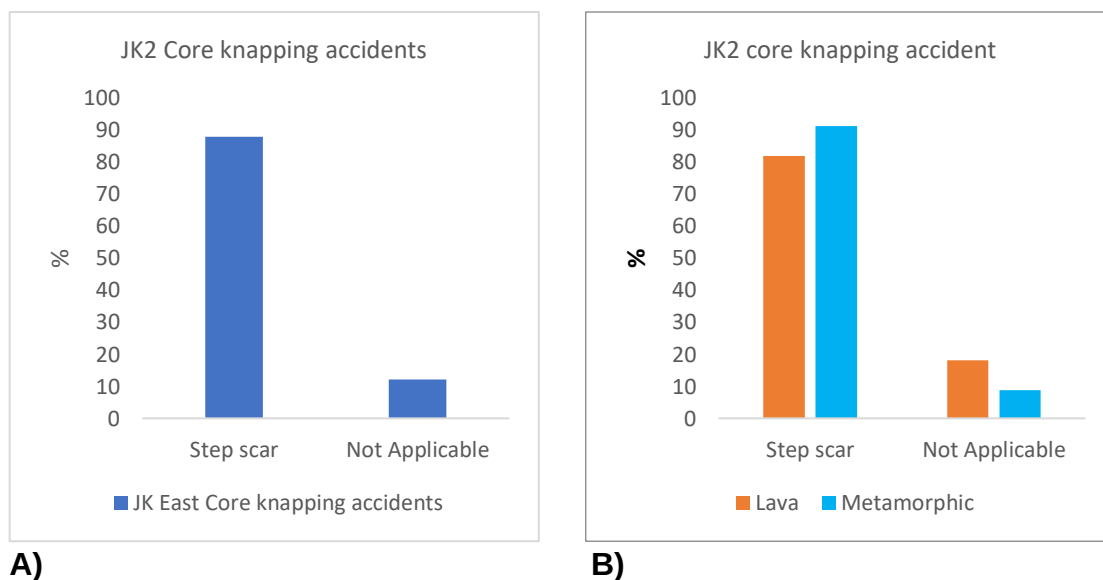
H)

Figure 7. 34: JK2 technical attributes of cores, per archaeological unit (left) and raw materials (Rightmire). A-B) shows cortex coverage. C-D) shows Core blank. E-F) Number of previous scars. G-H) Thickness Range.

There is clear evidence of knapping accidents in the JK2 core sample (Table 7.27; figure 7.35). The most common knapping accidents are step scars (n=167, 88%) (Table 7.27). Other cores do not contain knapping accidents (n=23, 13%) (Table 7.27). Figure 7.35B shows that step scars are more prevalent in metamorphic cores than in lava cores.

Table 7. 27: Table showing cores' knapping accidents at JK2 site.

Knapping accident	n	%
Step scar	167	88
Not Applicable	23	12
Total	190	100



A) **B)**
Figure 7. 35: JK2 Core knapping accidents per all raw materials (A) and rock type (B).

7.6.4.1 Core Exploitation Systems

At JK2, there are different flaking schemes that exhibit different techniques employed by hominins during core exploitation. There are three major exploitation systems documented, which include unifacial (n=83, 41%), multifacial (n=49, 26%), and bifacial (n=49, 26%) (Table 7.28). These exploitation systems have been subdivided into several flaking schemes (Table 7.29). As shown in table 7.29 multifacial

metamorphic (n=49, 39.5%) cores are the most frequent, followed by lava testcores (n=26, 39.3%), BSP lava (n=11, 16.7%) cores, UAU1 metamorphic (n=9, 7.3%), multifacial lava (n=8, 12.1%), UAUT metamorphic (n=7, 5.7%), UAB1 metamorphic (n=7, 5.7%), discoids metamorphic (n=5, 4.3%), and BALP metamorphic (n=5, 4%) (Table 7.29).

Table 7. 28: JK2 core exploitation system per raw material group.

	Raw material				Total	
	Lava		Metamorphic		n	%
	n	%	n	%		
Unifacial	38	20	45	24	83	44
Bifacial	20	11	29	15	49	26
Multifacial	8	4	50	26	58	31
Total	66	35	124	65	190	100

In addition, table 7.29 shows that there is predominance of multifacial (n=57, 30%) cores , followed by testcores (n=37, 19.5%), BSP (n=20, 10.5%), UAU1 (n=11, 5.8%), UAB1 (n=10, 5.3%), BALP (n=9, 4.7%), USP (n=8, 4.2%), discoids (n=8, 4.2%), UAU2 (n=6, 3.1%), USP2 (n=3, 1.6%), BAP (n=3, 1.6%), BP (n=3, 1.6%), and polyhedron (n=1, 0.5%) (also see figure 7.36A). As shown in figure 7.36B multifacial metamorphic (39.5%) cores are the most frequent, followed almost closely by lava testcores (39.4%). The prevalence of multifacial flaking scheme supports a model of high reduction intensity at the site. Moreover, the predominance of lava testcores is indicative that lava cobbles were abundant in the local environment and hominins were testing the blanks to determine the quality of the raw material (Table 7.30; figure 7.36B). Presumably, lava cobbles were of low quality. As the result, only small percentage of them underwent high reduction sequences (see Multifacial lava cores on figure 7.36B).

Furthermore, BSP cores (16.7%) are predominantly lava than metamorphic (7.3%) (also see table 7.29). Similarly, USP cores (6%) are predominantly lava than metamorphic (3%) (Figure 7.36B). In addition, discoids lava and metamorphic cores are almost similar to BALP cores in terms of frequency (Figure 7.36B). Morphologically, USP, BSP, and discoids fall within the Leakey 1971's description of choppers (also de la Torre and Mora 2018: 254). However, most other flaking schemes such as UAU1, UAU2, BALP, and UAB1 are indicative of short flaking sequences; most of them are predominantly metamorphic (Figure 7.36B; table 7.29).

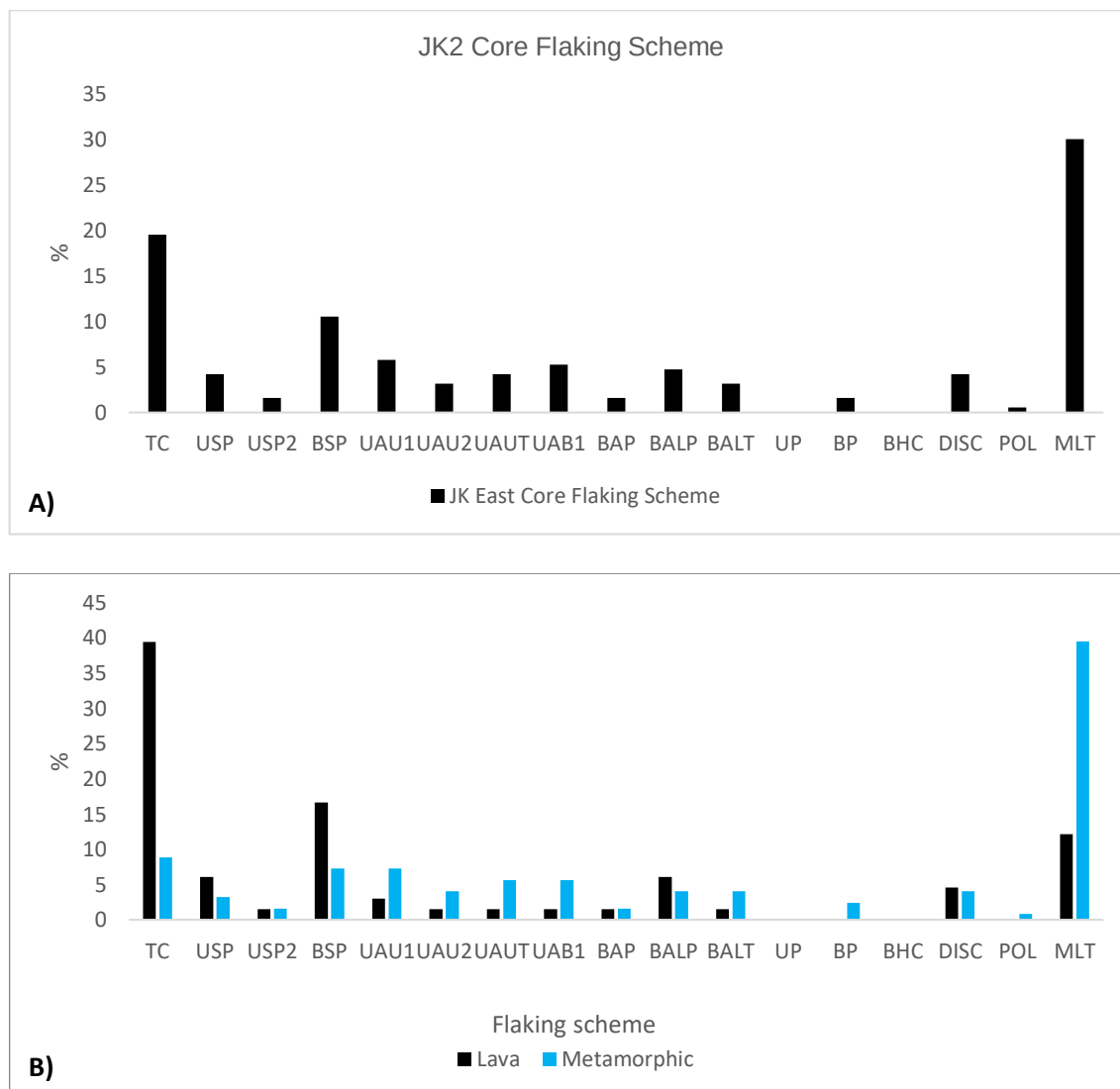


Figure 7. 36: Flaking schemes of JK2 cores. (See table 3.5 in chapter 3 for abbreviations).

Table 7. 29: JK2 Core Flaking Schemes per archaeological unit.

	Raw material				Archaeological unit				Total	
	Lava		Metamorphic		Coarse Sand		Fine Sand		n	%
	n	%	n	%	n	%	n	%		
TC	26	39.39	11.00	8.87	37.00	19.47	0.00	0.00	37.00	19.47
USP	4	6.06	4.00	3.23	8.00	4.21	0.00	0.00	8.00	4.21
USP2	1	1.52	2.00	1.61	3.00	1.58	0.00	0.00	3.00	1.58
BSP	11	16.67	9.00	7.26	20.00	10.53	0.00	0.00	20.00	10.53
UAU1	2	3.03	9.00	7.26	11.00	5.79	0.00	0.00	11.00	5.79
UAU2	1	1.52	5.00	4.03	6.00	3.16	0.00	0.00	6.00	3.16
UAUT	1	1.52	7.00	5.65	8.00	4.21	0.00	0.00	8.00	4.21
UAB1	3	1.52	7.00	5.65	10.00	5.26	0.00	0.00	10.00	5.26
BAP	1	1.52	2.00	1.61	3.00	1.58	0.00	0.00	3.00	1.58
BALP	4	6.06	5.00	4.03	9.00	4.74	0.00	0.00	9.00	4.74
BALT	1	1.52	5.00	4.03	6.00	3.16	0.00	0.00	6.00	0.00
UP	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BP	0	0.00	3.00	2.42	3.00	1.58	0.00	0.00	3.00	1.58
BHC	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DISC	3	4.55	5.00	4.03	8.00	4.21	0.00	0.00	8.00	4.21
POL	0	0.00	1.00	0.81	1.00	0.53	0.00	0.00	1.00	0.53
MLT	8	12.12	49.00	39.52	57.00	30.00	0.00	0.00	57.00	30.00
BIPO	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BIPCO	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	66	34.74	124.00	65.26	190.00	100.00	0.00	0.00	190.00	100.00

Table 7. 30: JK2 flaking schemes per core blank.

	Core Blank									
	Block		Cobble		Flake		Indet		Total	
	n	%	n	%	n	%	n	%	n	%
TC	10.0	11.8	26.0	30.6	1.0	50.0	0.0	0.0	37.0	19.5
USP	3.0	3.5	5.0	5.9	0.0	0.0	0.0	0.0	8.0	4.2
USP2	2.0	2.4	1.0	1.2	0.0	0.0	0.0	0.0	3.0	1.6
BSP	7.0	8.2	10.0	11.8	1.0	50.0	2.0	11.1	20.0	10.5
UAU1	8.0	9.4	2.0	2.4	0.0	0.0	1.0	5.6	11.0	5.8
UAU2	2.0	2.4	3.0	3.5	0.0	0.0	1.0	5.6	6.0	3.2
UAUT	5.0	5.9	3.0	3.5	0.0	0.0	0.0	0.0	8.0	4.2
UAB1	7.0	8.2	3.0	3.5	0.0	0.0	0.0	0.0	10.0	5.3
BAP	2.0	2.4	1.0	1.2	0.0	0.0	0.0	0.0	3.0	1.6
BALP	1.0	1.2	5.0	5.9	0.0	0.0	3.0	16.7	9.0	4.7
BALT	0.0	0.0	3.0	3.5	0.0	0.0	3.0	16.7	6.0	3.2
UP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BP	0.0	0.0	2.0	2.4	0.0	0.0	1.0	5.6	3.0	1.6
BHC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DISC	2.0	2.4	3.0	3.5	0.0	0.0	3.0	16.7	8.0	4.2
POL	0.0	0.0	1.0	1.2	0.0	0.0	0.0	0.0	1.0	0.5
MLT	36.0	42.4	17.0	20.0	0.0	0.0	4.0	22.2	57.0	30.0
BIPO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BIPCO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	85.0	44.7	85.0	44.7	2.0	1.1	18.0	9.5	190.0	100.0

The flaking schemes at JK2 is generally indicating a medium to high reduction intensity, with multifacial cores (30%) surpassed test cores (19.5%) flaking scheme (Table 7.29). Other predominant reduction schemes such as BSP, UAU1 and UAB1 are indicating medium flaking sequence (Table 7.29).

Furthermore, the medium to high reduction intensity is accentuated by the number of scars preserved on cores, with scar count ranging from 4-6 scars being prevalent. Hence, the predominance of 1-3 scars on core surfaces, 4-6 scars and 7-9 scars suggest that hominins preferred to detach multiple flakes from available cores.

Therefore, the flaking scheme shown in table 7.29 concurs with the argument of medium to high reduction intensity at JK2, with BSP (10.5%), TC (19.5%) and MLT (30%) (Tables 7.29; Figure 7.36).

7.6.5 Retouched Pieces

The retouched pieces (n=256) contribute 21% of the sample collection at JK2 site, with the total weight of 4 kg of the entire sample (Table 7.18; figure 7.24E). Figure 7.37A shows that retouched tools are 20-39 mm in length, with an average of 33.8 mm (Table 7.21; figure 7.38). The retouched tools have an average weight of 13 g and width 24.9 mm (Table 7.21).

Retouched pieces from the coarse sand unit are the longest (80-99 mm) than those from fine sand (Figure 7.37A). Lava retouched pieces are the longest, with an average length of 48 mm, followed by metamorphic, with an average length of 33.8 mm (Table 7.21). There is variation in length amongst the retouched pieces, with some items measuring 70 mm in length and other as short as 21 mm in length (Table 7.21).

Retouched pieces are mostly 20-39 mm in width, with quartzite being the most frequently used raw material, followed by phonolite and quartz (Figure 7.27C). In terms of thickness, most retouched pieces are 10-19 mm in thickness (Figure 7.37D). In terms of weight, most of retouched pieces are weighing 1-9 grams, with basalt and quartz being the most frequent raw material used (Figure 7.39).

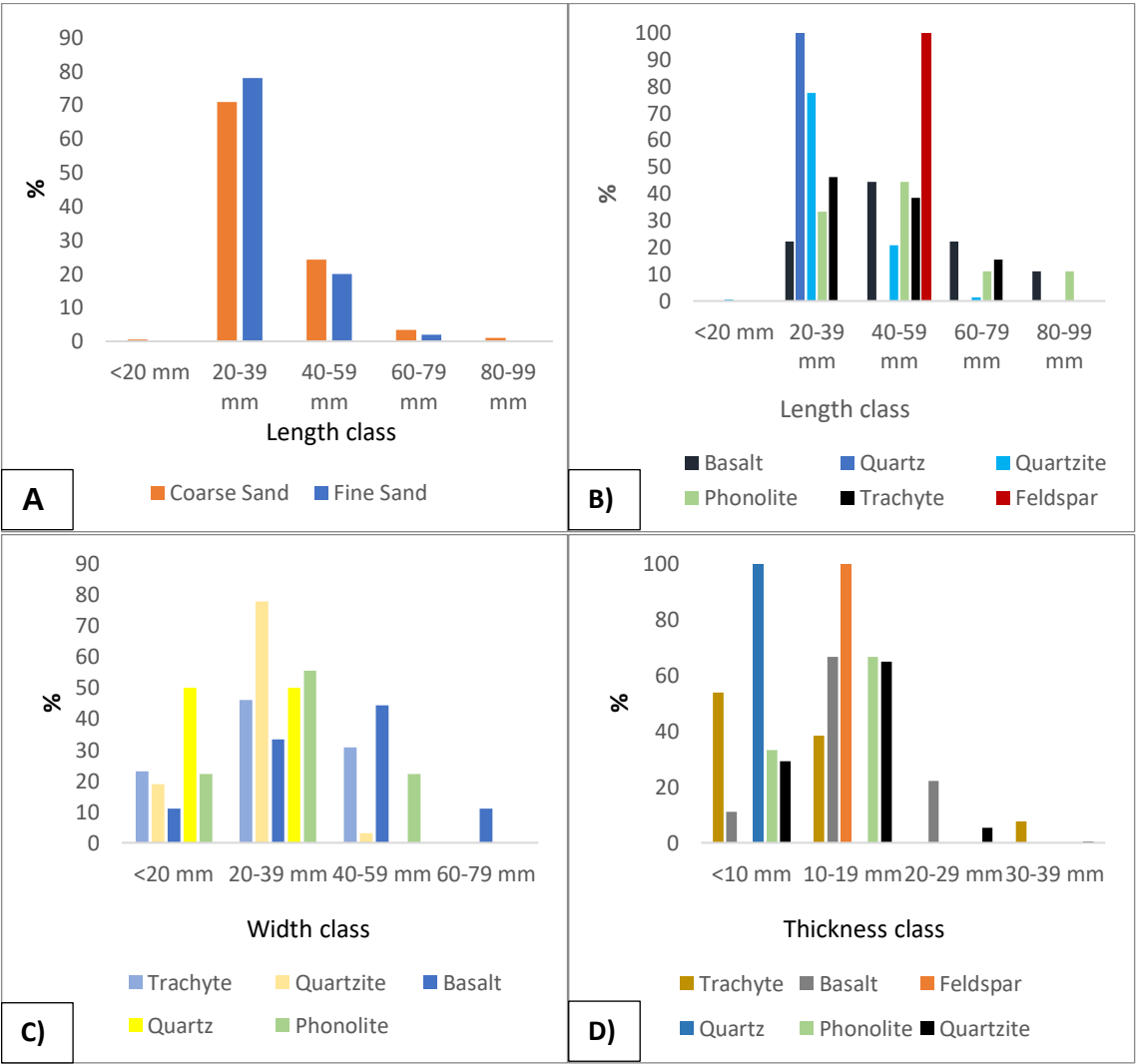
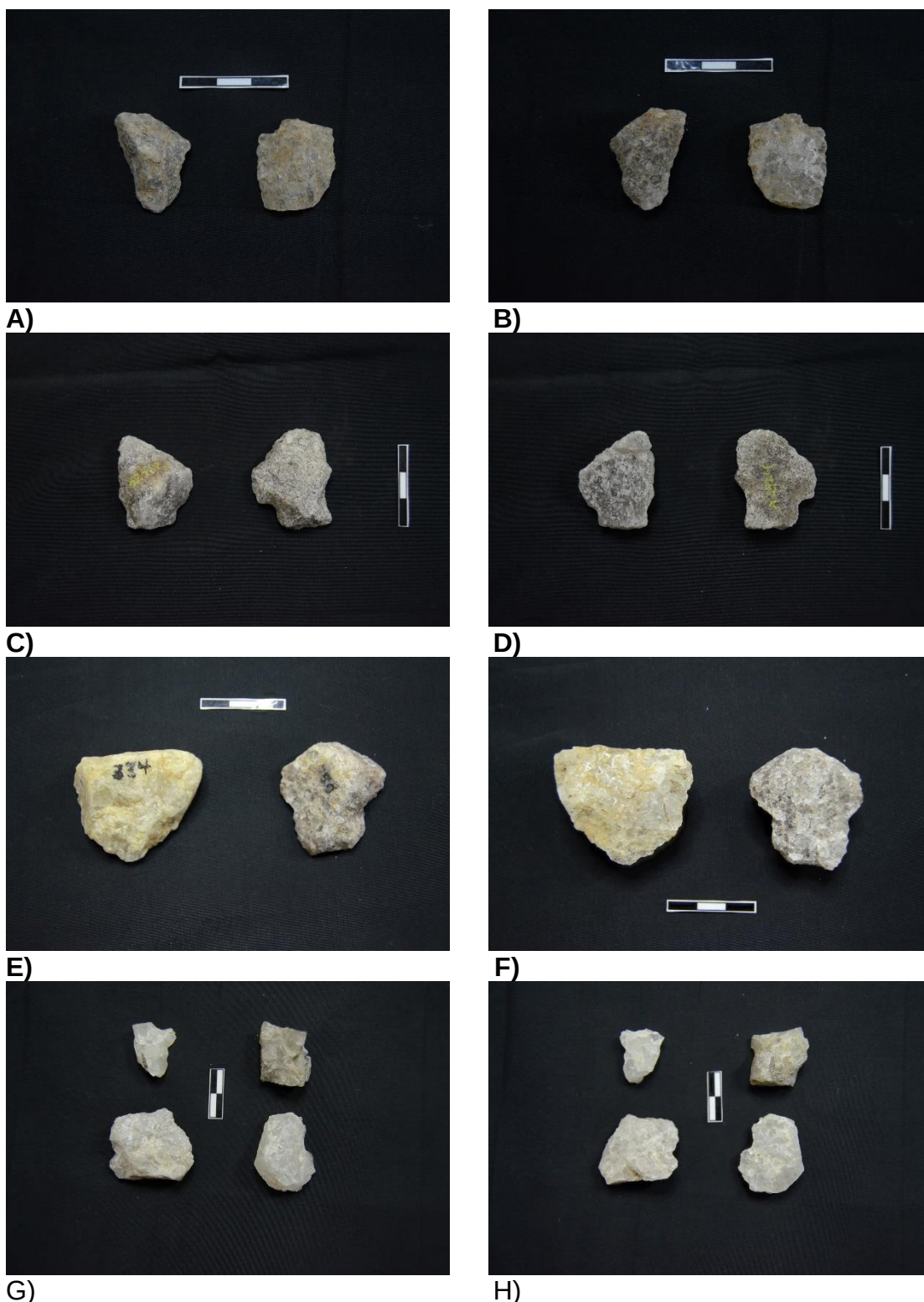


Figure 7. 37: A-B) JK2 Retouched Pieces Length Class Per Archaeological Unit (A); Per Raw Materials (B); Width class (C); Thickness class (D).

Table 7. 31: JK2 Retouched pieces attributes.

		Archaeological unit				Raw Material				Grand Total	
		JK2 Coarse Sand		JK East Fine Sand		Lava		Metamorphic		n	%
		n	%	n	%	n	%	n	%		
Length class	<20 mm	1	0	0	0	0	0	1	0	1	0.4
	20-39 mm	146	71	39	78	11	34	174	78	185	72.3
	40-59 mm	50	24	10	20	14	44	46	21	60	23.4
	60-79 mm	7	3	1	2	5	16	3	1	8	3.1
	80-99 mm	2	1	0	0	2	6	0	0	2	0.8
	Total	206	40	50	10	32	6	224	44	256	100
Cortex dorsal side	Cortex >50%	57	28	17	34	11	34	63	28	74	28.9
	Cortex <50%	69	33	13	26	17	53	65	29	82	32.0
	Cortical	2	1	2	4	0	0	4	2	4	1.6
	Non-cortical	78	38	18	36	4	13	92	41	96	37.5
	Total	206	40	50	10	32	6	224	44	256	100
Retouch Type	Denticulate	59	29	13	26	11	34	61	27	72	28.1
	Notch	141	68	35	70	21	66	155	69	176	68.8
	Point	0	0	0	0	0	0	0	0	0	0.0
	Sidescraper	6	3	2	4	0	0	8	4	8	3.1
	Total	206	40	50	10	32	6	224	44	256	100



G) H)
 Figure 7. 38: Retouched pieces from JK2 site, with dorsal side (left) and ventral side (right).

Denticulates, notches, and sidescrapers were recorded (Table 7.31 and Figure 7.40A-B), but not protoburins as originally claimed by Kleindienst (1973). The most predominant retouched types are notches ($n=176$, 68.8%), followed by denticulates

(n=72, 28.1%), which are succeeded distantly by sidescrapers (n=8, 3.1%). Points are missing (Table 7.31 and figures 7.38 and 7.39). In terms of raw material groups, most notches are predominantly metamorphic, followed closely by lava materials (Figure 7.40A; tables 7.31). Sidescrapers are only made up of metamorphic materials. Specifically, most notches are predominantly basalt, followed closely by quartzite, phonolite, and trachyte (Figure 7.40B).

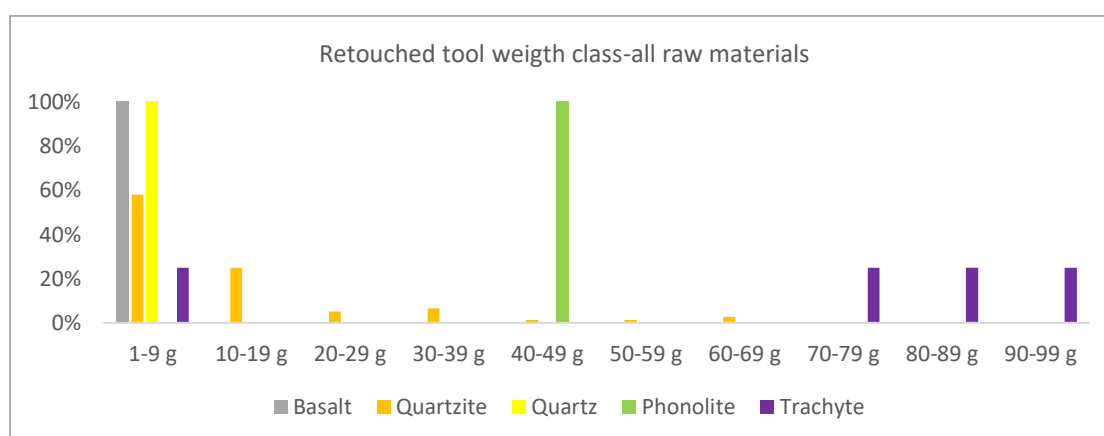


Figure 7. 39: JK2 Retouched pieces weight class per raw material.

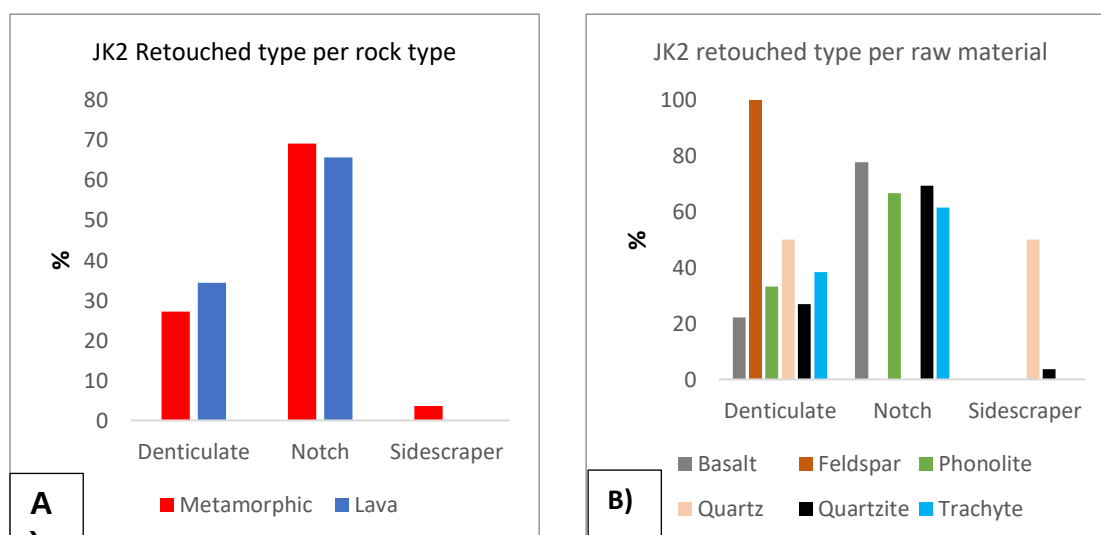


Figure 7. 40: JK2 Retouched pieces per rock type (A) and raw materials (B).

The stone tool makers at JK2 preferred to retouch small to medium-sized blanks. This is due to the fact that most retouched pieces measure between 20-39 mm and 40-59 mm in length (Figure 7.37A-B). Hence, medium sized blanks were one of hominins preferred sizes for retouching activity.

In terms of cutting edge, JK2 hominins retouched a total of 19 meters of cutting edge, with average cutting edge of 78.5 mm (Table 7.32). Some retouched pieces possessed maximum cutting edge reaching 23 mm and as small as 17 mm (Table 7.32).

Table 7. 32: JK2 Retouched Tools Cutting Edge.

Cutting Edge	min	max	mean	std. deviation	Total length (mm)
Flake	25.0	230.0	80.2	31.0	50059
Retouched tool	17.0	230.0	78.5	29.3	19967

7.7 Conclusion

The JK2 assemblage analysed here presents over 80 kg of exploited stone tools attributed to the small debitage *chaîne opératoire*, which includes small to medium-sized cores, flakes, and retouched tools. It can be suggested that most raw material types were obtained locally and transported to the site for the aim of making small flakes, and production took place on site. Exploitation of some cores seems to be discontinuous and hardly focused on removing the entire cortex. Moreover, the reduction of cores followed different strategies of knapping which resulted to different products. The flaking methods at JK2 are generally simple and involved short reduction sequence, which was principally expedient in nature.

7.8 Comparisons between Leakey and Kleindienst's assemblages

This section compares and summarises the Leakeys and Kleindienst's assemblages. As set out at the beginning of this chapter, Part I presented a detailed technological analysis of the Leakey's assemblage from JK West (Table 7.1); Likewise, Part II

presented a technological analysis of the JK2 assemblages excavated by M.R Kleindienst (Table 7.16) (Kleindienst, 1973; Leakey and Roe, 1994). This section compares the two assemblages.

The JK stone tool assemblage is numerically dominated by detached pieces (n=1048), which contribute 62% of the entire JK West and JK2 sample (Table 6.33; figure 6.40). Within detached pieces, flakes are the most predominant (n=843, 50%), succeeded by fragmented flakes (n=205, 12%) (Table 7.33).

Flaked pieces (n=636) contribute to 38% of the entire JK samples, with retouched pieces (n=358, 21%) being the most prevalent than cores (n=278, 17%) (Table 7.33). Weighing over 72 kilograms, core sample is the heaviest within the entire JK sample (Table 7.33). It is distantly succeeded by flakes, weighing 13.9 kilograms, fragmented flakes weighing 13.0 kilograms, whereas retouched pieces, weighing 5.5 kilograms are the least heavier (Table 7.33).

In absolute terms, JK2 flakes (n=641) are more abundant than JK West flake (n=202) (Table 7.33). In both sites, metamorphic materials appear to be used more frequently than lava materials. At JK West metamorphic flakes (n=194) are more abundant than lava (n=7) (Table 7.5). Likewise, in JK2 metamorphic flakes are more frequent than lava flakes.

Table 7. 33: JK West and JK2 technological categories and total weight of both sample assemblages.

		JK West				JK2				Total			
		Frequency		Weight		Frequency		Weight		Frequency		Weight	
		n	%	Sum	%	n	%	Sum	%	n	%	Sum	%
Detached	Flake	202	43%	2130	8%	641	53	11771	15	843	50	13901	13
	Flake Frag	83	17%	529	2%	122	10	12499	16	205	12	13028	12
	Total Detached	285	60%	2659	10%	763	63	24270	31	1048	62	26929	26
Flaked	Core	88	19%	21246	84%	190	16	51121	64	278	17	72367	69
	Retouched tool	102	21%	1498	6%	256	21	4000	5	358	21	5498	5
	Total Flaked	190	40%	22744	90%	446	37	55121	69	636	38	77865	74
Grand Total		475	100	25,403	100	1209	100	79,391	100	1684	100	104,794	100

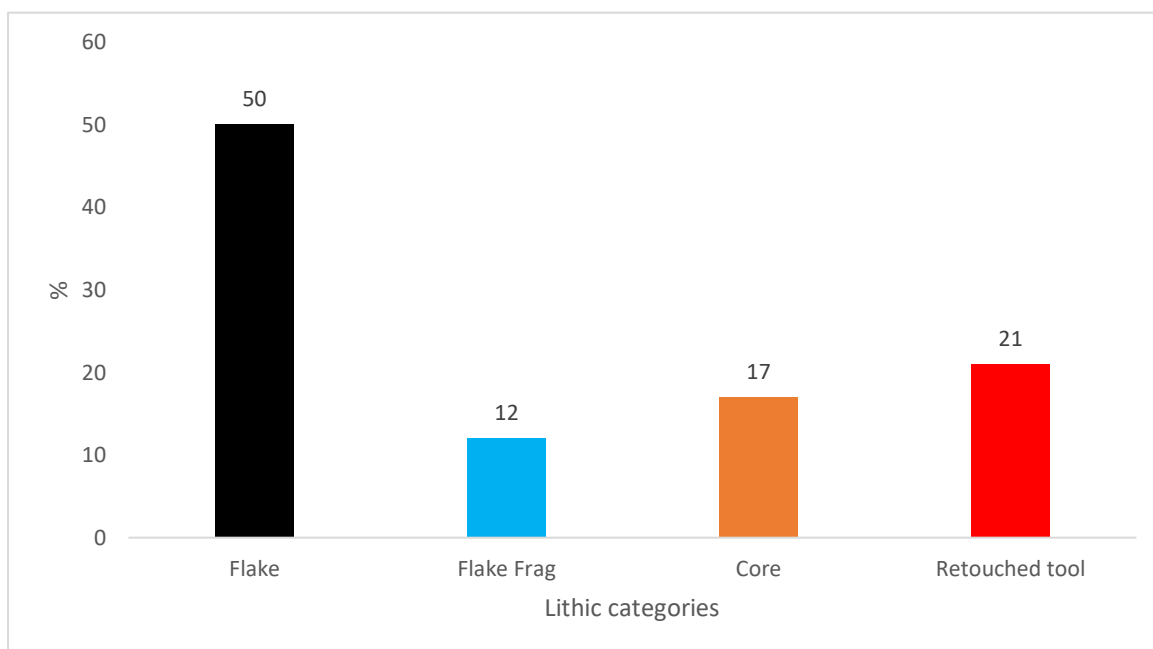


Figure 7. 41: JK site relative frequency of lithic technological categories.

Data on flake sizes shows that JK West and JK2 flakes length measure between 20-39 mm. With regards to striking platforms, most of them are unifaceted (Figure 7.11A-B and 7.29 A-B). In terms of Toth's flake types, most flakes are dominated by Toth's type V and VI, with varied frequencies per raw materials (Figure 7.11C-D and 7.29C-D).

The level of reduction intensity on flakes was determined by the level of dorsal cortex coverage and number of dorsal scars. As can be seen in figure 7.12AB most JK West flakes are non-cortical. Similar results are found in JK2 flakes (Figure 7.31A-B). Flake dorsal surface preserve few scars, with most of them preserving 1-3 scars. Figure 7.12 C-D shows that most flakes preserve 1-3 scars. Similarly, JK2 flakes preserve 1-3 scars per flake.

Cores at JK West and JK2 differ in terms of sample size selected, with JK West having fewer cores (n=88) than JK2 cores (n=190). There is similarity in cores sizes between

the two assemblages, with JK West cores having average length of 66.4 mm and 241 grams, whereas JK2 cores average length of 70.8 mm and 269 grams (Table 7.7 and 7.20), respectively.

In terms of reduction intensity, most cores preserve between 1-3 scars and 4-6 scars. As can be seen in figure 7.18C-D and 7.34 E-F most cores preserve 1-3 and 4-6 scars, suggesting that hominins at both sites exercised some kind of expedient strategy as cores were not fully exploited.

In terms of exploitation strategies, most cores at both JK West and JK2 were multifacially exploited (Tables 7.12 and 7.29). As can be seen in Table 7.12, most multifacial cores are metamorphic (n=30, 43.5%) than lava cores (n=4, 21.1%). In addition, table 7.29 shows that most multifacial cores are metamorphic (n=49, 39.5%) than lava cores (n=8, 12.1%). Overall, the most predominant raw material group at both JK West and JK2 was metamorphic, particularly quartzite and quartz. This suggests that hominins had access to primary quartzite source and were preferentially selecting quartzite blocks and cobbles for flake production.

Retouched pieces (n=358, 21%) are the second most prevalent technological category within the entire JK sample (Table 7.33; figure 7.40). Most retouched pieces measure between 20-39 mm in length (Tables 7.14 and 7.31). At JK West, an average length of retouch piece is 36 mm, slightly longer than that of JK2 33.8 mm (Tables 7.7 and 7.21). In terms of cortex coverage, most JK West retouched pieces are non-cortical; similar pattern was observed on JK2 retouched pieces, where most of them are non-cortical (Tables 7.14 and 7.31). In terms of retouched pieces type, both sites are dominated by notches (Tables 7.14 and 7.31), respectively.

In general, the JK West and JK2 assemblages share technological traits ranging from raw material procurement to flake characteristics, core exploitation strategies, and retouch technology. This diachronic pattern shows that two separate sites were occupied by a hominin group(s) that shared technology and knowledge of their local environment.

The investigation of the archaeological sample from the JK site contributes to our understanding of lithic technology in Bed III and serves as a framework for the subsequent chapter, which focuses on establishing an understanding of hominin technical skills at WK site in Bed IV.

Chapter 8: WK Site

8.1 Introduction

8.2 WK archaeological setting at Olduvai

The Wayland's Korongo (WK) site is situated on the south side of the Olduvai gorge, roughly two kilometres downstream of the intersection of the Main and Side Gorges (Figure 8.1), and it was excavated by M.D. Leakey in 1969 and 1970 (Leakey and Roe, 1994). According to Hay (1994, p. 10), Bed IV has an estimated age of between 0.6 and 0.8 million years. Nonetheless, new evidence from the Olduvai Gorge Coring Project (OGCP) places Bed III at 1.14 ± 0.05 and Bed IV at 0.93 ± 0.08 (Deino et al., 2021). Thus, WK site dates around 0.93 ± 0.08 (Deino et al., 2021). At WK, Leakey discovered artefacts in channel fills at three different levels. These are the lower, intermediate, and upper channels (Leakey and Roe, 1994). The results of the Leakey excavations at WK are shown below.

8.3 WK excavations by M.D. Leakey

WK excavations began in 1969, following the discovery of several handaxes and cleavers eroding on the surface. Following this observation, a 1-metre-wide trial trench was dug through the Bed III/IV junction at the lower end of Bed IV. During the excavation, Leakey discovered three artefact levels in the conglomerate (Leakey and Roe, 1994).

- a) At the Beds III-IV boundary, the lowest level was a pebble conglomerate 50 centimeters thick.
- b) The Intermediate Channel was a 30-centimeter-deep channel located 2.7 centimeters above the Beds III-IV junction.

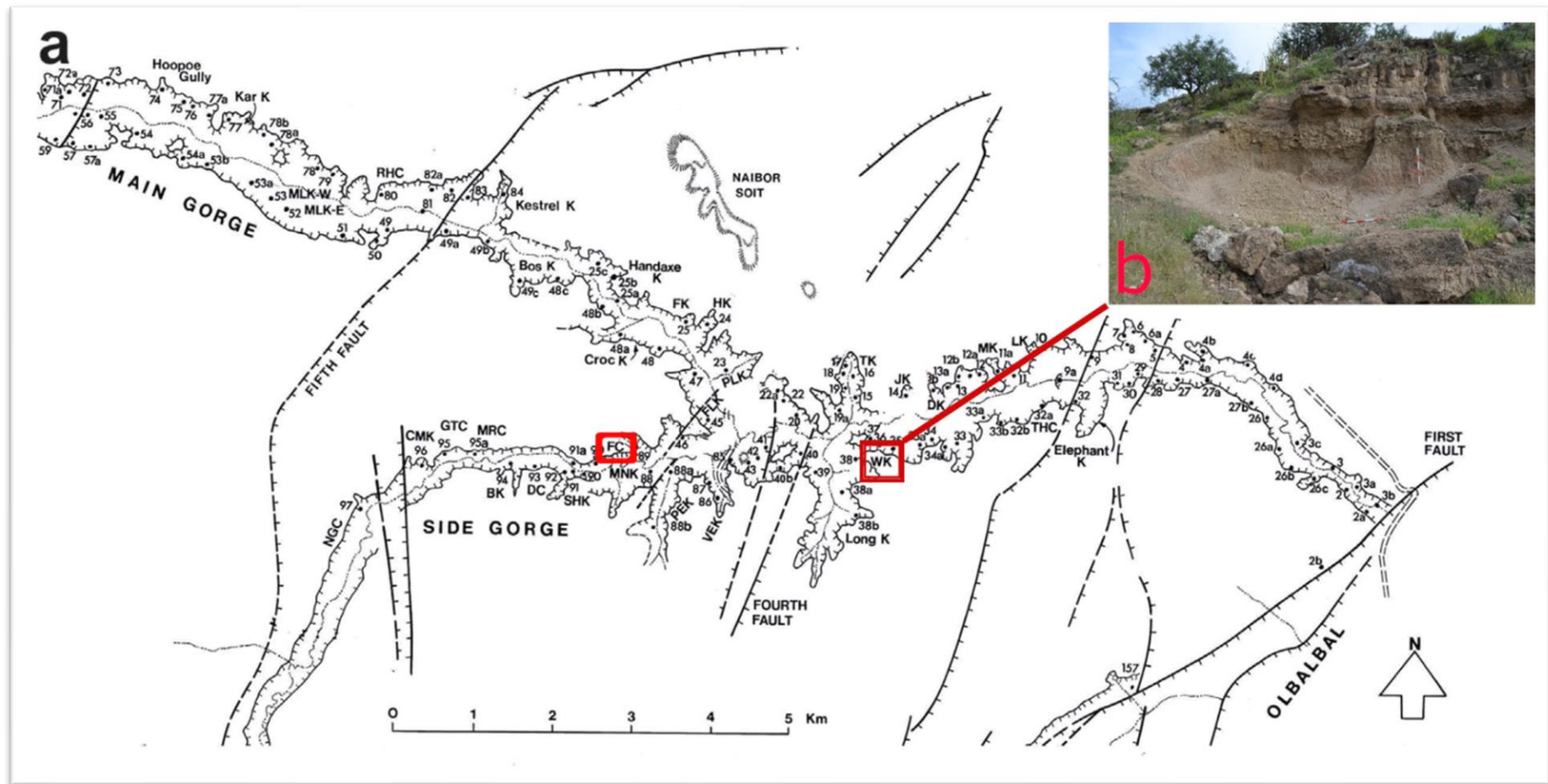


Figure 8. 1: Olduvai Map showing different localities a) and a view of the WK site (Leakey's trench) b) (Map adapted and redesigned from Hay 1976 (Hay, 1976). Photo taken by the author.

- c) The Upper Channel, which was about 1.5 meters higher, had an uneven surface with depressions and a 1-meter-deep channel in the southwest corner of the excavated area. Artifacts and fossils were concentrated in the depressions, particularly in the deep channel. A few more discoveries were made on the upper parts of the surface, where O.H 28's hip bone and femur were recovered (Leahey and Roe, 1994).

Following the trial trench, several trenches were dug nearby, revealing approximately 150.5 square meters of the main channel. The sample for this chapter was obtained from the main channel, initially published by M.D. Leahey (Leahey and Roe, 1994).

8.4 Technological analysis of the WK Main Channel

8.4.1 General features of the WK lithic assemblage

Leahey and Roe (1994) classified 429 tools, 429 utilised pieces, and 10047 debitage. For the first time since Leahey and Roe's (1994) study, this study sampled artefacts based on an new technological classification resolutions as outlined by de la Torre and Mora 2005 and de la Torre 2011 (de la Torre, 2011). In this study, a sample of flakes (n=103), flake fragments (n=10), cores (n=41), and retouched tools (n=46) from the WK Main Channel was sampled for technological analysis of the entire assemblage (n=10905) (table 8.1). The sample was chosen with the goal of sampling the most relevant lithic technological categories, and all major raw materials are represented in the sample (Tables 8.2 and 8.3).

Table 8. 1: Artefact excavated by M.D. Leakey at WK Site (Leakey and Roe, 1994).

Site	Assemblage	Category	n	%	Technology	Bed
WK	10905 artefacts	Tools	429	3.9	Acheulean	IV
		Utilised material	429	3.9		
		Debitage	10047	92.2		
		Total	10905	100.0		
	Tools	Bifaces	192	44.7		
		Choppers	35	8.1		
		Polyhedrons	7	1.6		
		Discoids	17	4.0		
		Spheroid/subspheroid	25	5.8		
		Scrapers, heavy-duty	25	5.8		
		Scrapers, light-duty	57	13.3		
		Burins	3	0.7		
		Laterally trimmed flakes	19	4.4		
		Outils ecaillés	33	7.7		
		Punches	14	3.3		
		Sundry tools (picks)	2	0.5		
		Total	429	99.9		
	Utilised material	Pitted anvils/hammerstones	107	24.9		
		Anvils	7	1.6		
		Hammerstones	9	2.1		
		Cobbles and blocks	58	13.5		
		Light-duty flakes	248	57.9		
		Total	429	100.0		
	Debitage	Whole flakes	405	4.0		
		Broken flakes	4357	43.4		
		Core fragments	5281	52.6		
		Cores	4	0.0		
		Total	10047	100.0		

Detached pieces (n=113, 57%) dominated the entire sample analysed, followed by flaked pieces (n=87, 43%) (Table 8.2). Despite their small number, flaked pieces contribute significantly more weight (8.7 kg, 88%) than detached pieces (1.2 kg, 12%). (Table 8.3; figure 8.2).

In terms of raw material composition, quartzite dominates (n=146, 73%), followed by basalt (n=26, 13%) and trachyte (n=18, 9%), with phonolite being the least represented (n=10, 5%) (Table 8.4).

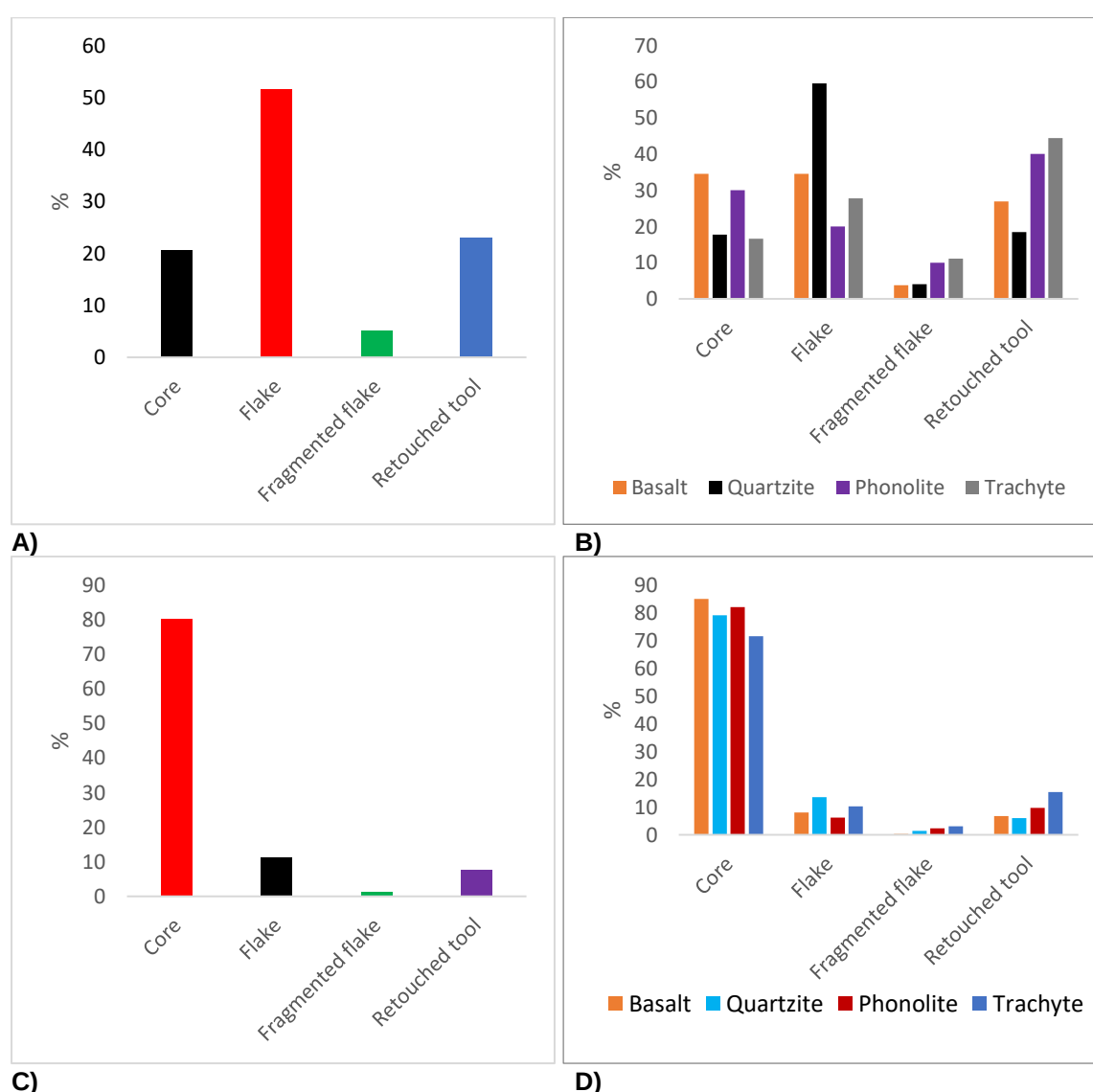


Figure 8. 2: A-B). Frequency of artefacts of the lithic categories from the WK Main Channel (A) and breakdown per raw materials (B). **C-D)** Relative frequency of weight of WK's lithic technological categories (C), and weight per raw material (D).

Table 8. 2: Table showing relative frequency and weight of artefacts analysed from the WK site Main Channel.

WK Site Main Channel					
		Frequency		Weight	
		n	%	grams	%
Detached	Flake	103	52	1099	11
	Flake Fragment	10	5	129	1
	Total Detached	113	57	1228	12
Flaked	Core	41	21	7912	80
	Retouched tool	46	23	740	7
	Total Flaked	87	43	8652	88
Grand Total		200	100	9880	100

Table 8. 3: Total weight of all lithic categories at WK site Main Channel.

Technological Category		Lava (g)	Metamorphic (g)	Total (g)
Detached	Flake	380	719	1099
	Flake Fragment	55	74	129
Flaked	Core	3740	4172	7912
	Retouched tool	423	317	740
Total		4598	5282	9880

The cores account for 21% (n=41) of the total sample size (Table 8.2, Figure 8.2A). With a total weight of 7.9 kilograms, cores are heavier than other lithic categories (Table 8.3, figure 8.2C). The weight of quartzite (4.1 kg) in the core category is greater than that of basalt (3.7 kg). Basalt and phonolite cores, on the other hand, are more common than quartzite cores (Figure 8.2D).

Flakes constitute 52% of the total sample examined and are the most prevalent in both the detached pieces and the entire sample (Table 8.2). The flake sample weighs slightly more than 1 kilogram, while flake fragments weigh 129 grams (Tables 8.2 and 8.3). Furthermore, retouched pieces account for 23% of the total sample examined, weighing 740 grams (Tables 8.2 and 8.3). Lavas are heavier (423 g) than metamorphic (317 g) (Table 8.3).

8.4.2 Taphonomic aspects of WK assemblage

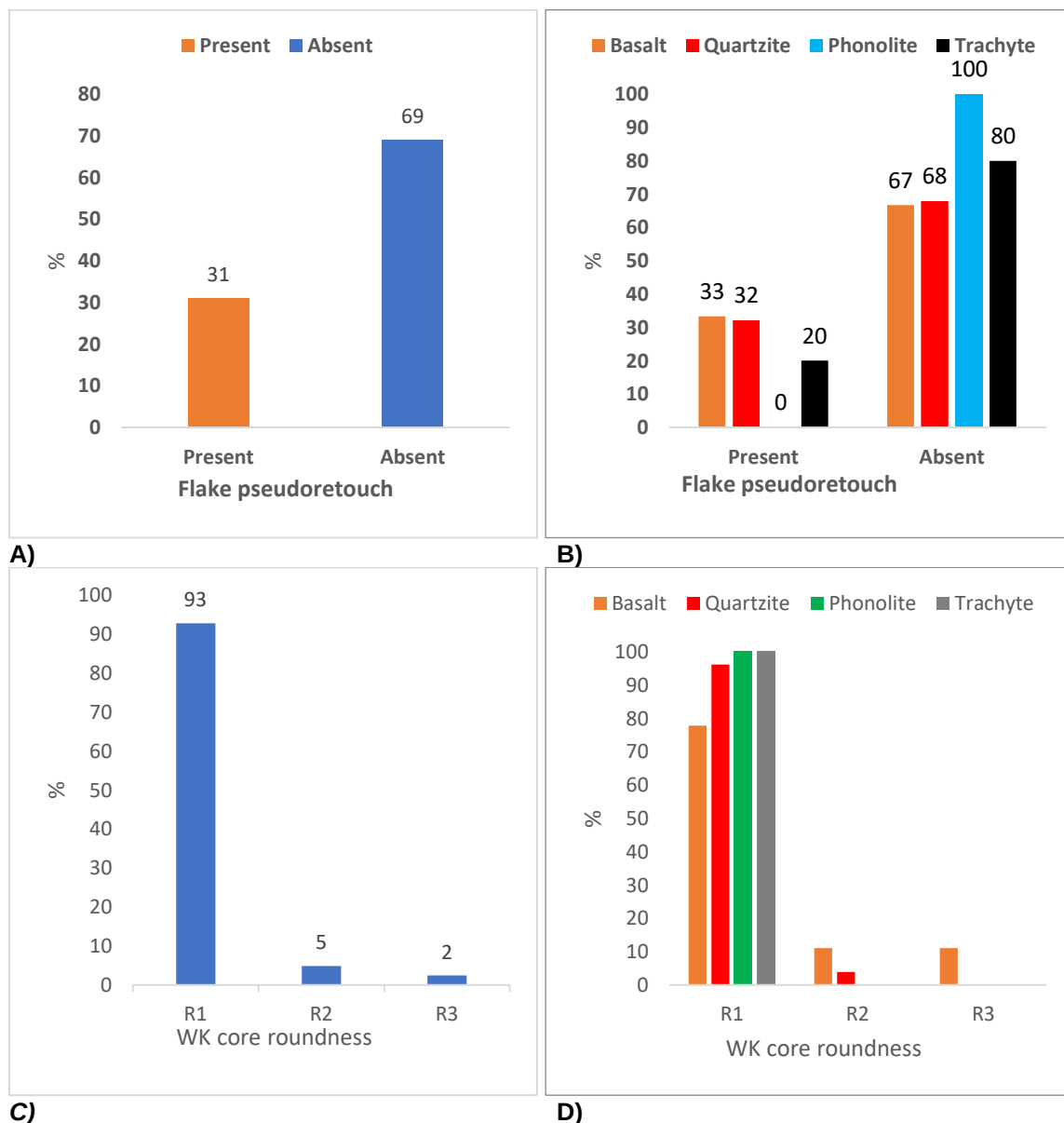
By examining the taphonomic characteristics of the stone tools analysed, we can gain a better understanding of the assemblage's post-depositional alterations. At WK, the majority of the flake sample (n=71, 69%) lacks pseudoretouch on the edges, while the remaining flake sample has pseudoretouch (n=32, 31%) (Figure 8.2A).

In terms of raw materials, the majority of basalt flakes do not have pseudoretouch (n=6, 67%), while half of them do (n=3, 33%). The majority of quartzite flakes (n=59, 68%) lack pseudoretouch, while only about half have it (n=28, 32%). Phonolite flakes (n=2, 100%) lack pseudoretouch on the edges. Furthermore, trachyte flakes show that the majority do not have pseudoretouch (n=4, 80%), while the minority do (n=1, 20%) (Figure 8.3B).

Table 8. 4: WK Main Channel technological categories per individualised raw materials.

	Lava								Metamorphic				Grand Total	
	Basalt		Trachyte		Phonolite		Total-Lava		Quartzite		Total-Metamorphic			
	n	g	n	g	n	g	n	g	n	g	n	g		
Flake	9	233	5	112	2	35	16	380	87	719	87	719	103	1099
Flake Frag	1	9	2	33	1	13	4	55	6	74	6	74	10	129
Total Detached	10	242	7	145	3	48	20	435	93	793	93	793	113	1228
Core	9	2489	3	783	3	468	15	3740	26	4172	26	4172	41	7912
Retouched tool	7	200	8	168	4	55	19	423	27	317	27	317	46	740
Total Flaked	16	2689	11	951	7	523	34	4163	53	4489	53	4489	87	8652
Grand Total	26	2931	18	1096	10	571	54	4598	146	5282	146	5282	200	9880
	Basalt		Trachyte		Phonolite		Total-Lava		Quartzite		Total-Metamorphic		Grand Total	
	Frequency %	Weight %	Frequency %	Weight %	Frequency %	Weight %	Frequency %	Weight %	Frequency %	Weight %	Frequency %	Weight %	Frequency %	Weight %
Flake	34.6	7.9	27.8	10.2	20.0	6.1	29.6	8.3	59.6	13.6	59.6	13.6	51.5	11.1
Flake Frag	3.8	0.3	11.1	3.0	10.0	2.3	7.4	1.2	4.1	1.4	4.1	1.4	5.0	1.3
Total Detached	38.5	8.3	38.9	13.2	30.0	8.4	37.0	9.5	63.7	15.0	63.7	15.0	56.5	12.4
Core	34.6	84.9	16.7	71.4	30.0	82.0	27.8	81.3	17.8	79.0	17.8	79.0	20.5	80.1
Retouched tool	26.9	6.8	44.4	15.3	40.0	9.6	35.2	9.2	18.5	6.0	18.5	6.0	23.0	7.5
Total Flaked	61.5	91.7	61.1	86.8	70.0	91.6	63.0	90.5	36.3	85.0	36.3	85.0	43.5	87.6
Grand Total	13	29.7	9	11.1	5	5.8	27	46.5	73	53.5	73	53.5	100	100

Roundness was also examined. It was observed that all complete flakes analyzed have fresh edges (n=103, 100%), which is consistent with the presence of the vast majority of complete flakes lacking pseudoretouch (n=71, 69%) (Figure 8.3A). This evidence corroborates with the roundness results of the core sample, whereas the level of rounding observed indicates that the majority of cores (n=38, 93%) exhibit fresh edges (Figure 8.3C-D).



C) **D)**
 Figure 8. 3: A-C) WK flake pseudoretouch all complete flake (A) and per raw materials (B).C-D) WK core roundness all cores (C) and per raw material (D). R=rounding.

Furthermore, there are some cores with slight rounding (n=2, 5%) and moderate rounding (n=1, 2%) (Figure 8.3C). This interpretation does not guarantee that the WK assemblage was altered after it was deposited on site, and thus the material may not be in its original primary context. The information provided here can aid in understanding the various processes that the WK artifacts have gone through from deposition to recovery.

All sampled cores, whole flakes, and retouched tools were subjected to a thorough technological analysis. In addition, generic data such as metric measurements and the weight of broken flakes were gathered to provide an overview of the raw materials transported from the source to the site.

8.4.3 Raw Materials at WK

The WK site assemblage is made up of raw materials sourced from various sources in the Olduvai area (Table 8.3). Within these raw material groups, four raw material types were identified: basalt, quartzite, phonolite, and trachyte (Table 8.4). According to raw materials analysis, metamorphic rocks are the most frequently used rocks at the WK site, accounting for 53.5 % of the weight of the sample analysed (Table 8.4). Lava, on the other hand, contributes 46.5 %, slightly less than half of the total sample studied (Table 8.4).

8.5 Flakes

Flakes (n=104, 52%) are the most prevalent artefacts within the detached pieces, followed by flake fragments (n=10, 5%) (Table 8.2). In terms of weight, flakes weigh slightly over 1 kilogram, making them the second heaviest within the WK sample analysed (Table 8.2 and 8.3). In absolute terms, metamorphic flakes (n=87) are more dominant than lava flakes (n=16) (Table 8.4). The relative frequencies of flakes per

raw materials show that quartzite flakes (60%) are the most frequent, followed by basalt (35%), trachyte (28%), and phonolite (20%) (Figure 8.2B).

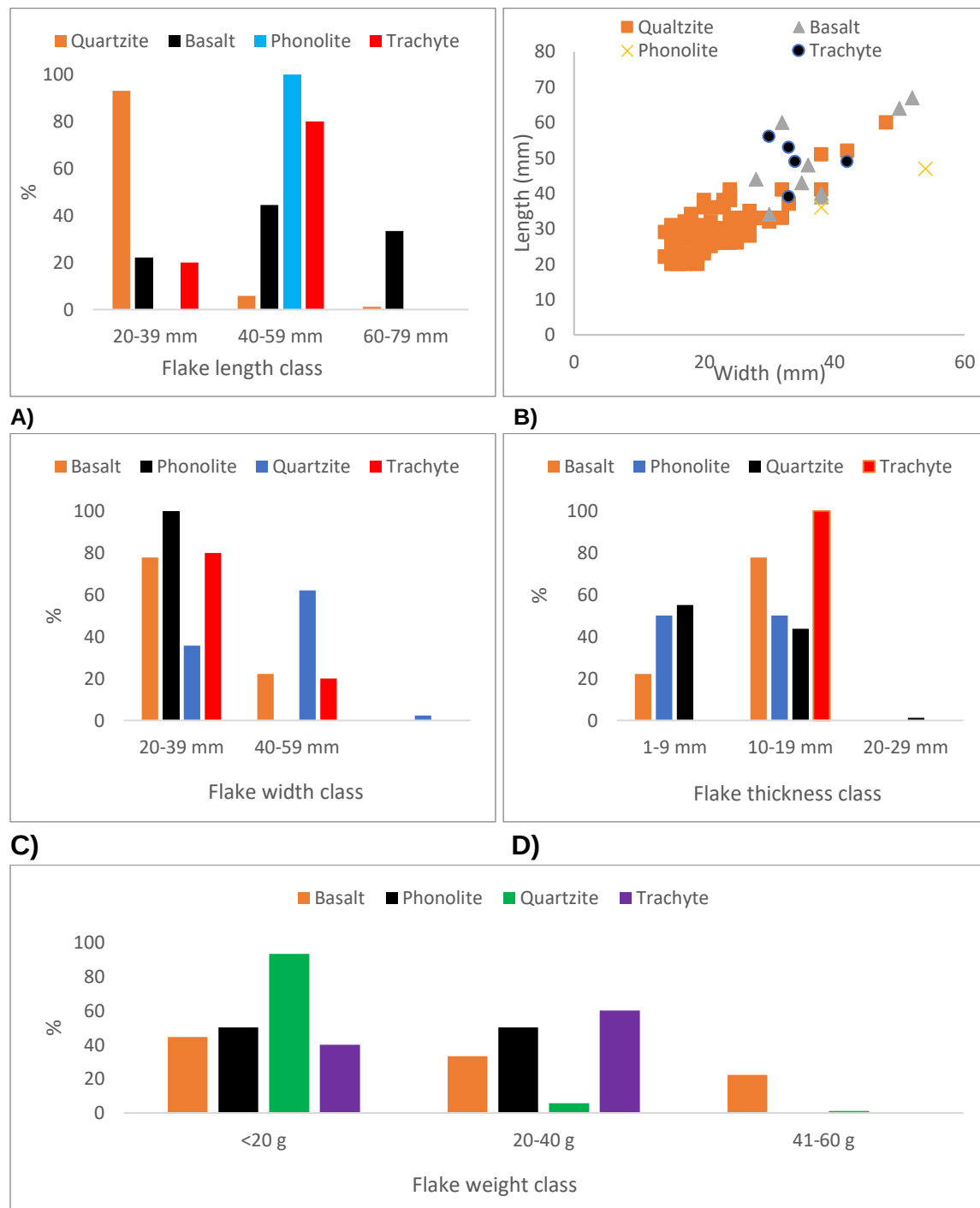
As shown in figure 8.4A, most flakes range in length from 40 to 59 mm, with an average length of 33.1 mm and a width of 24.7 mm (also see figure 8.5 and table 8.5). In terms of raw materials, metamorphic flakes (84%) outnumber lava flakes (16%). In addition, figure 8.4B shows that most flakes have similar length and width, with quartzite being more frequent than phonolite, trachyte, and basalt. Basalt flakes appear to be longer and wider (Figure 8.4B). Nevertheless, a substantial difference was shown with the flakes measuring up to 67 mm long and some as small as 20 mm (Table 8.5).

Figures 8.4C and D show that most flakes have a width of 20-39 mm and a thickness of 10-19 mm. As shown in figure 8.4D, flakes with thicknesses ranging from 10 to 19 mm are the most common, followed by flakes with thicknesses ranging from 1 to 9 mm. Trachyte flakes are the most pervasive raw material in the 10-19 mm thickness range, followed by basalt, phonolite, and quartzite. In summary, lava rocks appear to produce thicker flakes than metamorphic rocks, probably due to fine-grained nature.

Metamorphic (0.7 kg) dominates the detached pieces' raw material group, followed by lava flakes (0.3 kg), metamorphic flake fragments (74 g), and lava flake fragments (55 g) (Table 8.3). Furthermore, figure 8.4E depicts the weight classes, with the majority of flakes weighing less than 20 grams, with quartzite being the most prevalent, followed by phonolite, basalt, and trachyte.

Further evidence on flakes weight indicates that there are flakes weighing between 20 and 40 grams, with trachyte being the most common, followed by phonolite, basalt, and quartzite being the least represented (Figure 8.4E). This is interesting because as the weight increases, the frequency of quartzite use decreases. Figure 8.4E also

shows that basalt rocks were used to manufacture flakes weighing between 41 and 60 grams. There is no evidence of metamorphic rocks represented in this class.



E) Figure 8. 4: A-B) Flake length classes in the entire sample of WK Main Channel per raw material (A) and length-width scatterplots (B). C-D) Flake width classes per all raw materials (C) and thickness classes per raw materials (D); flake weight classes per all raw materials (E).

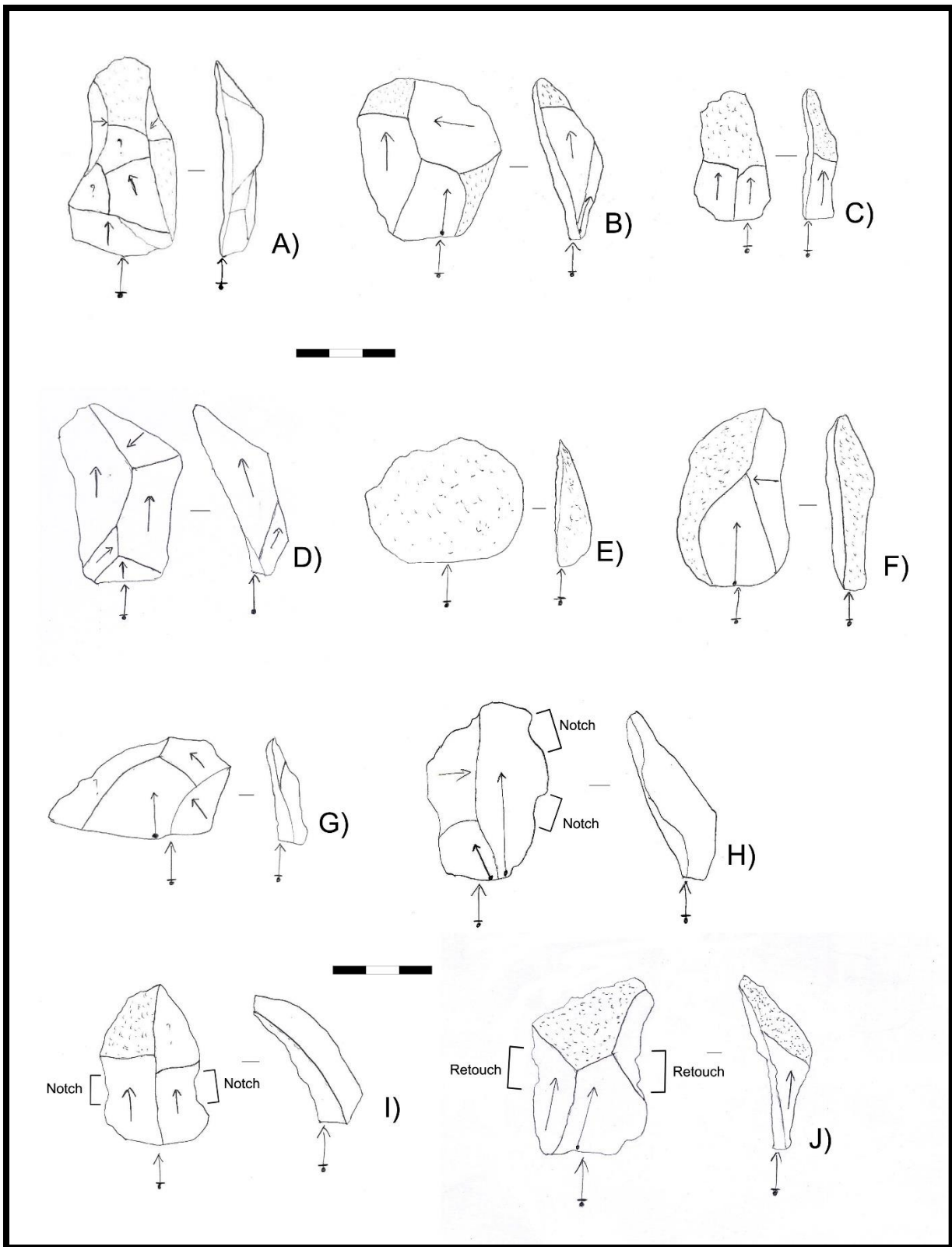


Figure 8. 5: WK flakes and retouched pieces. A-G) Whole flakes ranging of different sizes. H-J) Various retouched pieces indicating notch (H-I) and denticulate (J). Drawings by the author.

Table 8. 5: WK Main Channel Min, Max, Mean, St. deviation.

			Minimum	Maximum	Mean	Std. deviation
Wholeflake	Total (n = 103)	Length	20	67	33.1	10.1
		Width	14	52	24.7	8.1
		Thickness	4	20	10.2	3.3
		Weight	2	58	10.7	10.7
	Lava (n = 16)	Length	34	67	49.1	9.4
		Width	28	52	36.6	6.7
		Thickness	7	17	12.8	3.2
		Weight	10	55	23.8	13.2
	Metamorphic (n = 87)	Length	20	60	30.1	7
		Width	14	48	22.6	6.3
		Thickness	4	20	9.7	3.1
		Weight	2	58	8.3	8.3
Flake fragment	Total (n = 10)	Length	28	49	39.6	5.5
		Width	18	33	24.3	4.3
		Thickness	6	16	11.4	3.3
		Weight	3	24	12.9	6
	Lava (n = 4)	Length	36	49	41.5	5.6
		Width	24	26	25.3	1
		Thickness	8	14	11	2.9
		Weight	9	24	13.8	7.1
	Metamorphic (n = 6)	Length	28	45	38.3	5.6
		Width	18	33	23.7	5.7
		Thickness	6	16	11.7	3.7
		Weight	3	19	12.3	5.8
Core	Total (n = 41)	Length	47	88	64.1	12.1
		Width	39	78	55.5	9.8
		Thickness	21	61	41.4	10.5
		Weight	53	494	193	110
	Lava (n = 15)	Length	50	88	70.8	11.6
		Width	44	78	60.9	10
		Thickness	21	61	43.7	11.4
		Weight	66	494	249.3	128.2
	Metamorphic (n = 26)	Length	47	85	60.2	10.8
		Width	39	71	52.4	8.3
		Thickness	23	60	40.1	9.9
		Weight	53	319	160.5	84.6
Retouched tool	Total (n = 46)	Length	21	77	39.6	11
		Width	17	47	29.8	7.7
		Thickness	3	26	12.8	4.6
		Weight	2	57	16.1	11.1
	Lava (n = 19)	Length	35	77	48.3	9
		Width	27	47	35.3	6
		Thickness	3	20	12.8	3.9
		Weight	10	57	22.3	10.3
	Metamorphic (n = 27)	Length	21	48	33.5	7.8
		Width	17	44	25.9	6.4
		Thickness	7	26	12.9	5.2
		Weight	2	42	11.7	9.4

In terms of striking platform, the majority of flakes (n=74, 72%) are unifaceted, followed by non-faceted (n=23, 22%), bifaceted (n=4, 4%), and multifaceted (n=2, 2%) (Figure 8.6A, table 8.6). Figure 8.6B and table 8.6 show that unifaceted flakes are overrepresented in both metamorphic (n=63, 72%) and lava (n=11, 69%). On platforms, there are a few flakes that have two or more removals (Figure 8.6B, table 8.6).

Regarding cortex, Toth's flake types V and VI are overrepresented in figure 8.6C-D compared to the other types (I, II, III, and IV) (Also, see table 8.6). Overrepresentation of Toth's flake types V and VI indicates high reduction intensity at WK. Additionally, comparing Toth's flake types according to raw materials helps us understand variation in each type, with type V having an overrepresentation of trachyte, followed by basalt and quartzite. There is no evidence of phonolite. In Toth's type VI, phonolite is overrepresented, with quartzite, basalt, and trachyte being the least represented (Figure 8.6D).

Dorsal cortex was also examined separately (Figure 8.7). Figure 8.7A shows that there is a high frequency of non-cortical flakes, followed by < 50% cortex and >50% cortex, with 100% cortex being the least represented. Figure 8.7B shows a significant variation, with quartzite being the most prevalent within non-cortical, followed by phonolite and basalt, and trachyte being the least represented. Furthermore, variations can be seen in < 50% of the cortex, with basalt being the most abundant, followed by trachyte and quartzite (Figure 8.7B). Overall, the presence of variations in the cortex coverage of the flake sample indicates that different reduction strategies were used at WK when utilising cores from different rock types. This is consistent with the presence of variable percentages of Toth's flake types per raw material at the site (Figure 8.6D).

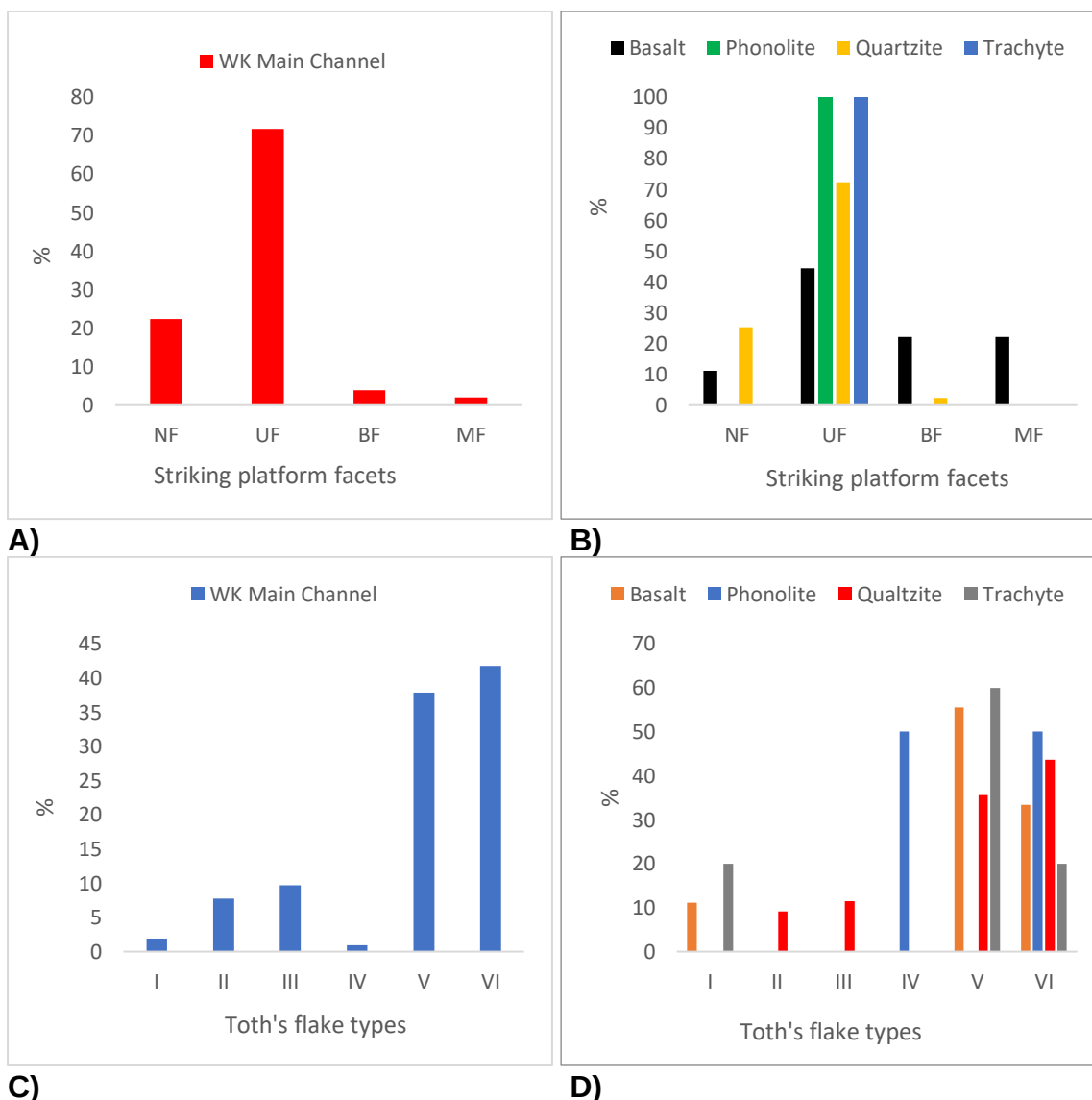


Figure 8. 6: Attributes of flakes in the WK Main Channel sample (left) and raw materials. A-B) Percentage of flake's striking platform types in the Main Channel (A) and per raw materials (B). C-D) Percentages of Toth's flake types in Main Channel (C) and percentages of frequency of Toth's flake types per raw materials (D).

Dorsal scars on flakes were also examined. Figure 8.7C shows that a 1-3 scar pattern predominates within the flake sample, followed by a 4-6 scar pattern. In terms of raw materials, quartzite dominates the 1-3 scar pattern, followed by trachyte and basalt (Figure 8.7D). This significant difference suggests that quartzite flakes were used more than trachyte and basalt.

Table 8. 6: WK Main Channel flake technological attributes.

		Raw Material				Grand Total	
		Lava		Metamorphic		n	%
		n	%	n	%		
Length Classes	20-39 mm	3	19	81	93	84	82
	40-59 mm	10	63	5	6	15	15
	60-79 mm	3	19	1	1	4	4
	Total	16	16	87	84	103	100
Striking platform preparation	Non-faceted	1	6	22	25	23	22
	Unifaceted	11	69	63	72	74	72
	Bifaceted	2	13	2	2	4	4
	Multifaceted	2	13	0	0	2	2
	Total	16	16	87	84	103	100
Cortex dorsal side	Cortical	3	19	0	0	3	3
	Cortex >50%	2	13	18	21	20	19
	Cortex <50%	6	38	19	22	25	24
	Non-cortical	5	31	50	57	55	53
	Total	16	16	87	84	103	100
Toth's flake types	I	2	13	0	0	2	2
	II	0	0	8	9	8	8
	III	0	0	10	11	10	10
	IV	1	6	0	0	1	1
	V	8	50	31	36	39	38
	VI	5	31	38	44	43	42
	Total	16	16	87	84	103	100

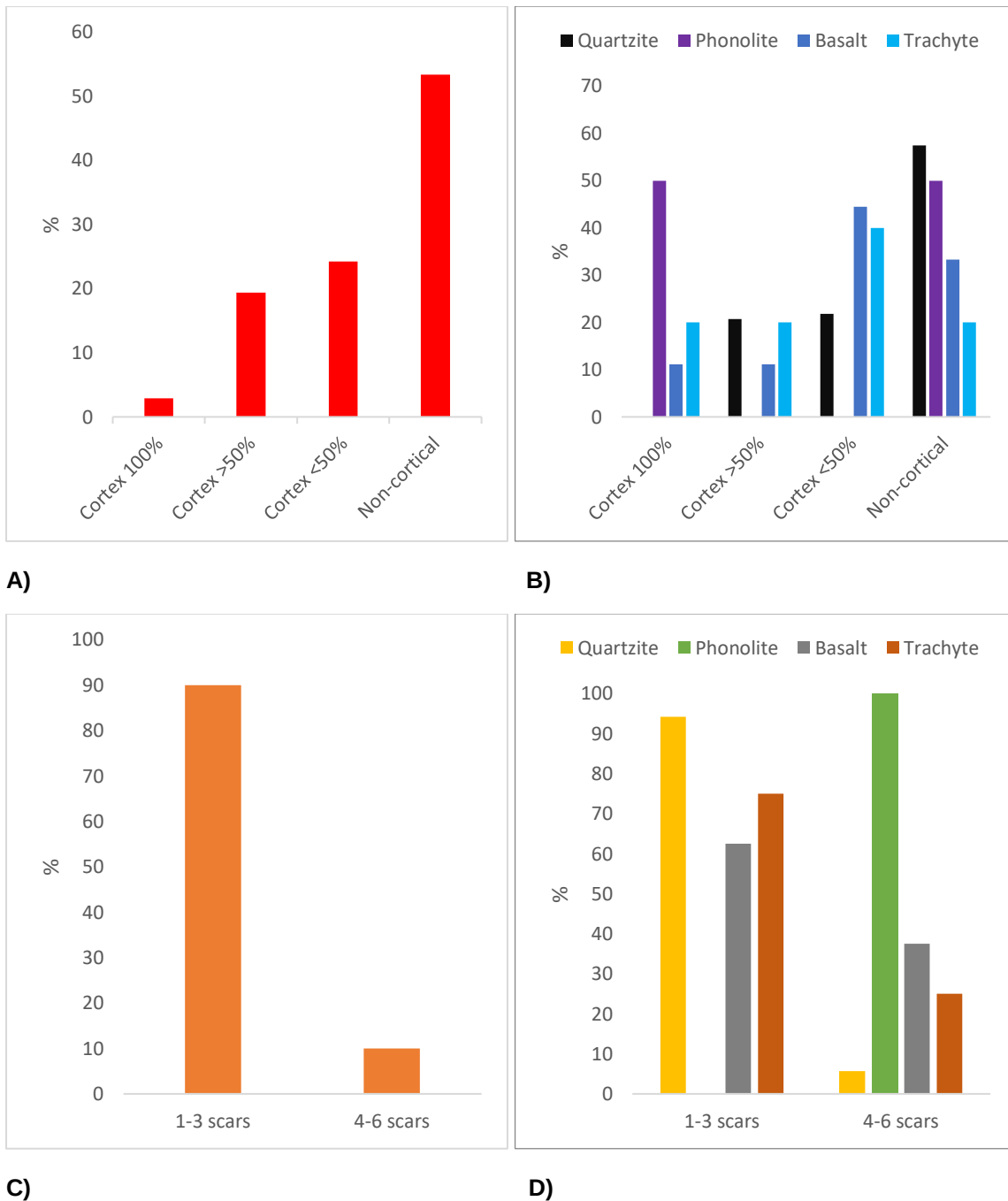


Figure 8. 7: A-B) WK Main Channel flake dorsal scar of the analysed sample (A) and raw materials (B). C-D) Flake dorsal cortex coverage of the analysed sample (C) and raw materials (D).

Furthermore, a 4-6 scar pattern shows phonolite dominating, followed by basalt, trachyte, and quartzite being the least represented (Figure 8.7D). This is interesting because the use of quartzite decreases as the number of flakes per core increases. It's most likely due to a lack of potential angles for detaching more flakes. Most

quartzite cores may have yielded 1-3 scars, and hominins may have jumped onto flaking lava cores to obtain more flakes.

As shown in table 8.7, the flakes sample contains over 7 meters of cutting edge in total, with an average of 75mm and a standard deviation of 23.3mm. Furthermore, there is a significant variation in cutting edge within the flake sample, with some flakes having a maximum cutting edge of 160 mm and others having a minimum cutting edge as short as 35 mm (Table 8.7). This is intriguing because it helps us understand that at WK, hominins produced flakes of varying sizes with varying cutting edges, each of which could perform a different function at the site.

Table 8. 7: WK Main Channel cutting edge for flakes and retouched tools.

Cutting Edge	min	max	mean	std. deviation	Total length (mm)
Flake (n = 103)	35	160	75	23.3	7719
Retouched tool (n = 46)	52	172	90.7	23.9	4172

8.6 Cores

This study sampled a collection of cores (n=41), totalling over 7.9 kilograms of flaked raw materials (Table 8.2 and 8.3). Metamorphic cores (n=26), particularly quartzite, are the most abundant in the core sample, followed by lava cores (n=15) distantly (Table 8.4). Quartzite has the highest weight contribution (4.2kg), followed by basalt (2.5kg), trachyte (783g), and phonolite (468g) (Table 8.4).

There is significant variation among cores, with an average length of 88 mm and mass of 494g (Table 8.5). It should be noted that there are also small-sized cores, with some specimens measuring 47 mm in length and 21 mm in width (see table 8.5 and figure

8.8A). Basalt and quartzite cores are longer (80-99mm) than phonolite and trachyte cores (Figure 8.8B).

Variations in core size are evident based on the raw material utilised at the site (Figure 8.8B). As shown in table 8.5, lava cores are larger on average than metamorphic cores and far heavier on average than metamorphic cores. The majority of metamorphic cores are 40-59 mm long, while a few lava cores are 80-99 mm long (Table 8.8, figure 8.8B). This is also reflected in core specimen weight, with lava cores being heavier on average than metamorphic cores (Table 8.5). As a result, larger cores were primarily formed by lava over metamorphic cores. Core width was also measured (Figure 8.8C-D). All cores are between 40 and 100 mm wide and between 40 and 100 mm long, as shown in figure 8.8C. Basalt cores are wider and longer in terms of raw materials, followed by trachyte, quartzite, and phonolite.

Cortex was also observed on core specimens (Figure 8.9A-B, table 8.8). Table 8.8 shows that only 5% of cores are completely non-cortical, with 66% having <50% cortex coverage and 29% having more than >50% cortex coverage. Cortex coverage varies in different raw materials, as shown in table 8.8 and figure 8.9B, with core preserving <50% being the most abundant within the core sample, with trachyte being the most prevalent (see figure 8.9B).

The second most abundant are cores that retain more than 50% of their original composition, with basalt being the most abundant, followed distantly by phonolite and quartzite (Figure 8.9B). Furthermore, figure 8.9B shows that the majority of phonolite cores are non-cortical, with quartzite trailing behind. This pattern demonstrates a significant variation in the cortex of core specimens per raw materials, which is important in explaining the level of reduction intensity at the site for each rock type.

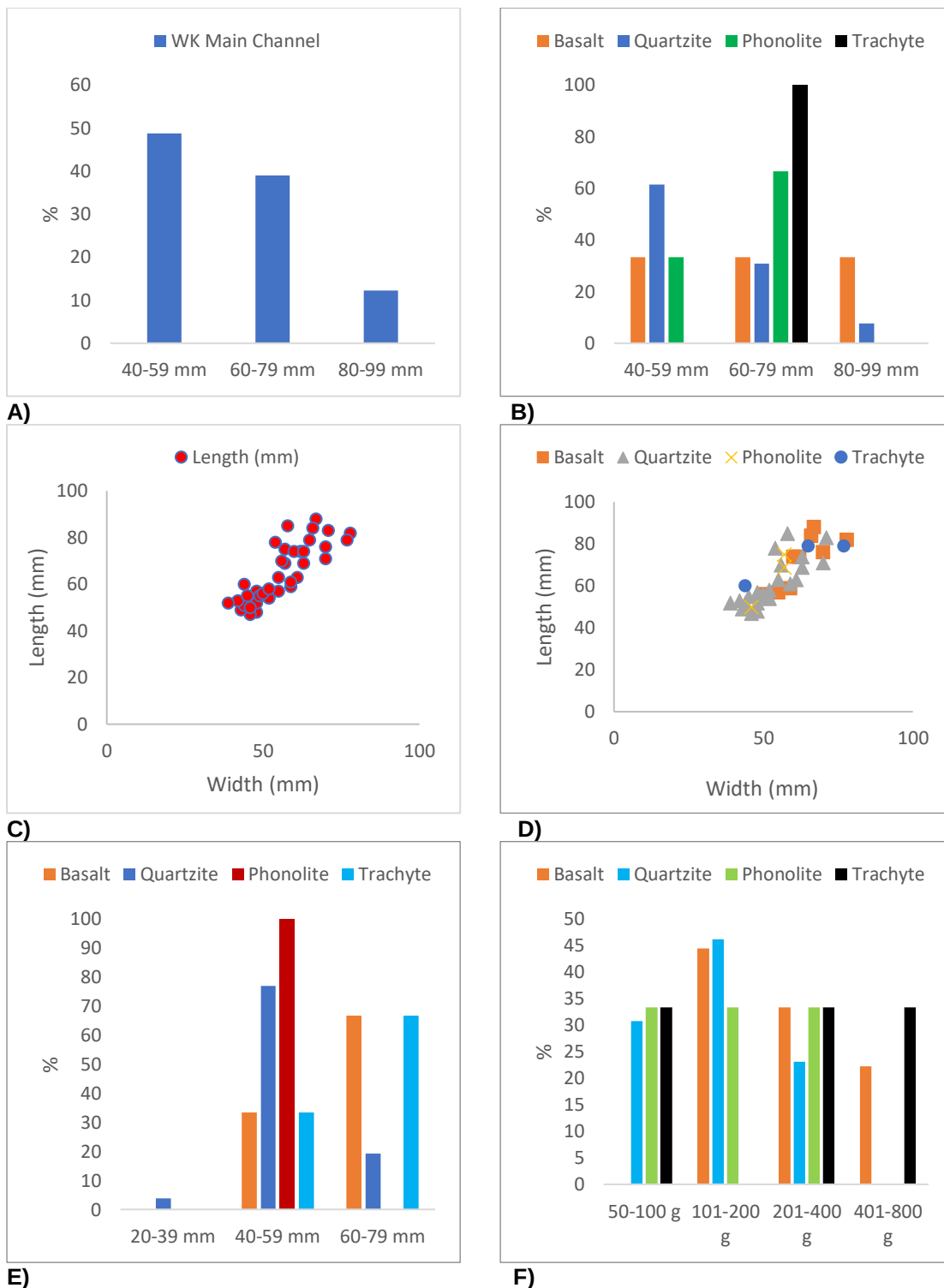


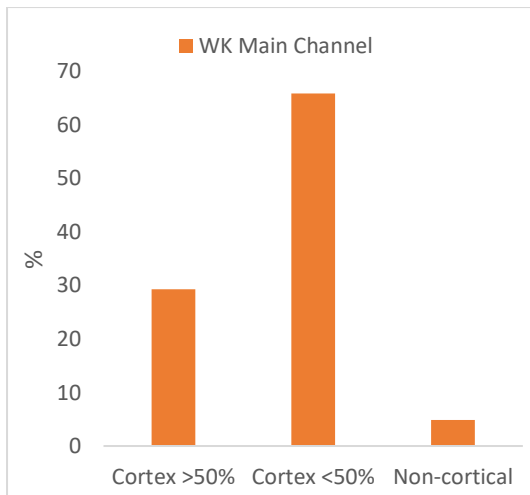
Figure 8. 8: A-B) WK Main Channel length classes of cores (A) and per raw material (B). C-D) Core length-width scatterplot (C) and per raw material (D). E-F) Core width classes per raw materials (E) and core weight classes per raw materials (F).

The number of flake scars preserved on WK cores sample can be used to determine the intensity of core reduction. Table 8.8 shows that 54% of cores preserve 1-3 scars, 39% preserve 4-6 scars, and only 7% preserve 7-9 scars. Figure 8.9A-B depicts the

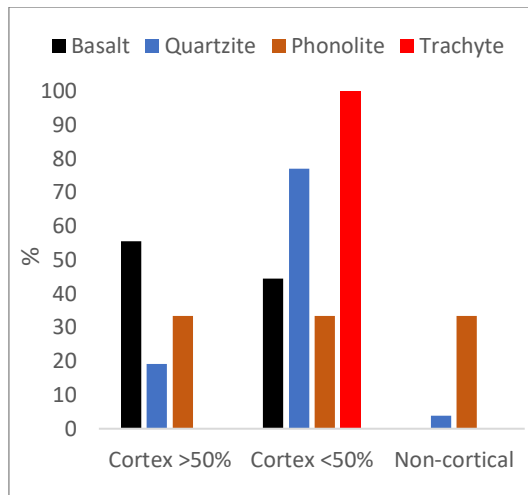
sample's reduction intensity pattern. Figure 8.9C-D depicts the intensity of reduction in raw materials, with phonolite dominating the 1-3 scars patterning, followed by basalt, quartzite, and trachyte. Moreover, figure 8.9D shows that quartzite cores dominate the 4-6 scars class and trachyte has 7-9 scars.

There is evidence of core blank type dependency at WK (Figure 8.9E-F, table 8.8). Figures 8.9E-F depict a clear dependency of cobble blanks, with basalt and trachyte being similar and phonolite and quartzite trailing behind. All block blanks are linked to metamorphic rocks (Figure 8.9F, table 8.8). According to McHenry and de la Torre (2018), the sources of each raw material determined the majority of core blanks, with metamorphic associated with hillslopes and lavas associated with river streams. The raw material availability from the sources may have influenced the core blank variations at WK. For example, there is a higher frequency of lava cobble blanks at WK than quartzite blocks; this could be due to the availability of lava cobbles closer to the site than quartzite block blanks. As a result, there are a lot of lava cobbles at WK.

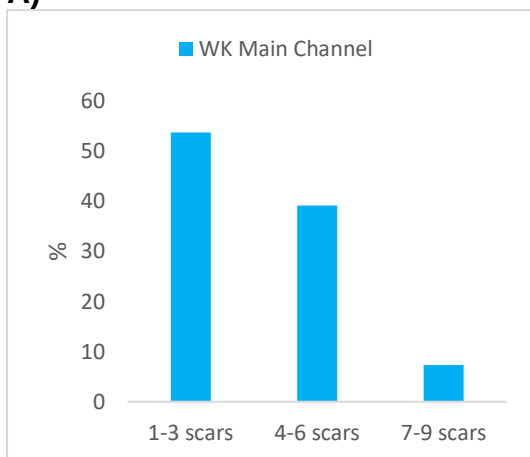
Accidents involving core knapping were also investigated (Table 8.9). Step scars are the most common knapping accidents in WK cores; a minimum of 36 cores (88% of the core sample) show step scars, which are mostly seen in metamorphic cores (n=25, 96%). Step scars are more abundant in metamorphic rocks (n=25) than in lava rocks (n=11) (Table 8.9).



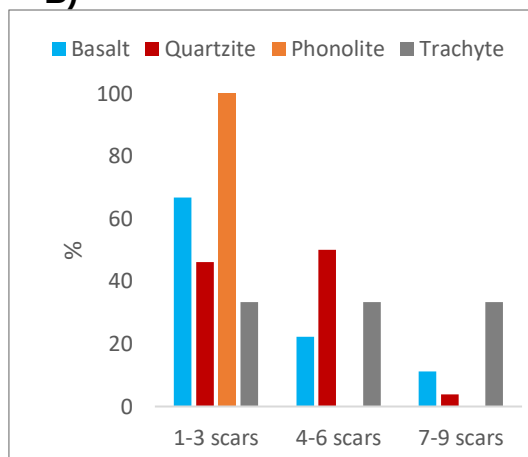
A)



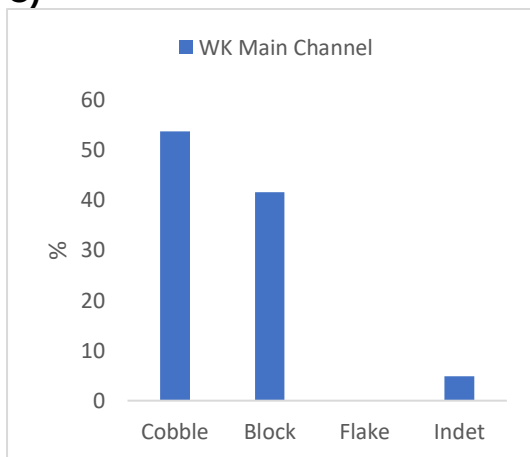
B)



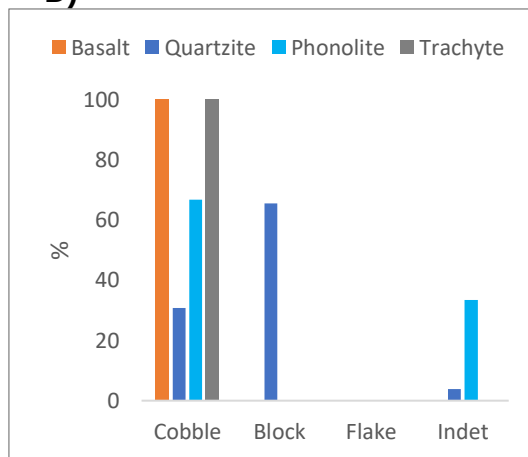
C)



D)



E)



F)

Figure 8. 9: Technological attributes of cores in the entire sample (left) and per raw materials A-B) Cortex coverage; C-D) Number of flake scars in cores; E-F) Core blanks.

Table 8. 8: Attributes of the core sample at WK Main Channel.

		Raw Material				Grand Total	
		Lava		Metamorphic		n	%
		n	%	n	%		
Length class	40-59 mm	4	27	16	62	20	49
	60-79 mm	8	53	8	31	16	39
	80-99 mm	3	20	2	8	5	12
	Total	15	100	26	100	41	100
Cortex	Cortex >50%	7	47	5	19	12	29
	Cortex <50%	7	47	20	77	27	66
	Non-cortical	1	7	1	4	2	5
	Total	15	100	26	100	41	100
Blank	Cobble	14	93	8	31	22	54
	Block	0	0	17	65	17	41
	Indet	1	7	1	4	2	5
	Total	15	100	26	100	41	100
Number of scars	1-3 scars	10	67	12	46	22	54
	4-6 scars	3	20	13	50	16	39
	7-9 scars	2	13	1	4	3	7
	Total	15	100	26	100	41	100

Table 8. 9: WK Main Channel core knapping accidents.

Core Knapping accident	Raw Material				Grand Total	
	Lava		Metamorphic		n	%
	n	%	n	%		
Step scar	11	73	25	96	36	88
N/A	4	27	1	4	5	12
Total	15	37	26	63	41	100

8.6.1 Core flaking systems

Three exploitation systems are described at WK (Table 8.10, figure 8.10). These exploitation strategies include unifacial, bifacial, and multifacial (Table 8.10). According to table 8.10 and figure 8.10, the most common flaking strategy in the WK core sample is multifacial (51%), followed by bifacial (39%), and unifacial (10%). The chi-square test results show that the raw material groups represented in each core exploitation type differ significantly ($\chi^2(4) = 12.909, p.003$) (Appendix 8.1). The exploitation strategy for bifacial reduction does not differ significantly depending on the raw materials (Figure 8.10). Nonetheless, there is a significant difference within the unifacial reduction, with lava being more popular than metamorphic (Table 8.10, figure 8.10).

Furthermore, there is significant variation per raw materials in discoid cores, with lava being more common than metamorphic. A similar pattern can be seen in test core, where lava predominates over metamorphic. Nonetheless, a different result in multifacial reduction has been observed, with metamorphic being more prevalent than lava; similar results can be observed in polyhedron and Unifacial simple partial reductions, respectively (Appendix 8.1).

Table 8. 10: WK Main Channel core knapping systems per raw material groups.

	Raw material				Total	
	Lava		Metamorphic		n	%
	n	%	n	%		
Unifacial	2	13	2	8	4	10
Bifacial	6	40	10	38	16	39
Multifacial	7	47	14	54	21	51
Total	15	37	26	63	41	100

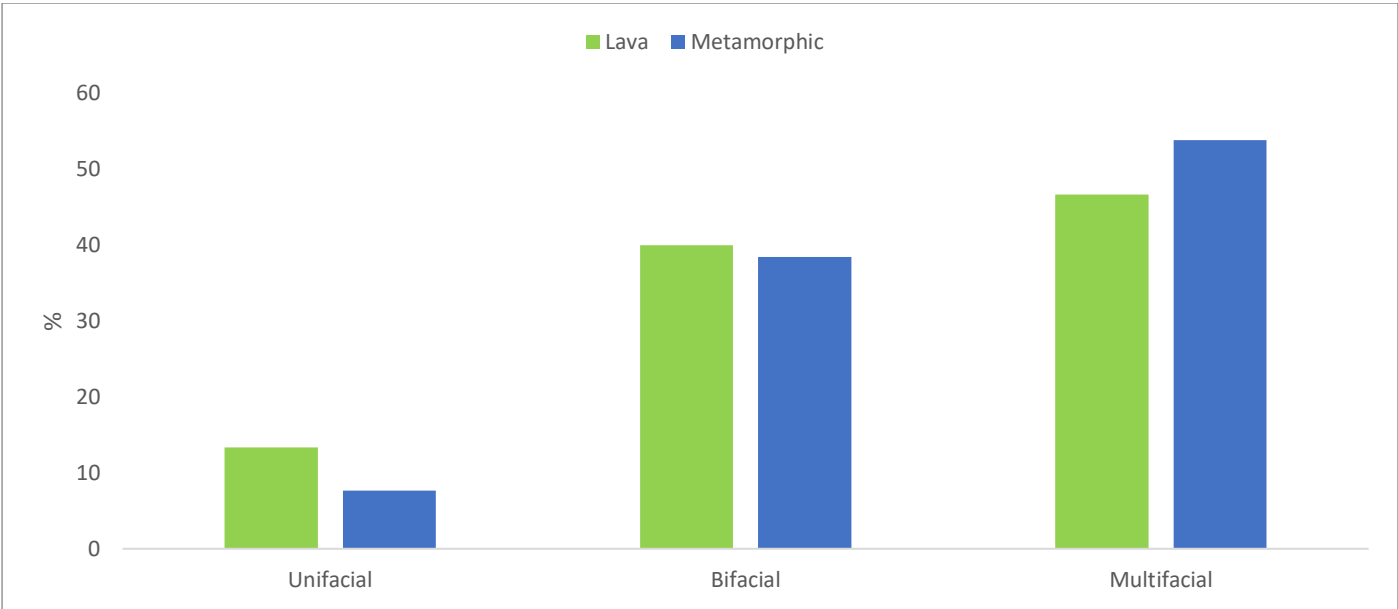


Figure 8. 10: WK Main Channel core exploitation systems per raw material groups.

8.6.1.1 Test cores

Test cores (n=3, 7%) are the most abundant in lava materials (Table 8.11, figure 8.11B). A flake is detached from a test core by removing one or two randomly distributed removals. WK test core evidence suggests that hominins tested some of the core blanks (such as river cobbles and tabular blocks) before using them to make stone tools. Most test core blanks were cobbles (Table 8.12). According to the available sample, the raw materials of the test cores appear to be dominated by lava (n=2), followed by metamorphic materials (n=1) (Table 8.11).

8.6.1.2 Unifacial cores

The unifacial cores (n=4, 10%) show only one knapping scheme (Table 8.11). Table 8.11 shows that the unifacial exploitation system is **USP**, which stands for unifacial simple partial exploitation (n=1, 4%) of metamorphic raw materials. In this strategy, the knapper uses a simple angle available between the knapping surface and the flaking surface to detach a flake while only partially exploiting the core. As a result, there is unifacial simple partial exploitation.

8.6.1.3 Discoid cores

Discoid cores (n=16, 39%) are predominated by metamorphic materials (n=10) followed by lava materials (n=6) (Table 8.11; figure 8.12B, C, E and F). Most discoid cores have core sizes ranging from 40 to 59 mm, followed by 60 to 79 mm and 80 to 99 mm (Figure 8.11C). Furthermore, the majority of discoid have 4-6 flake scars, followed by 1-3 scars and 7-9 scars (Figure 8.11D). This indicates that at the WK site, hominins used medium-sized cores to produce flakes, and the level of reduction intensity was low to medium, with some cores exhibiting high reduction intensity.

Table 8. 11: Flaking scheme in the WK Main Channel core assemblage by raw materials.

	Raw material				Total	
	Lava		Metamorphic		n	%
	n	%	n	%		
TC	2	13	1	4	3	7
USP	0	0	1	4	1	2
DISC	6	40	10	38	16	39
MLT	7	47	13	50	20	49
POL	0	0	1	4	1	2
Total	15	37	26	63	41	100

8.6.1.4 Multifacial cores

Multifacial cores (n=20, 49%) are found in both lava and metamorphic materials (Table 8.10-11, figure 8.10 and 8.13). Figure 8.10A shows that multifacial reduction appears to be the most prevalent reduction strategy across the entire WK core sample, with metamorphic materials being more abundant than lava (Figure 8.11B). The chi-square test reveals a statistically significant difference ($X^2(4) = 12.909, p.003$) (Appendix 8.1). Furthermore, most multifacial cores have lengths ranging from 40 to 59 mm, followed by 60 to 79 mm and 80 to 99 mm, respectively (Figure 8.11E). Within the multifacial reduction strategy, there is a predominance of 1-3 scars, followed by 4-6 scars (Figure 8.11F). Overall, the multifacial core exploitation strategy is characterised by large to medium cores with low to medium reduction intensity.

8.6.1.5 Polyhedron cores

There is only one polyhedral core (2%) made in metamorphic material (Table 8.11). It measures 60-79 mm in length and has 1-3 flake scars. It has a <50% cortex coverage, indicating a low to medium reduction intensity. The flaking surface of the specimen has two stepped scars, which may explain why the knapper abandoned the core.

Table 8. 12: WK Main Channel core blanks.

Core blank	Block		Cobble		Indeterminate		Total	
	n	%	n	%	n	%	n	%
TC	1	6	2	9	0	0	3	7
USP	0	0	1	5	0	0	1	2
DISC	8	47	7	32	1	50	16	39
MLT	8	47	11	50	1	50	20	49
POL	0	0	1	5	0	0	1	2
Total	17	41	22	54	2	5	41	100

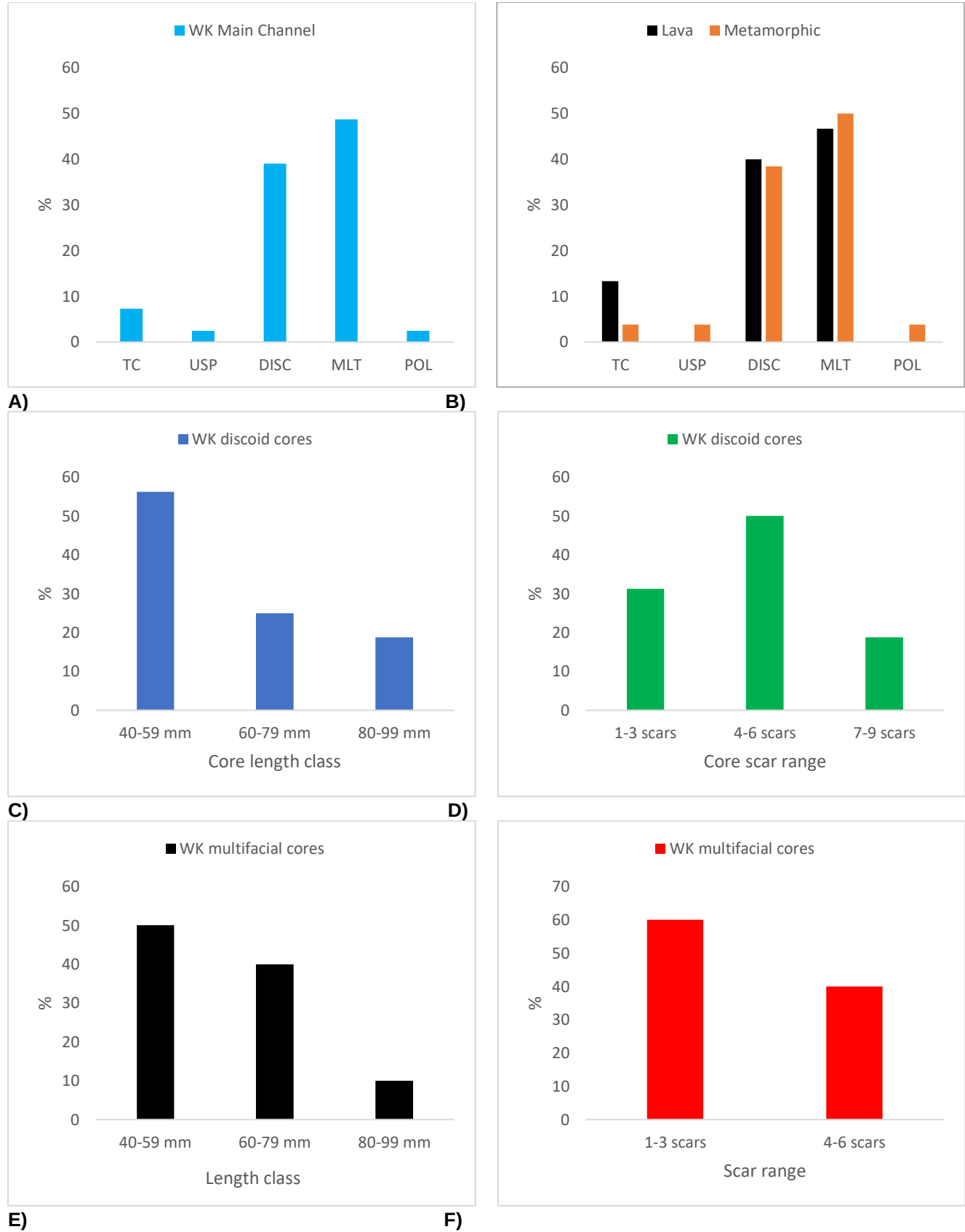


Figure 8. 11: WK core exploitation system at main channel (A) and raw materials (B) Discoids length class (D); Discoids scar range (D); multifacial core length (E); and multifacial scar range (F).

8.7 Retouched Pieces

Retouched pieces (n=46) account for 21% of the sampled assemblage at the WK site and total 740 grams in weight (Table 8.2 and 8.3, figure 8.2A). Figure 8.2B shows that trachyte dominates retouched tools, followed by phonolite, basalt, and quartzite. Most retouched tools are 20-39 mm long, with an average of 39.6 mm, as shown in figures 8.14A and B and table 8.13. (also see table 8.5, figure 8.15).

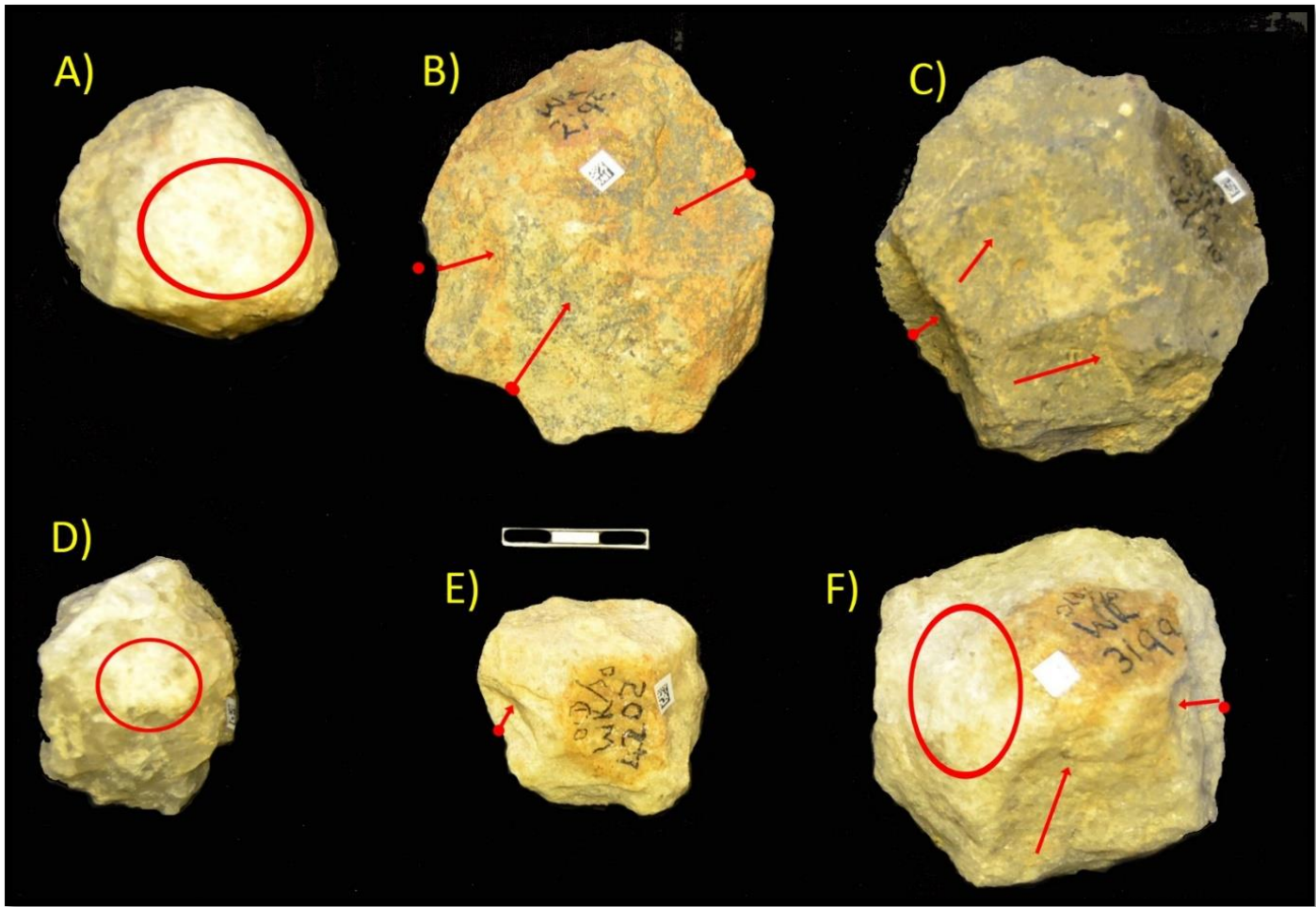


Figure 8. 12: WK cores - battered polyhedron A), discoid B-C), polyhedron D), discoid E), discoid F).



Figure 8. 13: Example of WK multifacial cores that were analysed in this study.

Figures 8.14C-D also show that the majority of retouched tools are 20-39 mm wide and 10-19 mm thick. Within the 20-39 mm width, phonolite appears to be the most abundant, followed by quartzite, trachyte, and basalt (Figure 8.14C), whereas basalt dominates the 10-19 mm thick specimen, followed

by trachyte, quartzite, and phonolite (Figure 8.14D). Most retouched pieces weigh 10-19 grams, with phonolite being the most abundant, followed by trachyte, quartzite, and basalt (Figure 8.14E).

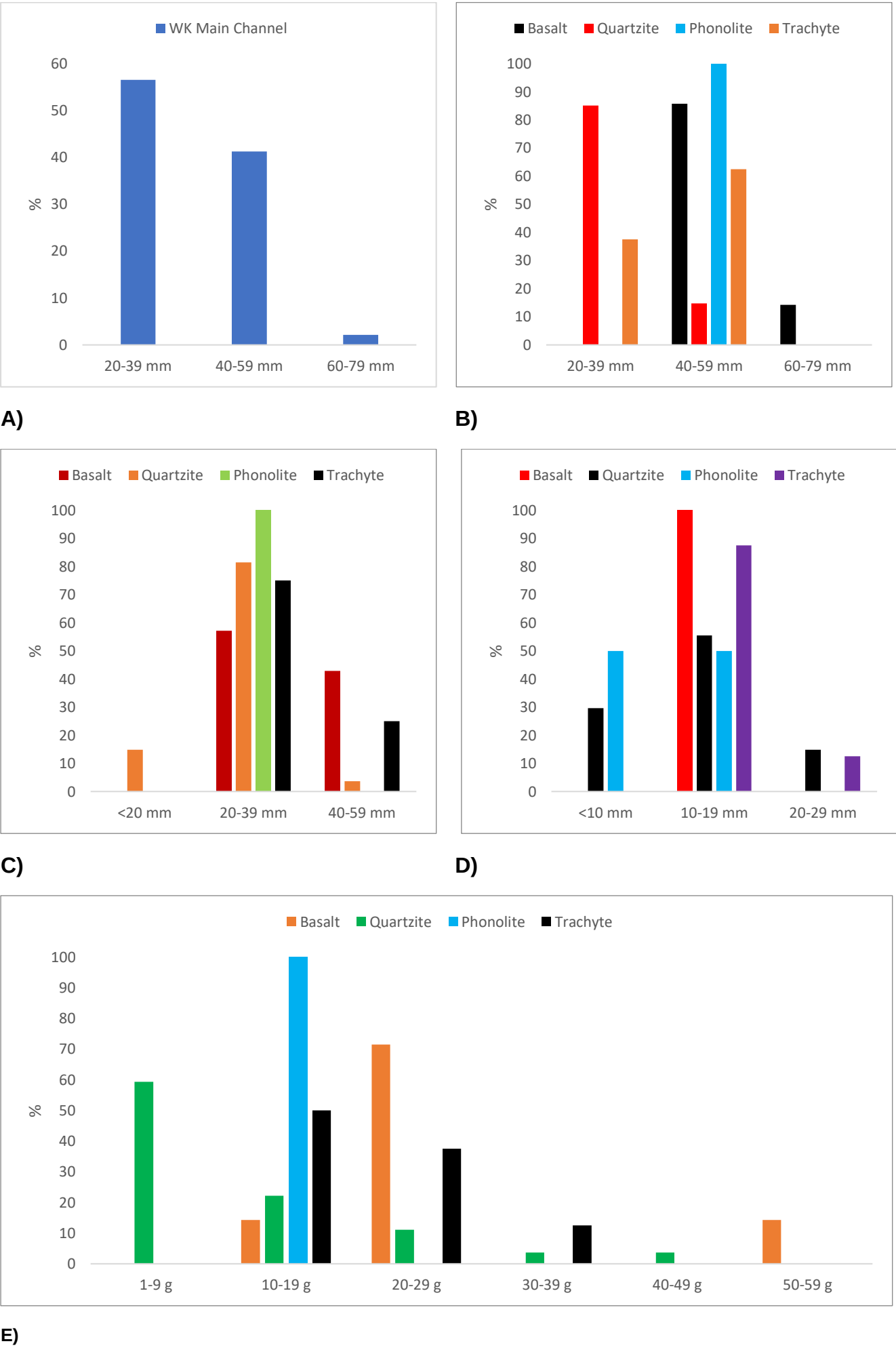


Figure 8. 14: Dimensions and metric of retouched tools; A-B) Length of all retouched tools sample (A) and raw materials (B). C-D) width per raw materials (C) and thickness per raw materials (D); E) Retouched tools weight ranges per raw materials.



Figure 8. 15: WK Main Channel retouched tools analysed by the author.

In terms of raw materials, quartzite (n=27, 18.5 %) is the most abundant, followed by trachyte (n=8, 44.4 %), basalt (n=7, 26.9 %), and phonolite (n=4, 40 %) (Table 8.4). Table 8.5 shows that lava retouched pieces have the longest average length of 48.3 mm, followed by metamorphic pieces with an average length of 33.5 mm.

Retouched pieces, on average, weigh 16.1 grams and have a width of 29.8 mm (Table 8.5). It should be noted that the length and weight vary significantly, with some retouched pieces measuring 77 mm in length and others as short as 21 mm in length (Table 8.5). Similarly, there is a significant weight difference, with some retouched pieces weighing as much as 57 grams and others weighing as little as 2 grams (Table 8.5).

Notches (n=29, 63%) are the most common retouched tool type, followed by denticulates (n=12, 26%) and sidescrapers (n=5, 11%) (Table 8.13, figure 8.16 and 8.17A). Notches appear more frequently in metamorphic rocks (n=20) than in lava rocks (n=9) (Table 8.13, figure 8.17B). Denticulates appear similar in metamorphic (n=6) and lava (n=6) rocks (Table 8.13). However, sidescrapers appear more frequently in lava (n=4) than in metamorphic (n=1) (Table 8.13, figure 8.17B).

Non-cortical retouched pieces dominate the sample (n=18, 39 percent), followed by those with <50% cortex (n=14, 30%), those with >50 percent cortex (n=13, 28 percent), and those with

100% cortex (n=1, 2%) (Table 8.13, figure 8.17C). Metamorphic (n=10) retouched tools outnumber lava (n=8) retouched tools in the non-cortical retouched tools (Table 8.13).

Furthermore, retouched tools with <50% cortex are more abundant in metamorphic (n=8) than in lava (n=6); similarly, retouched tools with >50% are more abundant in metamorphic (n=8) than in lava (n=5) (Table 8.13). Furthermore, a 100% retouched tool appears only in metamorphic (n=1) (Table 8.13, figure 8.17D).

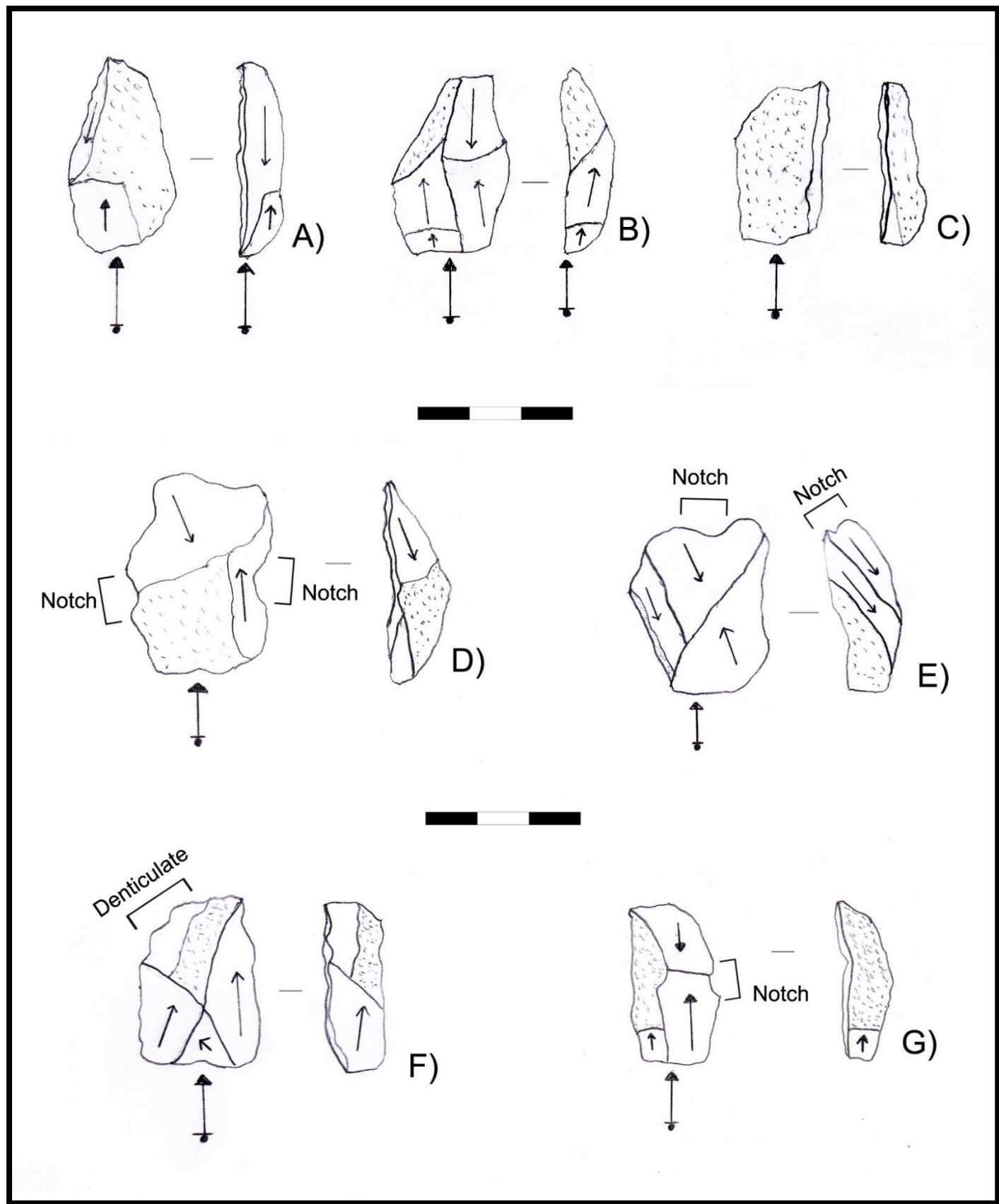
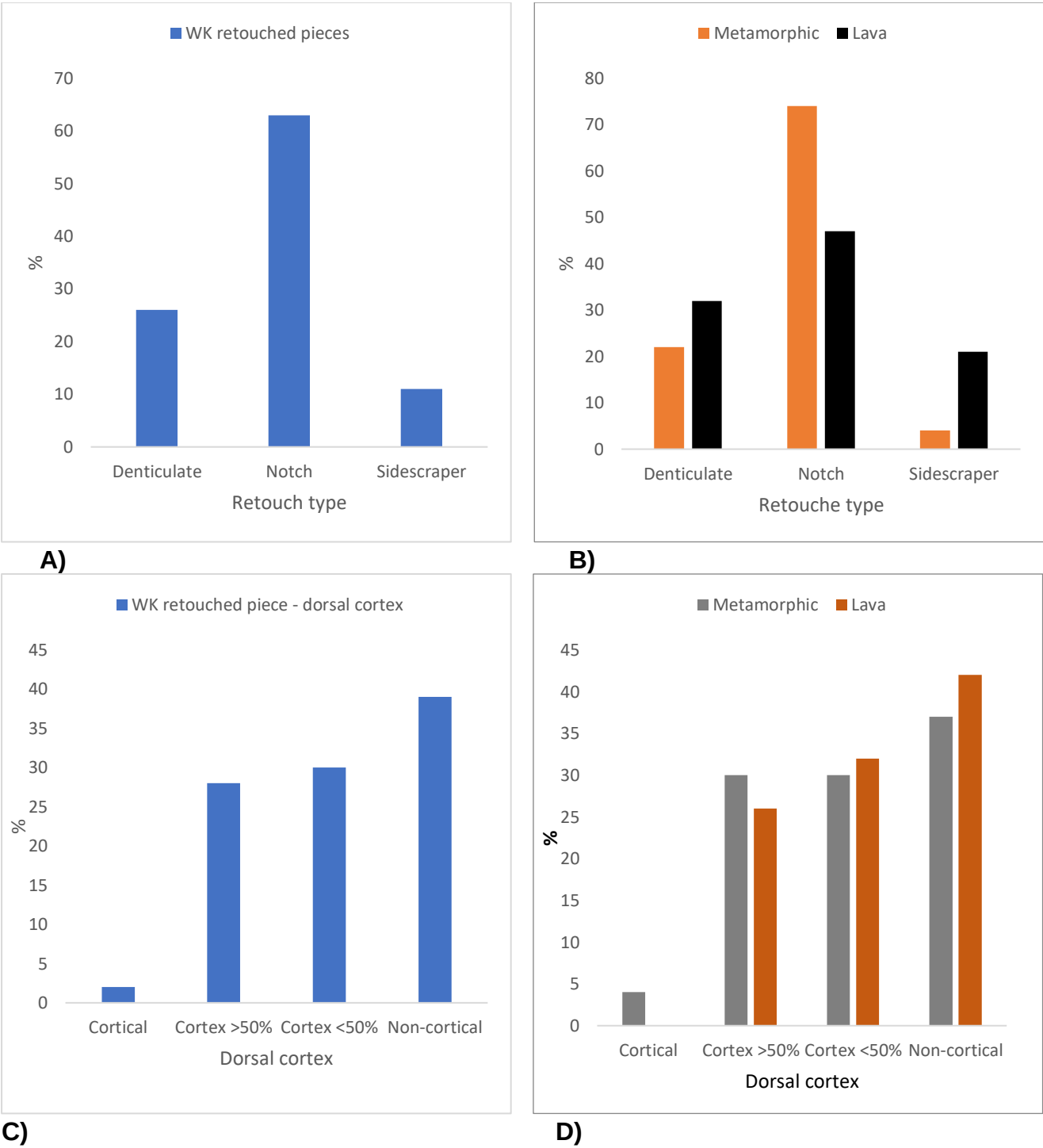


Figure 8. 16: WK detached pieces. A-C) Whole flakes. D-G) Retouched tools (D, E, & G – Notch; F – Denticulate).



C) D) Figure 8. 17: A-B) WK retouched pieces type (A), per raw material group (B); C-D) dorsal cortex (C) and per raw material (D).

8.8 Technological Strategies at WK

An examination of the core sample reveals a predominance of flake scar patterns ranging from 1-3 scars to 4-6 scars per core (Figure 8.9C-D, table 8.8). Figure 8.9C-D show that the most common reduction pattern is 1-3 scars and 4-6 scars, indicating that the reduction intensity at WK was low to medium (Table 8.8).

Additional analysis of reduction intensity at WK focused on core cortex. Figures 8.9A-B show a predominance of cores with <50 percent cortex coverage, indicating that knappers did not fully exploit cores. This evidence is consistent with Toth's flake type evidence, which shows a predominance of types V and VI (Figure 8.6C-D) flakes. Furthermore, Figures 8.6A-B show that most flakes have a unifaceted platform, indicating that knappers removed cortex from cores before detaching a flake from a core.

Table 8. 13: WK Main Channel retouched tools attributes.

		Raw Material				Grand Total	
		Lava		Metamorphic			
		n	%	n	%	n	%
Length class	20-39 mm	3	16	23	85	26	57
	40-59 mm	15	79	4	15	19	41
	60-79 mm	1	5	0	0	1	2
	Total	19	41	27	59	46	100
Cortex dorsal side	Cortical	0	0	1	4	1	2
	Cortex >50%	5	26	8	30	13	28
	Cortex <50%	6	32	8	30	14	30
	Non-cortical	8	42	10	37	18	39
	Total	19	41	27	59	46	100
Retouch Type	Denticulate	6	32	6	22	12	26
	Notch	9	47	20	74	29	63
	Sidescraper	4	21	1	4	5	11
	Total	19	41	27	59	46	100

The analysis of core length indicates that most cores were 40-59 mm and 60-79 mm in length (Table 8.8, figure 8.8A-B). This evidence indicates that hominins at WK used medium to large cores to manufacture flake products. This is consistent with the flake length results, which show that most flakes range in length from 40 to 59 mm (Figure 8.4A).

Further evidence was discovered during the analysis of knapping accidents, with the majority of cores (88%) demonstrating step scars (Table 8.9). It should be noted that the majority of these accidents are observed in metamorphic (n=25) cores rather than lava (n=11) cores.

It is clear that quartzites are more prone to causing accidents due to the nature of their texture, which is characterized primarily by coarse-grained rock particles (McHenry and de la Torre 2018). Thus, it can be argued that knapping accidents may not necessarily indicate poor knapping skills of the knapper but may be related to the rock texture.

8.9 Chapter conclusion

The WK sample analysed contains over 9 kilograms of utilised stone artifacts attributed to a small debitage *chaîne opératoire*, which includes medium and a few large-size cores, small flakes, fragmented flakes, and retouched tools. The raw material analysis reveals that the rocks used to manufacture stone tools were obtained from local sources near the sites where the sample was derived and were used to make stone artefacts.

A total of 200 stone artefacts were sampled and analysed (Table 8.2). The sample demonstrates a single reduction sequence observed at the WK assemblage, which is

primarily distinguished by a small debitage *chaîne opératoire*. The lithic assemblage from the sample described in this chapter focuses on the main technological features of the original assemblage excavated by the Leakeys at WK.

WK hominins exploited four major raw materials (basalt, quartzite, phonolite, and trachyte); raw material analysis reveals distinct differences in the use of each raw material in stone tool manufacturing. Overall, metamorphic (n=146, 73%) raw materials were used more than lava (n=54, 27%) raw materials (Table 8.4). The lava reduction sequence within cores has a very low flaking series (1-3 scars per core) compared to the metamorphic reduction sequence, which has a medium flaking series (4-6 scars per core) (Table 8.8). So, hominins most likely sourced both raw materials directly from sources (river streams and Naibor soit hillslopes), but preferred flaking quartzite over lava materials.

WK's flaking activities are determined by raw material availability and preference, but they are generally simple, consisting of short reduction sequences, and are primarily expedient. It should be noted that WK hominins were probably not interested in intensively exploiting cores, and the results of the sample analysis show that the reduction sequence at the site is very low (Table 8.8). Despite the low reduction and expedience patterns, there is clear selectivity and preference of raw materials in various stone tool categories. It is clear that the WK hominins preferred metamorphic raw materials for making stone artefacts (Table 8.7).

In general, raw material availability and preference, low reduction intensity, and expedience patterns at WK reveal a clear picture of small debitage Acheulean technology at WK. Considering the limited size of the sample examined and the consistent technological features observed at the site, more evidence should be

recovered through a thorough examination of the Leakey assemblage, including a comparison with the reduction sequence aimed at obtaining large, thick, and heavy flakes.

This will help us better understand the nature of smalldebitage, which is understood here to represent a short and low intensity reduction sequence, with knapping methods that are likely similar to those available in Oldowan technology. A study of the reduction sequence aimed at obtaining large flakes will help us to fully understand the WK's hominins' technological skills and thus be able to reconstruct full technological behaviour in the Olduvai's Bed IV sequence, which, when combined with those in Bed II and III, will allow us to have a full understanding of the Acheulean hominins' technological behaviour at Olduvai and, more importantly, highlight the Acheulean hominins' technological variability at Olduvai and elsewhere.

The experimental program was conducted in an attempt to better understand the technological attributes that demonstrate hominin technological capabilities found at the Acheulean sites in Olduvai (see Chapter 4). Chapters 6, 7, and 8 presented different technological capabilities derived from the analysis of archaeological lithic artefacts from unpublished data. The unpublished data will be compared with experimental data in part 2 of the next chapter. But, before proceeding to the detailed comparisons of experimental data with unpublished data, a comparison of the experimental results with published data (from HWKEE and EF-HR) will be presented and discussed in part 1 of the next chapter. This will broaden our understanding of the impact of experimental data on archaeological research.

Chapter 9: Comparison of experimental data with HWKEE and EF-HR assemblages

9.1 Introduction

This chapter compares experimental and archaeological data. It includes comparisons between experimental data and archaeologically published data from HWKEE and EF-HR, as well as the data analysed by the author, including FC East, JK West, JK2, and WK assemblages (de la Torre and Mora, 2018a; de la Torre and Mora, 2018b).

Therefore, this chapter consists of two main parts: the first part presents comparisons of the experimental and published archaeological data, followed by the comparisons between experimental and analysed archaeological data from FC East, JK West, JK2 and WK assemblages.

9.2 The sites of HWKEE and EF-HR, and the experimental assemblage

Two key sites for the understanding of early technological skills of Acheulean hominins in Olduvai are EF-HR and HWKEE. HWKEE is one of Olduvai's late Oldowan sites, dates to about 1.7 Ma and yielded abundant fossils and lithics (de la Torre and Mora, 2018a). Mary Leakey undertook the first excavations, at HWKEE, in the 1970s, but no data was published (Leakey, 1971). Between 2009 and 2014, OGAP undertook excavations, which unearthed a rich fossil and lithic assemblage; the published lithic assemblage is used as a reference for comparative analysis of experimental materials (de la Torre, McHenry and Njau, 2018; de la Torre and Mora, 2018a)

EF-HR is one of the Olduvai's early Acheulean sites dates to about 1.33 Ma, and it contains a lithic assemblage of over 2300 artefacts, which is accredited to be one of the largest early Acheulean assemblages in eastern Africa (de la Torre and Mora,

2018b). Mary Leakey first excavated EF-HR in the 1960s (Leakey, 1971). Her excavations made it one of the famous sites for the reference of the origins of the Acheulean because: first, it was thought to be the earliest Acheulean site at Olduvai until the discovery of older sites; second, it contained a large number of handaxes that allowed researchers to compare it with other Acheulean assemblage (Leakey, 1971; de la Torre and Mora, 2018b).

The large size of assemblage from both sites, a variety of lithic technological categories, and detailed technological analyses presented, make these sites an excellent reference for understanding technological strategies of Acheulean at Olduvai, and hence contribute to the technological discussions of this research (Leakey, 1971; de la Torre, McHenry and Njau, 2018; de la Torre and Mora, 2018a; de la Torre and Mora, 2018b).

9.3 Part 1: Comparisons of experimental and HWKEE and EF-HR assemblages

The comparisons focus on two key technological categories: flakes and cores. These categories were chosen for two reasons. First, they are complete and contain important technological attributes suitable for understanding lithic technology. Second, cores and flakes are the major technological categories that help in understanding reduction intensity of an assemblage (Inizan, 1992; de la Torre and Mora, 2018a).

9.3.1 Whole flake comparisons

Comparisons of flake attributes was undertaken by comparing length classes, dorsal cortex coverage and Toth's flake categories. These attributes help in understanding reduction intensity and technological skills of hominins. The experimental flake length classes provide the expected results within the archaeological flakes from HWKEE and EF-HR. There are a number of important differences between experimental and archaeological flake lengths. As shown in figure 9.1, there is significant difference in length classes between the experimental and archaeological (HWKEE) flakes.

The Chi-squared results of flake length classes strongly support the significant differences between the quartzite flake length classes of experimental and archaeological flakes (HWKEE) ($\chi^2(4) = 47.786$, $p < 0.001$) (see appendix 9.1). The adjusted residual results show that there is significant underrepresentation of quartzite flakes measuring 40-59 mm and 60-79 mm within archaeological flakes (HWKEE) (see appendix 9.1). Generally, the significant underrepresentation presented above may be due to hominins' selection of small cores during the Oldowan times at HWKEE. Also, it may be due to size of cores that were available for knapping activities at HWKEE about ~1.7 Ma at Olduvai (de la Torre and Mora, 2018a).

The same approach was used in comparing flake length classes of the Acheulean site of EF-HR. Figure 9.2 provides the comparisons of flake length classes between experimental and archaeological flakes (EF-HR). It is interesting to see a remarkable difference in length classes between experimental and archaeological flakes. Figure 9.2A shows a significant variation of lava flake length class when compared with archaeological flakes. Similar results are seen in figure 9.2B and 9.2C, whereas a pronounced variation is documented between experimental and archaeological flakes.

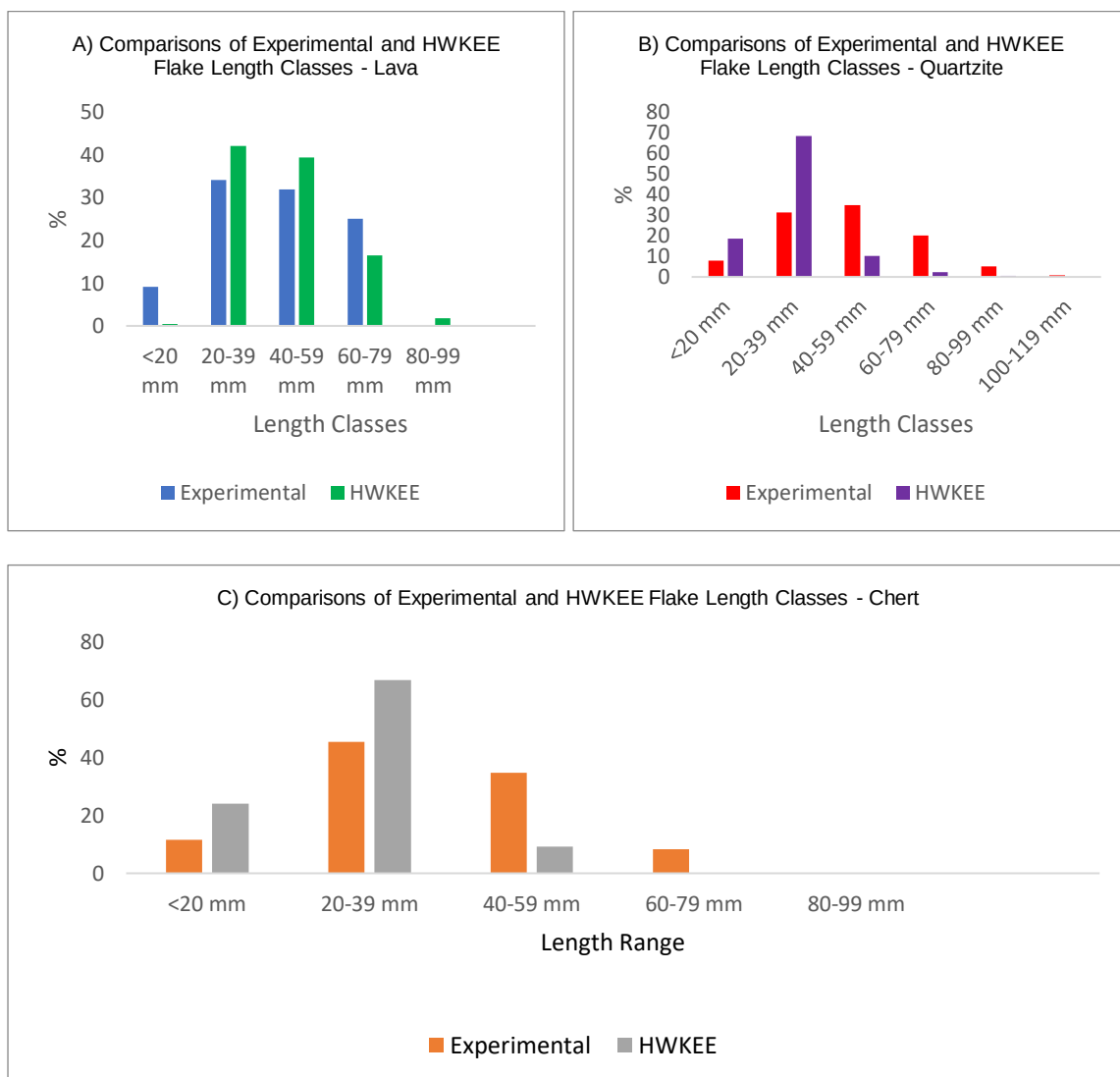


Figure 9. 1: A-C) Comparisons of Length ranges between experimental and HWKEE flakes per each raw material.

The Chi-square test suggests a strong variation in flake length classes between experimental and EF-HR flakes ($\chi^2(4) = 27.328, p < 0.001$) (Appendices 9.2, 9.3 & 9.4). The adjusted residuals indicate that there is underrepresentation of lava flakes measuring 60-79 mm (Figure 9.2A; appendix 9.2), whereas quartzite flakes show a substantial underrepresentation of flakes measuring 40-59 mm and 60-79 mm within the archaeological sample from EF-HR (Figure 9.2B; appendix 9.3).

Interestingly, chert flakes show a significant underrepresentation of flakes measuring 40-59 mm (Figure 9.2C; appendix 9.4). Overall, it is evident that experimental materials are dominated with high frequency of flakes that measure between 20 mm and 80 mm long, contrary to EF-HR flakes that show variation in flake length classes. This suggests that at EF-HR hominins used raw material that was available. Hence, the availability of raw material types and size might have influenced the size variation of flakes at EF-HR.

Further analysis of dorsal side cortex of flakes is presented in figures 9.3A-C and 9.4A-C. It can be seen that there is strong variation of flake dorsal surface cortex coverage between experimental and archaeological samples (HWKEE). In particular, a pronounced difference is seen in quartzite and chert raw materials (Figures 9.3B & C). Statistically, there is strong variation of dorsal side cortex of experimental and archaeological sample within quartzite materials ($\chi^2(3) = 40.640, p < 0.001$) (Appendix 9.5). The adjusted residuals highlight strong underrepresentation of cortical dominant and cortical quartzite flakes.

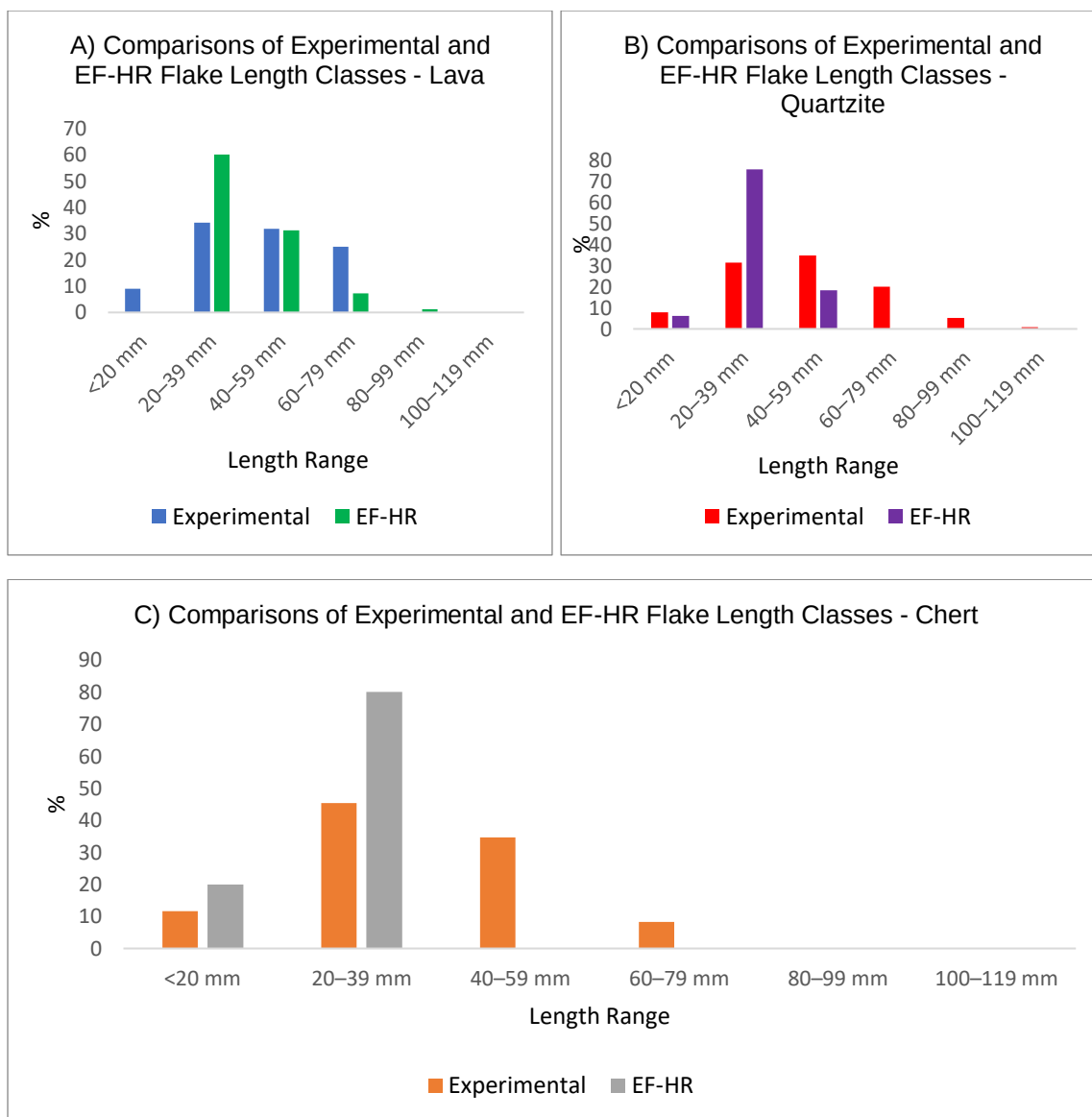


Figure 9. 2: A- C) Comparisons of Length ranges between experimental and EF-HR flakes per each raw material.

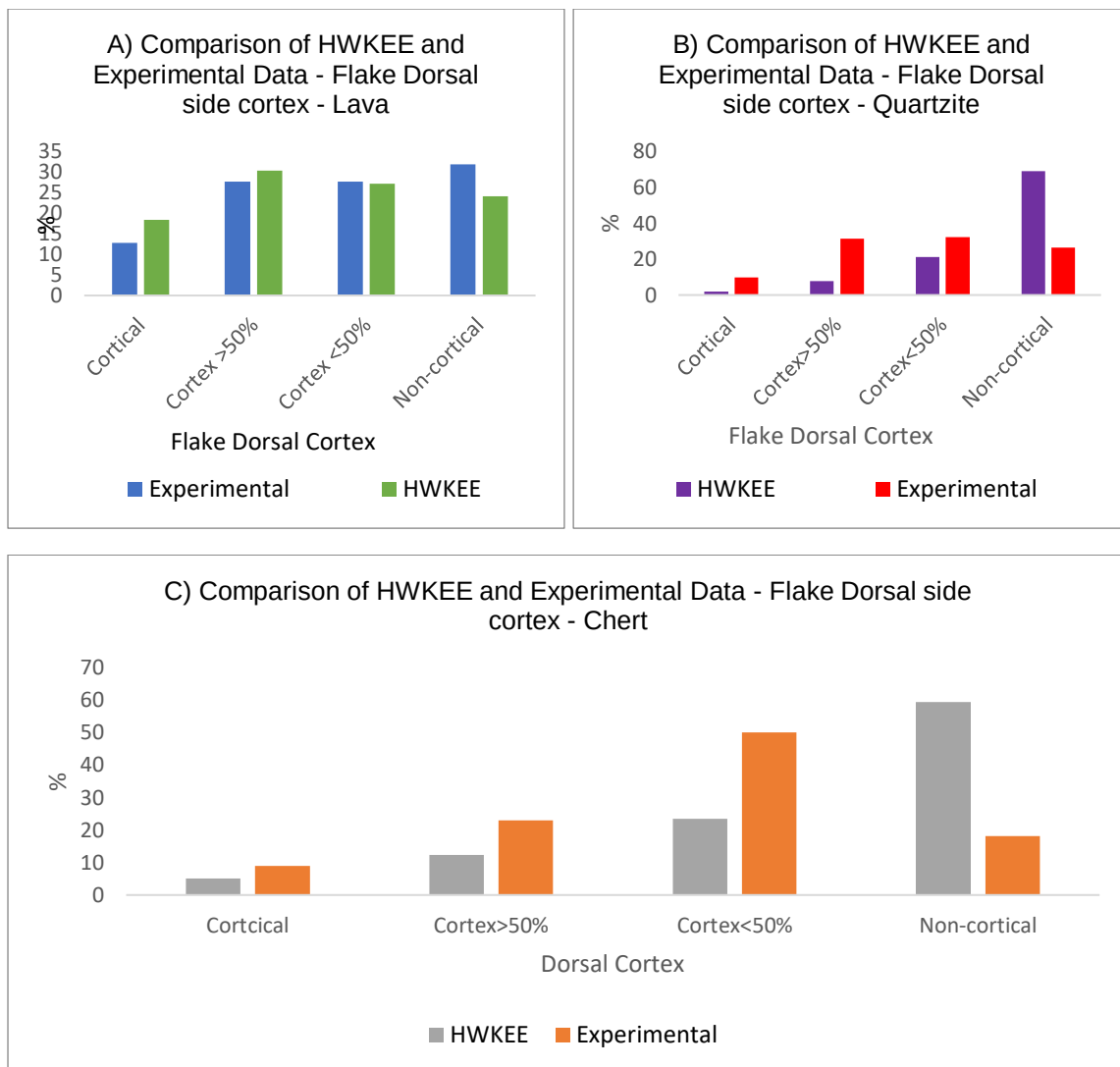


Figure 9. 3: A-C) Comparisons of flake dorsal side cortex between experimental and HWKEE flakes; lava flakes (A); quartzite flakes (B); and chert flakes (C).

Additionally, analysis of dorsal surface cortex of chert flakes shows a significant difference between experimental and archaeological samples (Appendix 9.6). As shown in figure 9.3C archaeological flakes retaining full cortex on dorsal surface appear in low percentage when compared with experimental sample. Also, there is underrepresentation of cortical and cortical dominant pieces. The most conspicuous result is seen on non-cortical dominant flakes (Figure 9.3C). This is contrary to the expected results. Hence, it can be argued that the high percentage of non-cortical flakes at HWKEE may be the results of high reduction of chert materials by hominins

during the late Oldowan times. Statistically, the adjusted residuals strongly support the significant difference of dorsal surface cortex of chert flakes between experimental and HWKEE flakes ($X^2(3) = 36.413, p < 0.001$) (Appendix 9.6).

In addition, the comparison of dorsal side cortex of flakes was undertaken with the Acheulean assemblage from EF-HR. As shown in figure 9.4, comparisons of chert and quartzite flakes show a significant variation of dorsal cortex on flakes. Most quartzite flakes that are cortical dominant are underrepresented within the archaeological sample, with cortex coverage showing statistically significant difference $X^2(3) = 45.387, p < 0.001$) (Appendix 9.7; Figure 9.4B). Interestingly, the adjusted residuals also indicate overrepresentation of non-cortical quartzite flakes at EF-HR (Appendix 9.7).

A further comparison within chert indicates strong differences in dorsal side cortex between experimental and archaeological samples ($X^2(3) = 36.628, p < 0.001$) (Appendix 9.8; Figure 9.4C). The adjusted residuals show that there is significant underrepresentation of cortical dominant chert flakes. However, the evidence shows a significant overrepresentation of non-cortical chert flakes at EF-HR site. This could possibly be due to high reduction intensity of chert raw materials at this site.

Additional analysis on cortex on striking platform and the relationship with dorsal cortex of flakes is shown in figures 9.5 and 9.6, respectively. During the analysis, all flakes were compared based on all raw material types. To determine variation between expected flake and archaeological flakes, chi-square was used to calculate different proportions.

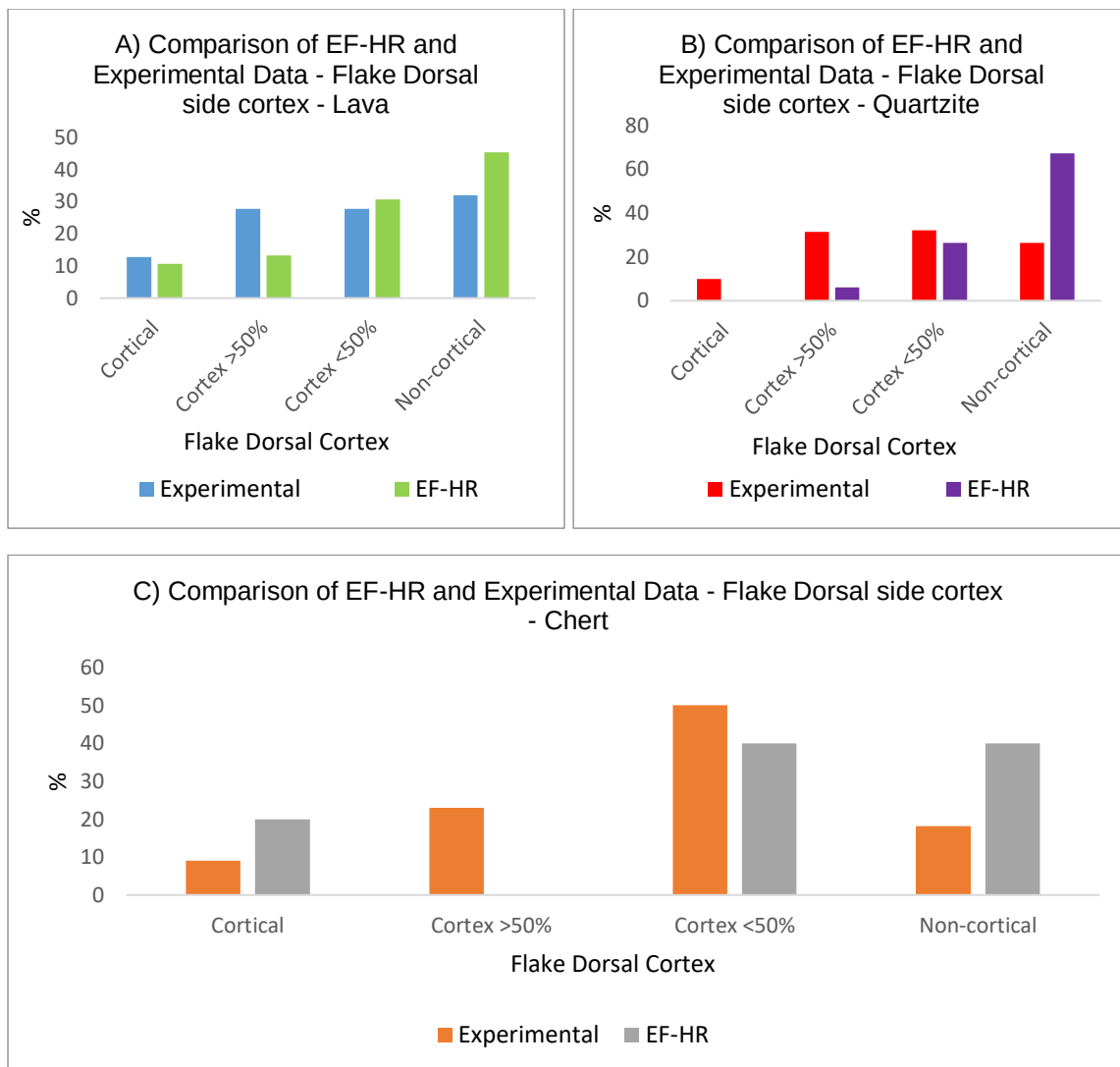


Figure 9. 4: A-C) Comparison flake dorsal side cortex between experimental and EF-HR flakes; lava flakes (A); quartzite flakes (B); and chert flakes (C).

Figure 9.5A shows that flakes retaining cortex on the platform and non-cortical on dorsal surface (i.e Toth's type III) are significantly underrepresented amongst lava materials. Contrary, lava flakes that are fully cortical on platform whilst retaining some cortex on the dorsal surface (type II) are strongly overrepresented. Statistically, there is a significant difference in Toth's flake types within lava raw material ($\chi^2 (5) = 24.206$, $p < 0.001$) (Appendix 9.9).

A further analysis on quartzite materials shows that there is significant difference between the expected model and archaeological data (HWKEE) ($\chi^2(5) = 43.222, p < 0.000$) (Appendix 9.10; Figure 9.5B). The adjusted residuals highlight a significant underrepresentation of flakes with some cortex on the dorsal surface whilst retaining full cortex on the platform (type II). Interestingly, however, the adjusted residuals show a significant overrepresentation of non-cortical flakes (type VI).

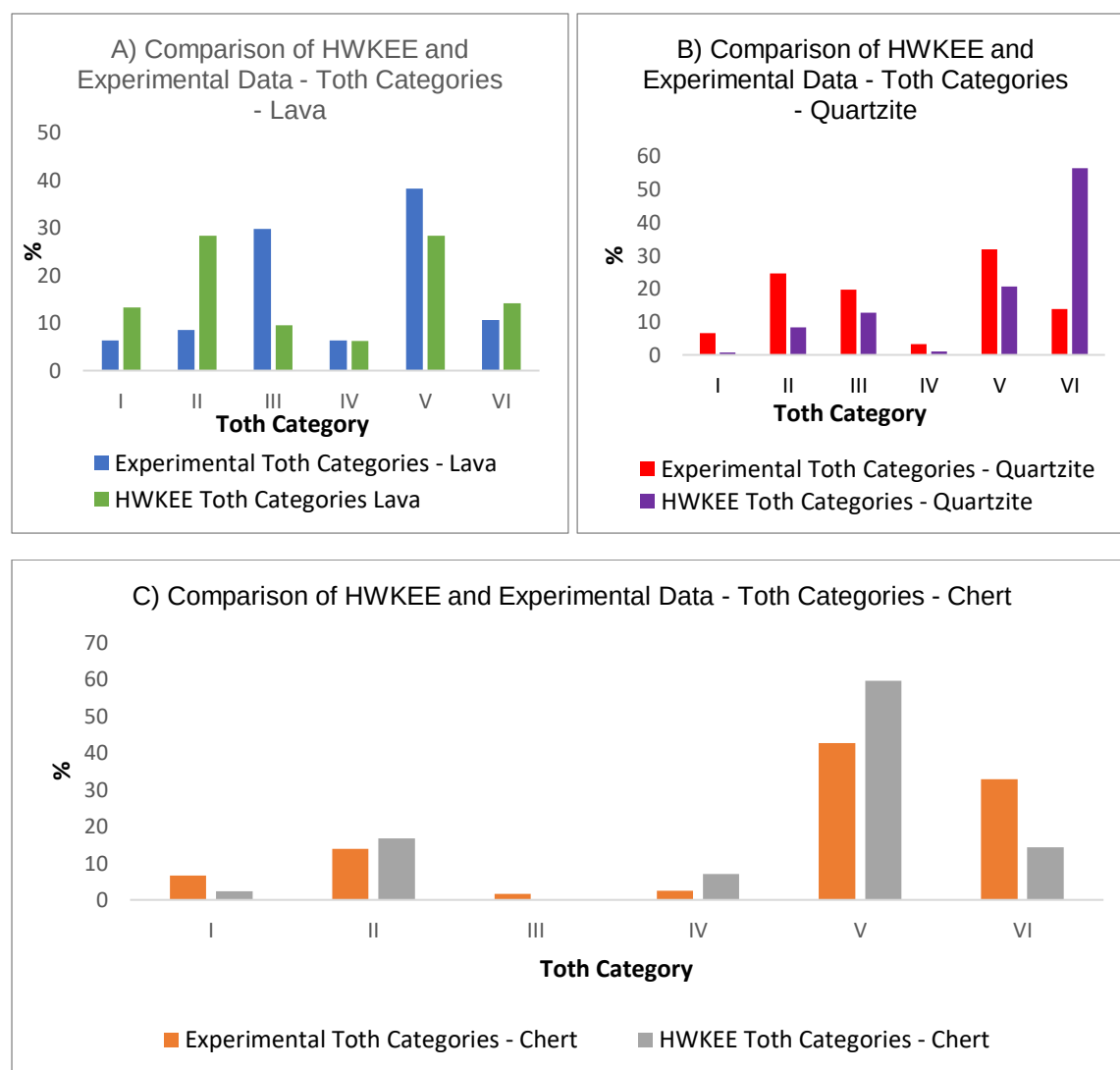


Figure 9. 5: A-C) Comparisons of Toth's flake categories between experimental and HWKEE site per raw materials.

Furthermore, analysis on chert materials show a statistically significant difference on Toth's flake type between experimental and archaeological flakes ($\chi^2(5) = 17.137, p$

< 0.004) (Appendix 9.11; Figure 9.5C). The adjusted residuals show a significant overrepresentation of type V flakes. Nonetheless, the adjusted residuals highlight a significant underrepresentation of non-cortical flakes (type VI).

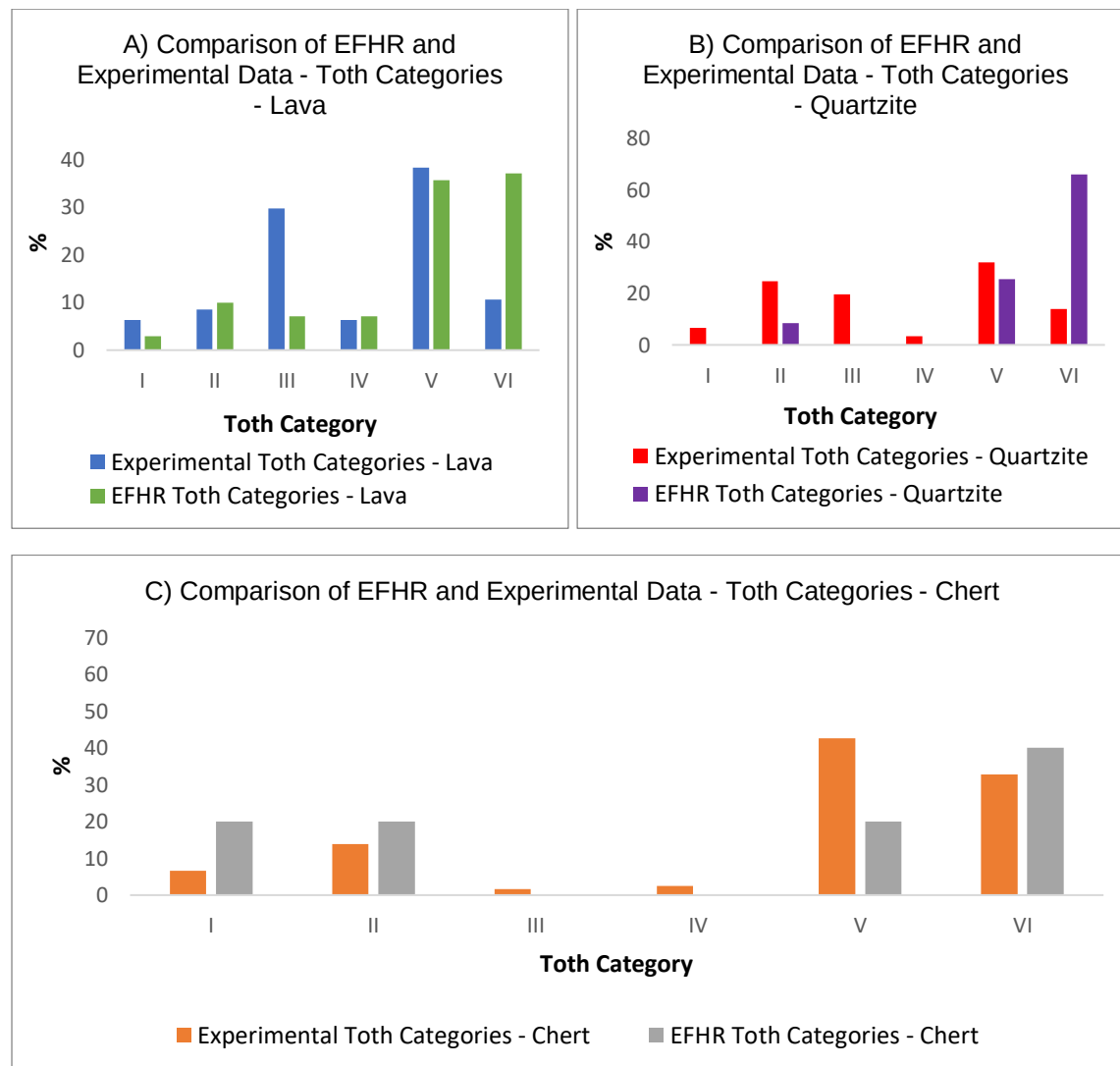


Figure 9. 6: A-C) Comparisons of Toth's flake categories between experimental and EF-HR site per raw materials.

Whilst comparing the lava flakes, a statistically significant difference was observed ($X^2(5) = 29.564, p < 0.001$), with adjusted residuals showing a significant underrepresentation of flakes preserving cortex on the platform whilst non-cortical on dorsal side (type III), as opposed to the overrepresentation of non-cortical flakes (type VI) (Appendix 9.12; Figure 9.6A). Additionally, comparison of quartzite flakes

highlights a pronounced variation ($X^2(5) = 71.950, p < 0.001$), with adjusted residuals presenting a statistically substantial underrepresentation of Toth's type III flakes, a pattern that shows contrary results with type VI flakes that are statistically overrepresented (Appendix 9.13; Figure 9.6B).

Another statistically significant difference was recorded in chert materials. The chi-square test shows a significant difference between experimental and archaeological chert flakes from EF-HR ($X^2(5) = 21.368, p < 0.001$), with adjusted residuals showing a significant overrepresentation of cortical flakes (type I). Nevertheless, data shows that there is also significant underrepresentation of flakes with some cortex on the dorsal side with non-cortical platform (type V) (Appendix 9.14; Figure 9.6C).

9.3.2 Core comparisons

Comparisons of core size differences are shown per raw material (Figures 9.7 and 9.8). As shown in figure 9.7A, there is overrepresentation of archaeological (HWKEE) lava cores that are in 60-79 mm and 80-99 mm, except cores that are larger than 100 mm appear to be underrepresented. Chi-squared test shows a statistically significant difference in length class of lava core ($X^2(2) = 47.069, p < 0.001$) (Appendix 9.15).

Most quartzite and chert experimental cores are in the >100 mm class, whilst the majority of HWKEE quartzite and chert cores are in the 40-59 mm and 60-79 mm classes, respectively (Figure 9.7B and 9.7C), with the two raw materials showing statistically pronounced differences ($X^2(3) = 67.299, p < 0.001$) within quartzite and ($X^2(3) = 57.473, p < 0.001$) within chert (Appendices 9.16 and 9.17).

This is also applicable to length classes per raw materials at EF-HR site (Figure 9.8), where the difference are significant in all raw materials. The chi-squared test result

shows a statistically significant difference ($X^2(2) = 40.417, p < 0.001$) (Appendix 9.18), with adjusted residuals showing majority of lava cores that are in the 60-79 mm and 80-99 mm are overrepresented.

Additionally, there is statistically significant difference of length classes of quartzite cores ($X^2(3) = 58.034, p < 0.001$), with adjusted residual highlighting underrepresentation of cores that are in >100 mm length class (Appendix 9.19).

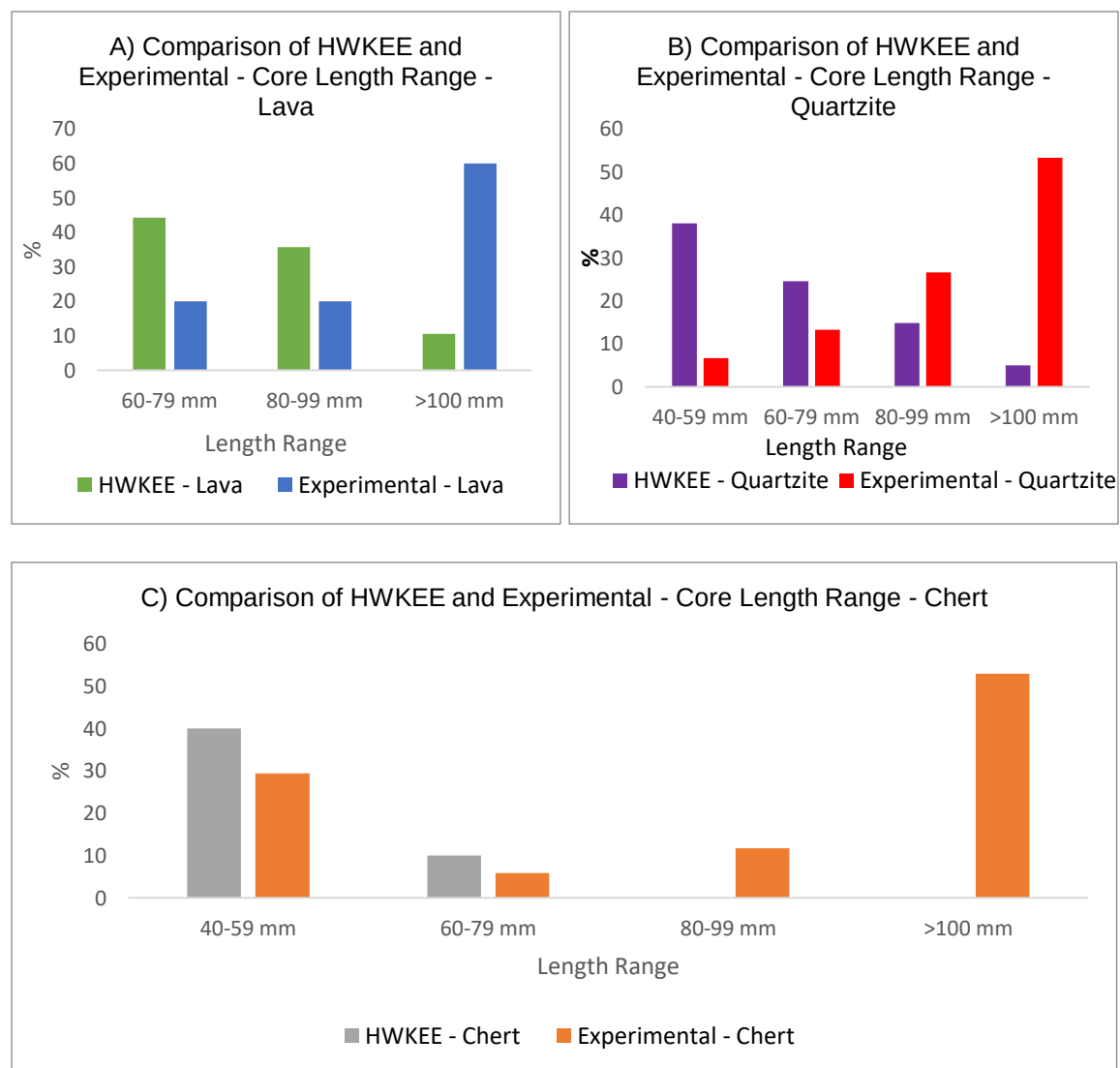


Figure 9. 7: A-C) Comparisons of length range between experimental and HWKEE cores per raw materials.

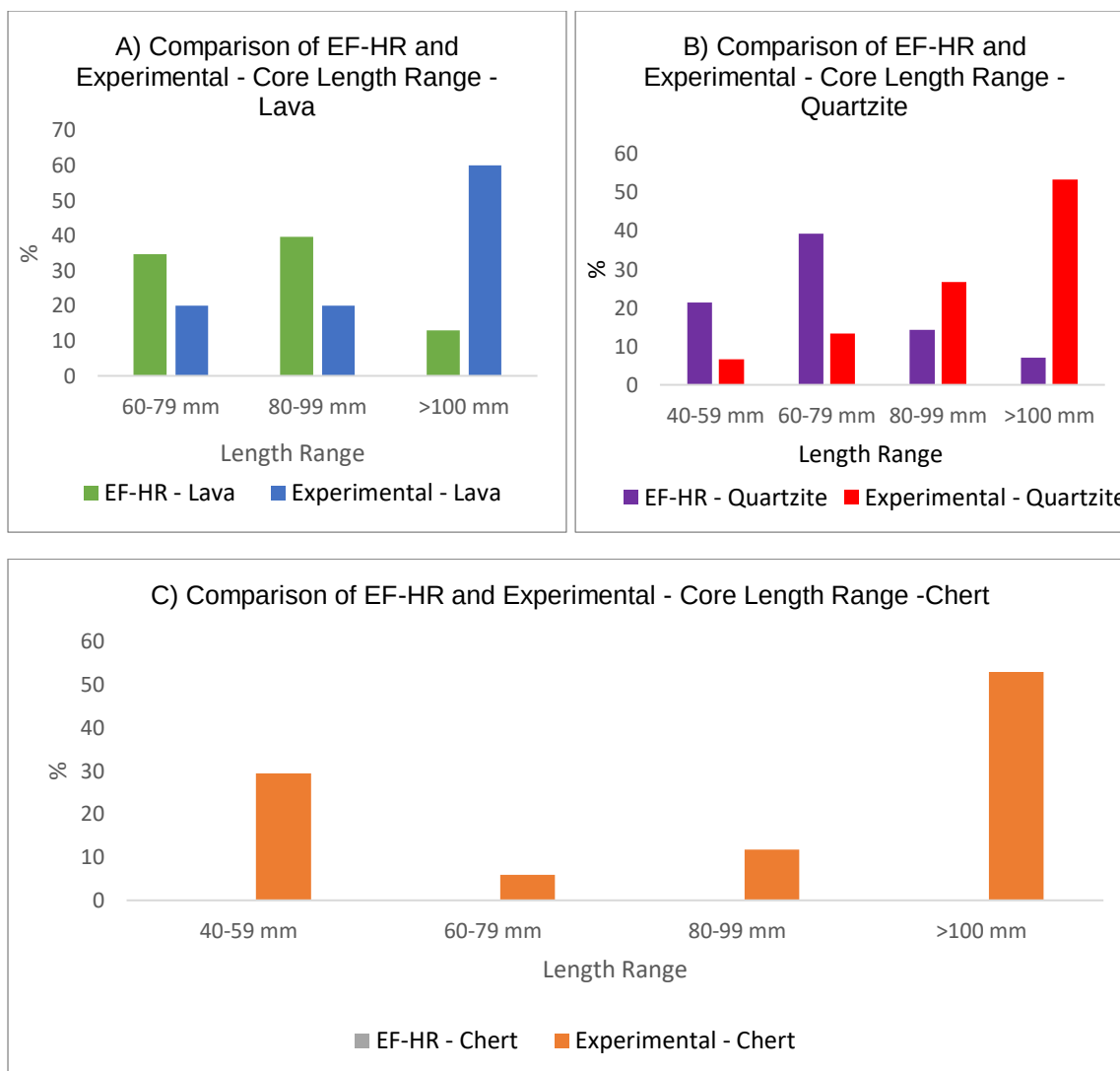


Figure 9. 8: A- C) Comparisons of length range between experimental and EF-HR cores.

As shown in figures 9.9A there is underrepresentation of lava core that are heavier than 800 g ($\chi^2 (5) = 58.709$, $p < 0.001$), thus supporting the observation on the size of experimental lava cores over those from HWKEE (Appendix 9.20). Majority of quartzite cores that are in 201-400 g class are underrepresented, whereas the chi-square test shows a statistically significant difference ($\chi^2 (5) = 61.341$, $p < 0.001$) (Appendix 9.21; Figure 9.9B). Moreover, there is remarkable variation of chert cores ($\chi^2 (3) = 16.108$,

$p < 0.001$), with adjusted residuals highlighting underrepresentation of cores that are in 50-100 g class (Appendix 9.22; Figure 9.9C).

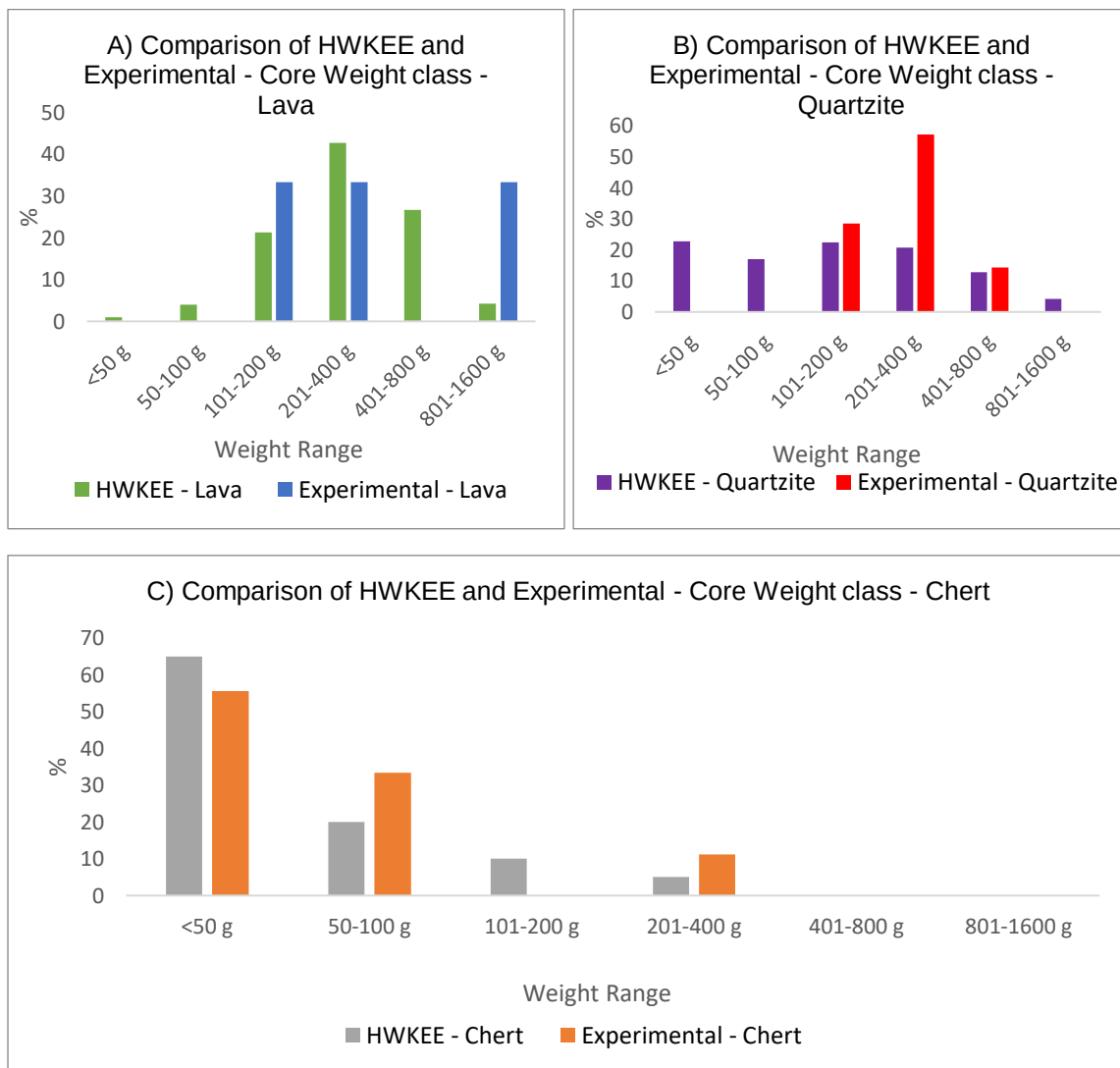


Figure 9. 9: A-C) Weight classes between experimental and HWKEE cores.

Weight class comparison with EF-HR lava cores show a significant difference ($X^2 (5) = 65.730$, $p < 0.001$), with the adjusted residuals showing a significant underrepresentation of cores that are in 101-200 g class (Appendix 9.23; Figure 9.10A). Furthermore, there is statistically substantial variation of quartzite core weight between experimental and archaeological samples ($X^2 (5) = 65.234$, $p, 0.001$), with

adjusted residuals showing underrepresentation of cores that are in 101-200 g and 201-400 g weight ranges (Appendix 9.24; Figure 9.10B).

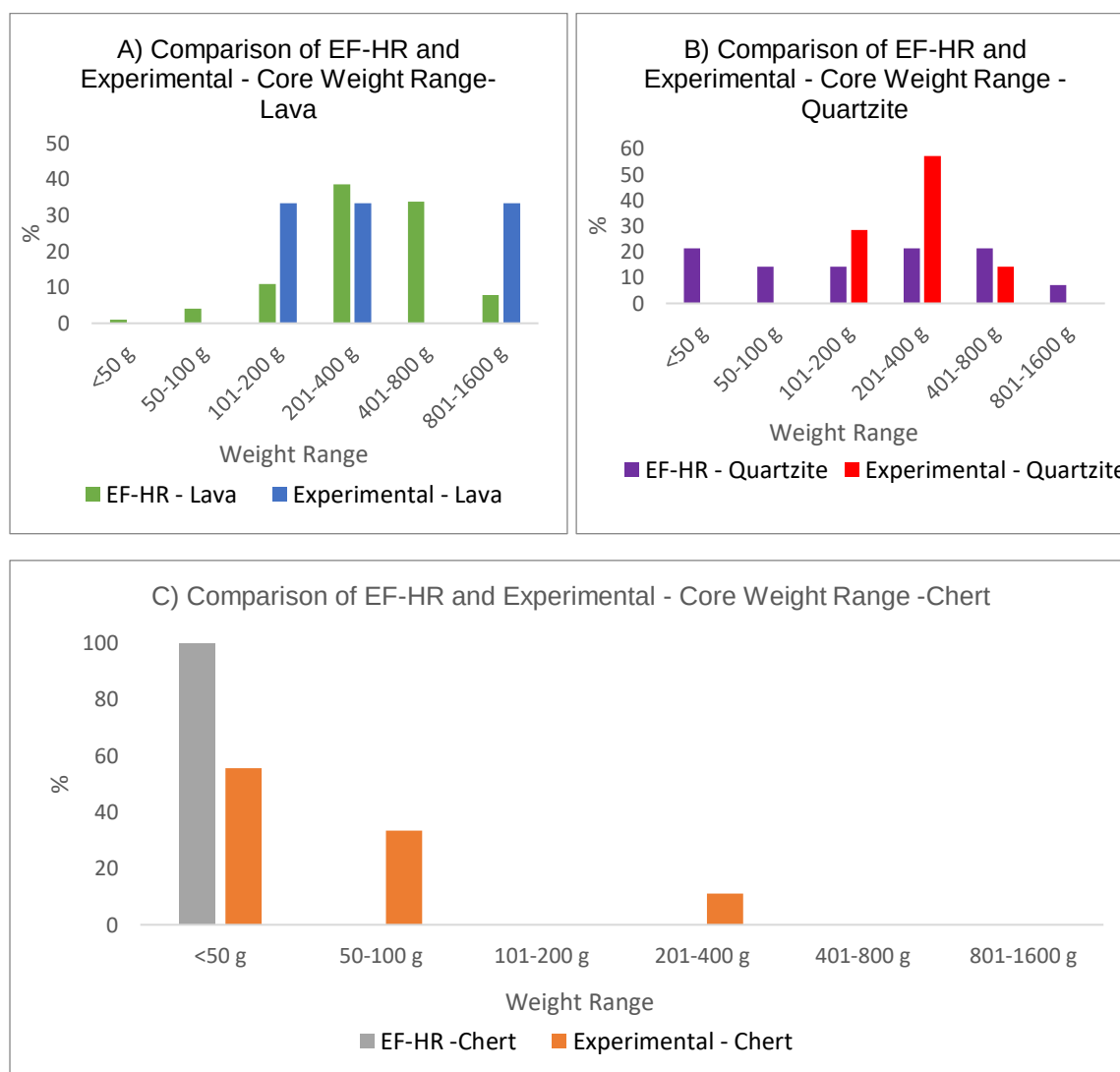


Figure 9. 10: A-C) Weight classes between experimental and EF-HR cores.

Reduction intensity was explored by comparing amount of cortex preserved on cores. As shown in figure 9.11A most HWKEE lava cores are cortical dominant than experimental lava cores, whereas HWKEE non-cortical dominant quartzite cores are less frequent (Figure 9.11B). Nonetheless, figure 9.12C shows most HWKEE chert

cores preserve more than 50% cortex are significantly overrepresented ($\chi^2(2) = 11.538, p < 0.003$) (Appendix 9.25).

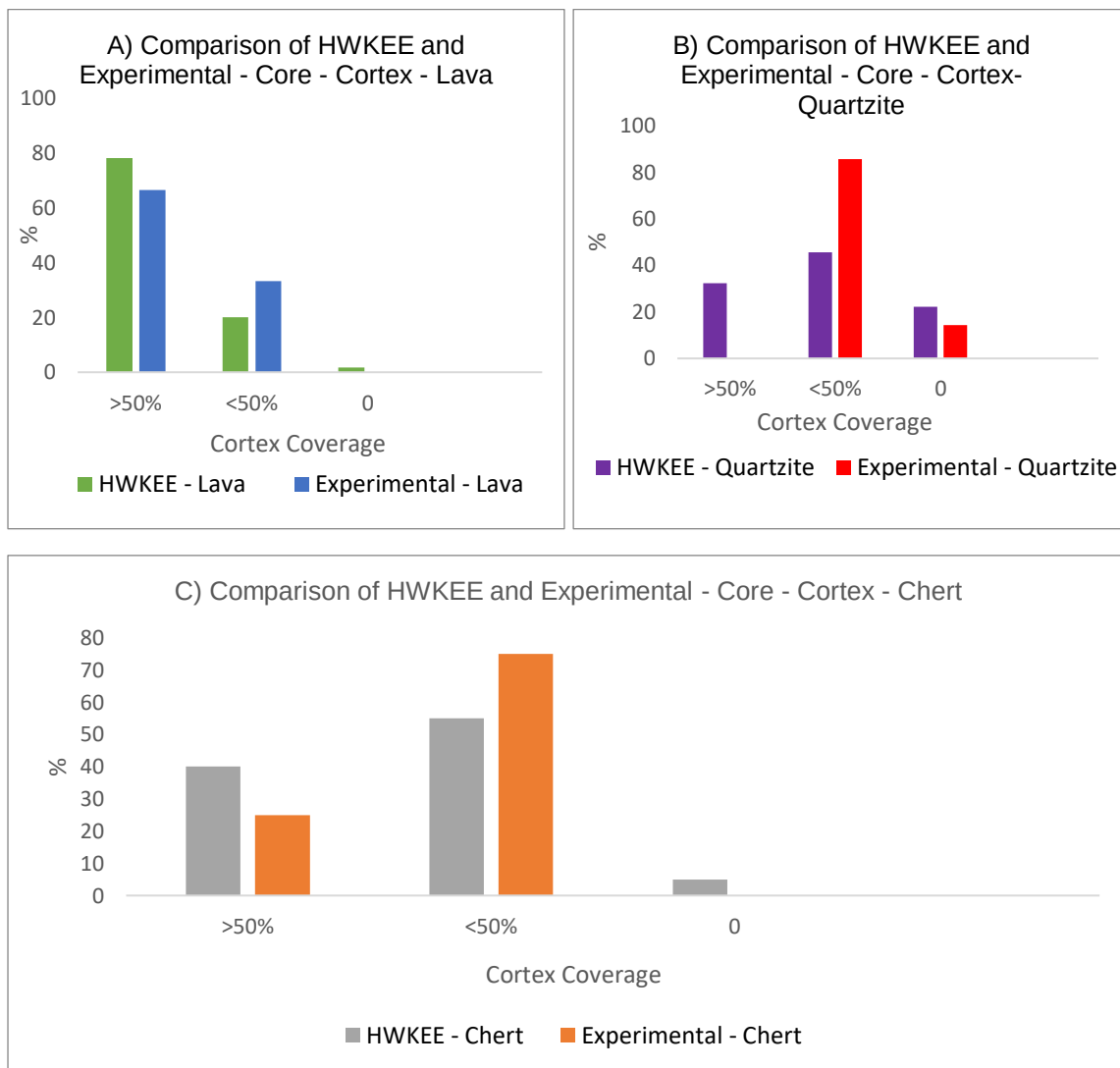


Figure 9. 11: A-C) Cortex coverage between experimental and HWKEE cores.

Moreover, reduction intensity via cortex was explored with EF-HR cores. As shown in figure 9.12B, a few EF-HR quartzite cores preserve less than 50% cortex, while most of them are non-cortical. The chi-square test shows a statistically significant difference

in raw material patterns ($X^2(2) = 83.688$, $p < 0.001$), with adjusted residuals showing underrepresentation of non-cortical dominant quartzite cores (Appendix 9.26).

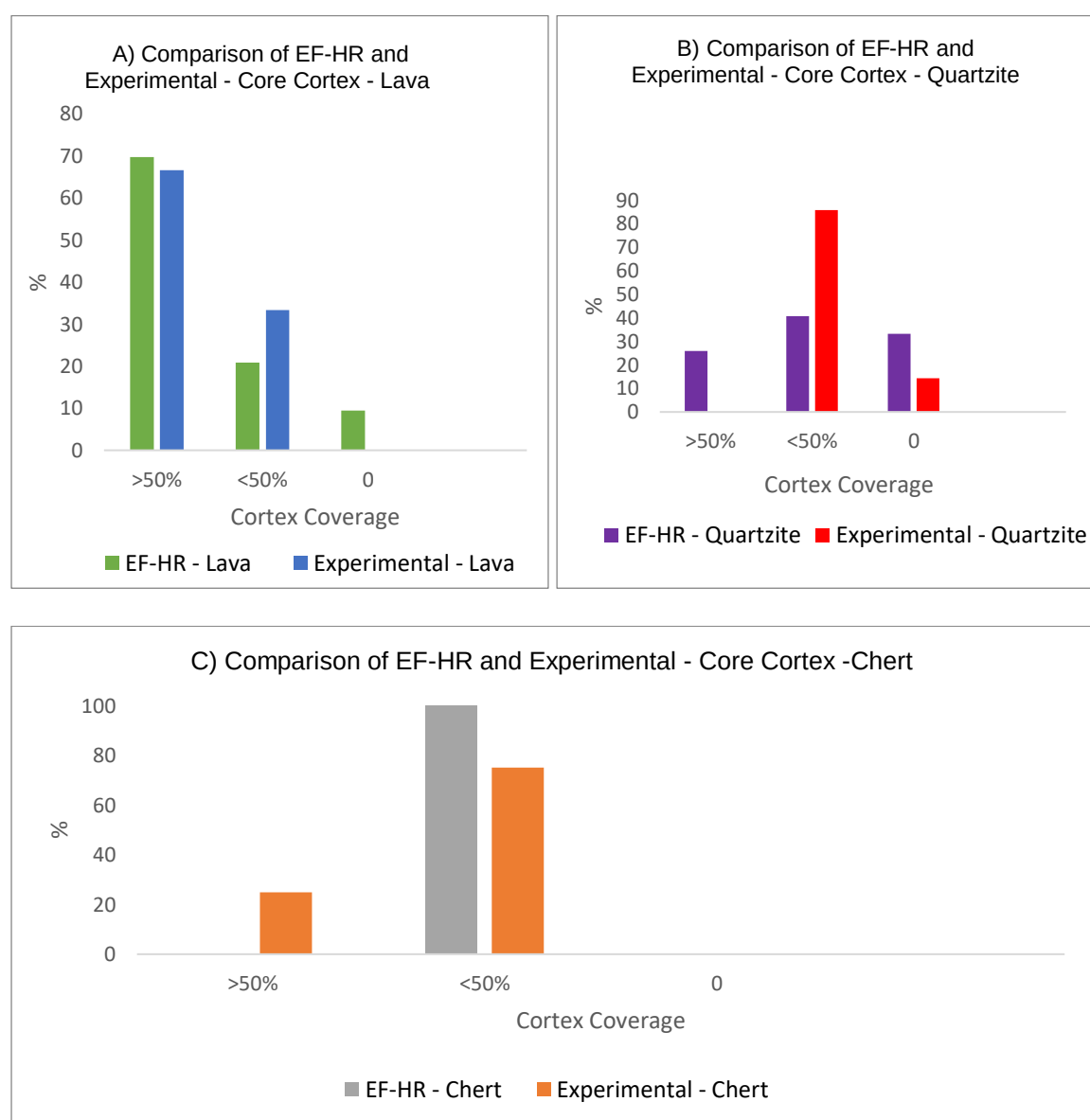


Figure 9. 12: A-C) Cortex coverage between experimental and EF-HR cores.

Furthermore, reduction intensity was explored via the number of flake scars on cores. As shown in figure 9.14A most HWKEE lava cores preserve 1-3 scars and 7-9 scars, whilst fewer preserve >9 scars. This shows a statistically significant different reduction intensity in lava raw material ($X^2(3) = 127.230$, $p < 0.000$), with adjusted residuals

highlighting a significant underrepresentation of lava cores preserving nine or more scars (Appendix 9.27).

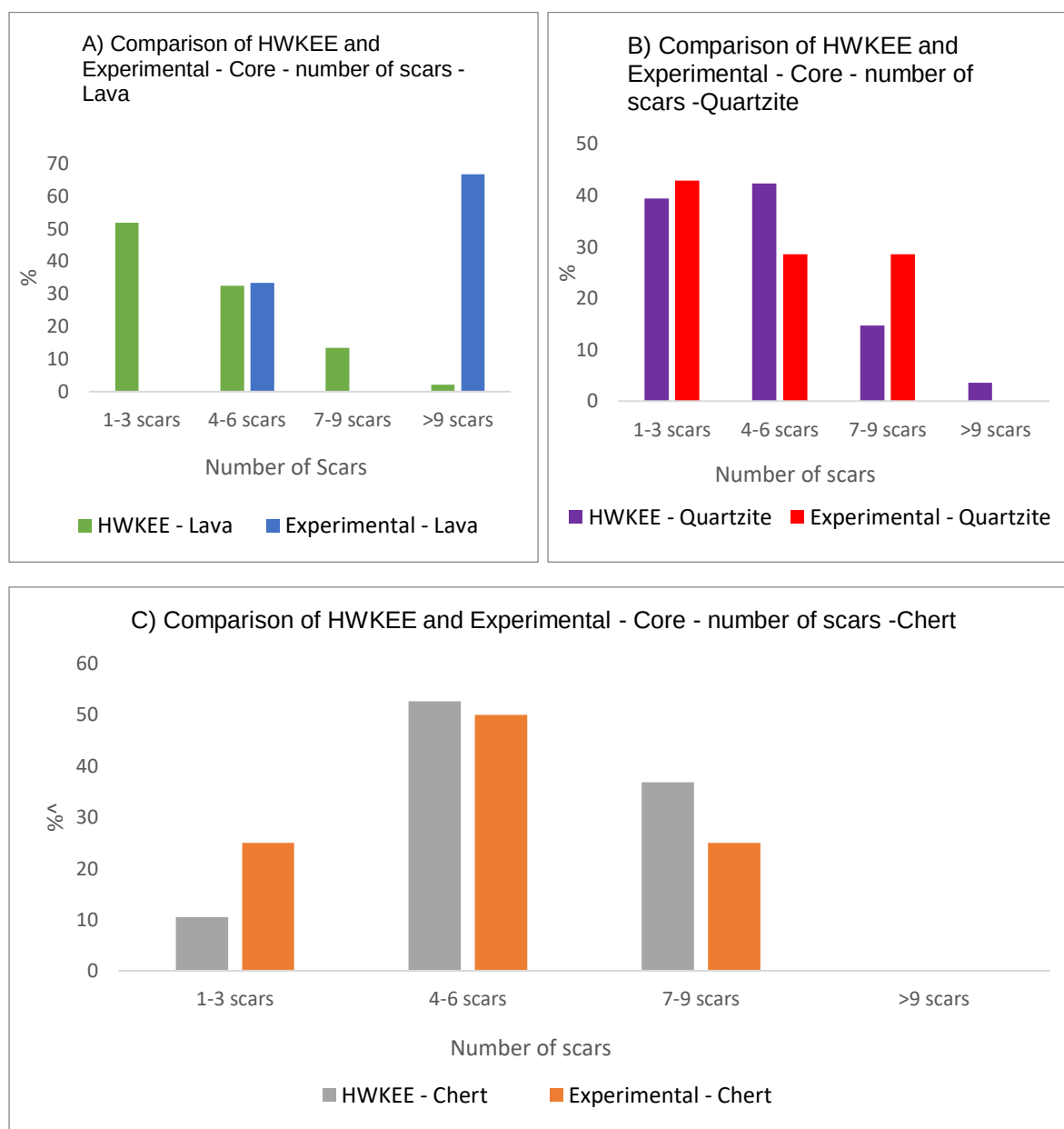


Figure 9. 13: A-C) Number of scars between experimental and HWKEE cores.

The chi-square test for EF-HR core scar counts ($X^2(3) = 97.830$, $p < 0.000$) confirms overrepresentation of 4-6 scars in lava, a significant underrepresentation of >9 scars in lava, and a predominance of 4-6 scars in chert (Appendix 9.28; Figures 9.14A-C).

The underrepresentation of >9 scars at HWKEE and EF-HR can be linked to low reduction intensity than expected.

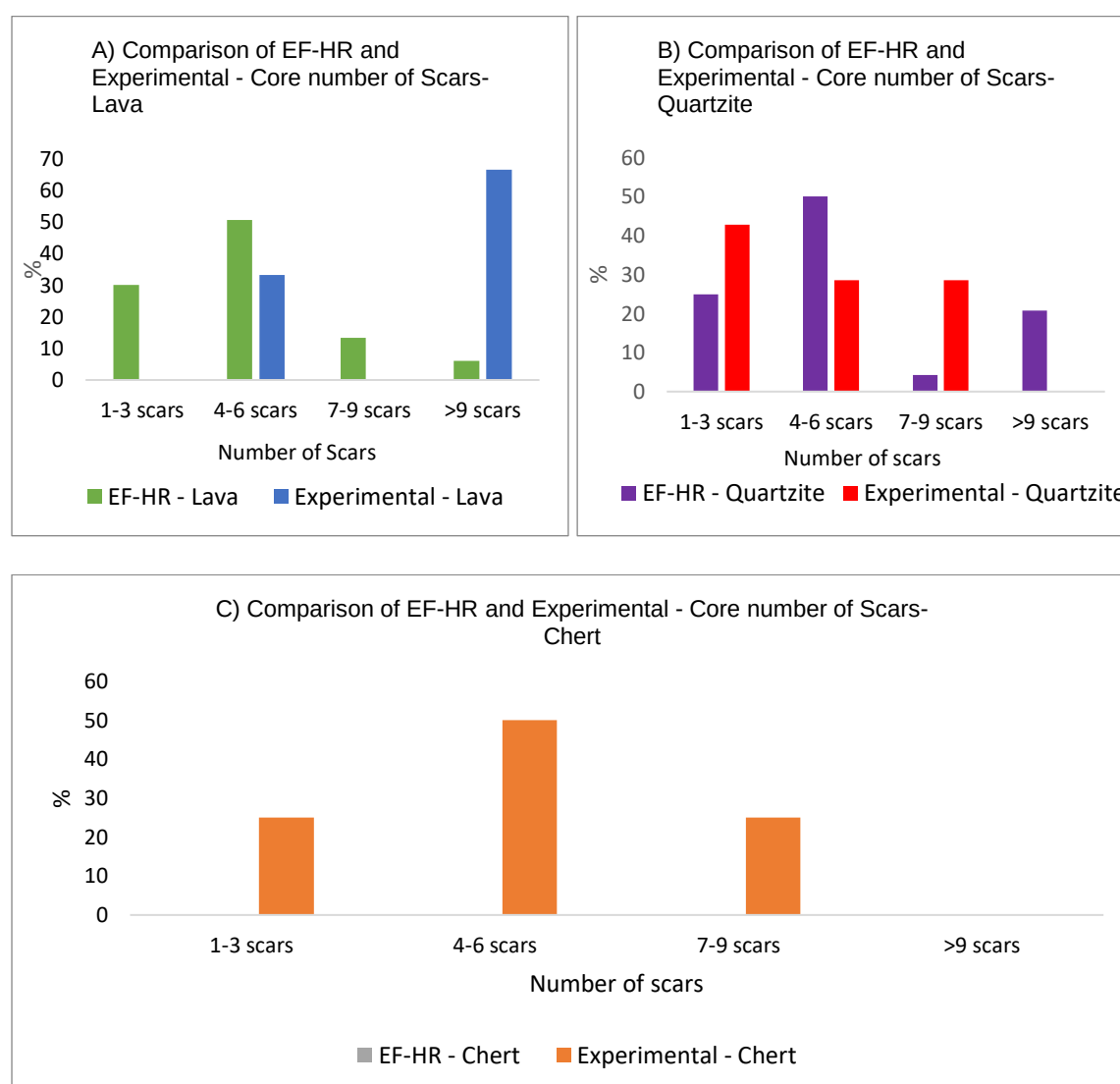


Figure 9. 14: A-C) Number of scars between experimental and EF-HR core.

9.4 Discussion

Prior studies have noted the importance of experimental studies in understanding archaeological assemblage (Jones, 1979, 1980, 1981; Toth, 1982, 1985). Several studies have shown that raw material is important in determining assemblage technological variation due to different properties (Stout et al., 2005; Blumenschine et al., 2008; Goldman-Neuman and Hovers, 2009, 2012), the availability of lithic raw

material and core reduction (Sassaman, Hanson and Charles, 1988; Kuhn, 1991; Braun et al., 2008; Caruana, Tasker and Stratford, 2019), the quality of raw material and its influence in formal or informal tool designs (Andrefsky, 1994, 2009), and the effects of distance of raw materials sources to reduction intensity of different Olduvai raw material types (Blumenschine et al., 2008).

It is interesting to note that experimental materials studied in this thesis played an important role in understanding the archaeological assemblages from HWKEE and EF-HR. Figures 9.1 and 9.2 show that at HWKEE and EF-HR hominins manufactured flakes that are in 20-39 mm and 40-59 mm length classes, respectively. This is consistent with majority of the core sizes at these sites (Figures 9.1 and 9.8). However, experimental materials highlighted that most of HWKEE and EF-HR assemblages lacked flakes that are in 60-79 mm and 80-99 mm (Figures 9.1 and 9.2).

It is clear that the scar counts affected the level of reduction intensity. Hence, figure 9.13 shows that most HWKEE lava cores produce fewer flakes than quartzite and chert. At EF-HR, however, both lava and quartzite cores appear to produce similar pattern of flake scar counts, with minor variation in frequencies (Figure 9.14). Interestingly, there is no evidence of chert cores at EF-HR. This may be explained possibly by the availability of raw material and distance from the source to the site. Also, at EF-HR there is clear dominance of lava raw material (de la Torre et al., 2017).

To some extent, cortex coverage also indicates the level of reduction intensity of materials as shown in flake dorsal surface and cores. Figure 9.3B and 9.3C show that most of quartzite and chert flakes at HWKEE were non-cortical, suggesting an increased degree of reduction for these raw materials at HWKEE. Alternatively, hominins might have reduced the amount of cortex on cores before transporting them

to the site, primarily to reduce weight or test the quality of raw materials. However, lava was also used, although it appears underrepresented (Figure 9.3A). This is also applicable at EF-HR whereas most non-cortical flakes are overrepresented in all raw materials (Figure 9.4).

Another way of measuring the reduction intensity was to examine cortex on cores. Thus, figure 9.11A shows that majority of lava cores at HWKEE are cortical dominant and appear to be overrepresented contrary to expected results. Hence, this indicates that at HWKEE there is less intensive reduction of lava materials. Figure 9.11B shows underrepresentation of non-cortical dominant quartzite cores and overrepresentation of non-cortical cores. This relationship may partly be indicating that low reduction intensity cores, was possibly due to its coarse-grain nature. Most coarse-grained quartzite is found at Naibor Soit, and if hominins needed some finer-grained quartzite they had to procure it far away, possibly Naisiusiu (de la Torre and Mora, 2018a). Cortical dominant and non-cortical chert cores are overrepresented compared to non-cortical dominant (Figure 9.11C). Overrepresentation of non-cortical cores indicates high reduction of chert cores. It is possible that these results are due to preferential reduction of good quality rocks such as chert.

With respect to EF-HR cores, figure 9.12A shows overrepresentation of cortical dominant cores and underrepresentation of non-cortical dominant lava cores. Nonetheless, there is overrepresentation of non-cortical cores. This difference could be attributed to low reduction of lava materials. Figure 9.12B shows that there is underrepresentation of non-cortical dominant and overrepresentation of non-cortical quartzite cores. Explanation to why there is high frequency of non-cortical quartzite cores at EF-HR is challenging. It seems possible that hominins exploited rocks that

were available near the EF-HR. Contrary, however, there is evidence of high reduction of chert cores at EF-HR (Figure 9.12C). This high reduction intensity may be linked to distance of source of chert source, which required hominins to curate cores. Hence, high reduction of chert on site.

Another important finding on reduction intensity was measured on Toth's flake comparisons. At HWKEE, there is underrepresentation of type V flakes made of lava and quartzite whilst type V chert flakes appear in high frequency. Additionally, there is presence of flake types I-VI at the site, and were manufactured in all three major raw materials, except type III chert that seems non-existent (Figure 9.5). This finding broadly shows that hominins, at HWKEE, had an almost complete flake reduction sequence. This is somewhat similar to EF-HR, except there is high concentration of type VI flake in all raw materials with exception of type I, II and III quartzite flakes and types III and IV chert flakes (Figure 9.6). Thus, it could be argued that at HWKEE hominin might have used cores on site, whilst at EF-HR hominins used cores that were already reduced before transported to the site. Alternatively, hominins might have taken away the flakes for further use at other locations.

It is most likely that the size and weight of cores might have played a great role in understanding the level of technological skills and raw material selectivity. It is shown that at HWKEE lava cores are bigger and heavier than quartzite and chert cores (Figures 9.7 and 9.9). To some extent, this result corroborates with the findings of EF-HR, whereas lava cores are bigger than quartzite cores with exception of chert cores that are missing (Figures 9.8 and 9.10). It is possible, therefore, that the distance from raw material sources to sites might have affected the level of reduction intensity that can be revealed in cores' and flakes' sizes and weight (Blumenschine et al., 2008).

This pattern matches with that of other sites in eastern Africa where raw materials used for stone tool manufacture were available in the hominins vicinities (Stout et al., 2005; Goldman-Neuman and Hovers, 2012; de la Torre and Mora, 2018a).

It is also important to bear in mind that researchers explain that at Olduvai HWKEE hominins did not necessarily practice a great deal of raw materials selectivity compared to EF-HR where evidence show that hominins selected high quality of lava from the river beds for production of handaxes and other large cutting tools (de la Torre et al., 2017; de La Torre and Mora, 2018c; de la Torre and Mora, 2018a; McHenry and de la Torre, 2018b).

The present results are significant for this PhD in two respects. First, the experimental results provide a referential framework for comparisons with other Acheulean sites where small flake production is prevalent at Olduvai, as will be shown in the following chapter. Second, the results from HWKEE and EF-HR sites provide the most updated evidence of Oldowan and Acheulean hominins behaviour, and both influence this research broadly.

As shown above that the experimental models can be used to archaeological materials and produce important technological results, these models are applied to the understanding of archaeological materials. Therefore, the current investigation, which take these results into account, involves detailed analysis of FC, JK and WK materials to establish an explicit understanding of hominin behaviour at Olduvai and map the contribution of Beds II, III and IV materials in the wider understanding of Olduvai hominin technological skills.

9.5 Conclusion

The experimental study was designed to provide a comparative framework that could help in understanding hominin behaviour at Olduvai Gorge, Tanzania. Investigations of our ancestors behaviour through studies on technological organisation (Bamforth, 1986; Nelson, 1991), stone tools raw material (Andrefsky, 1994; Kuhn, 1991; Kuhn, 1992; Stout *et al.*, 2005) and lithic curation (Binford, 1979; Bamforth, 1986; Andrefsky, 2009) have influenced how hominin behaviour can be understood at Olduvai.

This chapter used experimental materials to compare the Oldowan (HWKEE) and Acheulean (EF-HR) archaeological assemblages excavated by OGAP (de la Torre and Mora, 2018a; de La Torre and Mora, 2018c). During the comparison, the relative frequency of various technological attributes was used as a proxy to understand archaeological materials and interpret hominin behaviour. The comparisons show that at HWKEE hominins did not employ advanced strategies for the procurement of raw materials and manufacturing stone tools. In particular, the reduction sequence shows a very low reduction intensity and presence of all types of Toth's flakes and large lava cores indicate that hominin procured locally available raw material. Hence, the availability of raw material within a short distance suggests that HWKEE hominins mostly practiced expedient technology as opposed to curation.

Although EF-HR exhibits two reduction sequences (small debitage and LCT productions), the comparisons have focused entirely on the small debitage assemblage. As discussed above (see discussion section) most of EF-HR and HWKEE flakes and cores have shown some similarities with regards to flaking techniques and raw material procurement. Hence, this suggests that even some Acheulean hominins employed simple and expedient technology. Therefore, it can be

concluded that experimental materials play a huge role in understanding hominins' decisions in raw material selectivity and stone tool reduction intensity and will potentially help in establishing an understanding of hominins technological behaviour in Beds II, III and IV at Olduvai Gorge, Tanzania.

9.6 Part 2: Comparison of experimental data and FC East, JK West, JK2, and WK assemblages

9.6.1 Introduction

This part compares experimental materials and archaeological materials analysed for this PhD study. It compares flakes and cores analysed from FC East, JK West, JK2, and WK site. Part 1 of this chapter compares experimental data with published archaeological data from HWKEE and EF-HR sites; this part seeks to understand how experimental data can be used to understand hominins technological skills from Acheulean sites in Beds II, III, and IV, an area of focus for this PhD study. Thus, it is crucial to understand how cores and flakes' technology from experimental data help us to understand the technology of the Acheulean hominins at Olduvai.

9.6.2 The sites of FC East, JK West, JK2 and WK, and experimental assemblage

Three sites were analysed for this PhD study. These are FC East, JK West, JK2, and WK site. Chapters 6, 7, and 8 provide detailed background of each site and their chronology. The experimental flakes and cores provide suitable technological data that is comparable to that of analysed archaeological assemblages. To have a holistic understanding of the Acheulean hominin technology, a comparative analysis of the results is worthwhile.

The comparison of the experimental assemblage with that of the FC East, JK West, JK2, and WK site will contribute to the wider understanding of technological behaviour of hominins at Olduvai Gorge throughout the archaeological sequence. Hence,

providing a holistic understanding of the technological behaviour of *Homo erectus* at Olduvai Gorge.

9.6.2.1 Whole flake comparisons

Whole flake comparisons focused on length classes, dorsal cortex coverage, and Toth's flake categories. These attributes are crucial in establishing an understanding of technology and more importantly the reduction intensity process of the hominins. Thus, the experimental flake length dimensions provide the expected length results of archaeological flakes from FC East, JK West, JK2, and WK. It should be noted that within the experimental assemblage, the major raw materials used were basalt and quartzite. Thus, the comparison focuses only on these two raw materials, respectively.

9.6.2.1.1 Length

Comparison of flake length was undertaken per raw materials (Figure 9.15A). As shown in 9.16A, there are significant variations of basalt flake length between the experimental and archaeological flakes. The adjusted residuals show that there is overrepresentation of FC East flakes measuring 20-39 mm, JK2 and WK flakes measuring 40-59 mm, and FC East and WK flakes measuring 60-79 mm (Appendix 9.29; figure 9.15A). Statistically, a significant variation is confirmed by a Chi-squared test result ($X^2 (9) = 47.156, p < .001$) (Appendix 9.29).

Quartzite flakes show predominance of flakes measuring 20-39 mm, with adjusted residuals showing overrepresentation of FC East flakes (Appendix 9.30; figure 9.15B). The Chi-Squared test results of quartzite flakes length class strongly supports the significant variation between experimental quartzite flakes length class and archaeological flakes length class ($X^2 (16) = 132.037, p < .001$) (Appendix 9.30).

Interestingly, quartzite flakes show underrepresentation of flakes measuring 40-59 mm, with adjusted residuals showing overrepresentation of experimental flakes (Appendix 9.30; figure 9.15B). The Chi-Squared test results of quartzite flakes length classes support those significant differences existing between experimental and archaeological quartzite flake length classes ($X^2(16) = 132.037, p < .001$) (Appendix 9.30).

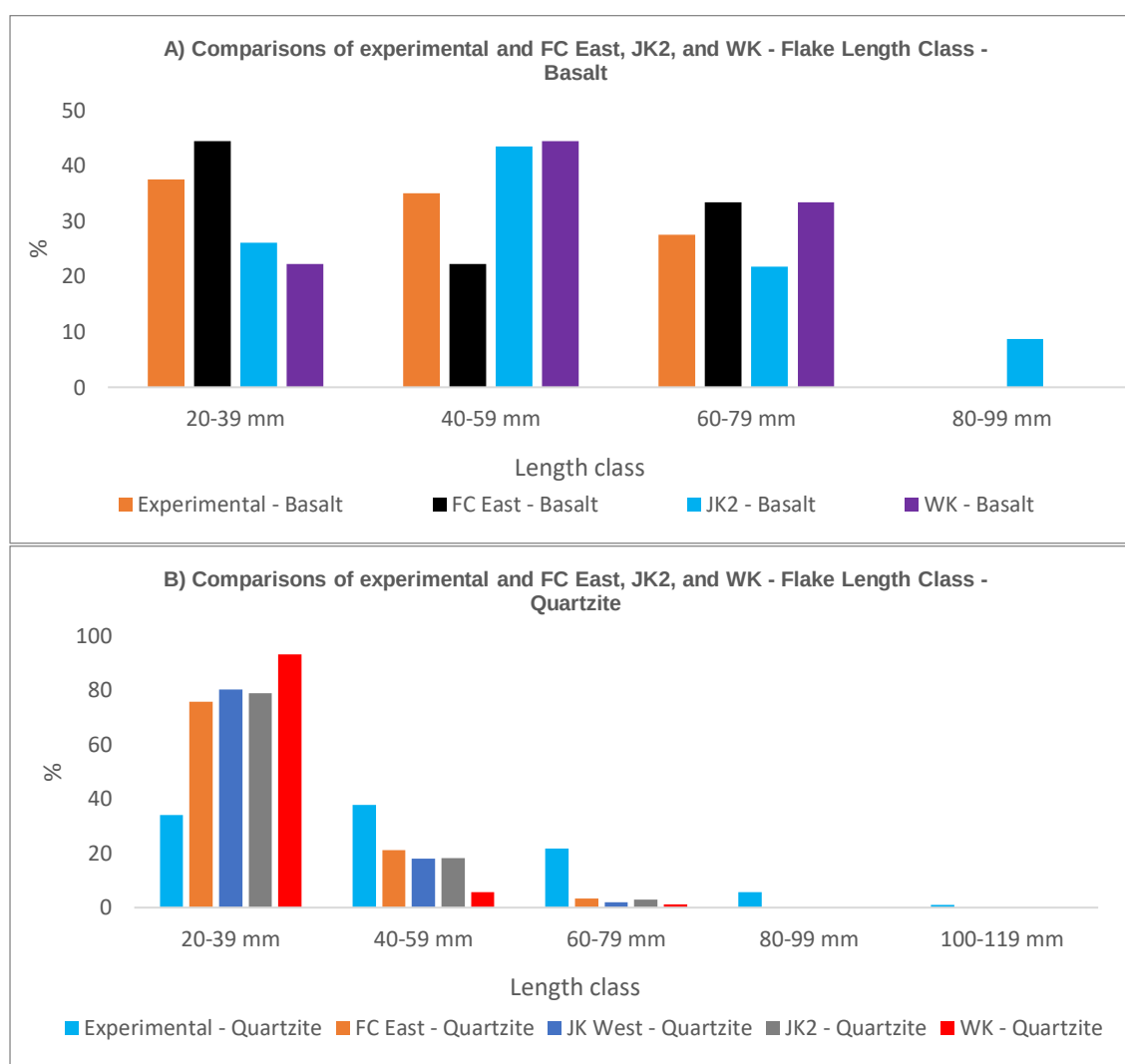


Figure 9. 15: A-B) Comparisons of length range between experimental and FC East, JK West, JK2, and WK flakes. A) Basalt raw materials; B) Quartzite raw materials.

9.6.2.1.2 Dorsal cortex

Comparison of flake dorsal cortex was performed per raw material (Figure 9.16). As can be seen in figure 9.16A, there is significant difference of basalt flake dorsal cortex between experimental and archaeological flakes. The adjusted residuals indicate that there is overrepresentation of FC East cortical (Cortex 100%) flakes (Appendix 9.31; figure 9.16A). Statistically, a significant variation is confirmed by a Chi-Squared test result ($\chi^2 (9) = 133.780, p < .001$) (Appendix 9.31). However, there is a significant underrepresentation of FC East and WK cortical dominant (cortex >50%) flakes. Interestingly, basalt flakes show predominance of non-cortical dominant (cortex <50%) FC East flakes, with adjusted residuals showing overrepresentation of FC East flakes (Appendix 9.31; figure 9.16A).

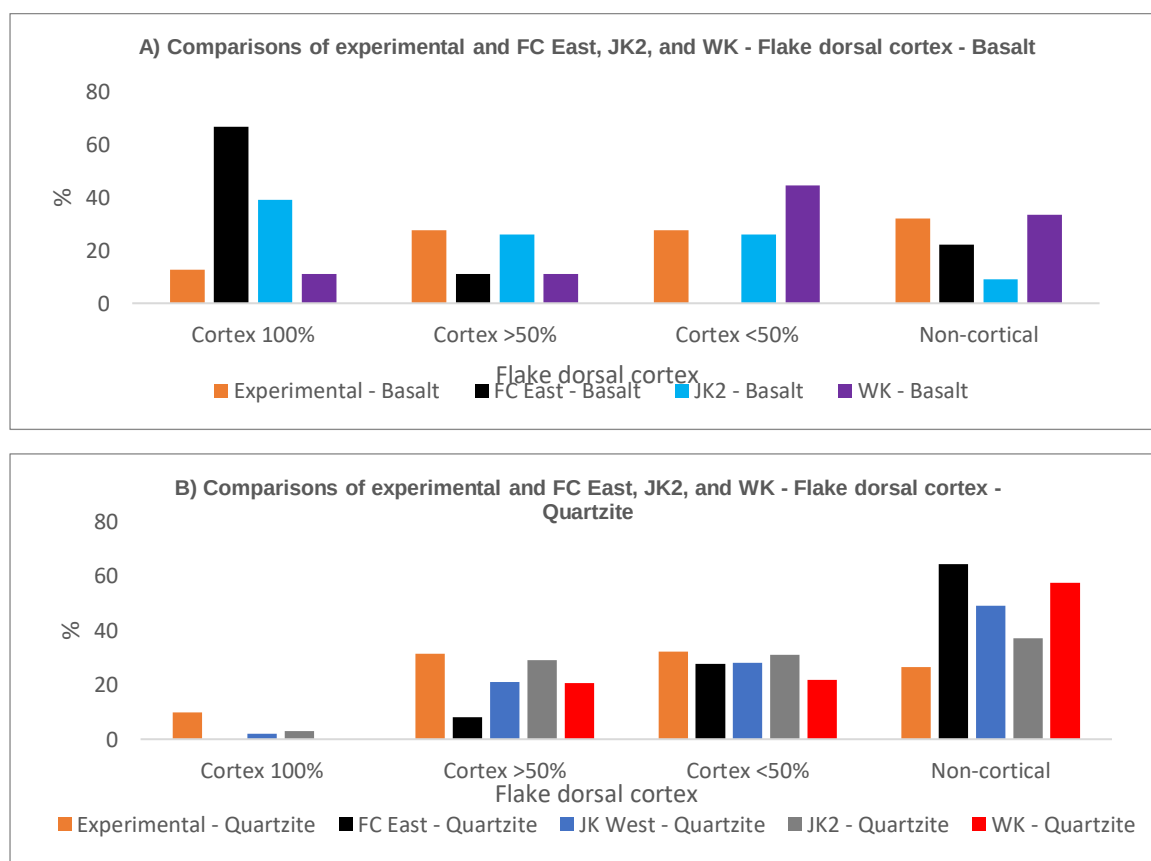


Figure 9. 16: A-B) Comparisons of dorsal cortex between experimental and FC East, JK West, JK2, and WK flakes. A) Basalt raw materials; B) Quartzite raw materials.

Furthermore, quartzite flakes dorsal cortex was undertaken (Figure 9.16B). Most quartzite flakes are non-cortical and non-cortical dominant. The Chi-Square test result indicates significant variation between experimental and all archaeological assemblages when considering quartzite flake dorsal cortex coverage ($X^2 (12) = 59.929, p < .001$) (Appendix 9.32). The adjusted residuals results show a significant overrepresentation of FC East non-cortical quartzite flakes, followed by WK flakes, JK West, and JK2 (Appendix 9.32; figure 9.16B).

9.6.2.1.3 Toth's flake types

Additional comparison of cortex involved Toth's flake types between experimental flakes and archaeological flakes (Figure 9.17). Figure 9.17A shows that the FC East Toth's types I flakes are significantly overrepresented between experimental and archaeological basalt flakes. In addition, basalt flakes with some cortex on the dorsal surface and non-cortical platform (types V) are strongly overrepresented from flakes from WK site. Similar results are observed amongst fully non-cortical flakes on the platform and dorsal surface (type VI) (Figure 9.17A). Statistically, there is significant variation in Toth's flake types within basalt raw material ($X^2 (15) = 225.344, p < .001$) (Appendix 9.33; figure 9.17A).

Analysis of quartzite flakes shows that there is significant variation between experimental and archaeological flakes ($X^2 (15) = 85.728, p < .001$) (Appendix 9.34; figure 9.17B). The adjusted residuals results highlight a significant overrepresentation of flakes with some cortex on the dorsal surface and non-cortical striking platform (type V) from JK2 and WK sites. More interesting, the adjusted residuals show a significant overrepresentation on non-cortical FC East, WK, and JK2 Toth's flake types (Appendix 9.34; figure 9.17B).

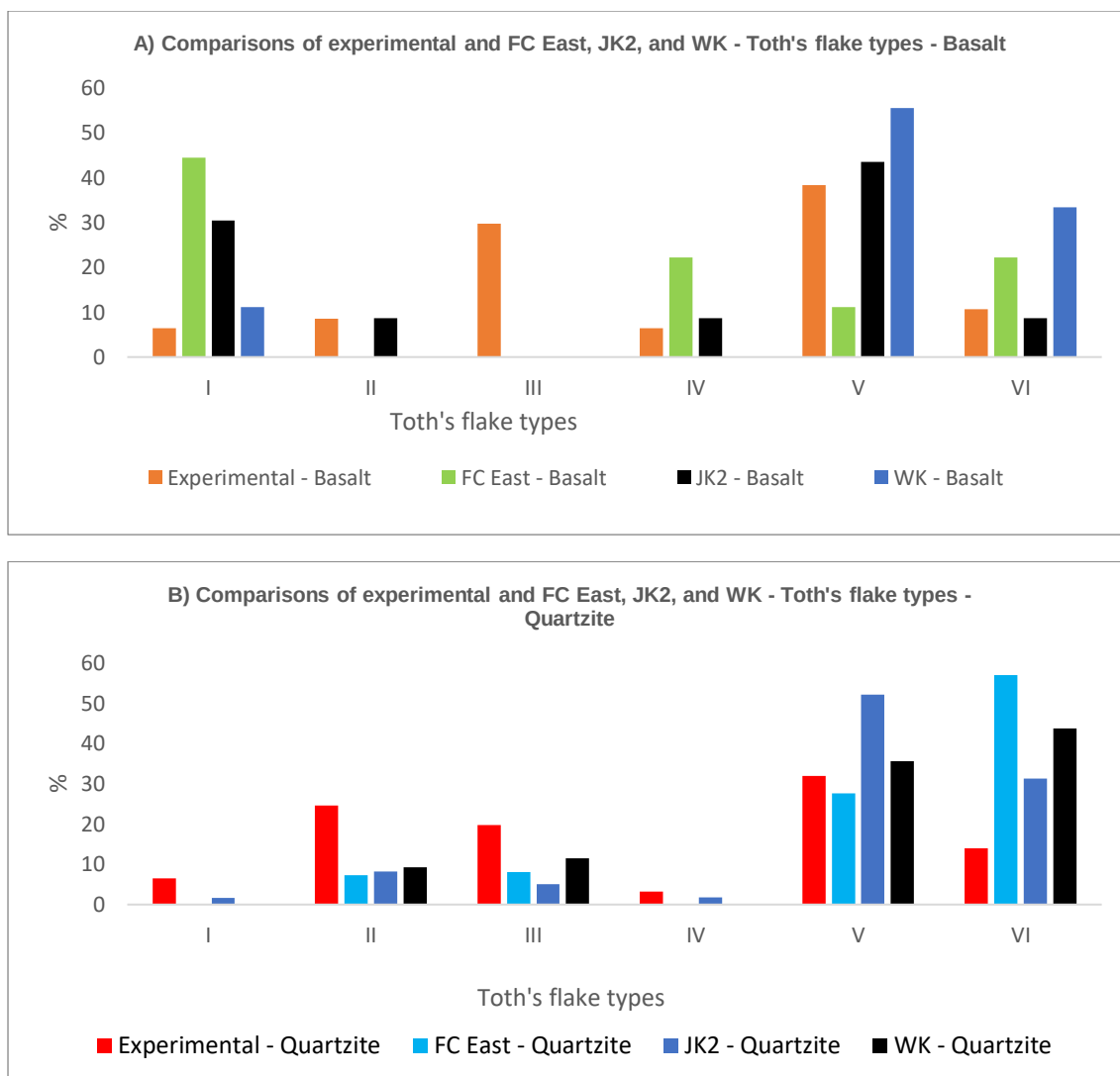


Figure 9. 17: A-B) Comparisons of Toth flake types between experimental and FC East, JK2, and WK flakes. A) Basalt raw materials; B) Quartzite raw materials.

9.6.2.2 Cores

Comparison of experimental and archaeological cores focused on four attributes: length class, weight, cortex, and number of flake scars.

9.6.2.2.1 Length

Comparison of core sizes of experimental and archaeological cores was undertaken per raw material used in the experimental assemblages. These are basalt and quartzite. Therefore, comparison focuses only on basalt and quartzite materials. As

can be seen in figure 9.18A, there is overrepresentation of JK West basalt cores that are in 80-99 mm, followed by FC East and JK2 basalt cores. In addition, there is overrepresentation of FC East basalt cores that are in 100-119 mm. However, there appears to be underrepresentation of JK2 basalt cores that are in 100-119 mm and 140-159 mm. Chi-Square test shows statistically significant differences in length class of basalt cores ($\chi^2(24) = 513.546, p < .001$) (Appendix 9.35; figure 9.18A).

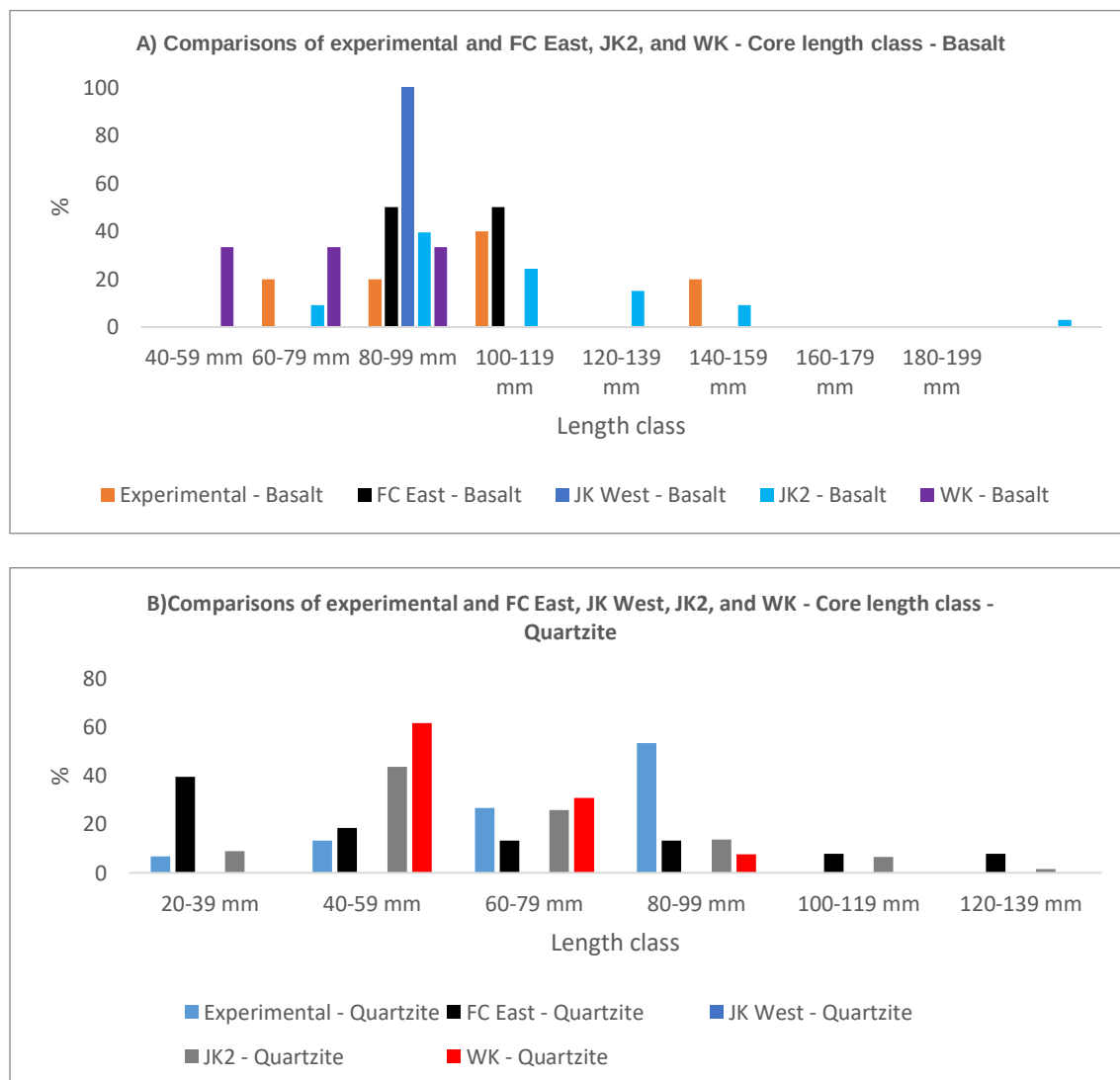


Figure 9. 18: A-B) Comparisons of core length class between experimental and FC East, JK West, JK2, and WK cores. A) Basalt raw materials; B) Quartzite raw materials.

As can be seen in figure 9.18B, there is overrepresentation of WK quartzite cores that are 40-59 mm, followed by JK2 and FC East quartzite cores. Additionally, there is

overrepresentation of FC East quartzite cores that are in 20-39 mm. However, there is underrepresentation of FC East cores that are in 60-79 mm. The Chi-square test result shows significant variation amongst quartzite cores in 80-99 and 100-119-mm length classes ($X^2(15) = 291.939, p < .001$) (Appendix 9.36; figure 9.18B).

9.6.2.2.2 Weight

As shown in figure 9.19A there is overrepresentation of FC East and JK2 basalt cores that are 201-400 grams. However, a substantial underrepresentation of JK2 basalt cores that are heavier than 800 grams. As it can be seen on figure 9.19A, most archaeological cores are between 101-200 and 401-800 grams, whereas the Chi-square test shows a statistically significant difference ($X^2(16) = 471.359, p < .001$) (Appendix 9.37; figure 9.19A).

Moreover, there is remarkable variation in quartzite ($X^2(20) = 245.263, p < .001$), with adjusted residuals highlighting overrepresentation of cores that are in 101-200 grams (Appendix 9.38; figure 9.19B). Weight comparison with FC East quartzite cores show significant differences with adjusted residuals showing a significant overrepresentation of cores that are in 401-800 grams (Appendix 9.38; figure 9.19B).

Moreover, there is statistically substantial variation in quartzite cores weight between experimental and archaeological samples ($X^2(20) = 245.263, p < .001$), with adjusted residuals showing underrepresentation of experimental cores that are in 401-800 grams (Appendix 9.38; figure 9.19B).

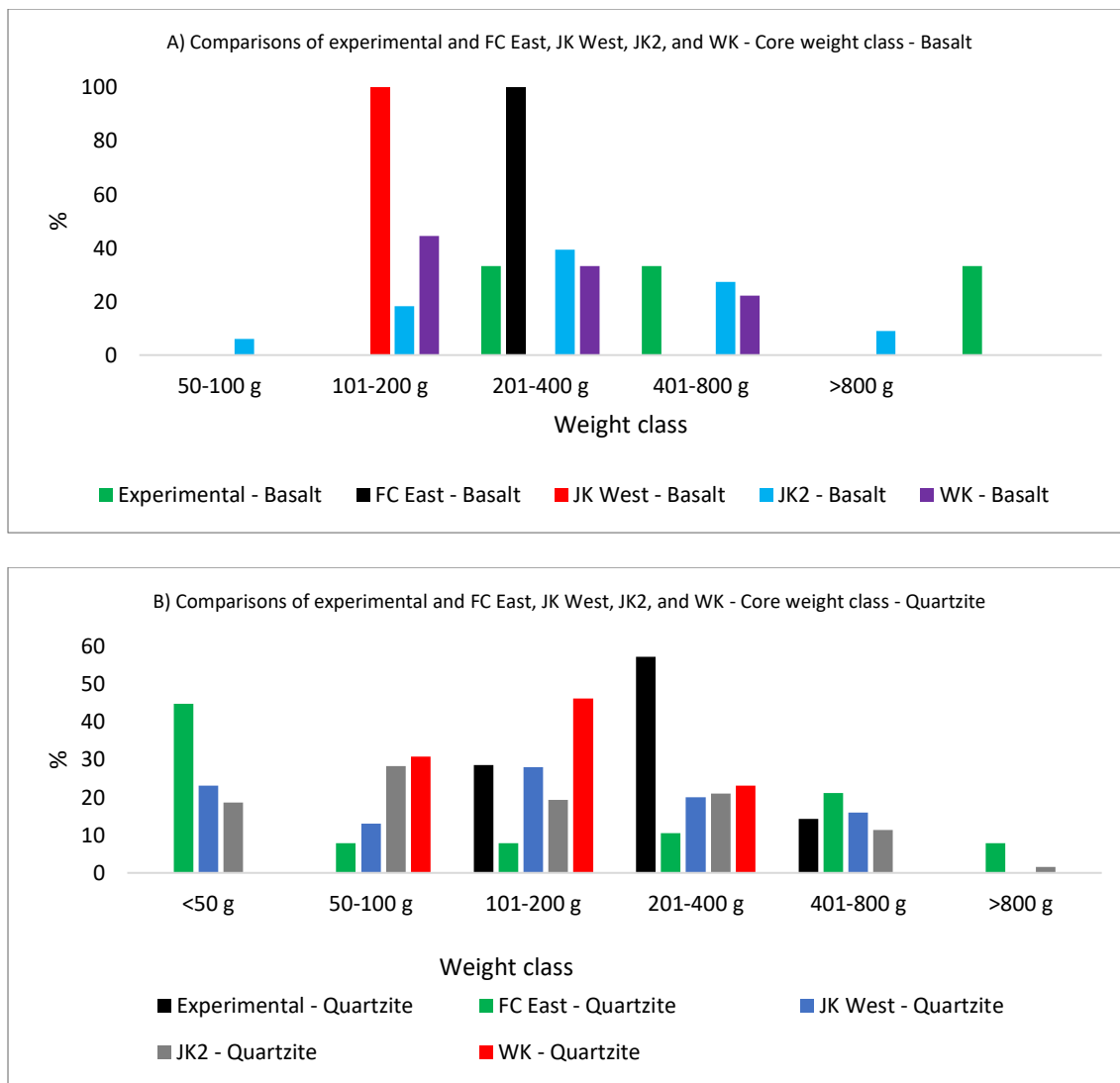


Figure 9. 19: A-B) Comparisons of core weight class between experimental and FC East, JK West, JK2, and WK cores. A) Basalt raw materials; B) Quartzite raw materials.

9.6.2.2.3 Cortex

Core cortex comparisons was undertaken to determine how experimental cores inform us about the reduction intensity of the archaeological cores. As shown in figure 9.20A most JK West basalt cores are non-cortical dominant than experimental. Similarly, there is overrepresentation of FC East and WK basalt cores that are non-cortical dominant. Furthermore, figure 9.20A shows that most JK2 basalt cores that are cortical dominant than experimental basalt cores; nevertheless, FC East and WK basalt cores

are significantly underrepresented. Therefore, the chi-square test confirms significant overrepresentation of non-cortical dominant JK West basalt cores and a significant underrepresentation of cortical dominant FC East and WK basalt cores ($\chi^2 (4) = 153.822, p < .001$) (Appendix 9.39; figure 9.20A).

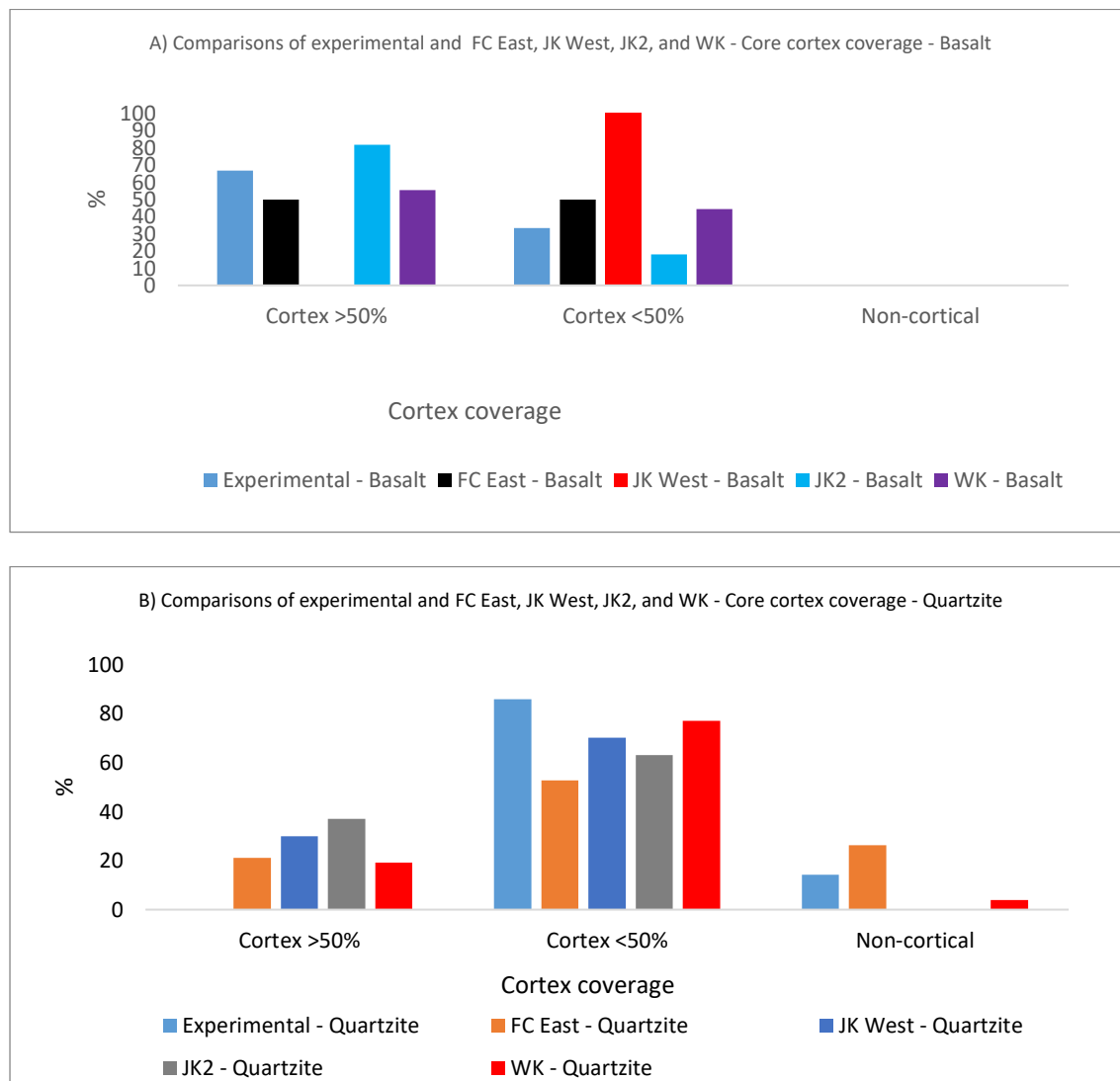


Figure 9. 20: A-B) Comparisons of core cortex coverage between experimental and FC East, JK West, JK2, and WK cores. A) Basalt raw materials; B) Quartzite raw materials.

Figure 9.20B shows that there is significant difference in quartzite cores that are non-cortical dominant and cortical dominant cores. In terms of cortical dominant cores, there is significant overrepresentation of JK2 cortical dominant quartzite cores; this is confirmed by the chi-squared test result ($\chi^2 (8) = 102.623, p < .001$) (Figure 9.20B).

The adjusted residuals show that there is significant underrepresentation of non-cortical dominant quartzite cores within FC East, JK West, JK2, and WK quartzite cores, whereas experimental cores remain the most pronounced (Appendix 9.40; figure 9.20B).

Generally, it is clear that the sites are predominated by cores that are non-cortical dominant, with significant interassemblage variations determined by raw materials utilised. Quartzite is the most predominantly used raw material, suggesting that it was most preferable, but the reduction level might have been influenced by its durability and versatility.

9.6.2.2.4 Number of scars

As shown in figure 9.21A there is significant overrepresentation of FC East basalt cores that preserve 4-6 scars. In addition, there is overrepresentation of JK West basalt cores that preserve >9 scars. This shows a statistically significant different reduction intensity in basalt cores ($X^2(12) = 474.662, p < .001$), with adjusted residuals highlighting a significant underrepresentation of JK2 basalt cores preserving nine or more scars (Appendix 9.41).

Figure 9.21B shows significant variation in reduction intensity between experimental and archaeological cores. Statistically, a significant variation in reduction intensity in quartzite materials ($X^2(12) = 86.702, p < .001$) is observed, with adjusted residuals highlighting a significant overrepresentation of WK quartzite cores that preserve 1-3 scars; additionally, there is overrepresentation of FC East, JK2, WK, and JK West quartzite cores that preserve 4-6 scars. Interestingly, however, there is a significant underrepresentation of FC East, JK2, WK, and JK West quartzite cores preserving 7-9 scars (Appendix 9.42; figure 9.21B).

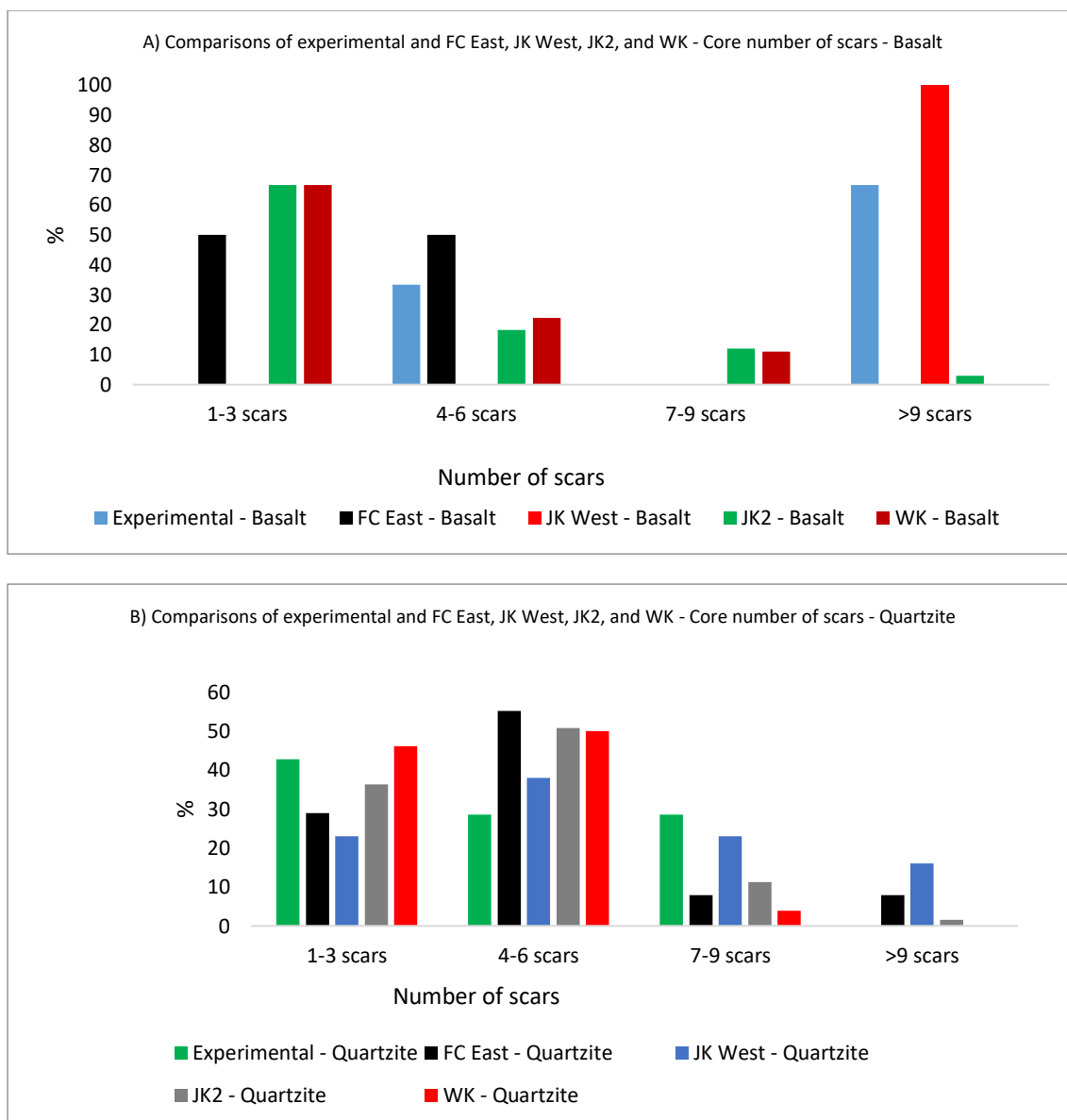


Figure 9. 21: A-B) Comparisons of core number of scars between experimental and FC East, JK West, JK2, and WK cores. A) Basalt raw materials; B) Quartzite raw materials.

Overall, it is evident that hominins at the sites utilised quartzite material more to manufacture flakes. This is seen in figure 9.21B, whereby quartzite was mostly used to manufacture 4-6 flakes per core. The level of quartzite reduction increased up to over nine scars per core. It can be suggested that despite the significant underrepresentation and overrepresentation of quartzite cores within the assemblage, quartzite material indicates that it was the most preferable raw material among all sites (Figure 9.21B).

9.7 Discussion and conclusion

Extensive research has shown that experimental materials are important in understanding archaeological materials (Jones, 1979, 1980, 1981; Toth, 1982, 1985). Different studies have shown the importance of raw material availability and reduction intensity (Kuhn, 1991; Braun et al., 2008a), lithic technological variations (Stout et al., 2005; Blumenschine et al., 2008; Goldman-Neuman and Hovers, 2012), raw material quality (Andrefsky, 2009) and the effects of distance between raw material source and the site in reduction intensity (Blumenschine et al., 2008).

In this study, results from experimental assemblage are used to establish an understanding of archaeological assemblages from FC East, JK, and WK site. Different technological attributes from experimental flakes and cores are compared with archaeological flakes and cores to understand hominin lithic technology. Each technological category was compared based on raw material type. Figure 9.16A shows that FC East, JK2, and WK hominins produced basalt flakes that are in 20-39 mm, 40-59 mm, and 60-79 mm length classes, respectively. This corroborates with the prediction of experimental basalt flakes (Figure 9.16A). However, experimental basalt flakes did not produce flakes that are in 80-99 mm in length. Additionally, figure 9.16B shows that FC East, JK West, JK2, and WK hominins manufactured quartzite flakes that are in 20-39 mm, 40-59 mm and 60-79 mm length classes. These results are consistent with the results from experimental quartzite flakes (Figure 9.16B).

In terms of flake dorsal cortex, reduction intensity was also compared. Figure 9.16A shows that hominins at FC East, JK2, and WK site produced basalt flakes with varied cortex coverage as predicted in the experimental assemblage results. However, there are significant differences, whereas there are more frequency of FC East and JK2

cortical flakes than expected (Figure 9.16A). Figure 9.16B shows that there is overrepresentation of non-cortical quartzite flakes from FC East, JK West, JK2, and WK site contrary to what was expected from the experimental quartzite flakes. Interestingly, non-cortical dominant quartzite flakes from FC East, JK West, JK2 and WK site produced almost exactly the same results as in the experimental flakes (Figure 9.16B). It should be noted that high frequency of non-cortical and non-cortical dominant quartzite flakes suggest an increase in the degree of reduction of quartzite material at these sites. In addition, hominins might have reduced core cortex before transporting raw materials to the site.

Another significant finding on reduction intensity was measured on Toth's flake comparisons. At FC East, JK2, and WK sites there is overrepresentation of types I and IV flakes made of basalt (Figure 9.17A). Additionally, there is overrepresentation of types V and VI basalt flakes from WK site. Moreover, there is significant overrepresentation of type V and VI quartzite flake from JK2 and WK sites (Figure 9.17B). However, there is a significant underrepresentation of types I, II, III, and IV quartzite flakes from FC East, JK2, and WK site (Figure 9.17B). Thus, it could be argued that hominins at these sites reduced cores on site, and produced different types of flakes.

It is clear that the size and weight of cores might have contributed to the understanding of the level of technological capacities and raw material economy of hominins. Figure 9.18A shows that most basalt cores are in 80-99 mm and 100-119 mm in length. The overrepresentation of basalt cores from JK West, FC East, and JK2 cores indicates that the experimental data produced results contrary to archaeological data. However,

there appears to be underrepresentation of JK2 basalt cores that are in 100-119 mm in length (Figure 9.18A).

As can be seen in figure 9.18B, there appears to be overrepresentation of WK, JK2, and FC East quartzite cores that are in 40-59 mm in length. Moreover, there is overrepresentation of FC East quartzite cores that are in 20-39 mm in length (Figure 9.18B). Furthermore, there is a substantial variation in quartzite cores that are in 80-99 mm and 100-119 mm in length (Figure 9.18B). Overall, these results suggest that the experimental data produced expected results with variations that may be associated with the core size and weight preferences of the hominins.

Figure 9.19A shows that most experimental cores are between 201-400 g and over 800 grams. There is significant overrepresentation of FC East and JK2 basalt cores that are 201-400 grams (Figure 9.19A). However, most archaeological cores are between 101-200 and 401-800 grams (Figure 9.19A). This suggests that the experimental data did not provide expected results, especially with the cores that are in 101-200 grams (Figure 9.19A). Furthermore, FC East quartzite cores show a significant variation, with overrepresentation of quartzite cores that are in 401-800 grams (Figure 9.19B). However, the experimental quartzite cores failed to represent cores that are < 50 and 50-100 grams, respectively (Figure 9.19B). It is possible that the experimental knappers selected slightly larger blanks than the hominins, whereas hominins selected all kinds of blank sizes ranging from <50 grams to >800 grams.

Another method of measuring the reduction intensity was to examine the cortex on cores. Figure 9.20A shows that majority of basalt cores at FC East, JK West, and WK site are non-cortical dominant and appear to be overrepresented compared to expected results. This suggests that low reduction intensity of basalt raw material took

place at these sites. Figure 9.20B shows underrepresentation of non-cortical dominant quartzite cores from FC East, JK West, JK2, and WK site. The overrepresentation of non-cortical dominant quartzite cores indicates low reduction intensity. Generally, it is clear that all sites are predominated by non-cortical dominant basalt and quartzite cores.

It is clear that core scar counts affected the level of reduction intensity. As shown in figure 9.21A there is overrepresentation of FC East basalt cores with 4-6 scar counts. However, there is underrepresentation of basalt cores with 1-3 scar counts. This indicates that experimental results lacked cores with 1-3 scar counts. As shown in figure 9.21B, there is significant variation in reduction intensity amongst quartzite experimental and archaeological cores. There is a significant overrepresentation of WK quartzite cores with 1-3 scars (Figure 9.21B). In addition, there is overrepresentation of FC East, JK West, JK2, and WK quartzite cores with 4-6 scars (Figure 9.21B). Generally, the archaeological results show that hominins utilised quartzite materials contrary to the results shown in experimental assemblage.

As shown above that the experimental models were used to predict archaeological results. The comparisons of both experimental and archaeological results (both published and unpublished) provided patterns and variations that are crucial in understanding hominin technological behaviour. The patterns suggest that the experimental materials aided in understanding hominin technological behaviour, whereas the variations suggest that the experimental data was partly unsatisfactory in providing the expected technological results.

The research used a techno-economic approach to explicitly analyse archaeological samples, which were then compared with experimental sample. The experimental data

reported in Chapter 4 were compared with archaeological samples (in this chapter) to determine the implications of experimental results for understanding hominin technological behaviour. To answer this study's major research questions, the next chapter discusses hominin technological behaviour based on the archaeological materials examined.

Chapter 10: Continuity and change in Acheulean debitage at Olduvai Beds II, III and IV: a comparison of the FC East, JK West, JK2, and WK assemblages

10.1 Introduction

This chapter brings together archaeological data collected from all assemblages studied (FC East, JK West, JK2, and WK) to investigate the technological behaviour of *Homo erectus* in Beds II, III, and IV of Olduvai Gorge.

To address one of the major research questions of this thesis, namely an assessment of the technological capabilities of Acheulean hominins, and whether or not stasis or technical change can be observed through the Olduvai Acheulean sequence a comparison of core exploitation between FC East, JK West, JK2, and WK will be presented. Statistical analysis of comparative results will be presented in order to understand core exploitation techniques of sites studied. Moreover, within cores, raw material types used, dimensions (length, width, weight), exploitation strategies, number of scars and cortex will be used to measure the level of reduction intensity and technological skills.

10.2 Core exploitation dynamics

10.2.1 General frequencies

In the analysed assemblages, a total of 190 cores were sampled from JK2, FC East 41 cores, JK West 88 cores, and WK 41 cores (see tables 6.5, 7.3, 8.2 in chapter 6, 7, and 8, respectively). These core counts do not include all cores from original excavations. It is worth noting that the author might have analysed more cores from

JK2 than in other sites. Thus, the frequency of core from each site does not represent the entire core sample excavated by the Leakeys or OGAP team. Figure 10.1 shows frequency of cores from different sites: JK West (22%), WK (22%), FC East (21%), and JK2 (17%). Within the flake category, the sample selected also varied. Like in cores, flakes' frequencies do not represent the analysis of all flakes, rather they represent a sample of flakes selected by the author. When considering frequency of flakes, there are no significant differences between sites, with FC East flakes making up to 70%, JK2 59%, WK flakes 54%, whereas JK West flakes 52% (Figure 10.1). Moreover, figure 10.1 indicates that JK West retouched pieces 26%, JK2 retouched pieces 24% and WK retouched pieces 24%, whereas FC East retouched pieces 9%.

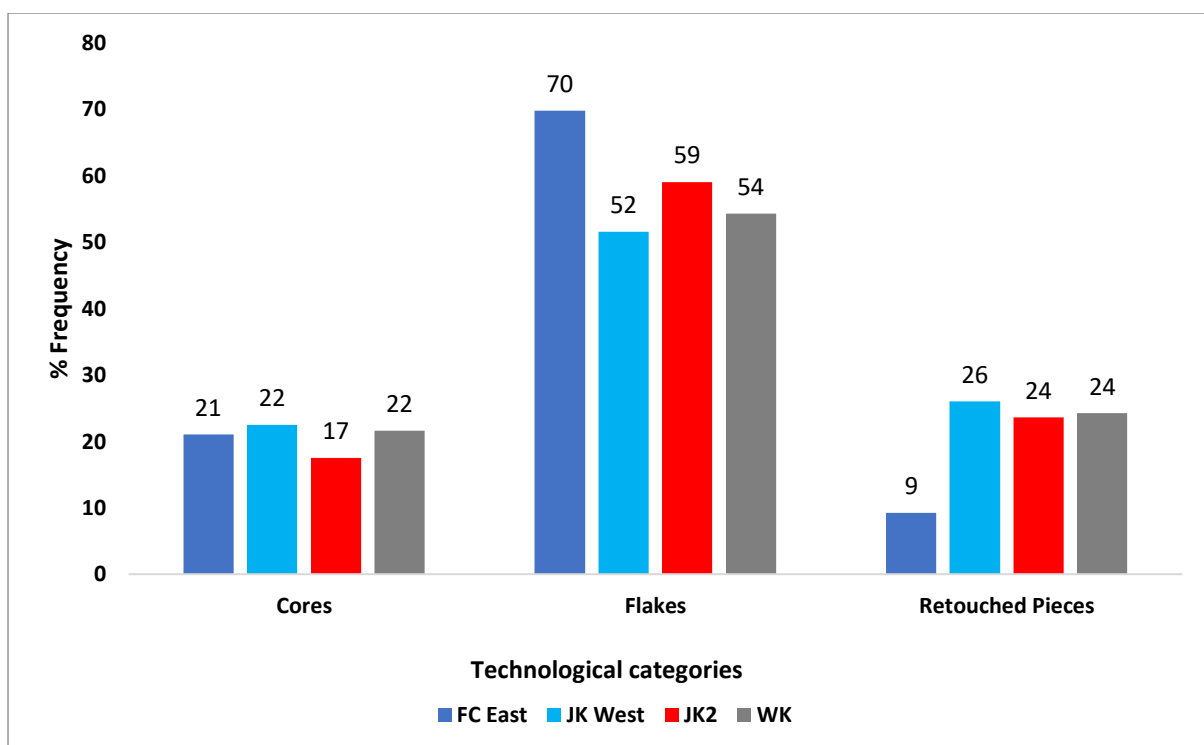


Figure 10. 1: Frequency of technological categories from FC East, JK West, JK2, and WK sites.

10.2.2 Raw Materials

All assemblages contain raw materials from various sources of the Olduvai Gorge. Although the sites utilised different types of raw materials such as basalt, quartzite, quartz, trachyte, and trachyandesite, the following comparison focuses only on raw materials that exist on all sites, namely basalt, quartzite, phonolite and trachyte. Figure 10.2 shows that the most prevalent raw material is quartzite, with FC East site showing prevalence, followed by JK West, JK2, and WK being the least prevalent. These findings show that hominins preferred quartzite raw material than other raw material such as basalt, phonolite, and trachyte.

It is worth noting that the quartzite raw material was abundant and versatile for various purposes during the prehistoric times. Interestingly, the correlation between raw materials' relative representation shows that quartzite was mostly used during the early Acheulean times (for example, FC East), and decreased as you go up in the sequence (for example, WK site). The increase of non-quartzite raw materials was associated with technological and raw material factors.

Raw material properties played a crucial role in raw material selectivity during Beds III and IV times. Figure 5.10A-B shows that most raw materials available were angular and sub-spheroid, making them suitable for knapping activities. In addition, figure 5.10C-D shows most lava cobbles had fine-grained groundmass. Hence, preferential for stone tool manufacture. Moreover, distance from the source to the site might have contributed to the increase of the use of lava materials in Beds III and IV sites (Figure 5.4). It should be noted that many analysed lava blanks in Beds III and IV have fluvial origin, and therefore were not procured from the primary sources, but rather procured from river beds.

In terms of technology, factors such as size, sphericity of the blank, and morphology played a crucial role in the preference of lava materials. Raw material study conducted shows that most cobble size ranged between 100-119 mm, with angular and sub-spheroid characteristics (Figures 5.12A-B; table 5.5). These features were suitable for flake production, particularly those of lava materials analysed. However, it should be noted that these are results from the sampled data; it does not necessarily imply that hominins abandoned the use of quartzite for stone tool production.

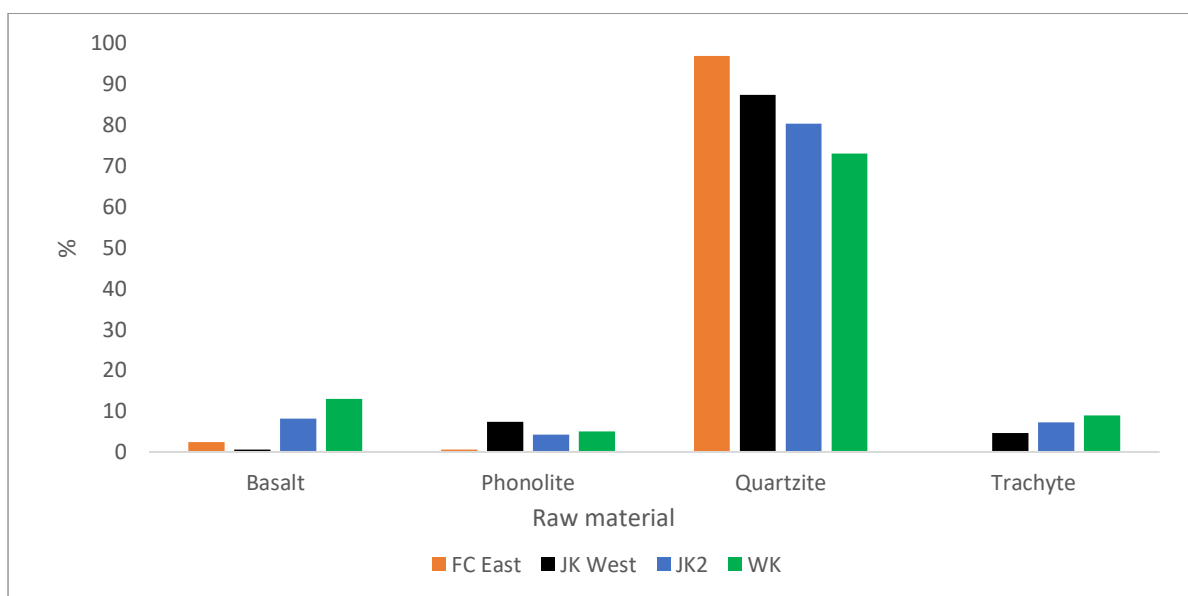


Figure 10. 2: Comparison of all raw materials used at all analysed sites.

10.2.3 Core dimensions

In assessing the level of reduction amongst cores, the dimensions were compared to understand core size.

10.2.3.1 Length

Comparison of core sizes of all sites were performed per raw material (Figure 10.3). As can be seen in figure 10.3A, there is overrepresentation of JK West basalt cores

that are in 80-99 mm, followed by FC East and JK2 basalt cores, whilst WK basalt cores appear to be least predominant. Chi-squared test shows a statistically significant difference in length class of basalt cores ($\chi^2(15) = 249.448, p < .001$) (Appendix 10.2).

As shown in figure 10.3B, there is predominance of quartzite cores that are in 40-59 mm length class, with WK quartzite cores being the most predominant, followed by JK2 and JK West quartzite cores, whilst FC East quartzite cores being the least frequent. The Chi- squared test result shows significant variations amongst quartzite cores in 60-79 mm and 80-99 mm length classes ($\chi^2 (15) = 110.581, p < .001$) (Appendix 10.3; figure 10.3B).

There are also variations in phonolite cores that are in 60-79 mm and 80-99 mm (Figure 10.3C). What is striking is that there are no cores made of phonolite within the FC East assemblage (Figure 10.3C). The chi-squared test result shows a statistically significant variation ($\chi^2 (8) = 193.921, p < .001$) (Appendix 10.4). The adjusted residuals highlight a significant representation of WK phonolite cores that are in 60-79 mm length class. In addition, the adjusted residuals show a significant statistical overrepresentation of JK2 phonolite cores that are in 80-99 mm length class (Appendix 10.4; figure 10.3C).

Furthermore, trachyte cores appear mostly within 60-79 mm and slightly in 80-99 mm and 100-119 mm length class (Figure 10.3D). As shown in figure 10.3D, there is predominance of WK trachyte cores that are in 60-79 mm, followed JK2 trachyte cores, whereas JK West trachyte cores being least represented. The chi-squared test result shows a statistically significant difference ($\chi^2 (8) = 146.768, p < .001$) (Appendix 10.5), with adjusted residuals showing majority of WK trachyte cores that are in 60-79 mm length class are overrepresented compared to JK2 and JK West trachyte cores.

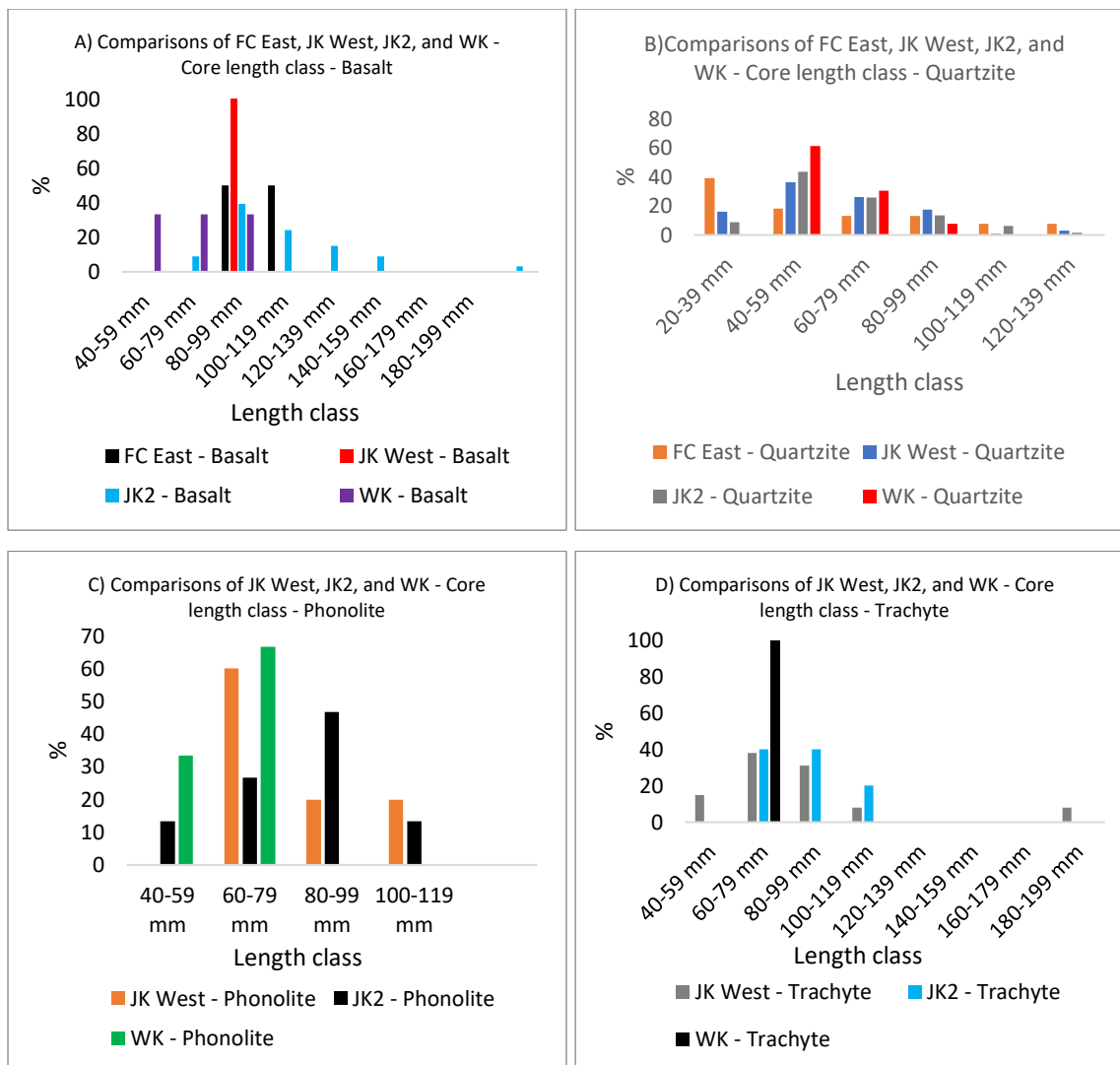


Figure 10. 3: A-D) Comparisons of length range between FC East, JK West, JK2, and WK cores. A) Basalt; B) Quartzite; C) Phonolite; and D) Trachyte.

10.2.3.2 Width

There are differences in core width between sites (Figure 10.4, appendices 10.6-10.9). As shown in Figure 10.4A, the majority of basalt cores are in the 40-59 mm in width, followed by the 60-79 mm width class, while the minority of basalt cores are in the 80-99 mm and 100-119 mm width classes and are from one site, JK2 (Figure 10.4A), with the four sites showing statistically significant differences ($X^2 (9) = 185.976, p < .001$) (Appendix 10.6).

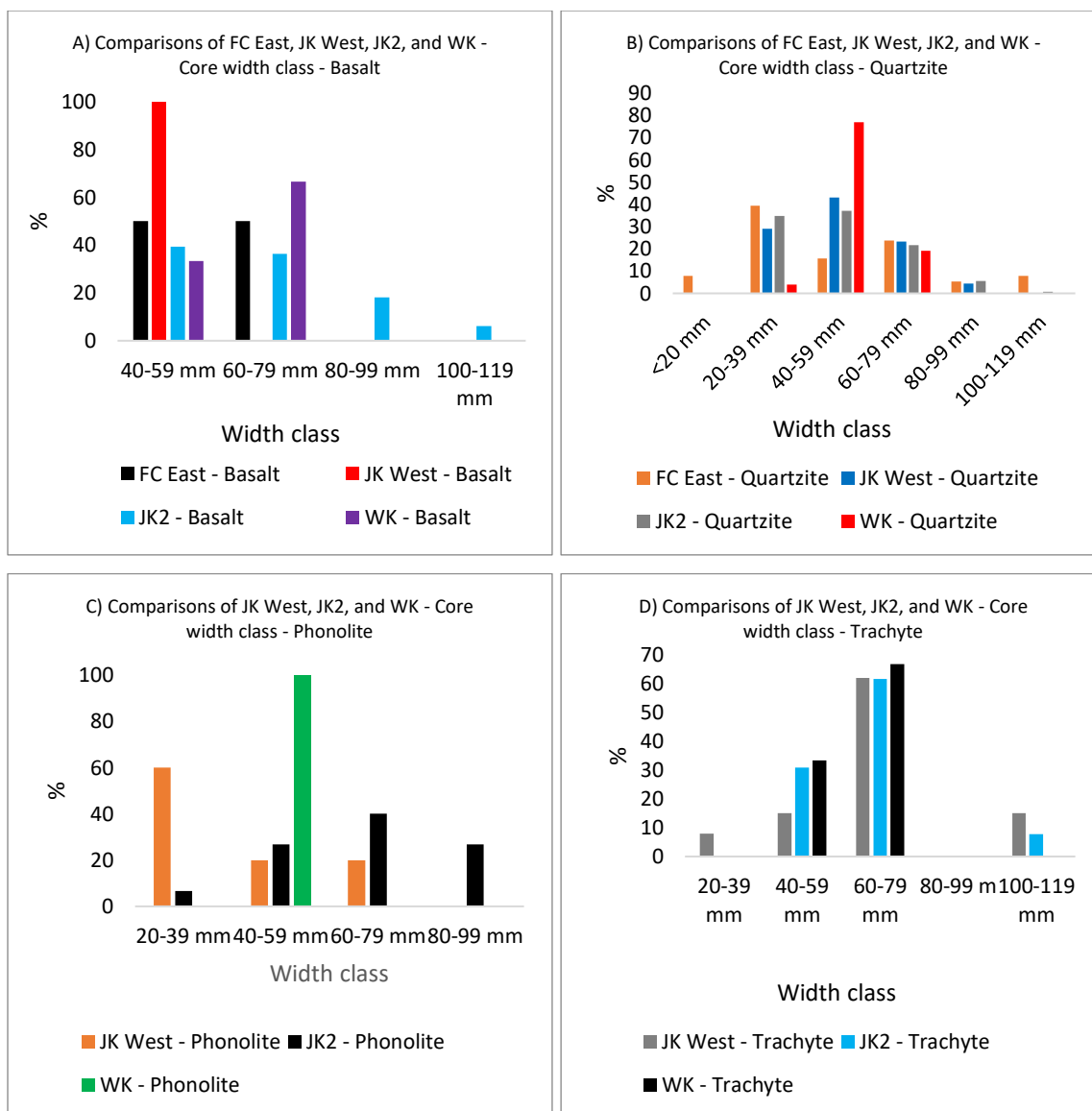


Figure 10. 4: Comparisons of width classes between FC East, JK West, JK2, and WK cores. A) Basalt; B) Quartzite; C) Phonolite; and D) Trachyte.

This also applies to quartzite width classes across all sites (Figure 10.4B), where differences are significant ($X^2 (15) = 122.112, p < .001$) (Appendix 10.7). Majority of quartzite cores are in 40-59 mm width class, with WK quartzite cores being the most predominant, followed by JK West quartzite cores, JK2 quartzite cores, whereas FC East quartzite cores being least represented (Figure 10.4B).

Furthermore, phonolites differ statistically between sites: most cores fall into the 40-59 mm and 60-79 mm width classes (Figure 10.4C), with significant differences ($X^2 (6)$

= 270.647, $p < .001$) (Appendix 10.8). This also applies to trachyte cores width classes (Figure 10.4D), where differences are significant ($X^2(6) = 38.436$, $p < .001$) (Appendix 10.9), thus supporting observations on the wider dimensional pattern of cores within FC, JK West, JK2 and WK.

10.2.3.3 Weight

The core weight of each site was also examined to determine the amount of weight transported to each site (Figure 10.5). As shown in figure 10.5A, most basalt cores are in the 101-200g weight class, followed by 201-400g and 401-800g weight classes. Within the weight class of 101-200g, there is predominance of JK West basalt cores, followed by WK basalt cores, whereas JK2 basalt cores are the least represented; no FC East basalt cores are represented in this weight class. In addition, within the weight class of 201-400g, there is predominance of FC East basalt cores, followed by JK2 and WK basalt cores; JK West basalt cores are not represented. This inter-assemblage variation of core weight classes is supported by the Chi-Squared test result, that shows a significant difference ($X^2(12) = 355.986$, $p < .001$) amongst weight ranges of different sites (Appendix 10.10).

In addition, the majority of quartzite cores from all sites appear mostly in 50-100g, 101-200g, and 201-400g classes (Figure 10.5B). What is interesting is that WK quartzite cores only appear in the medium weight classes (50-100g, 101-200g, and 201-400g). This may suggest that most quartzite cores at WK site were not heavily reduced to minimal weights, suggesting expedience strategy. The chi-square test shows a statistically significant difference amongst sites ($X^2(15) = 138.178$, $p < .001$) (Appendix 10.11). This indicates that there is an interassemblage variation of quartzite core weight among the sites.

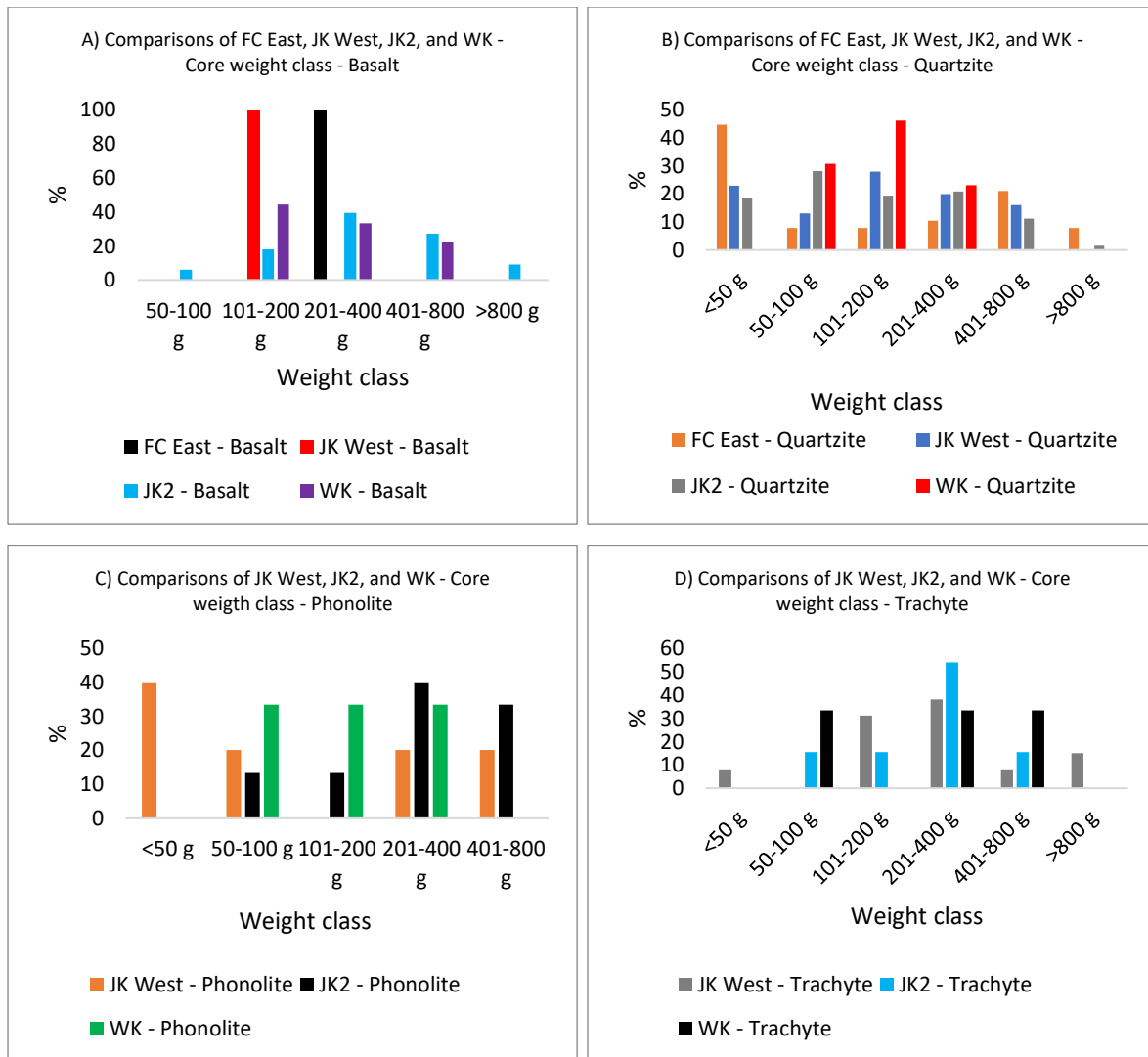


Figure 10. 5: Comparisons of weight class between FC East, JK West, JK2, and WK cores. A) Basalt; B) Quartzite; C) Phonolite; and D) Trachyte.

Moreover, there is a remarkable variation of phonolite cores ($\chi^2 (8) = 163.145$, $p < .001$), with adjusted residuals showing overrepresentation of WK phonolite cores that are in the 50-100 g and 101-200 g classes, whereas a slight underrepresentation is seen in 201-400g (Appendix 10.12, figure 10.5C). Interestingly, similar results are seen as in WK basalt cores; WK phonolite cores only appear in 50-100g, 101-200g, and 201-400g classes.

Furthermore, weight class comparison between sites shows a significant difference in trachyte materials ($\chi^2 (10) = 134.825$, $p < .001$), with adjusted residuals showing a

significant overrepresentation of JK West and WK trachyte cores that are in 101-200g and 201-400 g (Figure 10.5D; appendix 10.13). However, there appears to be predominance of WK trachyte cores that are in 401-800g weight class, followed by JK2 trachyte cores, whilst JK West trachyte cores being least represented. There are no FC East trachyte cores in this weight range.

10.2.4 Cortex

Comparison of cores also focuses on reduction intensity among sites. This was explored via cortex coverage observed on cores. As shown in figure in figure 10.6A, most JK2 basalt cores are cortical-dominant, followed by WK and FC East cores, whereas JK West non-cortical dominant basalt cores are more frequent than FC East, WK, and JK2 respectively (Figure 10.6A). The chi-square test shows a statistically significant difference in basalt raw materials ($X^2 (3) = 141.469, p < .001$), with adjusted residuals showing underrepresentation of non-cortical dominant FC East, JK2, and WK basalt cores (Appendix 10.14).

In addition, figure 10.6B shows that most quartzite cores are non-cortical dominant, whereas WK quartzite cores appear to be the most frequent, followed by JK West, JK2 quartzite cores, whilst FC East being the least represented. In terms of cortical dominant cores, figure 10.6B shows that most JK2 quartzite cores are the most frequent, followed by JK West, FC East and WK quartzite cores, respectively. In terms of non-cortical cores, the most frequent is FC East quartzite cores, followed by WK quartzite cores; JK2 and JK West are not represented. The quartzite cores' variations are supported by chi-square test results that shows a statistically significant difference in cortex coverage of cores ($X^2 (6) = 74.857, p < .001$) (Appendix 10.15).

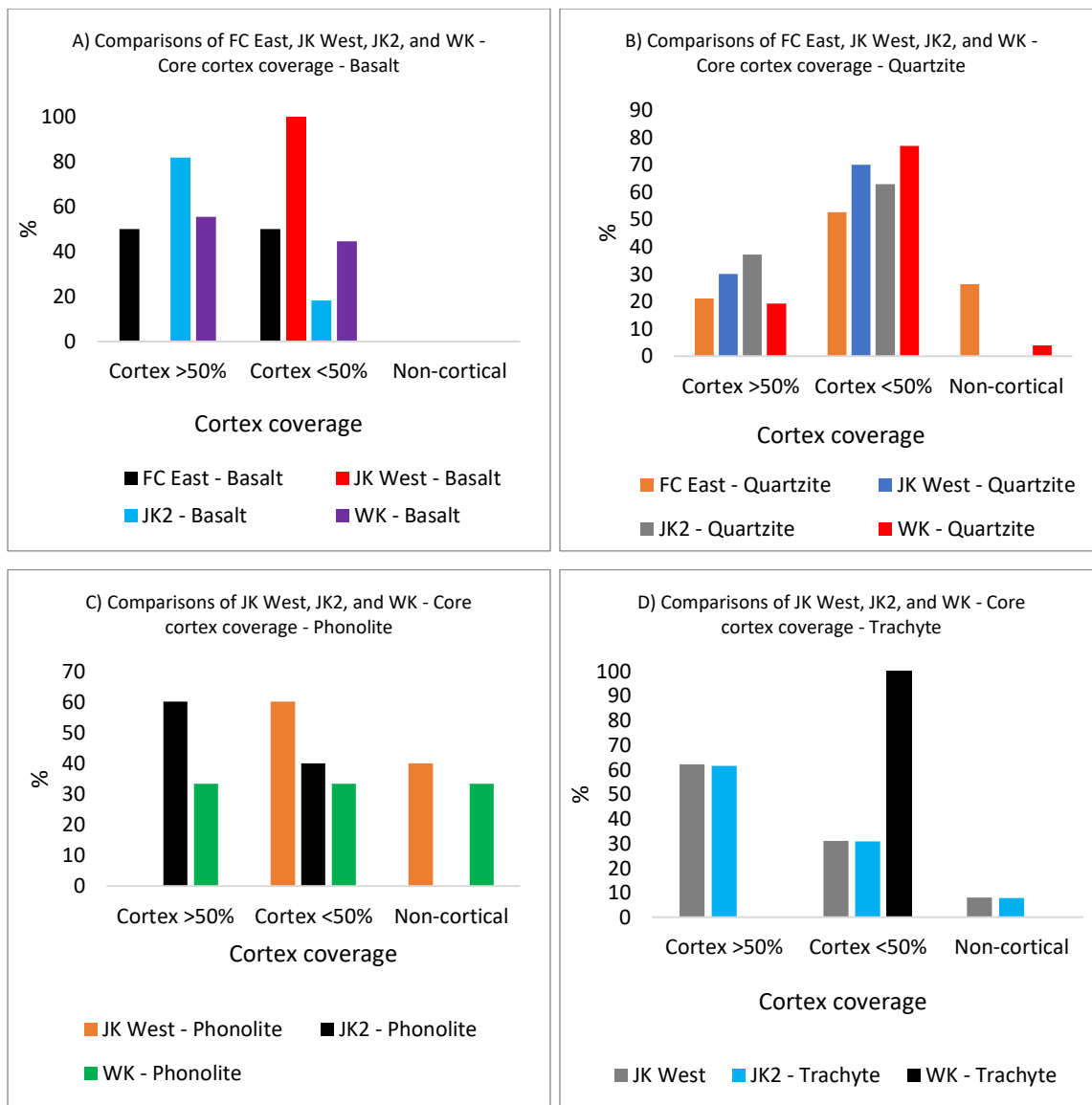


Figure 10. 6: Comparisons of cortex coverage between FC East, JK West, JK2, and WK cores. A) Basalt; B) Quartzite; C) Phonolite; and D) Trachyte.

Moreover, figure 10.6C shows that JK West phonolite cores are mostly non-cortical dominant. In terms of cortical-dominant cores, JK2 phonolite cores are the most frequent, followed by WK phonolite cores. Non-cortical cores are predominated by JK west phonolite cores, followed by WK phonolite cores (Figure 10.6C). The chi-squared test result shows statistically significant differences of phonolite core cortex among sites ($X^2(4) = 104.328, p < .001$) (Appendix 10.16).

Furthermore, as shown in figure 10.6D cortical dominant cortex ratios are similar at JK West and JK2 trachyte cores, whereas non-cortical dominant WK trachyte cores appear more frequently than JK West and JK2 trachyte cores. Regarding non-cortical trachyte cores, JK West and JK2 cores appear in similar frequencies, whereas WK trachyte cores are absent (Figure 10.6D). Observed differences are statistically significant ($X^2 (4) = 129.202, p < .001$) (Appendix 10.17).

10.2.5 Number of scars

The number of flake scars preserved on FC East, JK West, JK2, and WK cores can be used to compare reduction intensity. As shown in figure 10.7A, the majority of basalt cores preserve 1-3 scars and 4-6 scars, and only a few preserve 7-9 and >9 removals. Figure 10.7A and appendix 10.18 show basalt reduction intensity patterns across sites, which is statistically significant ($X^2 (9) = 431.330, p < .001$). The same applies to quartzite cores whereby most of them preserve 1-3 scars and 4-6 scars, and a few preserving 7-9 and over 9 scars (Figure 10.7B). The chi-square test shows a significant variation among sites ($X^2 (9) = 53.390, p < .001$) (Appendix 10.19).

Phonolite cores show a slightly contrary result: the majority of cores preserve 1-3 scars, with WK phonolite cores being the most frequent, followed by JK2 phonolite cores, while JK West phonolite cores being marginally represented (Figure 10.7C). The chi-square test shows a statistically significant variation ($X^2 (6) = 159.933, p < .001$) (Appendix 10.20). The prevalence of phonolite cores with a small number of scars could be linked to low reduction than other raw materials. In the case of quartzite (Figure 10.7B) and trachyte (Figure 10.7D), the high frequency of cores representing medium to high reduction could be linked with the dominance of raw materials.

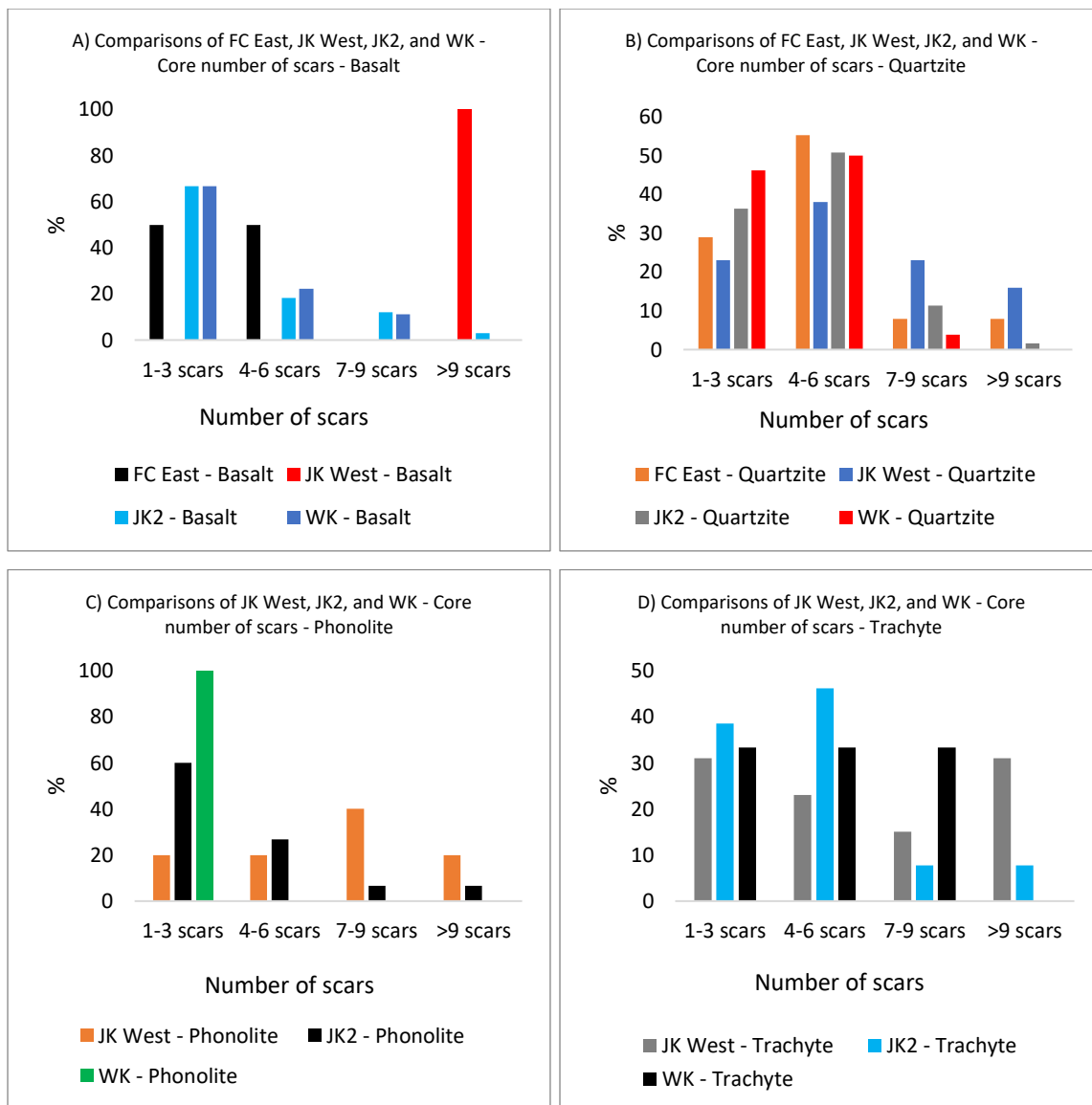


Figure 10.7: Comparisons of core number of scars between FC East, JK West, JK2, and WK cores. A) Basalt; B) Quartzite; C) Phonolite; and D) Trachyte.

Furthermore, figure 10.7D shows that most JK2 trachyte cores preserve 1-3 scars and 4-6 scars, whilst fewer preserve 7-9 scars and over 9 removals. The same is applicable to WK trachyte cores that appear to also preserve 1-3 scars and 4-6 scars, except there is predominance of WK trachyte cores that preserve 7-9 scars (Figure 10.7D). This shows a statistically significant difference in reduction intensity in trachyte raw material ($\chi^2(6) = 66.271, p < .001$), with adjusted residuals highlighting a significant inter-assemblage variation of trachyte cores with various numbers of flake scars (Appendix 10.21).

10.3 Flaking schemes

Core exploitation schemes are reported to reveal different strategies employed by hominins during core exploitation. All sites yielded different exploitation techniques that appear in different numbers and frequencies. As shown in table 10.1, basalt test cores (n=16, 35.6%) are the most prevalent, followed multifacial basalt cores (n=9, 20%), BSP basalt cores (n=5, 11.1%), USP (n=4, 8.9%), BALP (n=4, 8.9%), discoids (n=3, 6.7%), whereas others such as UAU1 (n=2, 4.4%), UAU2 (n=1, 2.2%) and UAB1 (n=1, 2.2%) being the least frequent (Table 10.1, figure 10.8). In addition, figure 10.8 shows that there is predominance of quartzite multifacial (n=101, 39.1%) flaking scheme, followed by discoids (n=30, 11.6%), test cores (n=21, 8.1%), whereas others being the least frequent (Table 10.1). Moreover, figure 10.8 shows that there is predominance of phonolite multifacial cores (n=9, 39.1%), followed by test cores (n=6, 26.1%), whereas others being the least prevalent (Table 10.1). Furthermore, table 10.1 and figure 10.8 show that there is predominance of trachyte test cores (n=11, 32.4%), followed by BSP (n=7, 20.6%), discoids (n=5, 14.7%), whilst other flaking schemes being less prevalent.

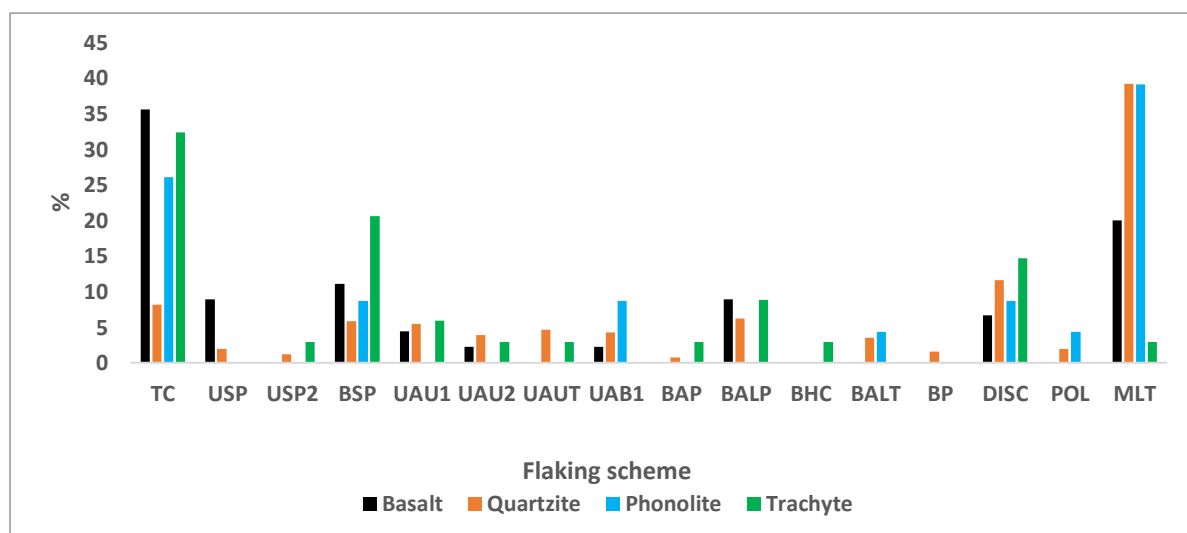


Figure 10. 8: Core flaking schemes of all sites per raw material.

With regards to exploitation scheme per raw materials, there are significant differences between different techniques employed at the sites. The comparison of flaking techniques was undertaken per raw materials; results from all sites were compared to determine different flaking techniques exhibited through the Acheulean hominins sequence. At FC East, the most prevalent flaking techniques are BALP (n=9, 22%) and multifacial (n=9, 22%) (Figure 10.9A; table 10.2), with quartzite (n=8, 21%) being the most prevalent raw material (Table 10.2). At JK West, multifacial (n=34, 29%) core flaking technique is the most predominant (table 10.3, figure 10.10A); in absolute terms, quartzite appears to be more abundant than other raw material (Table 10.3). In addition, figure 10.10B shows prevalence of multifacial flaking technique followed by testcore, whereas other flaking techniques appear to be less prevalent (Table 10.3). At JK2, the most prevalent flaking techniques are multifacial (n=57, 30%), followed by testcores (n=37, 19%), and BSP (n=20, 11%); other flaking techniques are marginally represented (Figure 10.11A, table 10.4). Within testcores, basalt appears to be the most prevalent raw material, followed by trachyte, and phonolite, whereas quartzite appears to be less prevalent (Figure 10.11B). Despite being less prevalent within testcores, quartzite appears to be the most predominant within multifacial technique, followed by phonolite, whereas basalt being left far behind (Figure 10.11B). Furthermore, WK flaking techniques are predominated by multifacial (n=20, 49%), followed by discoids (n=16, 39%), whereas other techniques are less prevalent (Figure 10.12A; table 10.5). Within discoids, trachyte is the most prevalent, followed by quartzite and phonolite, whereas basalt being the least prevalent (Figure 10.12B). However, within multifacial, basalt appears to be the most predominant, followed by quartzite, whereby phonolite being the least prevalent (Figure 10.12B).

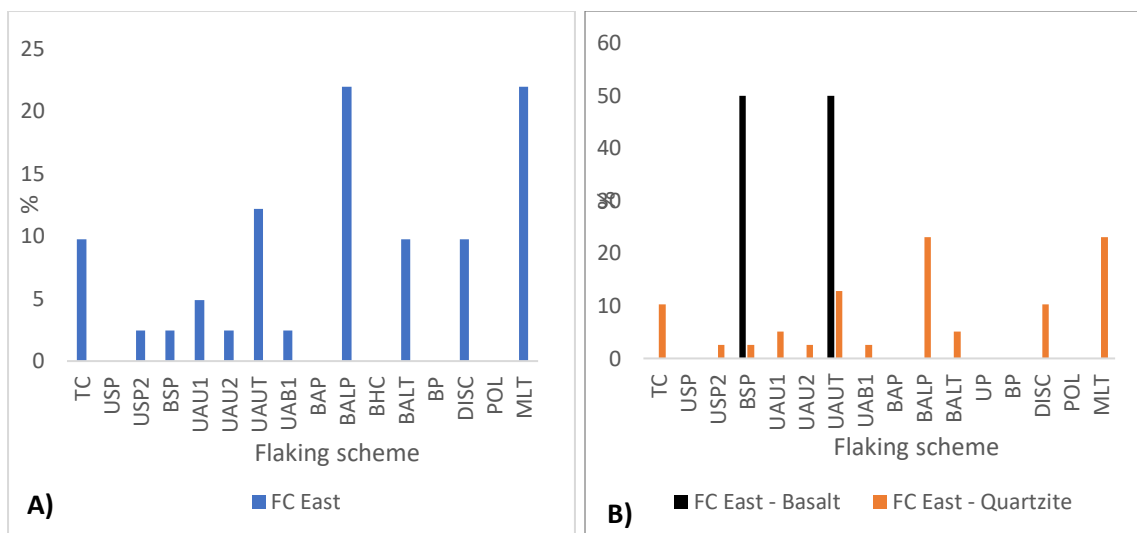


Figure 10. 9: FC East core flaking schemes. A) all flaking schemes; B) per raw material.

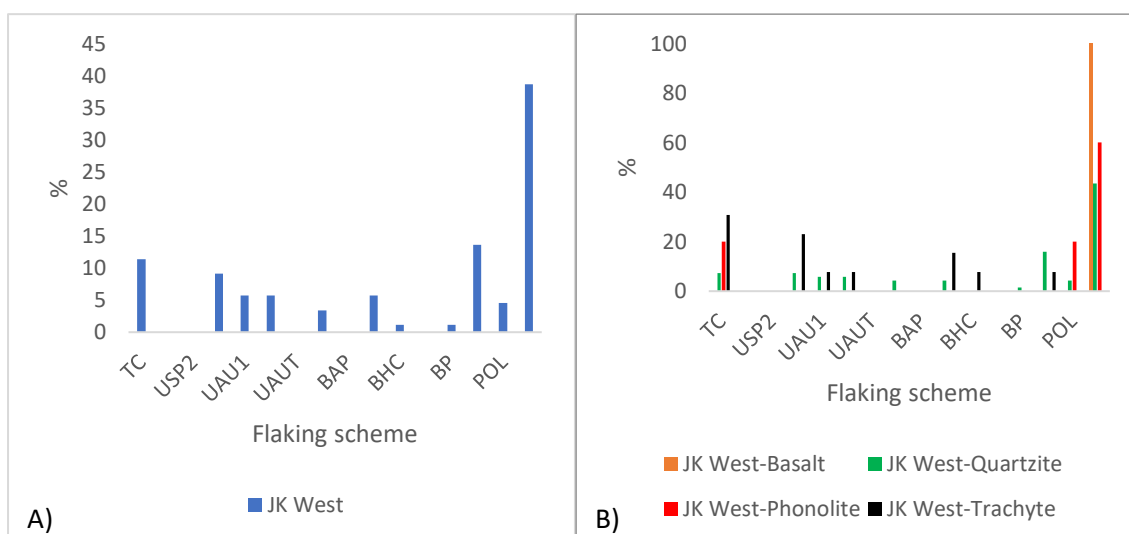


Figure 10. 10: JK West core flaking techniques. A) all raw materials B) per raw material.

Table 10. 1: Absolute and relative frequencies of core flaking schemes of all sites by raw material.

	Basalt	Quartzite	Phonolite	Trachyte	Total
Absolute frequency					
Flaking scheme	n	n	n	n	n
TC	16	21	6	11	54
USP	4	5	0	0	9
USP2	0	3	0	1	4
BSP	5	15	2	7	29
UAU1	2	14	0	2	18
UAU2	1	10	0	1	12
UAUT	0	12	0	1	13
UAB1	1	11	2	0	14
BAP	0	2	0	1	3
BALP	4	16	0	3	23
BHC	0	0	0	1	1
BALT	0	9	1	0	10
BP	0	4	0	0	4
DISC	3	30	2	5	40
POL	0	5	1	0	6
MLT	9	101	9	1	120
Total	45	258	23	34	360
Relative frequency					

TC	35.6	8.1	26.1	32.4	15.0
USP	8.9	1.9	0.0	0.0	2.5
USP2	0.0	1.2	0.0	2.9	1.1
BSP	11.1	5.8	8.7	20.6	8.1
UAU1	4.4	5.4	0.0	5.9	5.0
UAU2	2.2	3.9	0.0	2.9	3.3
UAUT	0.0	4.7	0.0	2.9	3.6
UAB1	2.2	4.3	8.7	0.0	3.9
BAP	0.0	0.8	0.0	2.9	0.8
BALP	8.9	6.2	0.0	8.8	6.4
BHC	0.0	0.0	0.0	2.9	0.3
BALT	0.0	3.5	4.3	0.0	2.8
BP	0.0	1.6	0.0	0.0	1.1
DISC	6.7	11.6	8.7	14.7	11.1
POL	0.0	1.9	4.3	0.0	1.7
MLT	20.0	39.1	39.1	2.9	33.3
Total	12.5	71.7	6.4	9.4	100.0

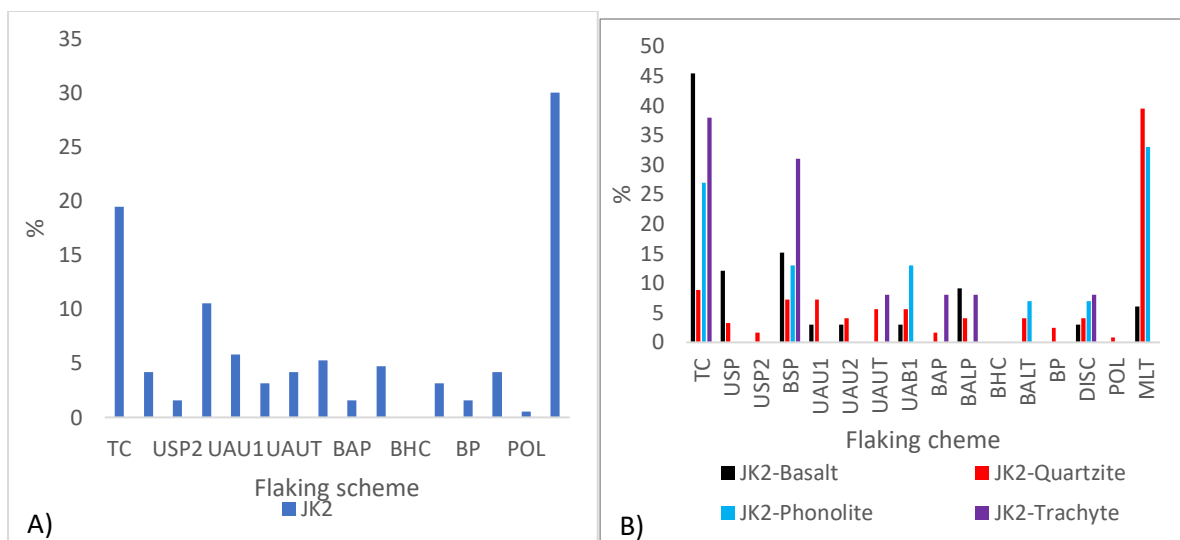


Figure 10. 11: JK2 core flaking schemes. A) all raw materials; B) per raw materials.

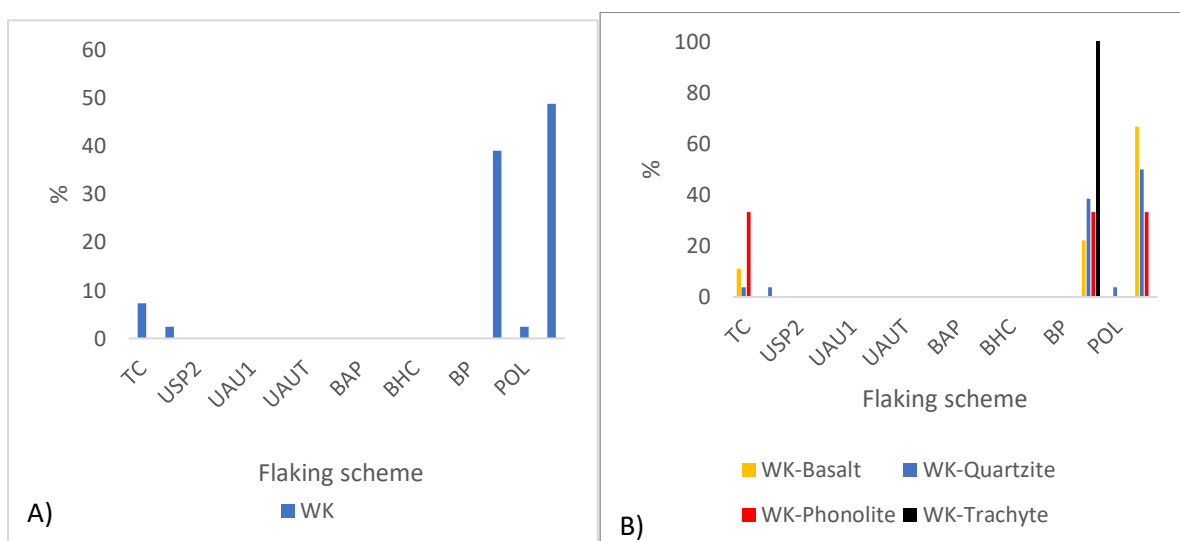


Figure 10. 12: WK core flaking techniques. A) all raw materials B) per raw materials.

Table 10. 2: FC East core flaking schemes.

FC East core flaking schemes											
	Basalt		Quartzite		Phonolite		Trachyte		Grand total		
Flaking scheme	n	%	n	%	n	%	n	%	n	%	
TC	0	0	4	10	0	0	0	0	4	10	
USP	0	0	0	0	0	0	0	0	0	0	
USP2	0	0	1	3	0	0	0	0	1	2	
BSP	0	0	1	3	0	0	0	0	1	2	
UAU1	1	50	1	3	0	0	0	0	2	5	
UAU2	0	0	1	3	0	0	0	0	1	2	
UAUT	0	0	5	13	0	0	0	0	5	12	
UAB1	0	0	1	3	0	0	0	0	1	2	
BAP	0	0	0	0	0	0	0	0	0	0	
BALP	1	50	8	21	0	0	0	0	9	22	
BHC	0	0	0	0	0	0	0	0	0	0	
BALT	0	0	4	10	0	0	0	0	4	10	
BP	0	0	0	0	0	0	0	0	0	0	
DISC	0	0	4	10	0	0	0	0	4	10	
POL	0	0	0	0	0	0	0	0	0	0	
MLT	0	0	9	23	0	0	0	0	9	22	
Total	2	100	39	100	0	0	0	0	41	100	

Table 10. 3: Table showing the JK West core flaking schemes identified in this study.

JK West core flaking schemes											
	Basalt		Quartzite		Phonolite		Trachyte		Grand total		
Flaking scheme	n	%	n	%	n	%	n	%	n	%	
TC	0	0	5	7	1	20	4	31	10	11	
USP	0	0	0	0	0	0	0	0	0	0	
USP2	0	0	0	0	0	0	0	0	0	0	
BSP	0	0	5	7	0	0	3	23	8	9	
UAU1	0	0	4	6	0	0	1	8	5	6	
UAU2	0	0	4	6	0	0	1	8	5	6	
UAUT	0	0	0	0	0	0	0	0	0	0	
UAB1	0	0	3	4	0	0	0	0	3	3	
BAP	0	0	0	0	0	0	0	0	0	0	
BALP	0	0	3	4	0	0	2	15	5	6	
BHC	0	0	0	0	0	0	1	8	1	1	
BALT	0	0	0	0	0	0	0	0	0	0	
BP	0	0	1	1	0	0	0	0	1	1	
DISC	0	0	11	16	0	0	1	8	12	14	
POL	0	0	3	4	1	20	0	0	4	5	
MLT	1	100	30	43	3	60	0	0	34	39	
Total	1	100	69	100	5	100	13	100	88	100	

Table 10. 4: Table showing the JK2 core flaking schemes identified in this study.

JK2 core flaking schemes										
Flaking scheme	Basalt		Quartzite		Phonolite		Trachyte		Grand total	
	n	%	n	%	n	%	n	%	n	%
TC	15	45	11	9	4	27	7	38	37	19
USP	4	12	4	3	0	0	0	0	8	4
USP2	0	0	2	2	0	0	1	0	3	2
BSP	5	15	9	7	2	13	4	31	20	11
UAU1	1	3	9	7	0	0	1	0	11	6
UAU2	1	3	5	4	0	0	0	0	6	3
UAUT	0	0	7	6	0	0	1	8	8	4
UAB1	1	3	7	6	2	13	0	0	10	5
BAP	0	0	2	2	0	0	1	8	3	2
BALP	3	9	5	4	0	0	1	8	9	5
BHC	0	0	0	0	0	0	0	0	0	0
BALT	0	0	5	4	1	7	0	0	6	3
BP	0	0	3	2	0	0	0	0	3	2
DISC	1	3	5	4	1	7	1	8	8	4
POL	0	0	1	1	0	0	0	0	1	1
MLT	2	6	49	40	5	33	1	0	57	30
Total	33	100	124	100	15	100	18	100	190	100

Table 10. 5: Table showing the WK core flaking schemes identified in this study.

WK core flaking schemes											
	Basalt		Quartzite		Phonolite		Trachyte		Grand total		
Flaking scheme	n	%	n	%	n	%	n	%	n	%	
TC	1	11	1	4	1	33	0	0	3	7	
USP	0	0	1	4	0	0	0	0	1	2	
USP2	0	0	0	0	0	0	0	0	0	0	
BSP	0	0	0	0	0	0	0	0	0	0	
UAU1	0	0	0	0	0	0	0	0	0	0	
UAU2	0	0	0	0	0	0	0	0	0	0	
UAUT	0	0	0	0	0	0	0	0	0	0	
UAB1	0	0	0	0	0	0	0	0	0	0	
BAP	0	0	0	0	0	0	0	0	0	0	
BALP	0	0	0	0	0	0	0	0	0	0	
BHC	0	0	0	0	0	0	0	0	0	0	
BALT	0	0	0	0	0	0	0	0	0	0	
BP	0	0	0	0	0	0	0	0	0	0	
DISC	2	22	10	38	1	33	3	100	16	39	
POL	0	0	1	4	0	0	0	0	1	2	
MLT	6	67	13	50	1	33	0	0	20	49	
Total	9	100	26	100	3	100	3	100	41	100	

Comparisons of all sites' core flaking techniques are shown per raw materials (Figure 10.13). As shown in figure 10.13A, there is predominance of multifacial basalt cores, with JK West basalt cores being the most prevalent, succeeded by WK and last JK2 (Figure 10.13A). Other flaking techniques were also employed on basalt materials. These include test cores (TC), with JK2 basalt cores being the most predominant, followed by WK basalt cores; UAU1 flaking technique was also applied, with FC East basalt cores being the most prevalent, followed distantly by JK2 basalt cores. The BALP technique was also used, with FC East basalt cores being the most predominant, followed distantly by JK2 basalt cores. The discoid flaking technique was also present with WK basalt cores being the most frequent, followed by JK2 basalt cores (Figure 10.13A).

An examination of basalt cores from FC East, JK West, JK2, and WK appears to reveal interesting trends of variations in exploitation strategies. The chi-squared test result suggests a strong variation in basalt flaking techniques amongst sites ($\chi^2 (24) = 665.557, p < .001$). For example, at JK2, there is prevalence of basalt testcores and lower representation of multifacial cores. This pattern indicates low utilisation of basalt raw material due to shorter distance from basalt raw material source to the site. Hence, prevalence of testcores and less prevalence of multifacial cores. At WK site, however, there is prevalence of multifacial cores and shortage of testcores, indicating that high reduction (multifacial cores) was associated with lengthy distance of basalt raw material source (Figure 10.13A).

A comparison of core flaking techniques within quartzite raw materials from all sites was also conducted. As shown in figure 10.13B there is predominance of quartzite multifacial core flaking strategy, with WK multifacial quartzite cores being the most

predominant, followed by JK West and JK2 quartzite multifacial cores, whereas FC East quartzite multifacial cores are less frequent. In addition to multifacial flaking technique, other flaking strategies are present; the second most prominent is discoids, particularly abundant in WK, followed by JK West and FC East quartzite cores (Figure 10.13B). Furthermore, test core, BALP, BP, BALT, BSP, UAU1, UAU2, UAUT, USP, and USP2 are also present. Interestingly, FC East quartzite cores appear the most frequent in some of these flaking techniques, for example, TC, USP2, UAUT, BALP, and BALT (Figure 10.13B). The chi-squared test result shows a significant variation of flaking technique within quartzite raw material per sites ($X^2 (42) = 191.796, p < .001$) (Appendix 10.23). Overall, there is presence of interassemblage variations of flaking techniques among sites.

Regarding phonolite cores, figure 10.13C shows predominance of the multifacial flaking technique, followed by test core, and discoids. Multifacial phonolite cores are particularly prevalent in JK West, followed by JK2 and WK phonolite cores. In terms of test cores, WK phonolite cores are the most frequent, followed by JK2 phonolite cores; JK West phonolite cores are less frequent (Figure 10.13C). The chi-squared test shows statistically significant differences between sites ($X^2 (12) = 166.041, p < .001$) among the multifacial, test core, and discoids flaking schemes (Appendix 10.24).

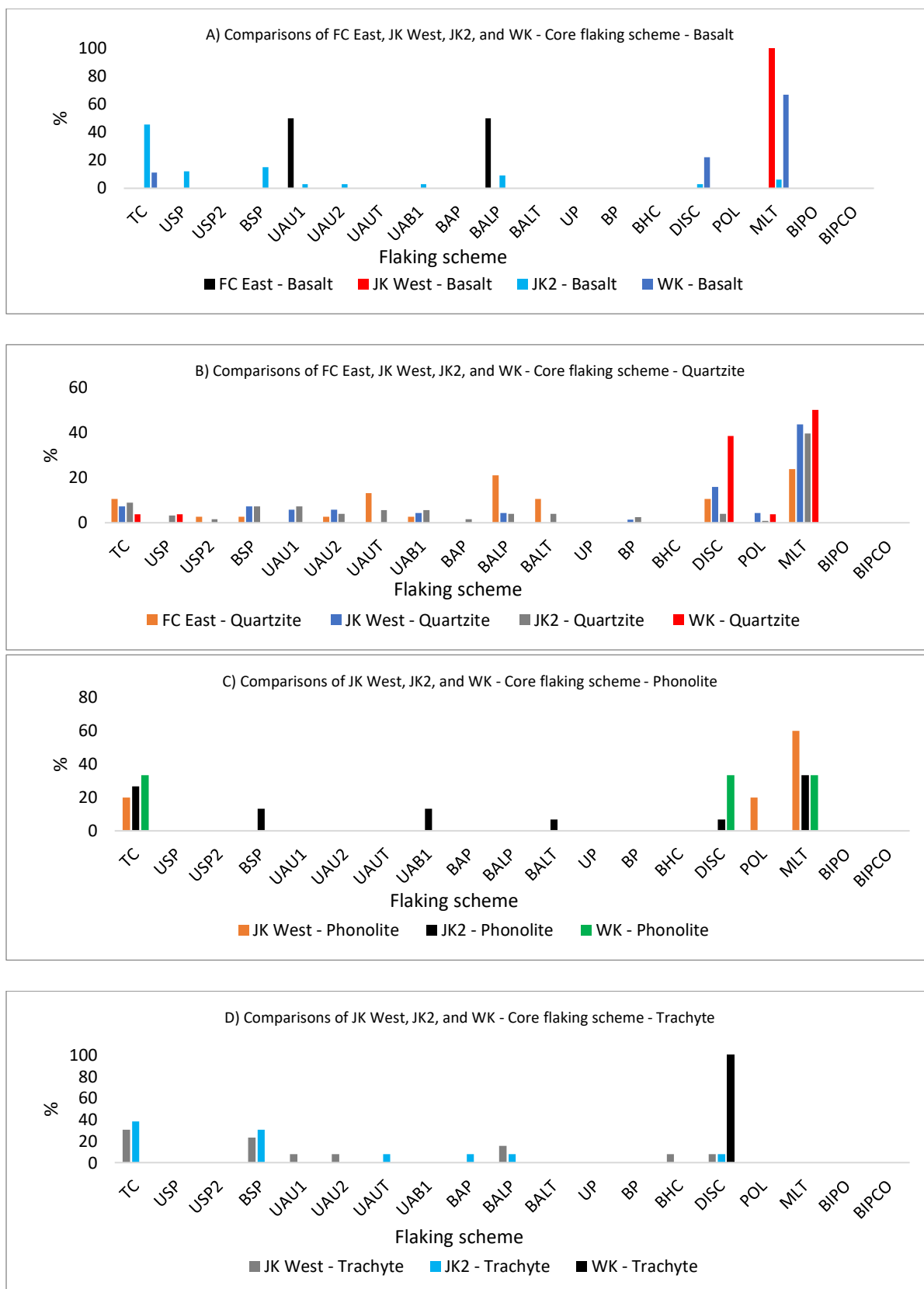


Figure 10. 13: Comparisons of core flaking schemes between FC East, JK West, JK2, and WK cores. A) Basalt; B) Quartzite; C) Phonolite; and D) Trachyte.

Figure 10.13D shows trachyte distributions, and a predominance of discoids, followed by test cores, BSP, and BALP flaking schemes. Regarding test cores, they are the most frequent in JK2, followed by JK West. JK2 trachyte BSP cores are more frequent than JK West trachyte BSP cores. Moreover, WK trachyte discoids cores are the most frequent flaking scheme, followed distantly by JK West and JK2 discoid cores. Statistically, there is some variation of core flaking scheme of JK West, JK2, and WK within trachyte materials ($\chi^2(16) = 305.544, p < .001$) (Appendix 10.25).

In summary, it is clear that multiple reduction schemes were employed in each assemblage, with multifacial method being the most predominant (Figure 10.13A-C). For the lithic materials from Bed II (FC East) most cores were centered on unidirectional removals of flakes and bifacial exploitation strategies. For the lithic materials from Bed III (JK West and JK2), JK West basalt cores appear only on multifacial exploitation scheme, whereas JK2 removals of flakes is centered on test cores, unifacial and bifacial as well as discoid flaking scheme. Moreover, WK basalt core flake removal is centered mostly on multifacial, followed by discoids, and test cores (Figure 10.13A).

In assessing dynamics of stasis or technological change, it is clear that there is technological variation that is largely influenced by the availability of raw materials used by hominins at each site. For example, the availability of quartzite raw materials across the Olduvai sequence allowed hominins to employ different flaking techniques (Figure 10.13B). Figure 10.13C shows that phonolite materials were utilized only in JK West, JK2, and WK site. Interestingly, FC East hominins do not seem to have had used phonolite raw materials. This does not suggest that phonolite was not available, but it may have been due to shortage of its supply which may be due to distance from

the FC East site to the source of phonolite materials, Engelosin, which is approximately 20 kilometres away. Therefore, the technological variation that has been presented may be due to the raw materials availability and technological capabilities of hominins from the studied sites.

10.4 Comparisons of flakes production during the Acheulean at Olduvai: FC East, JK West, JK2, and WK

10.4.1 General frequencies

A selected sample of whole flakes from each assemblage was considered for the analysis. The frequencies represented here do not represent the entire flake assemblage, they represented a portion of the total flake assemblage from each site (Figure 10.1).

In the comparison of technological categories from all studies assemblages, FC East flakes represent 70%, JK2 flakes 59%, WK flakes 54%, whereas JK West flakes 52%, respectively. Further comparisons of the flake category are being carried out below by comparing different flake technological attributes and per raw materials. These attributes aid in the understanding of reduction intensity and technological capabilities of hominins in flake production during the lower Pleistocene times at Olduvai.

10.4.2 Dimensions

10.4.2.1 Length

As shown in figure 10.14A, most of the basalt flakes are measuring 20-39 mm, 40-59 mm, and 60-69 mm, whereas those that are in 80-99 mm in length are less frequent and only represented in JK2. It should be noted that among sites, the JK West flake sample, basalt flakes were not represented (Figure 10.14A). The Chi-squared results of basalt flake length strongly support the significant interassemblage variation

between FC East, JK2, and WK assemblages ($X^2 (6) = 38.166, p < .001$) (Appendix 10.26). The adjusted residuals results show that there is significant underrepresentation of basalt flakes measuring 20-39 mm within the JK2 and WK flakes (Appendix 10.26). In addition, the adjusted residuals show that there is significant overrepresentation of basalt flakes measuring 40-59 mm and 60-79 mm within FC East, JK2, and WK assemblages. Generally, the significant underrepresentation and overrepresentation may be due to hominins preference of selecting small to medium size core blanks.

In addition, figure 10.14B shows that there is predominance of quartzite flake length classes measuring 20-39 mm, followed by 40-59 mm, whereas 60-79 being the least frequent. The Chi-squared test suggests that significant variation in flake length classes between the sites ($X^2 (6) = 11.724, p < .068$). The adjusted residuals indicate that there is predominance of quartzite flakes measuring 20-39 mm (Figure 10.14B; appendix 10.27) within the WK assemblage, whereas quartzite flakes from JK West, JK2, and FC East showing a slight underrepresentation of flakes measuring 20-39 mm (Figure 10.14B). Interestingly, WK quartzite flakes show a substantial underrepresentation within flakes measuring 40-59 mm (Figure 10.14B). The adjusted residuals also indicates that there is underrepresentation of WK quartzite flakes (Appendix 10.27).

Overall, it is clear that hominins at these sites utilised quartzites to manufacture smaller flakes; this is clearly seen in figure 10.8B, whereby as the size increases the frequency decreases.

Figure 10.14C shows the phonolite flake length class measuring 20-39 mm and 40-59 mm; there is variations in frequencies of phonolite flake length classes. The chi-square test shows this variation ($X^2 (9) = 415.283, p < .001$), with adjusted residuals showing

less frequency of JK2 phonolite flakes measuring 20-39 mm and 40-59 mm (Appendix 10.28).

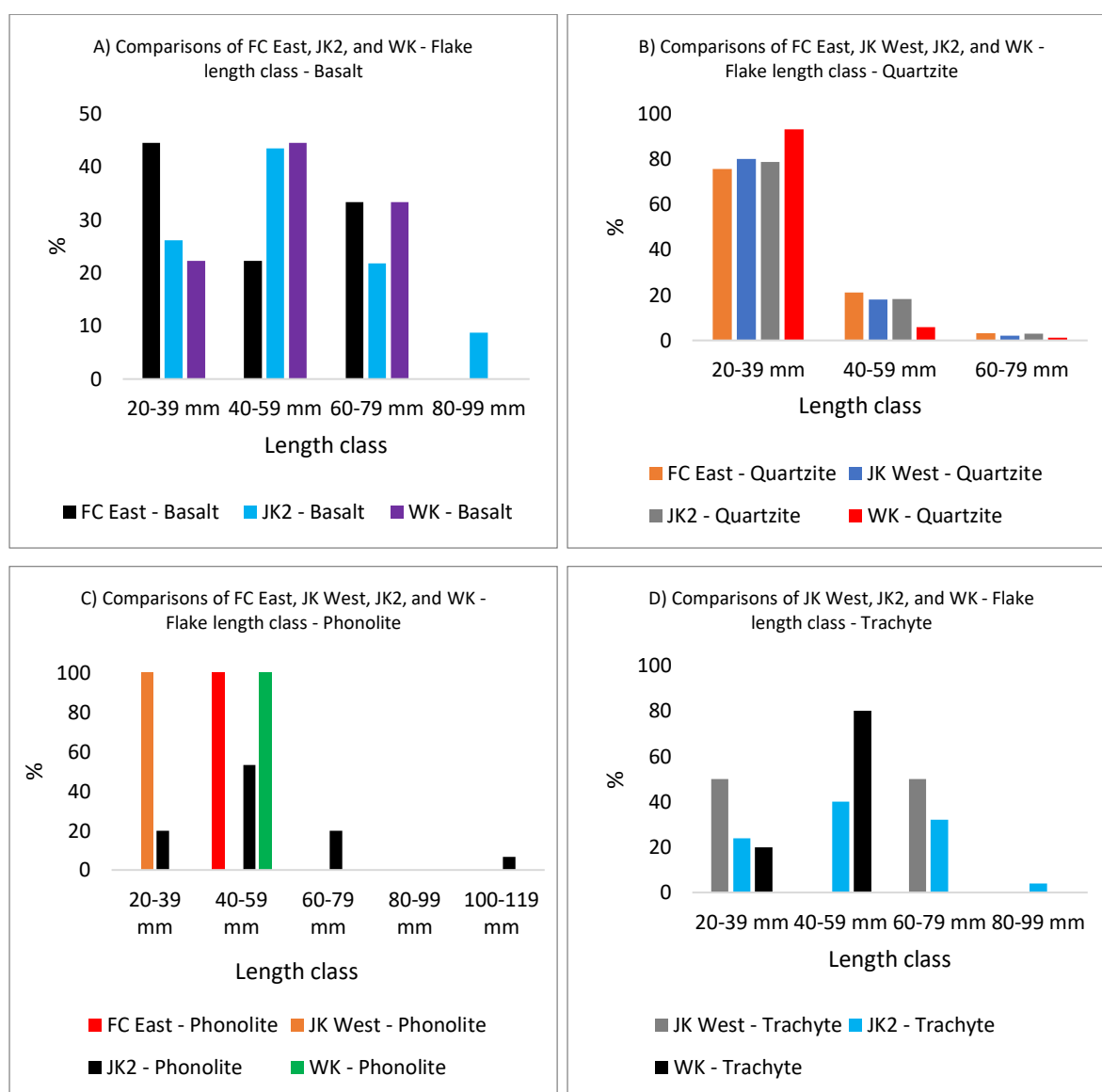


Figure 10. 14: Comparisons of length classes between FC East, JK West, JK2 and WK flakes per each raw material.

Figure 10.14D shows that there are important differences in trachyte flake length classes measuring 20-39 mm, 40-59 mm and 60-79 mm. The chi-squared test results of trachyte flake length class support the significant variation between trachyte flake lengths within JK West, JK2 and WK assemblages ($X^2 (6) = 151.863, p < .001$) (Appendix 10.29). The adjusted residuals results show that there is significant

underrepresentation of trachyte flake measuring 20-39 mm within WK and JK2, whereas JK West flakes remain the most pronounced (Appendix 10.29).

Generally, it is evident that the sites are predominated by flakes measuring 20-39 mm and 40-59 mm, with strong interassemblage variations determined by raw materials used to manufacture flakes. This suggests that all hominins used raw materials available to produce small to medium flakes, but the variations in level of reduction intensity might have been influenced by raw materials availability.

10.4.2.2 Width

Further analysis of reduction intensity was undertaken by comparing flake width classes. When comparing the width class of basalt flakes, there is significant variation in relative frequencies ($\chi^2 (6) = 58.280, p < .001$) (Figure 10.15A; appendix 10.30), with the majority of flake assemblages measuring 20-39 mm and 40-59 mm. It is clear that basalt flakes show significant interassemblage variation in the width class; figure 10.9A indicates that majority of flakes from FC East, JK2, and WK are narrower (20-39 mm wide), whereas a few of them are wider (40-49 mm). It can therefore be suggested that little difference between flake width and length dimensions in basalt flakes was observed between Beds II, III, and IV (Figure 10.14A and 10.15A).

Moving on to quartzite flake width comparisons, quartzite flakes show inter-assemblage variation in the width ($\chi^2 (12) = 34.598, p < .001$). The adjusted residuals results indicate underrepresentation of quartzite flakes that are in <20 mm width class from FC East and JK2, whereas JK West and WK are overrepresented (Appendix 10.31; figure 10.15B). However, it is interesting to see that there is high frequency of quartzite flakes that are in 20-39 mm in width class from FC East and JK2, whereas JK West and WK follow behind (Appendix 10.31; figure 10.15B). Overall, this would

suggest that, in terms of width dimensions quartzite flakes from all sites were in between <20mm and 20-39mm, with few flakes ranging 40-59 mm wide.

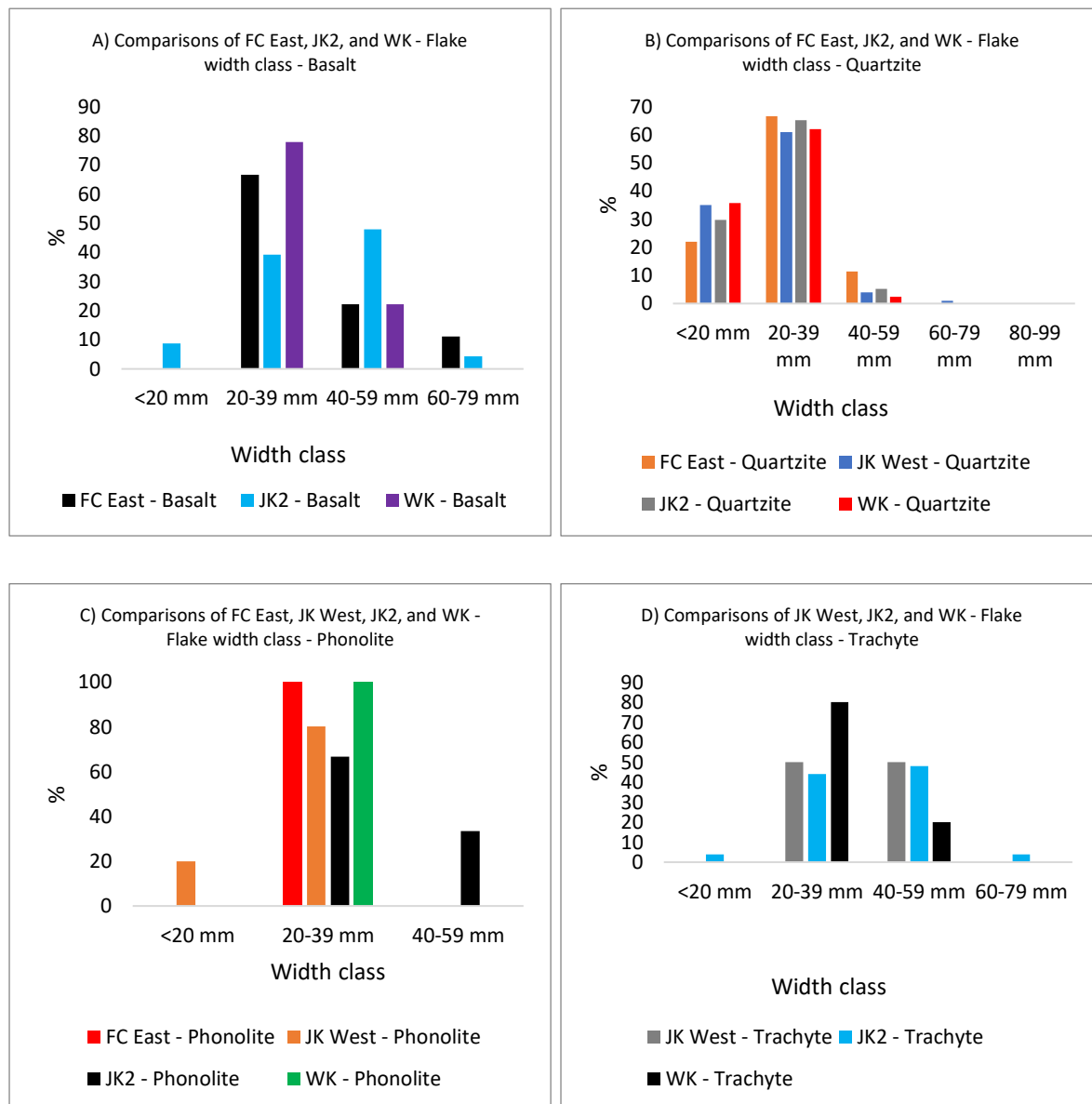


Figure 10. 15: Comparisons of width classes between FC East, JK West, JK2 and WK flakes per each raw material.

Moreover, phonolite flakes were predominantly within 20-39 mm width class (Figure 10.15C). A chi-square test indicates significant inter-assemblage variation ($\chi^2 (6) = 168.069, p < .001$), with the adjusted residuals showing overrepresentation of FC East and WK flakes and underrepresentation of JK West and JK2 flakes that are in 20-39 mm width class (Appendix 10.32; figure 10.15C).

Furthermore, trachyte flakes provide slightly similar results with basalt flakes (Figure 10.15A and D). Most trachyte flakes are in 20-39 mm and 40-59 mm width class. The chi-square test results indicate a slight variation between all assemblages when considering trachyte flake width class ($X^2 (6) = 43.133, p < .001$) (Appendix 10.33). The adjusted residuals results show a significant overrepresentation of WK trachyte flakes measuring 20-39 mm, whereas WK trachyte flakes show a substantial underrepresentation of flakes measuring 40-59 mm (Appendix 10.33; figure 10.15D).

Overall, it is evident that the flake assemblages from all sites are dominated with high frequency of flakes that measure between 20-39 mm and 40-59 mm wide. However, raw material types reveal some variation in width class, for example, all lava materials have low frequency of flakes measuring <20 mm wide, whereas quartzite shows contrary results (Figure 10.15A-D).

10.4.2.3 Weight

Turning to the weight of basalt flake assemblages, the results of Chi-Square test show a significant level of interassemblage variation ($X^2 (8) = 88.461, p < .001$) (Appendix 10.34). The relative frequency of weight ranges shows a degree of variation. The adjusted residuals corroborate this, as the majority of assemblages show a significant overrepresentation and underrepresentation.

As shown in figure 10.16A, most basalt flakes weigh less than twenty grams, with FC East flakes being the most predominant, followed by WK flakes, whereas JK2 flakes being the least predominant. In terms of quartzite raw material, similar results are exhibited in which most flakes weigh less than twenty grams, with WK flakes being the most predominant, followed by JK West flakes, FC East flakes and JK2 flakes being the least predominant (Figure 10.16B). The adjusted residuals results show a

substantial overrepresentation of WK flakes weighing less than twenty grams (Appendix 10.35).

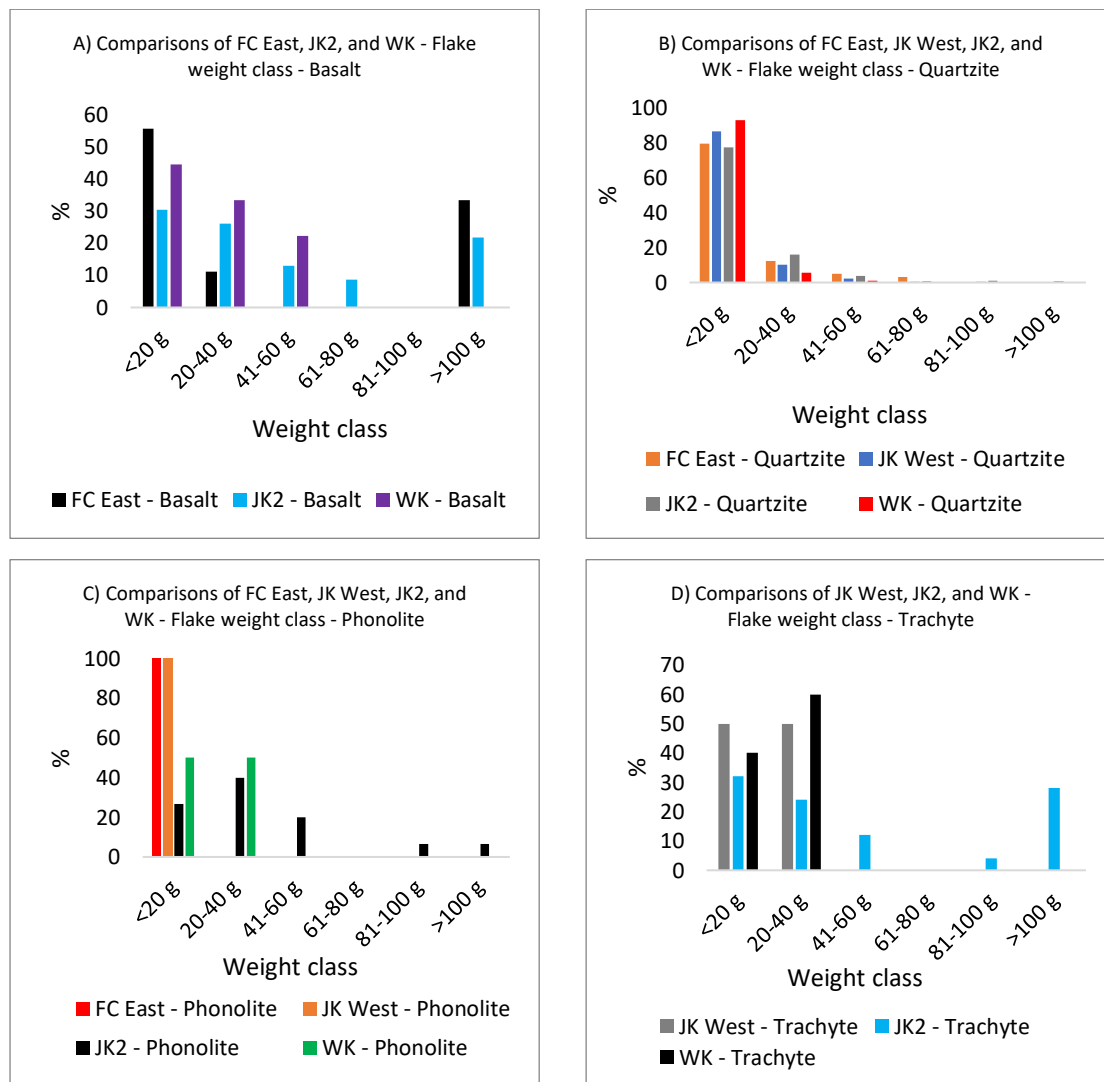


Figure 10. 16: Comparisons of weight classes between FC East, JK West, JK2 and WK flakes per each raw material.

Moreover, phonolite raw material portrays similar results whereas most flakes weigh less than twenty grams, with adjusted residuals results pointing at FC East and JK West flakes weight less than twenty grams being overrepresented (Appendix 10.36; figure 10.16C).

Furthermore, trachyte raw material exhibits a slight variation with the predominance of both flakes weighing less than twenty grams and those that weigh between 20 and 40

grams, with adjusted residuals showing overrepresentation of JK West flakes weighing less than twenty grams and overrepresentation of WK flakes weighing between 20 and 40 grams respectively (Figure 10.16D; appendix 10.37).

Overall, flakes from all sites weigh usually under twenty grams, with other flakes reaching as high as over a hundred grams with some variations depending on the raw material types used.

10.4.3 Dorsal cortex

Flake dorsal cortex was used to measure the level of reduction intensity. A comparison of flakes' dorsal cortex of different raw materials helps in the understanding of how each raw material produced a different level of reduction at different sites at Olduvai. As shown in figure 10.17A, most basalt flakes are fully cortical, with FC East flakes being the most prevalent, followed by JK2 and WK flakes. The chi square test results show a significant dorsal cortex variation on basalt flakes ($X^2 (6) = 105.164, p < .001$). The adjusted residuals show a significant overrepresentation of cortical FC East basalt flakes, cortical dominant JK2 basalt flakes, non-cortical dominant WK basalt flakes, and non-cortical WK basalt flakes (Appendix 10.38; figure 10.17A).

In terms of quartzite raw material, most flakes are non-cortical, followed by non-cortical dominant, cortical dominant, whereas cortical flakes are being least represented (Figure 10.17B). The chi square test results show significant overrepresentation of non-cortical flakes ($X^2 (9) = 26.232, p < .002$), with the adjusted residuals indicating overrepresentation of FC East non-cortical flakes (Figure 10.17B; appendix 10.39).

Phonolite dorsal cortex was also compared. As shown in figure 10.17C, there is predominance of non-cortical phonolite flakes. The chi square test results support the

significant differences between phonolite flakes dorsal cortex of the sites ($X^2 (9) = 345.681$, $p < .001$); the adjusted residuals show that there is a significant overrepresentation of phonolite flakes that are non-cortical within JK West (Appendix 10.40; figure 10.17C).

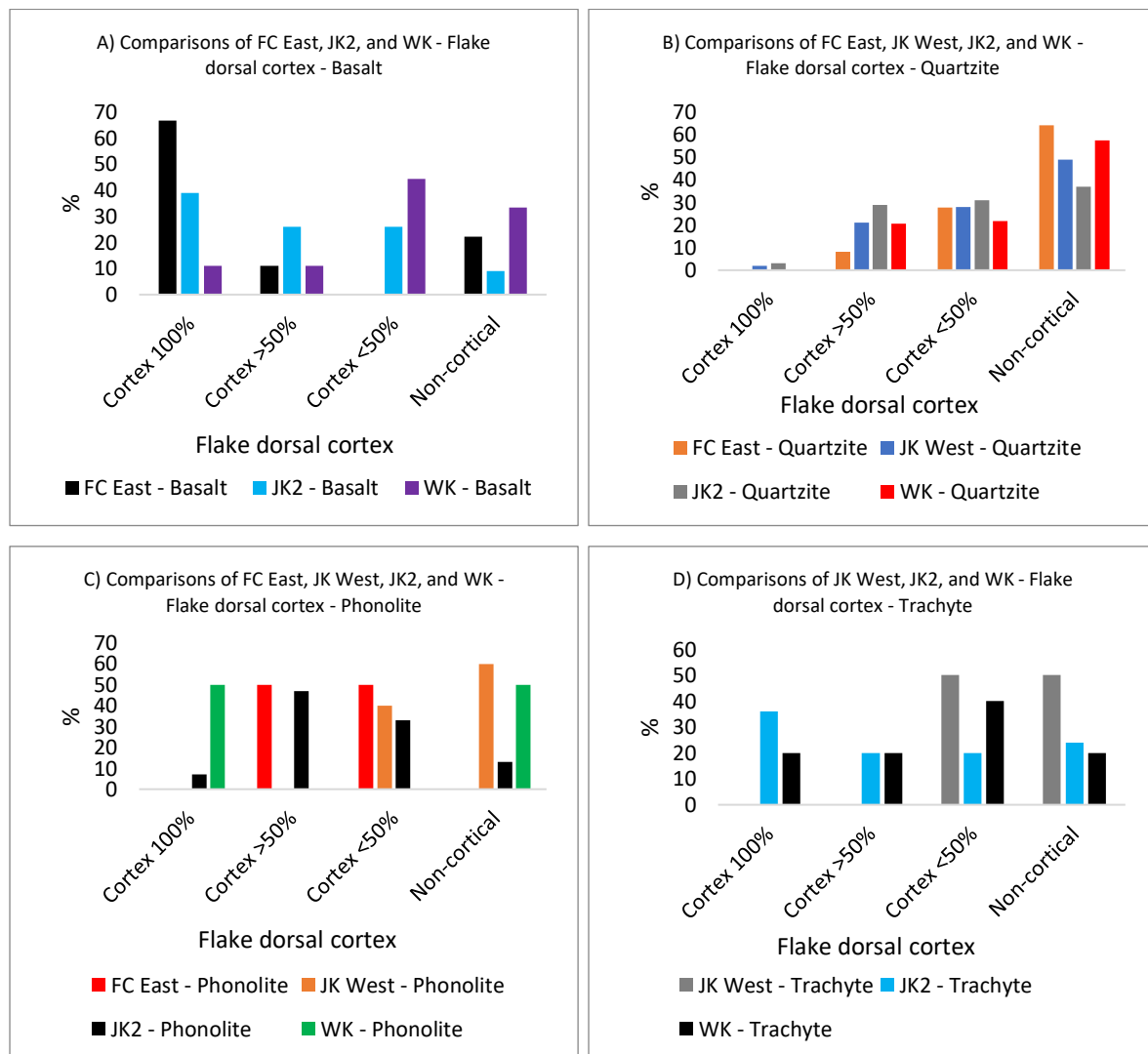


Figure 10. 17: Comparisons of dorsal cortex between FC East, JK West, JK2 and WK flakes per each raw material.

Furthermore, the analysis of dorsal cortex in trachyte flakes shows a significant variation between sites (Appendix 10.41; figure 10.17D). As shown in figure 10.17D non-cortical dominant flakes are the most predominant, with JK West flakes being the most prevalent, followed by WK, whereas JK2 trachyte flakes being underrepresented.

In addition, results on non-cortical flakes were also observed, with JK West being the most prevalent, followed by JK2, whereas WK flakes being underrepresented. Statistically, the adjusted residuals show significant differences of dorsal cortex of trachyte flakes between JK West, JK2 and WK flakes ($X^2 (6) = 84.521, p < .001$) (Appendix 10.41; figure 10.17D). Therefore, it can be argued that the high percentage of non-cortical and non-cortical dominant dorsal cortex on flakes at the sites indicate a high level of reduction. However, differences in raw material gave different results in reduction levels with quartzite showing a high percentage of non-cortical flakes than other raw materials; other raw materials gave different results (Figure 10.17A-D).

10.4.4 Toth's flakes

Further comparison of cortex was undertaken with the Toth's flake types from all sites studied. Toth's flakes comparison involves analysis of striking platform and the dorsal cortex of flakes, and all flakes were compared based on raw material types. To determine variation of Toth's flake types between sites, chi-square tests were used to calculate the differences. Figure 10.18A shows that the FC East flakes retaining cortex on the platform and on the dorsal surface (Toth's type I) are significantly overrepresented amongst basalt raw materials. Contrary, basalt flakes that are fully non-cortical on the platform and dorsal surface (type VI) are strongly overrepresented by flakes from WK site. Statistically, there is significant difference in Toth's flake types within basalt raw material ($X^2 (8) = 103.906, p < .001$) (Appendix 10.42; figure 10.18A).

Additional analysis on quartzite materials shows that there is significant difference between the sites ($X^2 (15) = 28.972, p < .016$) (Appendix 10.43; figure 10.18B). The adjusted residuals highlight a significant underrepresentation of flakes with some cortex on the dorsal surface and non-cortical platform (type V) from FC East.

Interestingly, however, the adjusted residuals show a significant overrepresentation on non-cortical FC flakes (type VI) (Appendix 10.43; figure 10.18).

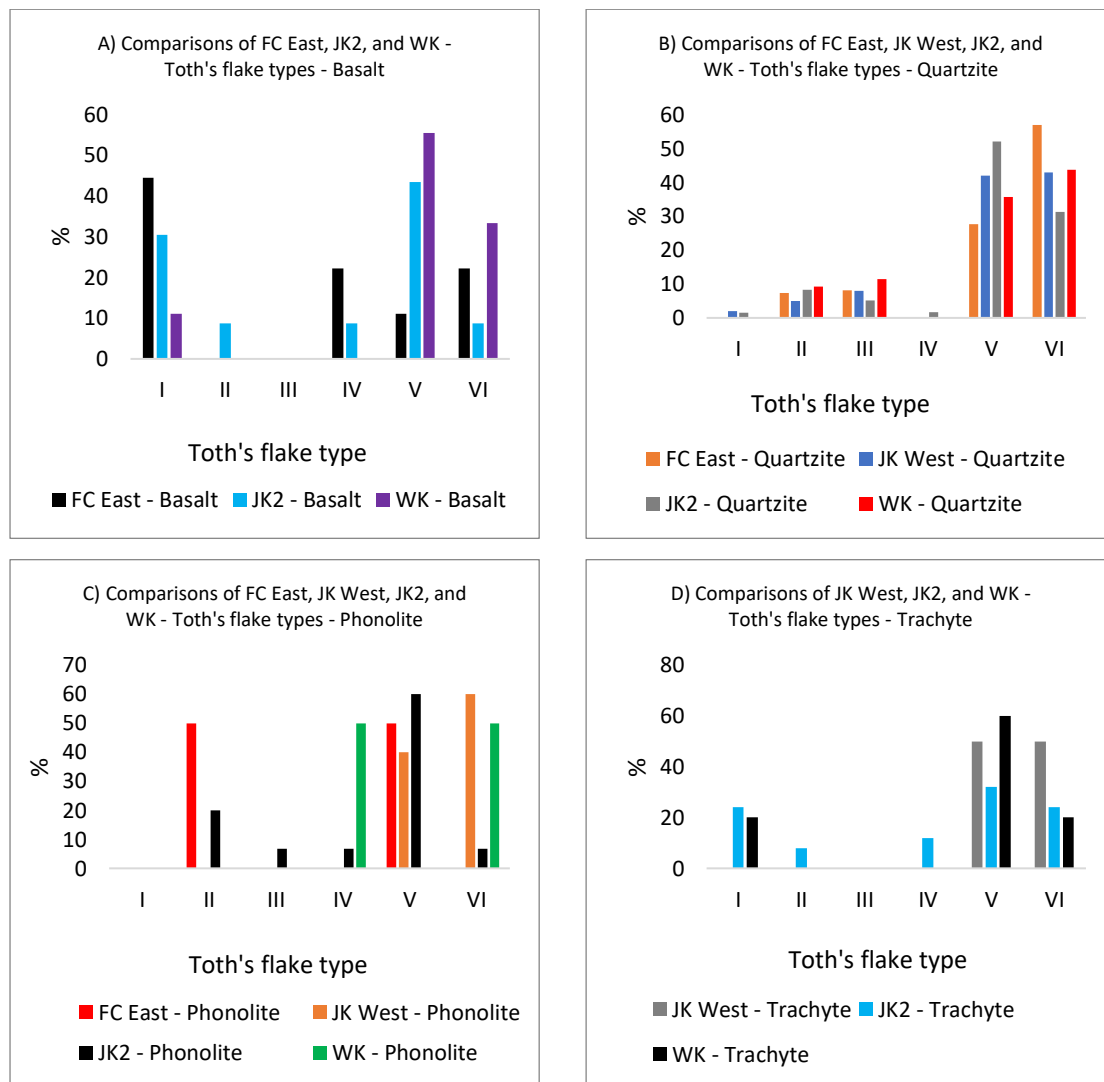


Figure 10. 18: Comparisons of Toth's flake types between FC East, JK West, JK2 and WK flakes per each raw material.

Moreover, the analysis of phonolite flakes shows a significant variation in Toth's flake types between the sites ($X^2 (12) = 387.609, p < .001$) (appendix 10.44), with the adjusted residuals showing a significant overrepresentation of type V flakes from JK2 and JK West respectively. However, the adjusted residuals show a significant underrepresentation of type V flakes from JK West (Appendix 10.44; figure 10.18C).

Furthermore, a significant difference was recorded in trachyte raw materials. The chi-square test shows a significant difference between Toth's flake types from all studied sites ($\chi^2 (8) = 87.989, p < .001$) (appendix 10.45), with the adjusted residuals showing a significant overrepresentation of flakes with some cortex on the dorsal surface and with non-cortical platform (type V) from WK site. Additionally, data shows that there is significant overrepresentation of non-cortical flakes (types VI) from JK West site (Appendix 10.45; figure 10.18D).

Generally, there is an increase in reduction intensity as you move up in the sequence. This is supported by an overall significant underrepresentation of non-cortical flakes from sites in the lower sequence coupled with an increasing overrepresentation of non-cortical flakes within sites located up in the sequence (JK2, JK West and WK sites). Thus, hominins at Olduvai increased production and utilisation of flakes during the Beds III and IV times. This may be due to the increased technological capacity and raw materials availability within their surroundings.

10.4.5 Striking platform facets

Further analysis of cortex on striking platforms and its relationship with reduction intensity is shown in figure 10.19. It can be seen that flake striking platforms are mostly unifaceted within all sites, and there is low frequency of flakes with two or more removals on their platforms (Figure 10.19A-D).

Figure 10.19A shows a slight stratigraphic trend with a presence of flakes with two or more removals of basalt raw material from WK site. This is confirmed by the adjusted residuals that show significant overrepresentation of flakes with two or more removals on their butts from WK site, and the Chi-Squared test confirms a statistically significant difference ($\chi^2 (6) = 91.234, p < .001$) (Appendix 10.46; figure 10.19A).

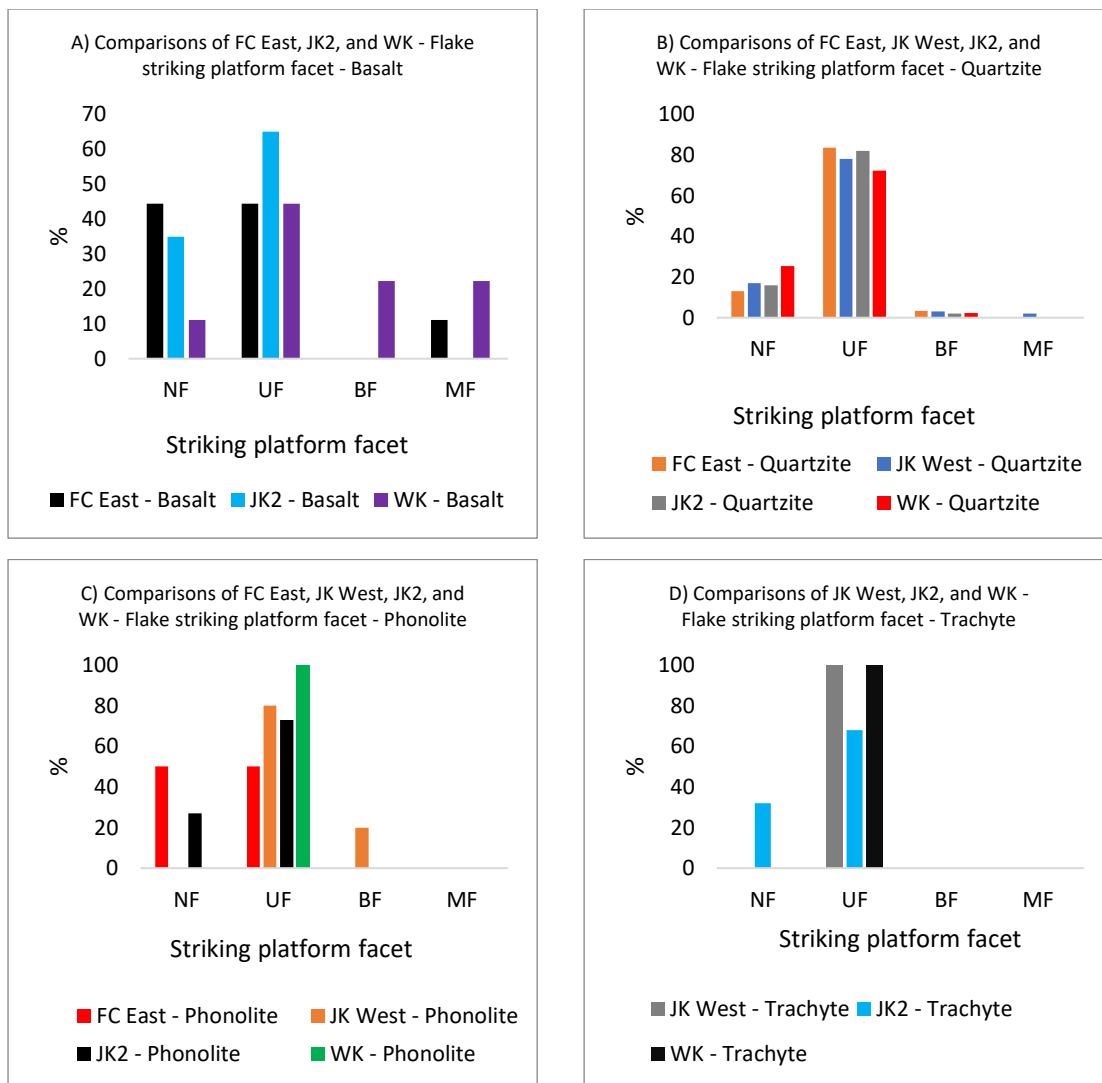


Figure 10. 19: Comparisons of striking platform facets between FC East, JK West, JK2 and WK flakes per each raw material.

In addition, differences exist between types of striking platform within quartzite raw material, as suggested by figure 10.19B and confirmed in the Chi-Square test ($X^2 (9) = 11.905, p < .219$). The adjusted residuals show overrepresentation of cortical striking platforms on quartzite flakes from WK site (Appendix 10.47; figure 10.19B). Conversely, there is a significant underrepresentation of non-cortical striking platform on quartzite flakes from WK site (Appendix 10.47; figure 10.19B).

Further analysis of striking platform cortex on phonolites material is shown in figure 10.19C. It can be seen that there is overrepresentation of phonolite flakes with cortical

butts from FC East flakes; conversely, a significant underrepresentation of fully non-cortical butts of flakes from FC East (Appendix 10.48; figure 10.19C). In addition, there is overrepresentation of unifaceted flakes from WK site (Figure 10.19C). Statistically, there is existing significant differences of flake striking platform within phonolite as confirmed by the Chi-Squared test ($\chi^2 (6) = 167.595, p < .001$) (Appendix 10.48).

In terms of trachyte raw material, there is no statistically significant difference existing between flake striking platforms of the sites ($\chi^2 (2) = 71.642, p < .001$), with the adjusted residuals highlighting underrepresentation of non-cortical butt of flakes from JK2 site (Appendix 10.49; figure 10.19D).

10.5 Comparisons of retouching patterns during the Acheulean at Olduvai: FC, JK West, JK2, and WK

10.5.1 General frequencies

Figure 10.1 indicates that most of the analysed retouched pieces belong to JK West (26%), followed by JK2 (24%) and WK (24%), whereas FC East retouched pieces (9%) being far behind. Comparisons of retouched pieces encompass dimensions, retouch types, and dorsal cortex.

10.5.2 Dimensions

10.5.2.1 Length

Comparison of retouched pieces' length was performed per raw material (Figure 10.20). As can be seen in Figure 10.20A, there is a significant variation of basalt retouched pieces length class between sites. The adjusted residuals indicate that there is overrepresentation of JK West flake measuring 20-39 mm (Appendix 10.50; figure 10.20A). Statistically, a significant difference is confirmed by a Chi-Squared test

result ($X^2 (6) = 263.256, p < .001$) (Appendix 10.50). Interestingly, quartzite retouched pieces show predominance of retouched pieces measuring 20-39 mm, with adjusted residuals showing overrepresentation of WK retouched pieces (Appendix 10.51; figure 10.20B). The Chi-Squared test results of quartzite retouched pieces length classes strongly support the significant differences between the quartzite retouched pieces length classes of sites ($X^2 (6) = 16.062, p < .013$) (Appendix 10.51).

In addition, phonolite retouched pieces length classes of retouched pieces were compared. It is interesting to see a clear difference in length classes between sites. Figure 10.20C shows a significant variation of phonolite retouched pieces length class when compared between sites. The Chi-Squared test suggests a strong variation in retouched pieces length classes ($X^2 (9) = 275.961, p < .001$), with adjusted residual showing overrepresentation of FC East retouched pieces measuring 20-39 mm; similarly, there is overrepresentation of WK retouched pieces measuring 40-59 mm (Appendix 10.52; figure 10.20C).

Moreover, trachyte retouched pieces show a significant variation in length classes between sites. Figure 10.20D shows a strong variation in various length classes, with adjusted residuals showing overrepresentation of JK2 trachyte retouched pieces measuring 20-39 mm and overrepresentation of WK retouched pieces measuring 40-59 mm. Statistically, the Chi-Squared test strongly support the significant differences of retouched pieces length classes ($X^2 (6) = 176.301, p < .001$) (Appendix 10.53; figure 10.20D).

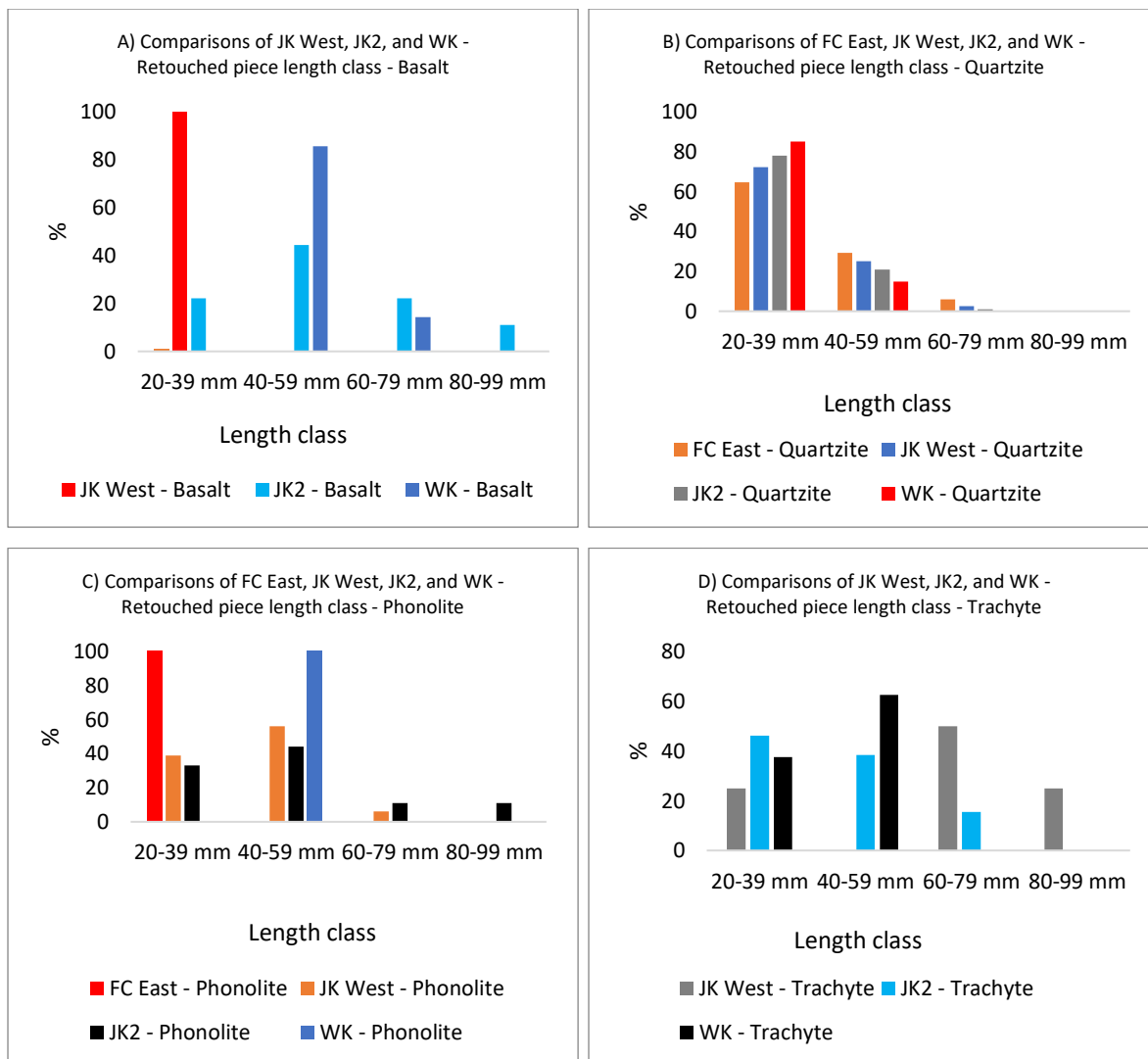


Figure 10. 20: Comparisons of retouched pieces length class between FC East, JK West, JK2 and WK sites per each raw material.

10.5.2.2 Width

Figure 10.21A-D shows that most retouched pieces measure between 20-39 mm and 40-59 mm wide. However, there is significant variation within the sample, with some retouched pieces measuring between 60 and 79 mm in width and others shorter than < 20 mm. Statistically, the Chi-Squared test confirms a significant variation within the basalt retouched pieces ($\chi^2 (6) = 124.007, p < .001$), with the adjusted residuals showing a significant overrepresentation of JK West retouched pieces measuring 20-39 mm in width (Appendix 10.54; figure 10.21A).

In addition, figure 10.21B shows that most quartzite retouched pieces are between 20 and 39 mm in width. It is interesting to see a remarkable difference in width class between sites. The Chi-Squared test suggests a strong variation in retouched pieces width class ($X^2 (6) = 24.962, p < .001$), with the adjusted residuals indicating that there is overrepresentation of FC East quartzite retouched pieces measuring between 20 and 39 mm in width (Appendix 10.55; figure 10.21B).

Moreover, figure 10.21C shows that most phonolite retouched pieces are measuring between 20 and 39 mm in width. It is interesting to see variation within this width class when comparing samples from different sites. Statistically, the Chi-Squared test shows a significant variation in width class of phonolite retouched pieces measuring between 20 and 39 mm ($X^2 (6) = 107.911, p < .001$), with the adjusted residuals showing overrepresentation of FC East and WK retouched pieces (Appendix 10.56; figure 10.21C).

Furthermore, figure 10.21D shows a significant variation of trachyte retouched pieces when comparing samples from the sites. The Chi-Square test supports the strong variation in retouched pieces width between the sites ($X^2 (6) = 131.546, p < .001$), with the adjusted residuals showing overrepresentation of WK trachyte retouched pieces measuring between 20 and 39 mm in width (Appendix 10.57; figure 10.21D).

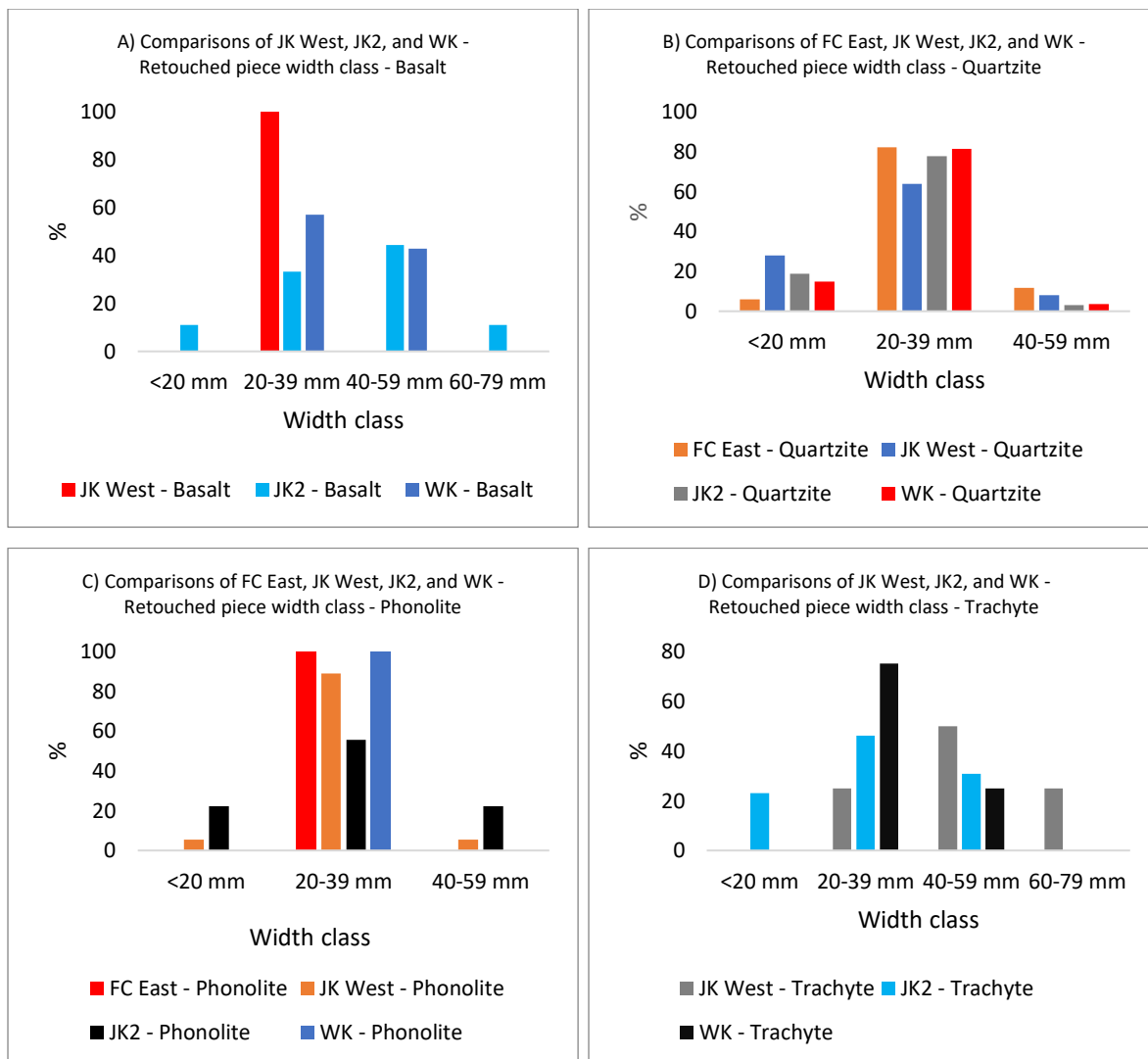


Figure 10. 21: Comparisons of retouched pieces width class between FC East, JK West, JK2 and WK sites per each raw material.

10.5.2.3 Weight

Figures 10.22A-D show that most retouched pieces weigh between 1 and 9 grams. There is significant variation in retouched pieces weight class, with some pieces weighing up >100 grams (Figure 10.22D). The significant variation is confirmed by the Chi-Squared test results that suggest strong variation within basalt retouched pieces ($\chi^2(10) 291.229, p < .001$), with the adjusted residuals showing overrepresentation of JK West retouched pieces weighing 1-9 grams (Appendix 10.58; figure 10.22A).

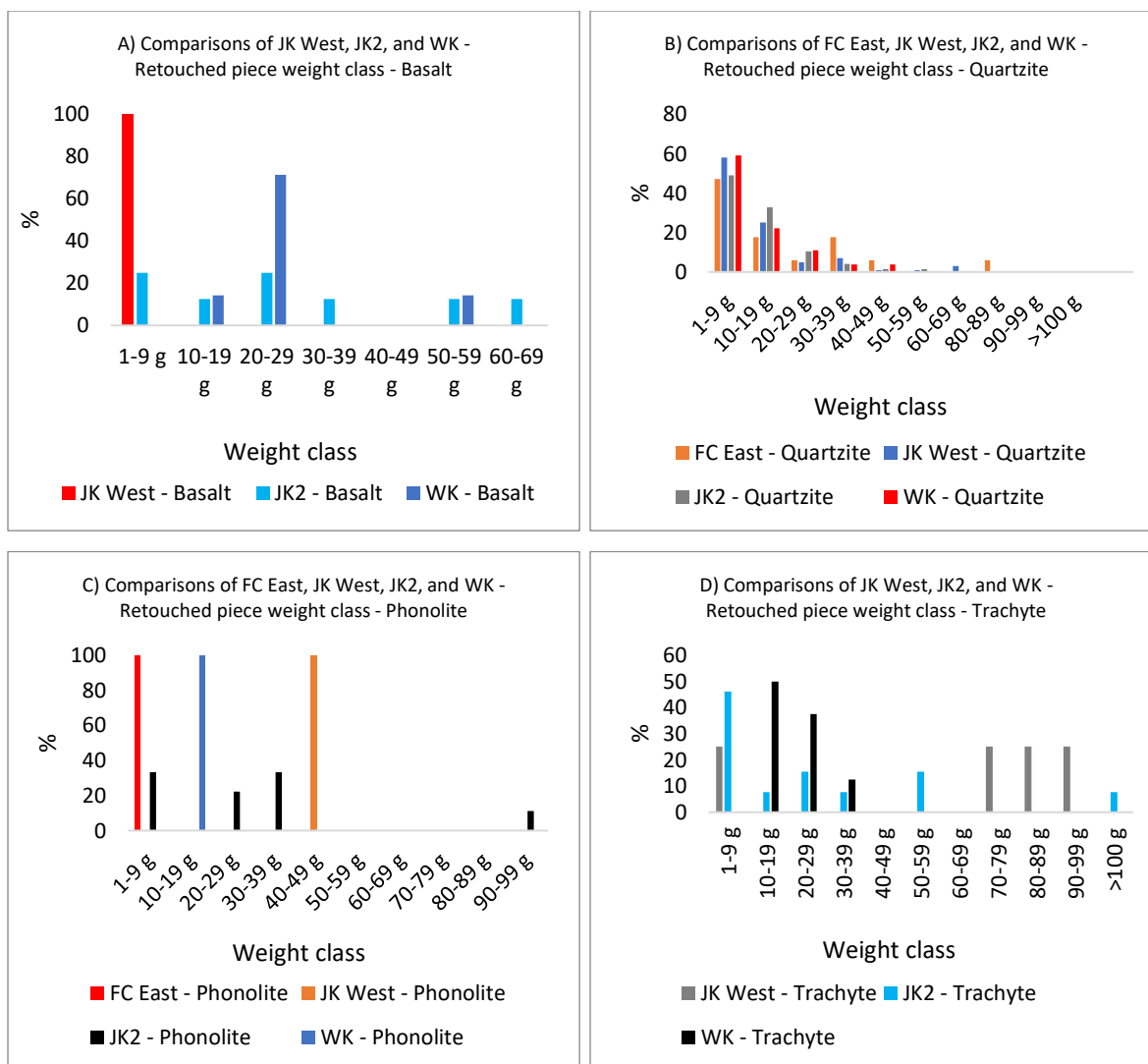


Figure 10. 22: Comparisons of retouched pieces weight class between FC East, JK West, JK2 and WK sites per each raw material.

Further comparison of retouched pieces weight focused on quartzite materials. Figure 10.22B shows that most retouched pieces weigh between 1 and 9 grams and 10 and 19 grams, respectively. It is interesting to see a remarkable weight trend with quartzite materials. The Chi-Squared test confirms the strong variation existing between sites (X^2 (21) 61.082, $p < .001$), with the adjusted residuals showing overrepresentation of WK retouched pieces weighing 1-9 grams and overrepresentation of JK2 retouched pieces weighing 10-19 grams, respectively (Appendix 10.59; figure 10.22B).

Moreover, figure 10.22C shows significant differences in weight class amongst phonolite retouched pieces, with the adjusted residuals showing overrepresentation of FC East retouched pieces weighing between 1 and 9 grams. The Chi-Squared test confirms the significant differences variation of weight between the sites (X^2 (15) 998.000, $p < .001$) (Appendix 10.60; figure 10.22C).

Furthermore, figure 10.22D shows another significant variation of trachyte retouched pieces weight between sites. The Chi-Squared test results supports a strong variation (X^2 (16) 369.093, $p < .001$), with the adjusted residuals showing overrepresentation of JK2 retouched pieces weighing between 1 and 9 grams (Appendix 10.61; figure 10.22D).

Generally, the weight of retouched pieces mostly predominated by retouched pieces weighing between 1 and 9 grams and 10 and 19 grams. However, there were significant weight differences existed and were mainly due to the raw material type or hominin preference of the weight size. For example, most quartzite retouched pieces fall between 1 and 9 grams and 10-19 grams. This suggests that hominins might have had certain weight preferences of their retouched pieces that they carried around as part of their toolkit. Moreover, it seems that hominins preferred quartzite raw materials other than other types of raw materials; this may be due to their availability or durability during use.

10.5.3 Retouch types

Regarding the retouched pieces types, notches ($n=273$, 66%) dominate all assemblages sampled, followed by denticulates ($n=117$, 28%) and sidescrapers ($n=26$, 6%) (Figure 10.23, table 10.6). Analysis of retouched pieces types shows a significant difference between the samples. As shown in figure 10.24A, most basalt

retouched pieces are notches, particularly in JK West. Statistically, there is slight variation of retouched type within basalt materials ($\chi^2 (4) = 90.471, p < 0.001$), with the adjusted residuals of retouched type showing overrepresentation of JK West notches (Appendix 10.62; figure 10.24A).

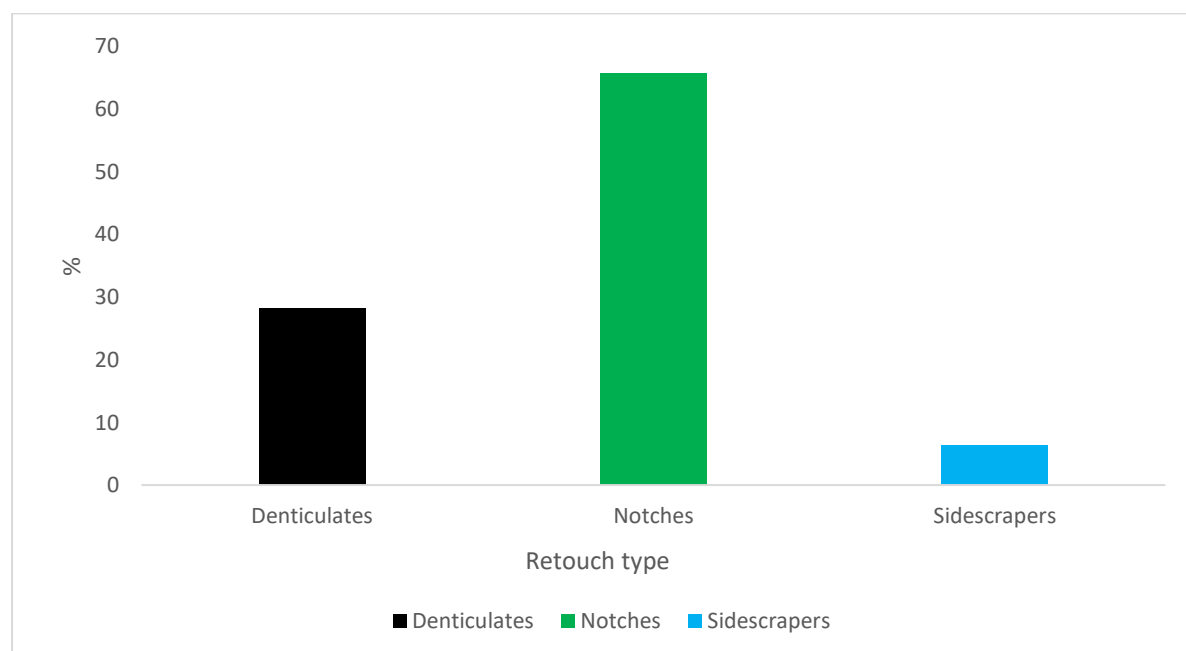


Figure 10. 23: Frequency of retouched types of all sites' samples.

Figure 10.24B shows that the most prevalent retouched types within quartzite being notches, with WK retouched pieces being the most frequent. Statistically, there is significant difference in retouched piece types within quartzite raw materials ($\chi^2 (6) = 58.786, p < .001$), with the adjusted residuals showing significant overrepresentation of WK notch retouched pieces type (Appendix 10.63; figure 10.24B).

Further analysis of retouched pieces types on phonolite raw materials shows that there is significant differences between sites ($\chi^2 (6) = 198.533, p < .001$) (Appendix 10.64; figure 10.24C). The adjusted residuals highlight a significant overrepresentation of FC East denticulates retouched pieces. Interestingly, however, JK West and JK2 notches

retouched pieces types appear to be overrepresented over WK notches retouched pieces type (Appendix 10.64; figure 10.24C).

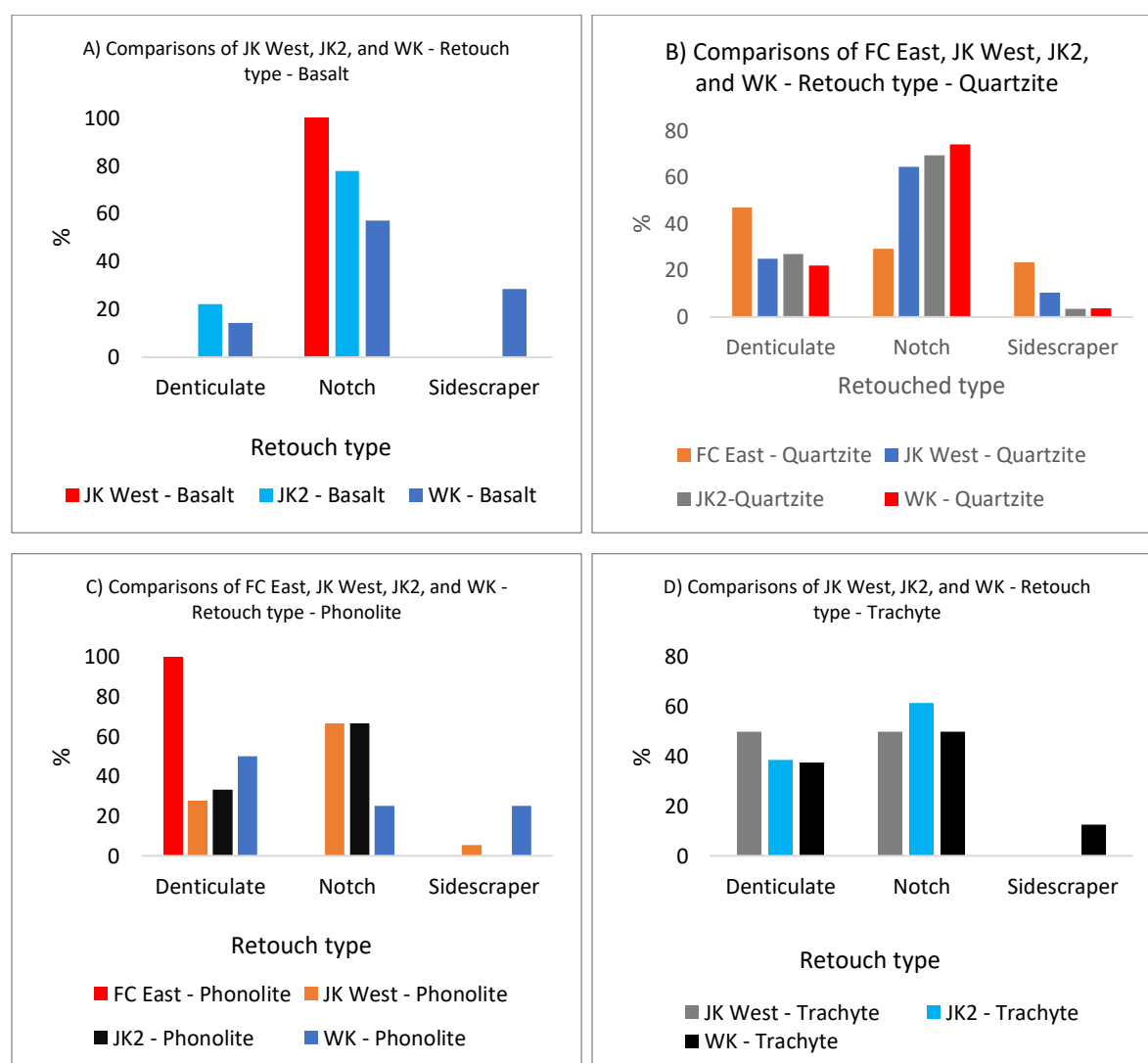


Figure 10. 24: Comparisons of retouched piece types between FC East, JK West, JK2 and WK sites per each raw material.

Furthermore, comparisons of trachyte retouched pieces types appear to be dominated by notches type. Statistically, there is slight significant difference of notch type between sites ($X^2(4) = 29.978$, $p < .001$) (Appendix 10.65; figure 10.24D), with the adjusted residuals showing significant overrepresentation of JK2 notch retouch type.

Overall, all sites exhibit different retouched types manufactured from different raw materials. Notch retouched types appear to be the most prevalent, followed by denticulates, whilst sidescrapers being underrepresented. It is clear that the Acheulean hominins at Olduvai retouched different raw materials available at their disposal, and exhibited their technological skills through different retouch types, with notch types being the most preferred than other types of retouches. This may primarily be due to the preference or the level of skills in shaping the stone tools.

Table 10. 6: Retouched types of all sites sampled.

Retouch type	FC East		JK West		JK2		WK		Total	
	n	%	n	%	n	%	n	%	n	%
Denticulates	9	47	26	27	70	28	12	26	117	28
Notches	6	32	63	64	175	69	29	63	273	66
Sidescrapers	4	21	9	9	8	3	5	11	26	6
Total	19	100	98	100	253	100	46	100	416	100

10.5.4 Dorsal cortex

Further comparison of dorsal cortex on retouched pieces is presented in figure 10.25A-D. It can be seen that there is significant difference of retouched pieces dorsal surface cortex coverage between sites (Figure 10.25). In particular, a pronounced variation is observed in basalt raw material, with non-cortical dominant retouched pieces being the most prevalent. Statistically, there is slight variation of non-cortical dominant cortex coverage within basalt materials ($X^2(4) = 82.389, p < .001$), with the adjusted residuals highlighting overrepresentation of JK West non-cortical dominant cortex coverage (Appendix 10.66; figure 10.25A).

Additional comparison of dorsal surface cortex of quartzite retouched pieces shows a significant variation between sites (Appendix 10.67; figure 10.25B). As shown in figure 10.25B most retouched pieces are non-cortical, with JK West retouched pieces being the most prevalent. The Chi-Square test result shows a significant difference of non-cortical cortex coverage between sites ($X^2(9) = 38.703, p < .001$), with the adjusted residuals showing a significant overrepresentation of JK West non-cortical retouched pieces (Appendix 10.67; figure 10.25B). The predominance of non-cortical and non-cortical dominant of dorsal cortex on retouched pieces suggests that hominins selected blanks that have undergone high reduction intensity. As can be seen in figure 10.25A-B, JK West hominins appear to have selected basalt and quartzite blanks that were highly reduced.

Further comparison on phonolite materials shows a statistically significant difference of non-cortical dominant retouched pieces between sites ($X^2(6) = 180.463, p < .001$), with the adjusted residuals showing significant overrepresentation of FC East retouched pieces (Appendix 10.68; figure 10.25C). In addition, figure 10.25C shows predominance of non-cortical JK West retouched pieces. FC East and JK West hominins preferred highly reduced blanks for retouched pieces (Figure 10.25C). Nevertheless, JK2 hominins appear to have selected blanks that have undergone low reduction intensity (Figure 10.25C).

Furthermore, comparison of trachyte retouched pieces shows some variation of dorsal cortex coverage between sites (Appendix 10.69; figure 10.25D). The adjusted residuals show a significant overrepresentation of JK West non-cortical retouched pieces. Nonetheless, the adjusted residuals show underrepresentation of JK West non-cortical dominant retouched pieces ($X^2(4) = 107.198, p < .001$) (Appendix 10.69;

figure 10.25D). It is clear that JK West hominins selected highly reduced blanks over non-cortical dominant blanks. This is supported by the absence of cortical-dominant blanks within trachyte retouched tools. In all raw materials, JK2 and WK sites hominins appear to have selected blanks that have undergone low reduction intensity. This is interesting because it shows that hominins did not have to wait for blanks that have undergone high reduction intensity.

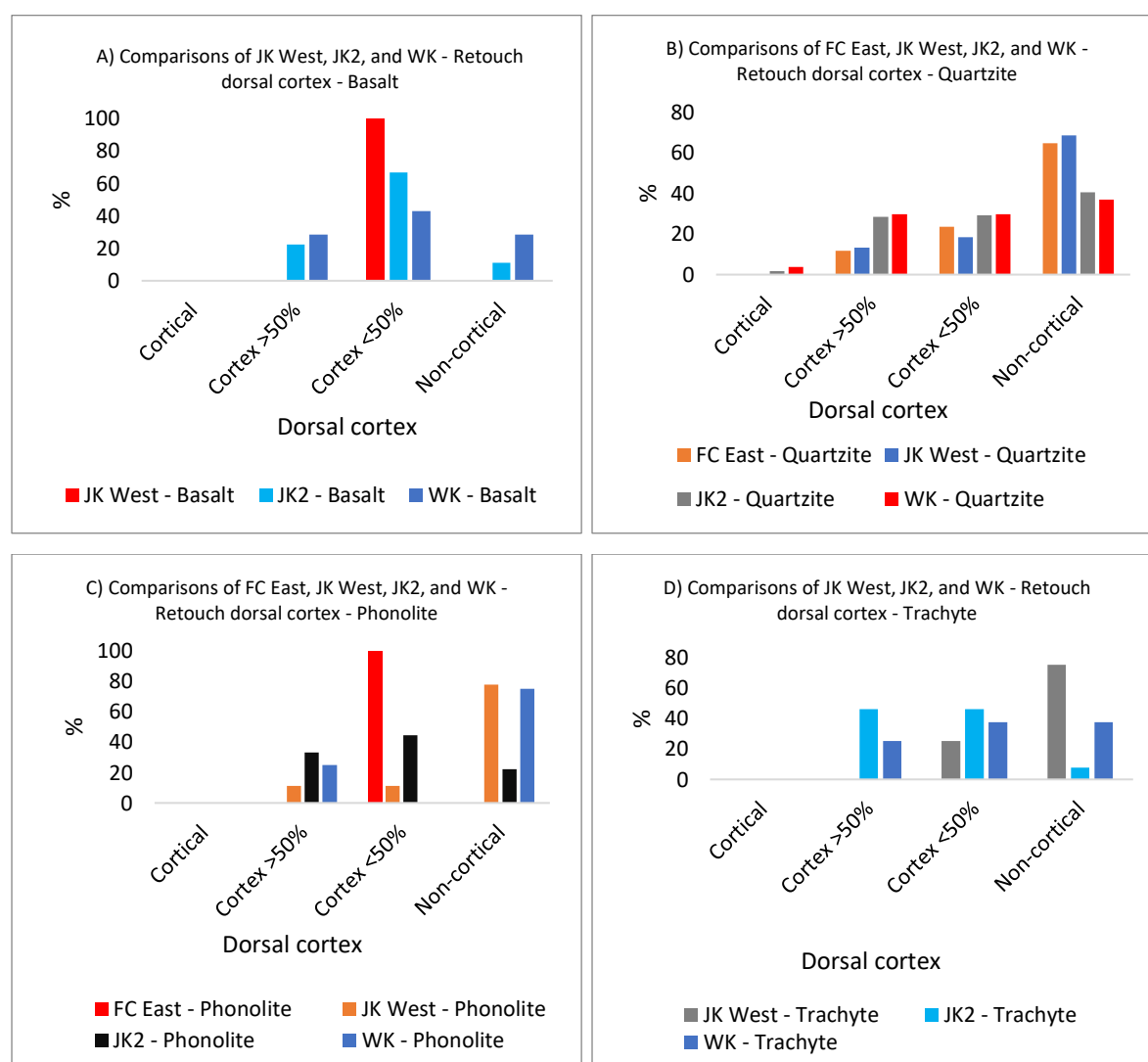


Figure 10. 25: Comparisons of retouched piece types between FC East, JK West, JK2 and WK sites per each raw material.

Generally, retouched pieces from all sites exhibit different levels of dorsal cortex coverage. It is clear that quartzite raw material shows a wide range of dorsal cortex

coverage than other raw materials. The most striking difference is that other raw materials do not exhibit cortical retouched pieces except quartzite raw material (Figure 10.25B). Thus, it can be suggested that the Acheulean hominins at Olduvai retouched different raw material types that were reduced at different levels of reductions.

10.5.5 Flakes and retouched pieces dimensions

Further comparison was undertaken on flake and retouched tools dimensions. As shown in figure 10.26A, there is predominance of flakes and retouched pieces measuring 40-59mm in length within basalt, with retouched pieces being the most frequent than flakes. This suggests that JK2 hominins selected blanks measuring 40-59mm in length. In addition, at WK site there is predominance of retouched pieces measuring 40-59mm in length. Moreover, WK hominins selected blanks measuring 60-79mm in length (Figure 10.26B). As show in figure 10.26A-B, both in JK2 and WK sites hominins selected larger basalt flakes for retouching; this is corroborated by the presence of higher frequency of larger sized retouched pieces measuring between 40-59mm and 80-99mm in length (figure 10.26A-B).

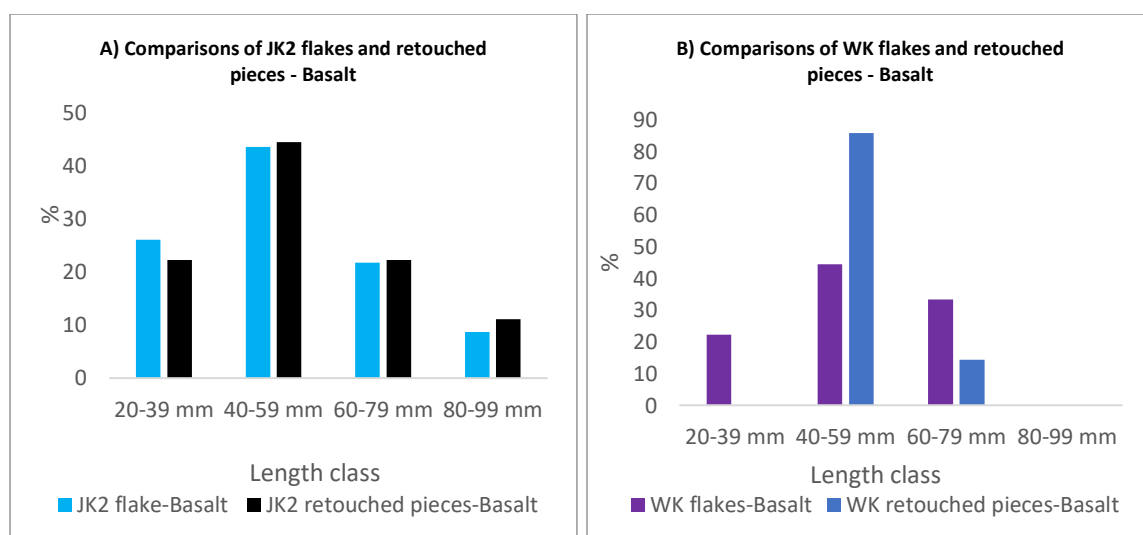


Figure 10. 26: Comparisons of flakes and retouched pieces within basalt raw material. A) JK2 site B) WK site.

In terms of quartzite raw material, most FC East retouched pieces are measuring 20-39mm in length. Similarly, FC East flakes are measuring 20-39mm in length (Figure 10.27A). In addition, figure 10.27A shows predominance of retouched pieces measuring 40-59mm and 60-79mm in length. This suggests that hominins at FC East selected blank size based on the available flakes. The higher frequency of retouched pieces in 40-59mm and 60-79mm suggests that hominins demanded larger retouched pieces. It should be noted that the size of the retouched pieces at FC East was largely determined by the flake sizes (Figure 10.27A).

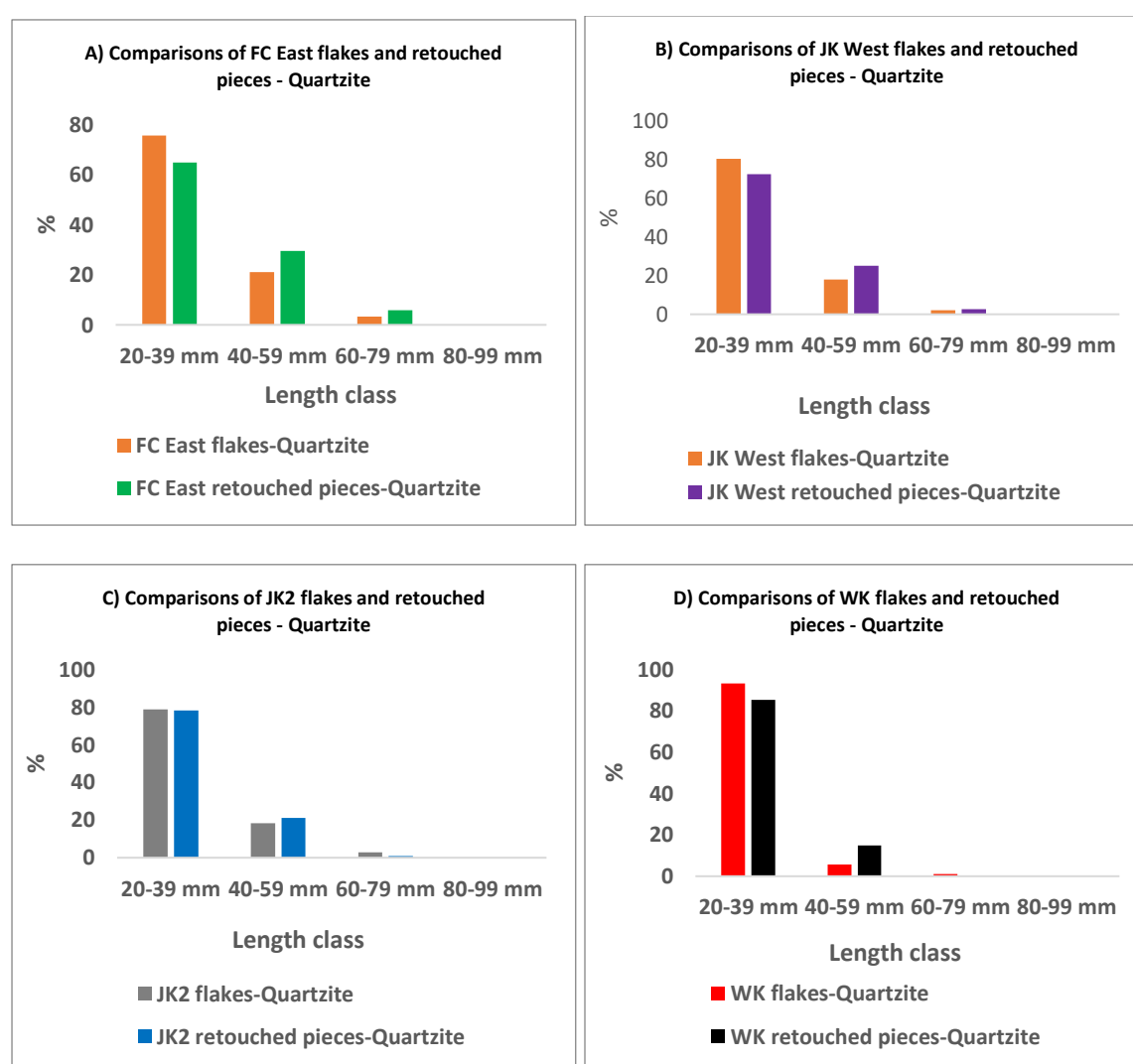


Figure 10. 27: Comparisons of flakes and retouched piece within quartzite raw material. A) FC East; B) JK West; C) JK2; and D) WK site.

At JK West most retouched pieces measure 20-39 mm in length (Figure 10.27B). In addition, there is presence of retouched pieces measuring 40-59mm and 60-79mm in length (figure 10.27B). As shown in figure 10.27B, most retouched pieces exhibit similar length with flakes, suggesting hominins used available flake blanks for retouching. Interestingly, JK West exhibits similar patterns as shown in FC East site, with retouched pieces measuring 40-59mm in length being more frequent than flakes (Figure 10.27B).

At JK2 most retouched pieces and flakes are measuring 20-39 mm in length, followed by 40-59 mm, and 60-79 mm (Figure 10.27C). As shown in figure 10.27C, retouched pieces size frequencies are almost similar to flakes, suggesting that JK2 hominins selected blanks sizes similar to flakes. Predominance of retouched pieces measuring 40-59 mm in length suggests that hominins intended to have larger number of retouched pieces that are larger than regular flakes (Figure 10.27C).

At WK site, most flakes and retouched pieces measure 20-39 mm in length (Figure 10.27D). In addition, there is predominance of retouched pieces measuring 40-59 mm in length. The retouched pieces sizes are consistently similar in size with WK flakes, suggesting that hominins selected blanks that had similar sizes to flake.

Generally, hominins at FC East, JK West, JK2, and WK selected quartzite retouched pieces blanks that were almost the same size as the regular flakes. It can be argued that hominins retouched regular flakes to increase a number of tools in their toolkits.

In terms of phonolite, figure 10.28A shows FC East phonolite flake measuring 20-39 mm in length and retouched piece measuring 40-59 mm in length. At FC East hominins did not prefer phonolite raw material for flake production and retouching. Hence, lower frequency of flakes and retouched pieces. At JK West, phonolite flakes and retouched

pieces measure 20-39 mm in length. The flake and retouched piece size appear to be in the same size range. At this site, hominins selected blanks of the same size as that of flakes (Figure 10.28B).

At JK2, there is variation in flakes and retouched pieces occurrence. Figure 10.28C shows variations in phonolite flakes and retouched pieces, with flakes and retouched pieces measuring 40-59 mm in length being the most prevalent. In addition, phonolite retouched pieces measuring 20-39 mm in length are more frequent than flakes. JK2 hominins had selected blanks that were larger than regular flakes. This is proved by the presence of JK2 retouched pieces measuring 80-99 mm in length (Figure 10.28C).

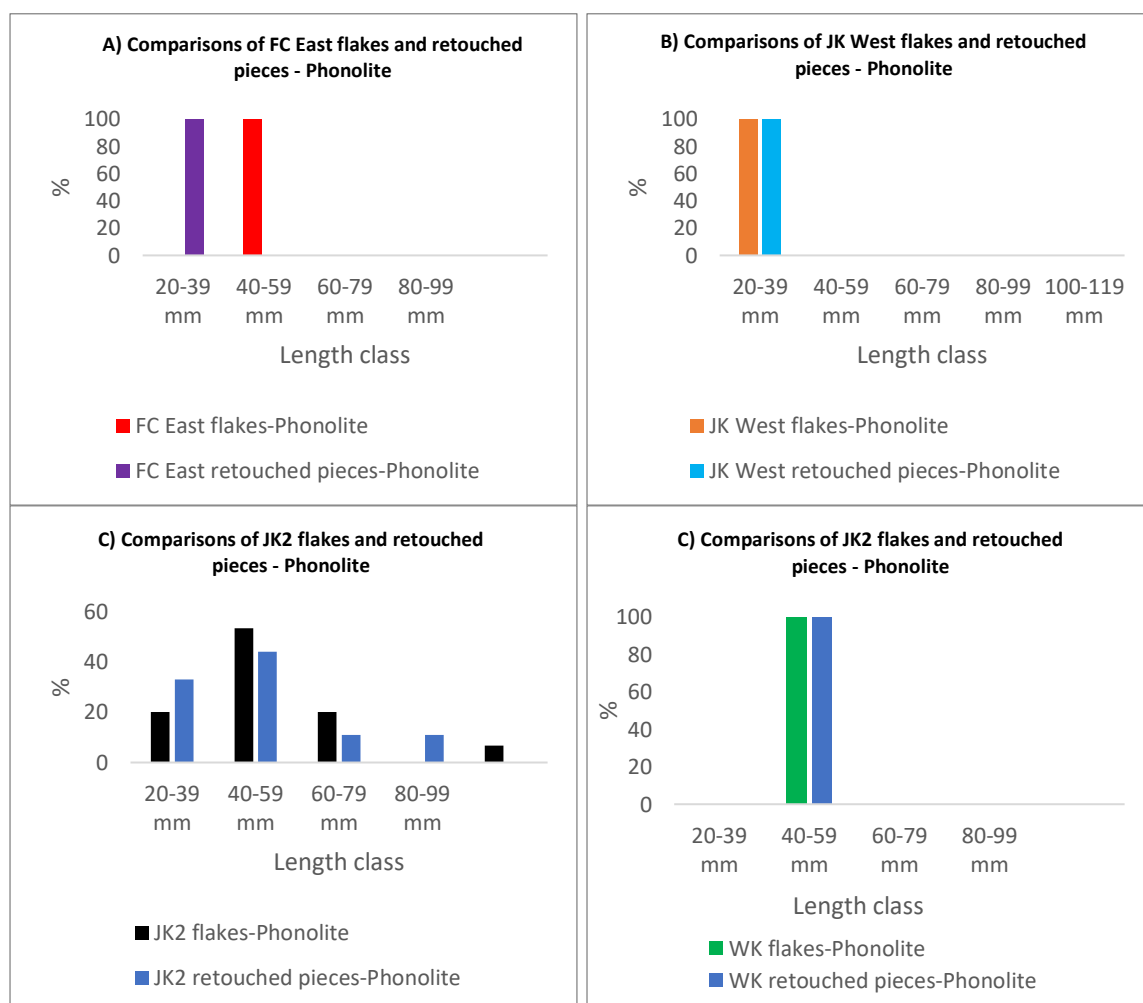


Figure 10. 28: Comparisons of flakes and retouched piece within phonolite raw material. A) FC East; B) JK West; C) JK2; and D) WK site.

At WK site, there is presences of flakes and retouched pieces measuring 40-59 mm in length (Figure 10.28D). It can be said that hominins selected blanks that are larger in size. Absence of other flake and retouched pieces size may be due to shortage of phonolite raw material at the site or hominins preferred other raw material such as quartzite over phonolite. In terms of trachyte, JK West flakes and retouched pieces measure 20-39 mm and 60-79 mm in length (Figure 10.29A).

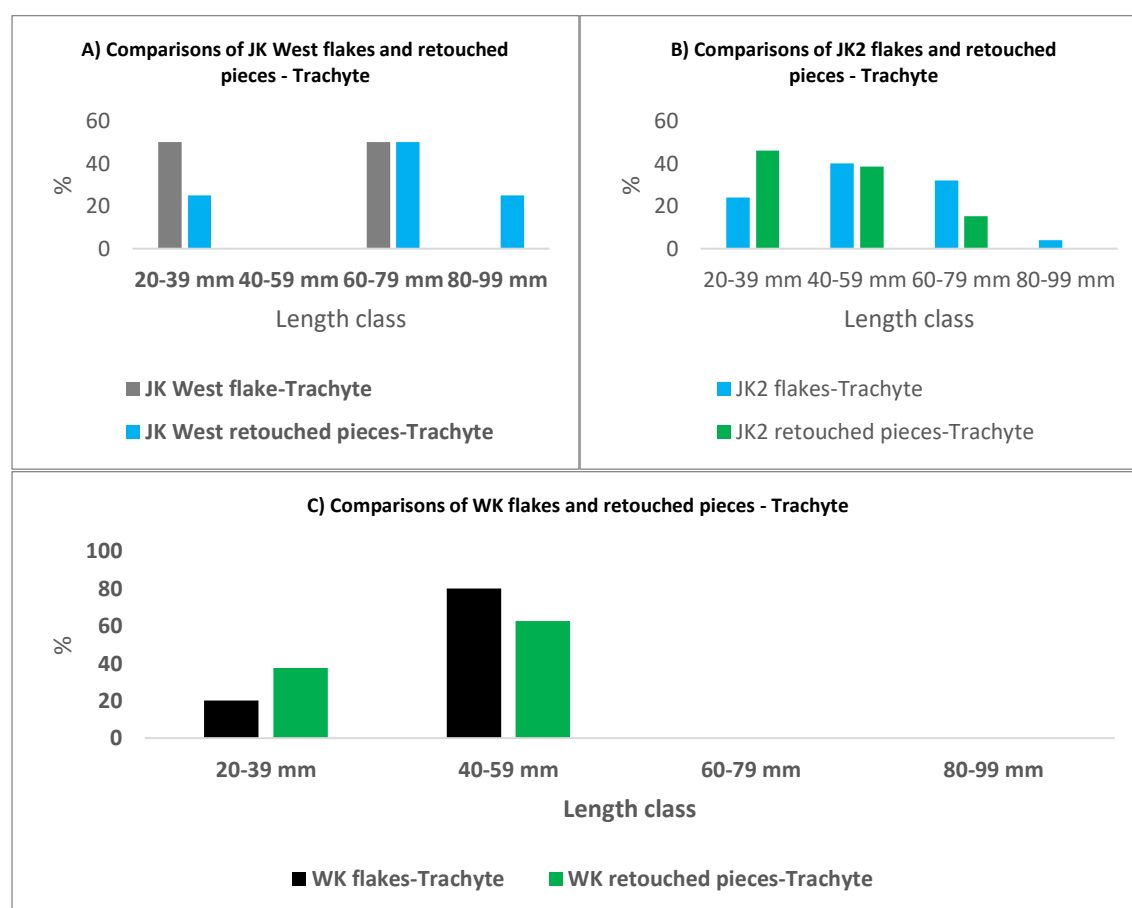


Figure 10. 29: Comparisons of flakes and retouched piece within phonolite raw material. A) FC East; B) JK West; C) JK2; and D) WK site.

In addition, there is retouched pieces measuring 80-99 mm in length. Within JK2, there is predominance of flakes and retouched pieces measuring 20-39 mm, 40-59 mm, and 60-79 mm in length (Figure 10.29B). Figure 10.29B shows predominance of retouched

pieces measuring 20-39 mm in length over flakes. This suggests that JK2 hominins may have preferred smaller sized retouched tools.

Furthermore, at WK site there is predominance of flakes and retouched pieces measuring 40-59 mm in length, succeeded by 20-39 mm in length (Figure 10.29C). Within 20-39 mm in length, there is predominance of retouched pieces over flakes. In addition, there is predominance of flakes measuring 40-59 mm in length (Figure 10.29C). It can be said that WK hominins selected larger flake blanks for retouched pieces at the site.

In summary, the comparisons of flakes and retouched pieces aimed at understanding hominins preferences of raw material and size of retouched blanks selected for retouching. As seen in figures 10.26-10.29 hominins utilised four major raw materials, with quartzite being the mostly used across all sites (Figure 10.27). In terms of sizes, some sites show that hominins selected blanks larger than flakes while other were determined by the flake sizes.

This chapter compared technological attributes of lithic materials from FC East, JK, and WK sites. The comparisons focused on three major technological categories, cores, flakes, and retouched pieces. The chapter intended to establish an understanding of hominin technological behaviour by examining different core exploitation strategies, flake production stages, and retouching patterns. The next chapter presents the inter-assemblage characteristics and how they help in understanding the technological strategies of the Acheulean hominins at Olduvai.

Chapter 11: Technological strategies of hominins in Beds II, III, and IV at Olduvai

11.1 Introduction

Chapters 6, 7, and 8 presented a detailed technological analysis of assemblages of each site, focusing on different attributes and characteristics of stone tool categories and the relationship between each other. Specifically, this chapter presents the relationship between core exploitation, flake production, and retouch technology in each assemblage and analyses the patterns of similar lithic categories discerned in other sites. Thus, the inter-assemblage characteristics will be presented to understand technological strategies of hominins throughout the sequence of Beds II, III, and IV.

11.2 Lithic technological organisation of Olduvai Acheulean hominins

In recent decades, there has been an increasing interest in technological organisation studies, with general literature presenting issues on lithic technologies and analyses (Inizan, 1992; Alpers-Afil *et al.*, 2009; Nelson, 1991; Bamforth, 1991), organisation of technology (Nelson, 1991; Binford, 1979; Bamforth, 1991), and other specifically reporting on lithic technologies of East African sites (Delagnes and Roche, 2005; de la Torre and Mora, 2014; de la Torre *et al.*, 2014; de la Torre, McHenry and Njau, 2018; de La Torre and Mora, 2018c; de la Torre and Mora, 2018a; Proffitt, 2018; Policarpo *et al.*, 2017; Shipton, 2018).

11.3 Raw Materials selectivity during the Olduvai Acheulean

In recent years, there has been numerous studies that focused on raw material and selectivity patterns (Stout *et al.*, 2005; Goldman-Neuman and Hovers, 2012). The raw

material economy and selectivity has been associated with grain size of the rock (Stout et al., 2005; Goldman-Neuman and Hovers, 2012). To understand lithic raw material selectivity, this thesis dedicated chapter 5 to a detailed study on lithic raw material economy of the Acheulean hominins in each site analysed. Comparison of the archaeological and geological samples (see chapter 5) demonstrate a degree of raw material selectivity implemented by the Acheulean stone toolmaker at Olduvai as follows:

11.3.1 Rock type

Data on rock type frequency distribution shows similarities between cobble conglomerates and artefact assemblages, most notably preference of basalt and phonolite materials in the FC East, JK West, JK2, and WK (Figure 5.8 and 5.13 in chapter 5). As shown in figure 11.1A-B, higher frequency of basalt and quartzite rock type indicates that these rocks contributed to the process of decision-making as to which raw material should be selected and procured from its source to the site.

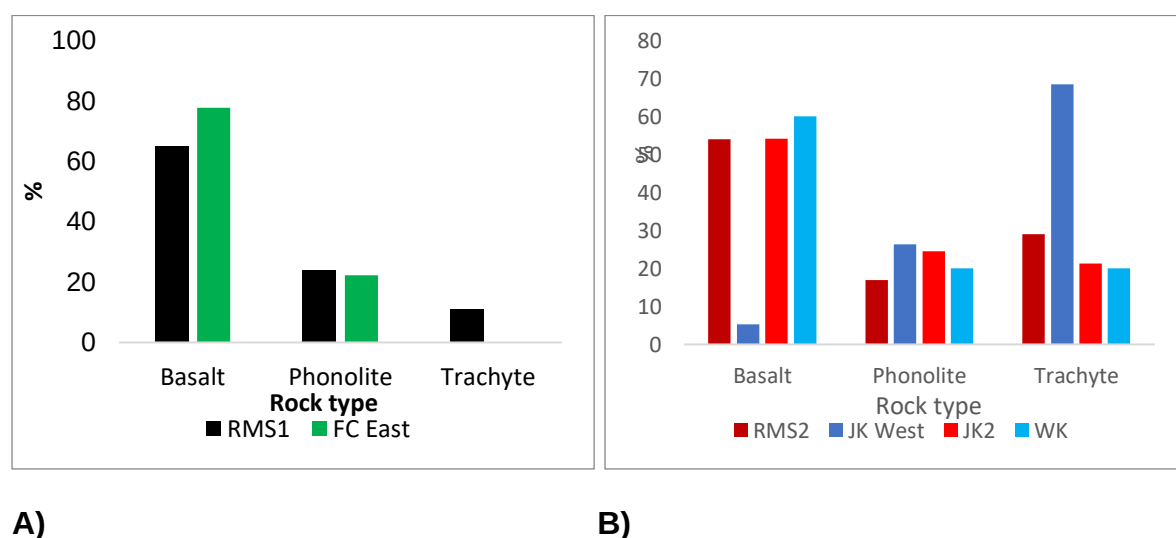


Figure 11. 1: A-B) Frequency of rock type between RMS1 and RM2 with archaeological samples from FC East, JK West, JK2, and WK sites. A) Comparison between RMS1 and FC East B) comparison between RMS2 and JK West, JK2, and WK sites.

11.3.2 Rock size

Rock size selection played an important role in raw material selectivity of prehistoric toolmakers at Olduvai. Comparison of cobble length from conglomerate with flake sizes helped in establishing the preferential size of cobbles for exploitation. Figure 11.2A-B indicates that conglomerate cobbles from RMS1 have length class of 70 to 180 mm, which corresponds to flake length class of FC East which ranges between 20 and 80 mm. As shown in figure 11.2B, most basalt and phonolite flakes have length between 20 and 80 mm. This suggests that hominins preferentially produced small and medium-sized flakes, mainly using basalt and phonolite raw materials at FC East.

In addition, cobble sizes of RMS2 have ranges from 60 to 199 mm (Figure 11.2C). A comparison of the cobble sizes and archaeological flake length suggests that the cobble sizes were compatible with the flakes produced at the sites. Figure 11.2D shows that JK West flake length ranges from 20-39 mm. Additionally, JK2 flake length ranges from 20-39 mm to 100-119 mm (Figure 11.2E). Furthermore, WK flake length ranges from 20-39 mm to 60-79 mm (Figure 11.2F). Thus, it can be suggested that rock size contributed to the raw material selection for flake production of the Acheulean hominins at Olduvai.

11.3.3 Groundmass

Rock groundmass was compared to understand raw material selectivity of hominins at Olduvai. Apart from preferentially exploiting basalt and phonolite rocks, hominins preferentially selected fine-grained rocks and avoided coarse-grained rocks (Figure 11.3A).

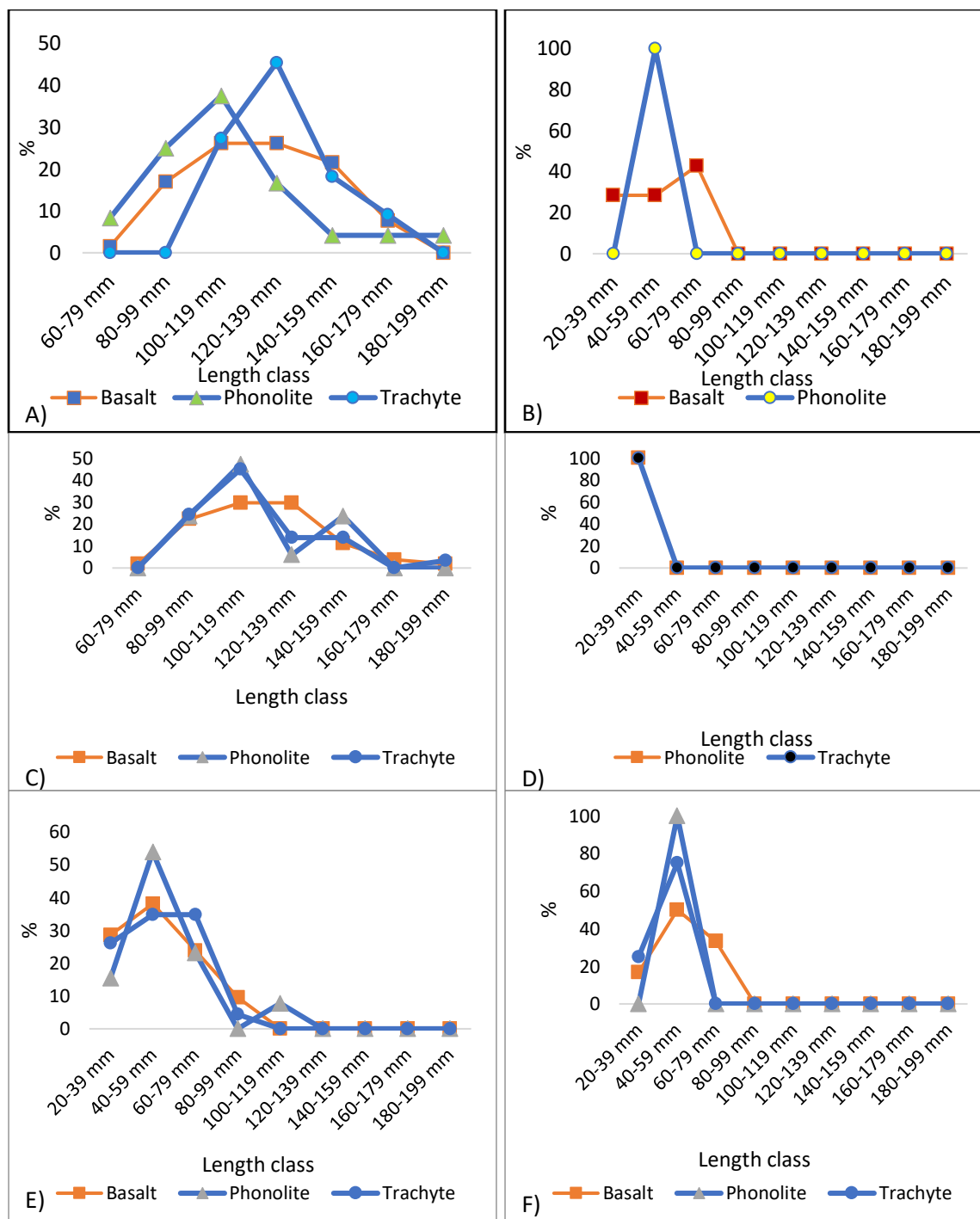


Figure 11. 2: Length distribution of rock types. (A) RMS1 sample; (B) whole flakes in the FC archaeological assemblage; (C) RMS2 sample; (D) JK West flake length; (E) JK2 flake length; and (F) WK flake length.

As shown in figure 11.3A, JK West, JK2, and WK artefacts had fine-grained groundmasses, with exception of JK West which had few artefacts with coarse-grained groundmasses. Therefore, it can be suggested that Acheulean hominins at Olduvai

selected raw material with finer groundmasses and evaded coarse-grained raw materials.

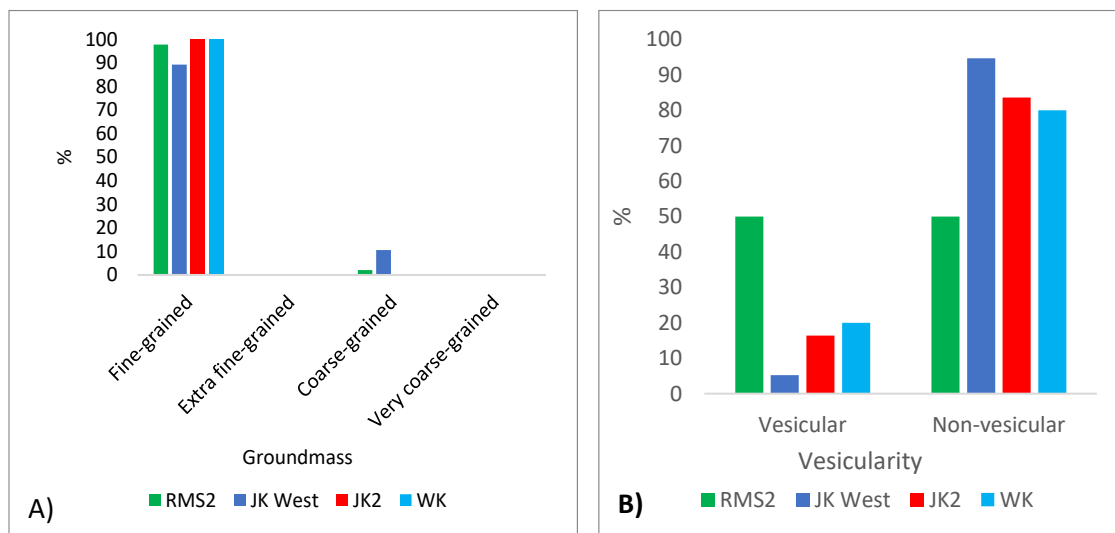


Figure 11. 3: Comparisons of raw material samples and archaeological materials from JK West, JK2, and WK. (A) Groundmass (B) Vesicularity.

11.3.4 Vesicularity

Rock vesicularity was also used in determining the level of raw material selection by hominins at Olduvai. A comparison of cobble conglomerates and individual assemblage further show that overall hominins avoided vesicular rocks and preferred homogeneous rock (Figure 11.3B). Rock vesicularity observed at each assemblage shows variation (figure 11.3B) but reveals a similar characteristic pattern of preference for non-vesicular rocks. This may confirm that rock vesicularity at Olduvai was one of the factors that determined raw material selectivity by Acheulean toolmakers.

11.4 Technological behaviour of the Acheulean hominins at Olduvai

Numerous technological strategies observed at the analysed sites may aid in the reconstruction of hominins technological behaviour at Olduvai. An extensive analysis

of different technological attributes within cores, flakes, and retouched pieces, provides detailed data for behavioural reconstruction.

11.5 Core attributes: hominin behavioural implications at FC East, JK West, JK2, and WK sites

11.5.1 Rock type

Core attributes have played a significant role in establishing an understanding of how hominins procured raw materials from sources and exploited cores to produce flakes. An examination of FC East core raw materials reveals predominance of metamorphic rocks (n=56) which contribute to over 11 kilograms of raw material transported to the site, whereas lava raw materials (n=2 cores) contribute to only 427 grams of raw material procured to the site (see table 6.5 in chapter 6). It is worth noting that abundance of metamorphic raw materials at FC East, coupled with its weight contribution to the site indicate that hominins regularly visited metamorphic rock sources and transported raw material back to the site. Thus, it may be suggested that hominins at FC East considered different aspects such as distance from the site to the raw material source and planned how the raw material would be exploited.

In addition, JK West core raw materials reveal predominance of metamorphic rocks (n=69) which contribute to over 13 kilograms of the overall weight of the core assemblage (n=88, 21.2 kg) (see table 7.5 in chapter 7). Lava materials at JK West contribute 7.6 kilograms of the overall weight of cores transported to the site (Table 7.5 in chapter 7). It should be noted that predominance of metamorphic cores at JK West may be associated with the distance from the source to the site, which is approximately 3 kilometres (See figure 5.4 in chapter 5). This transport behaviour may

have been influenced by the ability of forethinking about raw materials to be transported to the site.

JK2 core raw materials are dominated by metamorphic rocks (n=124) which contribute to over 25.6 kilograms of the entire weight of the core assemblage (see table 7.18 in chapter 7). In addition, lava cores (n=66) contribute to 25.5 kilograms of the entire weight of the core assemblage. At JK2, metamorphic and lava raw materials appear to contribute almost similar weight to the core assemblage weight. It is worth noting that at JK2, hominins transported both lava cobbles from the nearby conglomerates and tabular blocks from Naibor Soit and other nearby sources such as Naisiusiu Hills. This behavioural pattern shows that hominins understood the importance of lava and metamorphic materials. In addition, this demonstrates that hominins were making decisions based on their knowledge of the landscape.

The WK core assemblage are predominated by metamorphic rocks (n=26) which contribute to 4.1 kilograms of the entire core assemblage; lava cores (n=15), however, contribute 3.7 kilograms of the entire core assemblage. It should be noted that at WK, hominin understood the importance of utilising different raw material types, which were procured from both the nearby conglomerates such as RMS1 (see figure 5.4 in chapter 5) and primary sources such as Naibor Soit Hills. The transport behaviour demonstrated here suggests that hominins at WK preferred to use both raw materials from nearby conglomerate and those that required extra effort in transport, particularly quartzite from Naibor Soit Hill.

Generally, it is evident that all sites are dominated by metamorphic raw materials, followed by lava rocks. This suggests that hominins transported raw materials from primary sources and those found at nearby conglomerates to manufacture flakes, but

variations in raw materials preference, particularly metamorphic, might have been influenced by other factors such as durability of quartzites than basalts, phonolites, and trachytes.

11.5.2 Core dimensions

Core sizes played an important role in understanding hominin behaviour. As shown in figure 6.6A, FC East core length range between 20 and 39 mm and 120-139 mm, respectively. Based on the frequency of core length dimensions, it is evident that hominins at FC East preferred small and medium-sized cores for flake production.

At JK West, most cores sizes range from 40-59 mm to 60-79 mm (Figure 7.17A in chapter 7). In addition, most JK West core had width class ranging from 20-39 mm and 40-59 mm (Figure 7.17C). This length and width dimensions at JK West demonstrate that JK West hominin utilised medium size cores.

JK2 core dimensions range from 20-39 mm to over 100 mm in length, with 40-59 mm length being the most predominant, followed by 60-79 mm and 80-99 mm (Figure 7.35A in chapter 7). In addition, core width class range from 20-39 mm to 100-119 mm (Figure 7.35C in chapter 7). This may suggest that JK2 hominins preferred medium to large cores sizes. However, they occasionally utilised small cores (Figure 7.35A).

WK core length ranges from 40-59 mm to 80-99 mm (Figure 8.8A-B), and width ranges from 40-59 mm to 60-79 mm (Figure 8.8E). This evidence indicates that hominins at WK preferred to utilise medium to large cores to manufacture flake artefacts.

Generally, all sites demonstrate that hominins preferred to utilise small to medium-sized cores, which are consistent with the small debitage *chaîne opératoire*. Therefore, hominins at all sites procured cobbles and tabular blocks that had similar dimensions

with most cores analysed at the sites. These cores were exploited to produce small flakes and retouched pieces.

11.5.3 Core number of flake scars

The number of flake scars at the analysed sites can be used to understand hominin behaviour, particularly how cores were reduced and the intensity of reduction. An examination of the core sample from FC East reveals a predominance of flake scar patterns ranging from 1-3 scars to 4-6 scars per one core (Figure 6.17E-F). Figure 6.17F shows number of scars per raw material, with 4-6 scars being the most prevalent pattern. This suggests that reduction intensity at FC East ranged from low to medium. However, there are occasions that some cores reached up to over nine flake scars (Figure 6.17E-F in chapter 6).

At JK West cores are predominated by scar pattern ranging from 1-3 scars to 4-6 scars per core (Figure 7.13C-D in chapter 7). Figure 7.13D shows that most cores have 1-3 scars, followed by 4-6 scars, whereas 7-9 scars being marginally represented. This indicates low reduction intensity at JK West. Overall, the evidence shows low to medium reduction intensity due to presence of cores with 1-3 scars and 4-6 scars per core.

JK2 cores are predominantly characterized by cores with flake scar patterns ranging from 1-3 scars to 4-6 scars, with 7-9 scars and over 9 scars per core being marginally represented (Figure 7.37E-F). As can be seen in Figure 7.37E, most cores possess 1-3 scars and 4-6 scars per core. Similar patterns are observed in figure 7.37F with variations in flakes scars and raw materials. This evidence indicates that like JK West, JK2 exhibit a low to medium reduction intensity, with few cores exhibiting high reduction intensity at the site. This behaviour pattern suggests that hominins practiced

expedience system of core exploration with occasional curation, especially to those few cores that are heavily exploited.

Furthermore, the WK site is predominated by flake scar patterns ranging from 1-3 scar to 4-6 scars (Figure 8.9 in chapter 8). The predominance of 1-3 scars and 4-6 scars indicates that the site exhibits low to medium reduction intensity. Hence, it can be argued that hominins at WK exhibited a behavioural pattern that shows preference of low reduction intensity.

Generally, all sites exhibited low to medium reduction intensity. This is due to the number of flake scars observed from cores. Cores from all analysed samples indicate that hominins detached fewer flakes per core. This behaviour may suggest that hominins manufactured flakes when required for use. Hominins from all analysed sites practiced expedience rather than curation. Curation might have occurred occasionally due to some cores possessing up to 9 scars or more.

11.5.4 Core cortex coverage

Core cortex is significant in establishing an understanding of the level of reduction of a core. FC East is predominated by cores preserving <50% cortex, followed by non-cortical, whereas >50% cortex being the least represented (Figure 6.17C-D in chapter 6). This evidence corresponds to the FC East core flake scars as shown in figure 6.17E-F), and suggests that at FC East, hominins normally did not fully exploit cores to its exhaustion stage. Therefore, it can be argued that FC East hominins had abundant raw material resources that did not require them to fully reduce cores to the exhaustion stage.

The JK West core sample is dominated by cores preserving <50% cortex, followed by >50% cortex, whereas non-cortical cores are the least represented (Figure 7.18A-B in chapter 7). Figure 7.18B shows predominance of cores preserving <50% cortex, especially basalt cores, followed by quartzite, phonolite and trachyte. This is corroborated by the number of flake scars shown in figure 7.18C-D, whereas most cores preserve 4-6 scar and 7-9 scar patterns.

JK2 is dominated by cores preserving <50% cortex per core, followed by those that preserve >50% cortex (Figure 7.37A-B). It should be noted that this evidence suggests that JK2 hominins did not fully exploit the cores. Presence of cores preserving >50% cortex indicates low reduction intensity. This is supported by the number of flake scars as presented above (Also see figure 7.37E-F in chapter 7).

At WK site, most cores preserve <50% cortex (Figure 8.9A-B in chapter 8). Figure 8.9A shows that most cores possess <50% cortex, followed by >50% cortex, whereas non-cortical cores are marginally represented. This suggests that the level of reduction at WK was between low and medium, and occasionally high reduction occurred in a few cores. The high level of reduction might have been due to occasional high demand of flake product by the toolmakers. This evidence is corroborated by the number of flake scars on WK cores as shown in figure 8.9C-D (see chapter 8).

11.5.5 Core exploitation systems

Different exploitation systems were documented from the analysed core samples (Table 11.1). At FC East, the most predominant core reduction type was bifacial (n=18, 44%), followed by unifacial (n=14, 34%), whereas multifacial (n=9, 22%) was marginally represented (Table 11.1). In addition, JK West is dominated by multifacial

(n=38, 43%), followed by bifacial (n=29, 33%), whereas unifacial (n=21, 24%) are the least represented (Table 11.1).

JK2 cores are dominantly characterized by unifacial (n=83,44%), followed by multifacial (n=58, 31%), whereas bifacial (n=49, 26%) are less abundant (Table 11.1). Furthermore, WK cores are dominated by multifacial (n=21, 51%), followed by bifacial (n=16, 39%), whereas unifacial (n= 4, 10%) are the least represented (see table 11.1).

Table 11. 1: Table showing core exploitation systems from studied sites at Olduvai.

		Raw material				Total	
		Lava		Metamorphic		n	%
		n	%	n	%		
FC East	Unifacial	1	50	13	33	14	34
	Bifacial	1	50	17	44	18	44
	Multifacial	0	0	9	23	9	22
	Total	2	5	39	95	41	100
JK West	Unifacial	5	6	16	18	21	24
	Bifacial	9	10	20	23	29	33
	Multifacial	5	6	33	38	38	43
	Total	19	22	69	78	88	100
JK2	Unifacial	38	20	45	24	83	44
	Bifacial	20	11	29	15	49	26
	Multifacial	8	4	50	26	58	31
	Total	66	35	124	65	190	100
WK	Unifacial	2	13	2	8	4	10
	Bifacial	6	40	10	38	16	39
	Multifacial	7	47	14	54	21	51
	Total	15	37	26	63	41	100

The core exploitation types presented above indicate that hominins at FC East, JK West, JK2, and WK sites employed variable reduction strategies during core exploitation. Each site exhibits these exploitation strategies at different levels of

frequencies, which demonstrate how hominins repeatedly practiced certain reduction strategies to a core. Thus, it can be argued that at all sites hominins employed different core exploitation strategies to obtain flakes using different reduction types which depend on the available angles of the original core blank.

11.6 Flake attributes: hominin behavioural implications at FC East, JK West, JK2, and WK sites

Flake attributes have also played an important role in determining hominin technological behaviour at Olduvai during the Acheulean times. Different attributes were recorded during lithic analysis; these included flake dimensions, dorsal cortex, striking platform, and Toth's flake categories.

11.6.1 FC East flake attributes

At FC East, most flakes measure between 20-39 mm, 40-59 mm, and 60-79 mm in length (figure 6.12A and 6.13A-B in chapter 6). In addition, most flakes are 20-39 mm in width and 10-19 mm in thickness, with <20 grams in weight (Figure 6.12C, D, and E, table 6.7 in chapter 6). In terms of striking platforms, most flakes are unifaceted (n=109, 81%), followed by non-faceted (n=21, 16%), whereas bifaceted (n=4, 3%) and multifaceted (n=1, 1%) are the least presented (Table 6.7 in chapter 6). Dorsal cortex on flakes was also examined, with most flakes being non-cortical (n=81, 60%), followed by <50% cortex on dorsal side of a flake (Figure 6.7 in chapter 6). This suggests that there were previous removals before a flake was detached from a core. In addition, dorsal cortex was also measured using Toth's flake types, with most flakes being Toth's types V and VI. These Toth's flake types indicate a late stage of reduction of cores. Thus, high proportions of types V and VI flakes suggest that earlier stages of

flake production were missing from the sample selected. Generally, FC East hominins preferred small flakes with length ranging from 20-39 mm and weight class <20 grams.

11.6.2 JK West flake attributes

At JK West, hominins produced flakes with length ranging from 20-39 mm and 40-59 mm (Figure 7.8 in chapter 7). Moreover, most flakes are 20-39 mm in width and 1-9 mm in thickness, with most of them being <20 grams in weight (Figure 7.8 and 7.10 and table 7.6 in chapter 7). The flakes' striking platforms are mostly unifaceted (n=155, 77%), followed by non-faceted (n=37, 18%), bifaceted (n=7, 3%), whereas multifaceted (n=3%) are the least abundant (figure 7.6 in chapter 7). In addition, most flakes are non-cortical (n=102, 50%), followed by <50% cortex (n=56, 28%), >50% cortex (n=41, 20%), whereas cortical (n=3, 1%) are the least abundant (Table 7.6 in chapter 7). Additional analysis on cortex is shown by Toth's flake categories, which are dominated by Toth's flake types VI (n=90, 45%) and V (n=84, 42%) (Figure 7.6 in chapter 7). Overall, JK West hominins preferred small flakes (20-39 mm in length), which were 20-39 wide, 1-9 mm thin, and lighter than <20 grams. Moreover, most flake platforms are unifaceted, indicating that hominins prepared platforms on cores before flake removal.

11.6.3 JK2 flake attributes

JK2 flakes are mostly 20-39 mm (n=468, 73%) in length, followed by 40-59 mm (n=135, 21%) (Table 7.20 in chapter 7). Most flake' striking platforms are unifaceted (n=517, 81%), followed by non-faceted (n=111, 17%), whereas bifaceted (n=13, 2%) are the least represented (Table 7.20). In terms of dorsal cortex, most flakes are non-cortical (n=223, 35%), followed by <50 cortex (n=192, 30%), whereas >50% cortex (n=188, 29%) and cortical (n=38, 6%) are the least abundant (Table 7.20). This is

corroborated by the evidence on Toth's flake types, where the most prevalent are types V (n=326, 51%) and VI (n=191, 30%) (Table 7.20). Overall, the JK2 hominins preferred small-sized flakes ranging from 20-39 mm in length to medium flakes 40-59 mm in length. These flakes were mostly non-cortical or preserved little cortex on the dorsal side, indicating medium to high reduction stage. Flake striking platforms are mostly unifaceted, suggesting that hominins prepared platforms before detaching flakes.

11.6.4 WK flake attributes

WK flake attributes were also examined to understand hominins behaviour and technological skills. As shown in table 8.6 in chapter 8, most WK flakes measure 20-39 mm (n=84, 82%) in length, followed by 40-59 mm (n=15, 15%), and 60-79 mm (n=4, 4%). In terms of striking platform, most flakes are unifaceted (n=74, 72%), followed by non-faceted (n=23, 22%), whereas bifaceted (n=4, 4%) and multifaceted (n=2, 2%) are the least abundant (Table 8.6 in chapter 8). In terms of flake dorsal cortex, most flakes are non-cortical (n=55, 53%), followed by <50% cortex (n=25, 24%), cortex >50% (n=20, 19%), whereas cortical are the least represented (Table 8.6). The dorsal cortex evidence is supported by the evidence on Toth flake types, with Toth's flake type VI (n=43, 42%) being the most prevalent, followed by type V (n=39, 38%) (Table 8.6 in chapter 8). Thus, it can be argued that WK hominins produced small flakes that were produced during the later stages of flake production. Most cores were prepared before flakes were detached, hence the large number of Toth's flake types V and VI in the sampled assemblage.

11.7 Retouched pieces attributes: hominin behavioural implications at FC East, JK West, JK2, and WK sites

Retouched pieces attributes were also used to determine hominins' ability to modify artefacts. Retouched pieces were analysed based on length, dorsal cortex and retouching types.

11.7.1 FC East retouched pieces attributes

At FC East, most retouched pieces measure 20-39 mm in length, followed by 40-59 mm in length, whereas 60-79 mm in length are the least represented (Table 6.14 and figure 6.25A-B in chapter 6). In terms of dorsal cortex, most retouched pieces are non-cortical (n=12, 67%), followed by <50% cortex (n=4, 22%), whereas >50% cortex (n=2, 11%) are the least represented (Table 6.14). Denticulates (n=8, 44%) are the most prevalent, followed by notches (n=5, 28%), and sidescrapers (n=4, 22%) (Table 6.14).

11.7.2 JK West retouched pieces attributes

At JK West, retouched pieces measure 20-39 mm (n=132, 65%) in length, followed by 40-59 mm (n=58, 28%), whereas 60-79 mm (n=10, 5%) and <20 mm (n=2, 1%) are the least abundant (Table 7.13, figure 7.22 and 7.23 in chapter 7). In terms of dorsal cortex, most JK West retouched pieces are non-cortical (n=144, 70.6%), followed by <50% cortex (n=36, 17.6%), while >50% cortex (n=24, 11%) are the least prevalent. Most retouched types are notches (n=132, 64.7%), followed by denticulates (n=54, 26.5%), while sidescrapers (n=16, 7.8%) and points (n=2, 1%) being the least represented (Table 7.13 in chapter 7). In summary, JK West hominins preferred retouched pieces with dimensions similar to those of the flakes (20-39 mm), particularly notches.

11.7.3 JK2 retouched pieces attributes

At JK2, most retouched pieces measure 20-39 mm in length, with an average weight of 61.5 g and width of 31.2 mm. Most retouched pieces are notches (n=176), followed by denticulates (n=72), whereas sidescrapers (n=8) are the least represented (Table 7.24 and figure 7.23 in chapter 7).

11.7.4 WK retouched pieces attributes

At WK site, figures 8.14-15 and table 8.13 show that most retouched pieces measure 20-39 mm (n=26, 57%) in length, followed by 40-59 mm (n=19, 41%), while 60-79 mm ranges (n=1, 2%) are the least represented. In terms of dorsal cortex, most retouched pieces are non-cortical (n=18, 39%), followed by <50% cortex (n=14, 30%), whereas >50% cortex (n=13, 28%) are the least prevalent (Table 8.13 in chapter 8). Moreover, evidence on retouched types indicates that notches (n=29, 63%) are the most prevalent, followed by denticulates (n=12, 26%), whereas sidescrapers (n=5, 11%) are the least abundant (Table 8.13). Overall, WK hominins preferred retouched pieces of similar sizes to that of flakes, suggesting that they may have used flake blanks to produce retouched pieces, with most of them being notches.

11.8 Conclusion

This chapter has presented different technological strategies exercised by hominins from FC East, JK West, JK2, and WK sites.

The results in lines of raw materials selectivity show that hominins from all sites selected locally available raw materials for stone tool manufacture. In particular, data on rock type selection shows that hominins from the sites (notably FC East, JK West, JK2, and WK) selected cobble (basalt, phonolite, and trachyte) from nearby

conglomerates and tabular quartzite blocks from nearby raw material sources. This evidence is corroborated by higher frequency of these rock types (Figure 11.1A-B).

In addition, rock size played an important role in raw material selection. It is apparent from figure 11.2A-B that most conglomerate cobbles selected from RMS1 had length ranging from 70-180 mm, indicating that FC East hominins preferred to use medium to large-sized cores. Similarly, JK West, JK2, and WK cobble sizes have lengths ranging from 60-199 mm, suggesting the hominins from all sites had almost similar preferences in selecting rock size for stone tool manufacture, despite being existing in different time periods.

Furthermore, JK West, JK2, and WK hominins preferred rocks with fine-grained groundmass and avoided coarse-grained rocks (Figure 11.3A). Figure 11.3B shows that hominins preferentially selected non-vesicular lava cobbles for knapping activities. This suggests that hominins from these sites were knowledgeable of the rock properties and were aware of which rocks were suitable for stone tool manufacture, a behaviour that suggests a presence of planning and decision making amongst the hominin groups.

Regarding technological behaviour of the Olduvai Acheulean hominins, it is clear that hominins from all sites preferentially selected metamorphic materials over lava cobbles. At FC East metamorphic core materials contribute to over 11 kilograms of raw materials procured and transported to the site, whereby lava core materials only contribute to about 427 grams (see table 6.5 in chapter 6). Similarly, JK West core materials contribute to over 13 kilograms of the weight of the entire assemblage, whereas lava core materials (7.6 kg) contribute to about half of the metamorphic materials (table 7.5 in chapter 7). However, JK2 core materials contribute to over 25.6

kilograms, almost similar to lava core materials that contribute to 25.5 kilograms of the overall weight. Furthermore, WK metamorphic core materials contribute to 4.1 kilograms of overall weight, while lava core materials contribute to 3.7 kilograms, almost similar contribution.

Further evidence on core dimensions indicates that hominins from all sites exploited cores with length ranging from 20 mm to over 140 mm. FC East cores length class were between 20-39 mm and 120-139 mm (figure 6.6A); JK West core length size was between 40-59 mm and 60-79 mm (Figure 7.17A); JK2 core length was between 20-39 mm and over 100 mm (Figure 7.35A); and WK core length was between 40-59 mm and 80-99 mm (Figure 8.8A-B). As can be seen from the patterns above, it is clear that hominins from all sites exploited all kinds of core sizes, from small, medium to large cores.

The findings on the number of flake scars on cores indicate that all sites exhibit similar reduction pattern. At FC East, cores exhibit flake scar pattern ranging from 1-3 scars to 4-6 scars (Figure 6.17E-F). Similar pattern is observed at JK West, JK2, and WK site (see figures 7.13C-D, 7.37E-F, and 8.9).

The findings on core cortex coverage show similar patterns in core exploitation. At FC East there is predominance of non-cortical dominant (<50% cortex) cores (Figure 6.17C-D). Likewise, JK West, JK2, and WK have similar core cortex pattern (figures 7.18A-B, 7.37A-B, and 8.9A-B).

The results on the core exploitation systems show an inter-assemblage variation in exploitation pattern. FC East shows that the most predominant exploitation strategy was bifacial, followed by unifacial, whereas multifacial are marginally represented. Contrary results were observed at JK West, with multifacial being the most

predominant, followed by bifacial, whereas unifacial strategy are the least represented. JK2 is dominated by unifacial cores, followed by multifacial, whereas bifacial cores are marginally represented. WK, however, exhibit contrary results, with multifacial cores being dominant, followed by bifacial, whereas unifacial cores are the least represented (Table 11.1).

Flake attributes were also part of features that help in explaining hominin technological strategies. Most flakes at FC East are between 20-39 mm and 60-79mm in length, with most of them possessing unifaceted striking platforms and non-cortical dorsal cortex. In terms of Toth's flake types, most of them are dominated by Toth's flake types V and VI (Figure 6.12A, C-E, 6.13A-B; table 6.7). In addition, JK West flakes possess length ranging between 20-39 mm and 40-59 mm, with most of them having unifaceted striking platforms and non-cortical dorsal side and later stages of Toth's flake types, notably V and VI (Figures 7.8, 7.6; table 7.6). Similarly, JK2 flakes are mostly 20-39 mm and 40-59 mm, with unifaceted striking platforms, and non-cortical dorsal sides. Most flakes are from the later stages of production, with most of them being Toth's flake types V and VI. Furthermore, WK flakes are between 20-39 mm and 40-59 mm in length, with unifaceted striking platforms, and non-cortical dorsal cortex, with Toth's flake types V and VI (Table 8.6).

Regarding retouched pieces, attributes are also compared. Most FC East retouched pieces are between 20-39 mm and 40-59 mm in length, with most of them having non-cortical dorsal sides. FC East retouched pieces are mostly denticulates (Table 6.14; figure 6.25). In JK West with most retouched pieces are measuring 20-39 mm and 40-59 mm in length. However, the JK West retouched pieces types are mostly notches (Figure 7.22 and 23; Table 7.13). Similarly, JK2 retouched pieces are mostly 20-39

mm and most of them are notches (Table 7.24; figure 7.23). Furthermore, WK retouched pieces are measuring between 20-39 mm and 40-59 mm in length, with most of them having non-cortical dorsal sides; most of them are notches (Table 8.13).

Generally, there is a clear similar pattern in technological strategies exhibited by hominins from all sites in Beds II, III, and IV, with inter-assemblage variation in some aspects relating raw material selection, core exploitation, flake production and retouching forms. A summary of the findings, together with explanations addressing the research questions are provided in the next chapter.

Chapter 12: Conclusion and future research

12.1 Conclusions

As set out in chapter one, most Beds II, III, IV sites have received less attention especially in studies related to lithic technology and hominin behaviour. This thesis, is therefore, dedicated to filling that existing gap at Olduvai, a pivotal site for studying hominin technological behaviour and its role in our evolutionary trajectory.

This study aimed to identify and present the technological behaviour of *Homo erectus* in Beds II, III, and IV of Olduvai Gorge, Tanzania.

The main research questions were as follows:

1. *Through a technological analysis of relevant small debitage lithic assemblages, what were the technological capabilities of Acheulean hominins who lived in Beds II, III, and IV?*
2. *Is there identifiable stasis or technological change within the Acheulean small debitage assemblages in Beds II, III, and IV?*

In addition, secondary research questions were designed to support answers to the main research questions. Secondary research questions are as follows:

1. *What is the raw material economy of *Homo erectus* during Beds II, III and IV at Olduvai Gorge, and is there a relationship between technological capabilities and organisation and raw material?*
2. *How did raw material availability and distance affect reduction intensity and *Homo erectus* mobile toolkit design's efficiency compared to other periods such as the Oldowan?*

3. *What were the palaeogeographical and ecological contexts of sites in Beds II, III and IV during the lake regression and transgression periods; how did they change over time and how the changes influenced hominins behaviour in response to raw material sources?*
4. *What is the technological organisation during Acheulean times at Olduvai?*

Through a comprehensive lithic technological analysis, it can be stated that *Homo erectus* at Olduvai had a well-defined and complex technological capability. It was found that the hominins were able to locate and select certain raw material from their locally available sources. They were able to preferentially select certain raw materials based on their quality and texture. In these local sources, hominins were picking specific sizes of rocks for flake production. Various core exploitation strategies were used to produce flakes. Hominins used cores to make specific flakes with consistent characteristics throughout the sequence. For example, most flakes in FC East, JK West, JK2 and WK sites are between 2 and 3 centimetres long. Furthermore, hominins preferred exploitation strategies that usually incorporated multifacial exploitation and test core.

12.2 Results

Homo erectus at Olduvai produced tools through retouching flakes. As can be seen in the analysed retouched tools, hominins retouched flakes to produce notches, and sidescrapers; these retouched tools occurred in varied frequencies. This research is addressing the previously existing knowledge gap at Olduvai by utilising technological evidence to specifically focus on the research of Beds II, III and IV sites.

The first chapter includes a detailed account of how the research subject was developed using data from different studies, as well as how research questions were

developed and detailed explanations of how they will be addressed. The second chapter covers a full background of this study. To begin, it describes the geographical position of Olduvai Gorge, as well as its geology, stratigraphy, and ecological surroundings. It also defines and describes the Acheulean industrial complex and its origins. This is followed by an explanation of Acheulean technology and various sites where Acheulean technology is found. This is followed by an introduction of *Homo erectus*, the Acheulean's maker, and studies on the Acheulean in Olduvai. The second half of this chapter explores different theoretical aspects of analysing technical organization, such as raw material economy studies, distance decay models, tool curation, expedience, toolkit design and mobility patterns, *chaîne opératoire*, and mobility thinking.

The third chapter involves a detailed discussion of the materials and methods used in this research, with a focus on the experimental sample and archaeological assemblages. This is followed by methods used in this thesis's lithic technological analysis. It finally discusses and address various lithic categories and technological attributes that have been used to provide a detailed analysis of the stone tools.

The fourth chapter describes the actualistic studies that were used in this thesis. The purpose of this research was to gain a better understanding of the lithic technologies from the Olduvai Acheulean sites. It examined experimental materials made from Olduvai lithic raw materials in an attempt to generate predictive results that can aid in understanding of Olduvai lithic assemblages. It comprises a thorough examination of the experimental sample, which is then compared to Olduvai published data on Oldowan and Acheulean technological behaviour. As a result, the actualistic studies have generated a predictive model that can be compared to the archaeological

assemblages in Chapter 9 to investigate and understand hominin technological behaviour at Olduvai.

Chapter five presents raw material economy of the Acheulean hominins at Olduvai. Here it is argued that most raw material sources were not significantly far from the sites. Hominins were able to collect raw materials from short distances resulting in less reduction intensity of most cores.

Chapter six of this thesis was set out to provide evidence of hominin technological skills in Bed II through the study of the lithic assemblages from FC East. At FC East results shows that hominins utilised small, medium and a few large-sized cores, small flakes, fragmented flakes and retouched tools. Hominins obtained raw materials for stone tool manufacture locally, and metamorphic materials were preferentially selected as the main raw materials. Analysis shows that FC East exhibit a single reduction sequence characterised by small debitage *chaîne opératoire*. No existing large cutting tools were identified.

Chapter seven presents two samples of JK assemblages that were selected to provide evidence on hominin technological behaviour. Results show that JK hominins were preferentially selecting local raw materials from primary sources and riverbeds to manufacture stone tools. Evidence on flake production shows that hominins produced flakes mostly from quartzite and most flakes measure between 2 and 3 centimetres in length. In addition, hominins utilised cores that were tested before being exploited. This is due evidence of test cores and multifacial exploitation strategies. Also, hominins exploited cores using other strategies involving unifacial and bifacial exploitation techniques.

Chapter eight presents technological analysis of WK site. The Bed IV site contains one of the late Acheulean technologies at Olduvai. This study selected a sample that contained small debitage Acheulean technology. There were no large cutting tools materials analysed. The analysed materials from WK indicate that hominins selected locally available raw materials, preferably, metamorphic materials (Table 8.4). Hominins at WK exploited cores to produce flakes that were mostly small in size, mainly measuring 2 to 3 centimetres (Table 8.6), a size that was consistent with the size of most cores that measure between 4 and 6 centimetres. Most cores contained 1-3 and 4-6 flake scars, a pattern that indicates low to medium reduction intensity that exhibit expedient fashion of exploiting cores.

Moreover, WK assemblage contains retouched tools. Retouch technology that existed at WK shows that hominins preferred certain types of retouched tools, which are denticulates, sidescrapers, and notches. Notches are the most preferred retouched tools at WK site (Table 8.13). Therefore, WK assemblage, like other sites, exhibit a small debitage Acheulean technology that exhibits hominin's ability to plan and organise different technological operations ranging from raw material procurement, tool production and discard.

Through a technological analysis of relevant small debitage lithic assemblages, what were the technological capabilities of our stone tool-using ancestors who lived at Olduvai during Acheulean times? Evidence on hominin lithic technology was presented above, and it can, arguably, be suggested that technological capabilities existed amongst the Acheulean sites at Olduvai. This is confirmed by the evidence of a well-defined technology that is characterised by a systematic technological organisation. Hominin at FC East, JK West, JK2, and WK sites had a clear and

organised technology that represent standardised tool production methods. Multifacial cores, for example, indicate that hominins were able to rotate a core and detached flakes from multiple platforms; test cores indicate that hominins examined different blanks before selecting ideal blanks for flake production. Furthermore, the selection of raw materials, particularly homogenous rocks, demonstrates hominins' ability to identify and select raw materials for tool production.

Is there identifiable stasis or technological change during the Acheulean at Olduvai?

The evolution of stone tools from simple tool technology to complex and more refined technology may reflect both the advancement of tool-making ability and development in cognitive complexity. Mary Leakey's distinction of most stone tools focused on typological aspects (Leakey 1971; Leakey and Roe 1994). At Olduvai, different raw materials were utilised to manufacture stone tools, which were manufactured using various techniques such as TC, USP, BSP, UAU1, multifacial, polyhedron, just to mention a few. These complex techniques yielded different toolkit designs and sizes. Evidence from FC East, JK West, JK2 and WK sites show different sizes of cores and flakes (see chapter 6, 7, and 8). This evidence presents interassemblage variations, which are crucial in understanding stasis or technological change. The time period from Beds II, III, and IV is characterised by an increase in complexity in stone tool manufacture. Therefore, based on the archaeological evidence from the sites, it appears that there were some notable technological changes during the Acheulean period. While core elements of the Acheulean toolkit remained consistent, there are instances of innovation and variations in toolkit design and production techniques over time. This suggests a degree of both stasis and technological change within the Acheulean at Olduvai.

What is the raw material economy of Homo erectus during Beds II, III and IV at Olduvai Gorge, and is there a relationship between technological capabilities and organisation and raw material? Hominins at FC East, JK West, JK2 and WK site had a clearly defined raw material economy. These sites show that hominins had preferentially selected raw materials from locally available primary and secondary sources such as nearby raw materials conglomerates. In addition, it should be noted that hominins were knowledgeable of the rock properties and selected homogeneous rocks that had good qualities for knapping activities. This is indicative of the organised and well-planned lithic technology that represents these hominins capabilities and organisational skills.

How did raw material availability and distance affect reduction intensity and Homo erectus mobile toolkit design's efficiency compared to other periods such as the Oldowan? At Olduvai raw materials were available from different sources that were locally available. This study has shown that raw material sources were locally available, and hominins were able to collect raw materials from nearby sources (see chapter 5). Due to short distances between raw material sources and sites, hominins were able to easily access different types of raw materials within a short period of time. Hence, this allow low reduction intensity and their technology was mostly expedient. Additionally, their toolkit contained small debitage materials, particularly small cores, flakes with length ranging 2-3 cm and retouched pieces. Thus, it can be argued that short distances and raw material availability affected hominins' reduction intensity and their toolkit designs.

What is the technological organisation during Acheulean times at Olduvai? As defined in chapter two, technological organisation involves selection and integration of strategies for making, using, transporting, and discarding tools and the materials

needed for their manufacture and maintenance (Nelson, 1991). It is clear that the Acheulean hominins at all sites had a clear technological organisation. Hominins selected suitable raw materials for stone tool making, transported the raw materials to sites where they manufactured different stone tools using various core exploitation strategies. Hominins were also able to retouch flakes to produce retouched tools that were utilised at these sites. This was part of the maintenance of these stone tools. Therefore, it can be argued that the technological organisation of the Acheulean hominins at Olduvai involved a whole process from the selection of raw materials to the discard process.

What were the palaeogeographical and ecological contexts of sites in Beds II, III and IV during the lake regression and transgression periods; how did they change over time and how the changes influenced hominins behaviour in response to raw material sources? Chapter five provides a detailed description of raw materials used by hominins at Olduvai and the environment where they were found within Olduvai. Olduvai raw materials were found in both highlands and lowlands outcrops. For example, McHenry and de la Torre (2018) assert that at Olduvai, four large Pleistocene volcanoes that surrounded Olduvai palaeobasin were the potential sources of lithic raw materials. These include Lemagrut (a source of trachyandesite), Satiman (phonolite and phono-tephrites), Ngorongoro (basalt and trachyandesite), Olmoti (basaltic and trachytic lavas), and Engelosin (green phonolite).

According to McHenry and de la Torre (2018) palaeodrainages from these volcanoes transported raw material into the Olduvai palaeobasin. These raw materials in forms of lava cobbles were selected by hominins and procured to their sites for stone tool manufacture. Therefore, these palaeogeographic and ecological activities have

allowed availability of raw materials for hominins. Hence, they potentially influenced hominin behaviour, especially, in transporting raw materials and stone tool manufacture. For example, all sites show that raw materials were locally procured. This allowed hominins to undertake lower reduction intensity of the cores.

Despite addressing the above research questions this study has some limitations. These include methodological, analytical, data size and sample. Data used in this study was enough for establishing an understanding of the Acheulean hominins, but the sample is overall small. Due to resource and time constraints, however, it was impossible to include all excavated materials by OGAP from FC East site, all Leakey and Kleindienst materials from JK site, and all Leakey materials from WK site. Moreover, as the study focuses on small flake production, it is lacking a comprehensive technological analysis of Large Cutting tools (Acheulean handaxes, cleavers, picks etc). The combination of both small debitage and LCTs would bring more data on hominin behaviour at Olduvai. This work stands a detailed assessment of the technology of Acheulean hominins at Olduvai Beds II, III and IV, however, which could form the basis for future comparisons within the East and southern African contexts.

The analysed stone artefacts are tangible links to human past, providing us with valuable insights about the lives, technologies, and cultures of our ancestors. In this study, each analysed artefact carried unique information of our ancestors' skills as well as how they interacted with their environment.

During the analysis, researcher delved into various aspects such as the manufacturing techniques, raw materials utilised, reduction intensity, just to mention a few. Through a comprehensive study of these artefacts, this thesis has been able to reconstruct

technological skills and raw material economy of our ancestors at Olduvai, and thus contributed to put together a narrative of our past and appreciate the resilience of human societies throughout time.

In conclusion, this PhD thesis has endeavoured to shed light on the technological behaviour of hominins, delving deep into their evolutionary history and exploring the factors that have influenced the development and sophistication of their tool-making abilities. The research presented herein has provided valuable insights into the technological and cultural aspects that have played pivotal roles in shaping hominin technological trajectories.

As the study of hominin technological behaviour remains an ongoing endeavour, this thesis serves as a foundation for future research and inquiry in the field. It emphasizes the value of continually reassessing existing evidence and incorporating new archaeological discoveries and analytical methods to enrich our knowledge of the past.

12.3 Areas of future research

12.3.1 Archaeological excavations

The analysis of archaeological assemblages in this thesis (chapters 6, 7, and 8) regarding the technology of the Acheulean hominins at Olduvai sheds light on an additional area of future research. The assemblage unearthed by the Leakeys and Kleindienst at JK West, JK2, and WK require a comprehensive investigation that involves fresh excavations at the sites; the excavations will allow a detailed correlation between archaeological materials from the sites, and hence help in creating a holistic understanding of hominins technical skills during the lower Pleistocene times.

12.3.2 Technological analysis of other Acheulean sites at Olduvai and other eastern Africa sites

This study has sampled some of the Acheulean sites at Olduvai to study the Acheulean hominin behaviour. The assemblages have provided useful information that paves the way for further research. A consideration of further research that involves a full technological analysis of excavated materials from both the studied sites and the other Acheulean sites within Olduvai and other eastern African sites is paramount.

Ultimately, the knowledge gained from this research not only deepens our appreciation for the ingenuity of our Acheulean ancestors but also offers valuable lessons that can inform contemporary discussions on technological behaviour, hominins adaptability, innovation, and the ongoing coevolution of technology and culture. As we continue to unravel the complexities of our evolutionary heritage, this study serves as a testament to the enduring significance of understanding technological behaviour in hominins, fostering an enriched perspective of our shared human history.

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12.4 Appendices

Appendix 6

Appendix 6. 1: FC East adjusted residual values for core reduction types per raw materials.

Adjusted residuals of FC East core exploitation strategies – raw materials					
			Raw material group		Total
			Lava	Metamorphic	
Core exploitation type	Bifacial	Count	50	44	94
		Expected Count	47.0	47.0	94.0
		Adjusted Residual	.9	-.9	
	Multifacial	Count	0	23	23
		Expected Count	11.5	11.5	23.0
		Adjusted Residual	-5.1	5.1	
	Unifacial	Count	50	33	83
		Expected Count	41.5	41.5	83.0
		Adjusted Residual	2.4	-2.4	
Total		Count	100	100	200
		Expected Count	100.0	100.0	200.0

Appendix 6. 2: FC East adjusted residual values for core exploitation systems per raw materials.

Core exploitation raw material crosstabulation					
			Raw material		Total
			Lava	Metamorphic	
Core exploitation	BALP	Count	50	21	71
		Expected Count	35.1	35.9	71.0
		Adjusted Residual	4.4	-4.4	
	BALT	Count	0	10	10
		Expected Count	5.0	5.0	10.0
		Adjusted Residual	-3.2	3.2	
	BSP	Count	0	3	3
		Expected Count	1.5	1.5	3.0
		Adjusted Residual	-1.7	1.7	
	DISC	Count	0	10	10
		Expected Count	5.0	5.0	10.0
		Adjusted Residual	-3.2	3.2	
	MLT	Count	0	23	23
		Expected Count	11.4	11.6	23.0
		Adjusted Residual	-5.0	5.0	
	TC	Count	0	10	10
		Expected Count	5.0	5.0	10.0
		Adjusted Residual	-3.2	3.2	
	UAB1	Count	0	3	3
		Expected Count	1.5	1.5	3.0
		Adjusted Residual	-1.7	1.7	
	UAU1	Count	50	3	53
		Expected Count	26.2	26.8	53.0
		Adjusted Residual	7.6	-7.6	
	UAU2	Count	0	3	3
		Expected Count	1.5	1.5	3.0
		Adjusted Residual	-1.7	1.7	
	UAUT	Count	0	13	13
		Expected Count	6.4	6.6	13.0
		Adjusted Residual	-3.7	3.7	
	USP2	Count	0	3	3
		Expected Count	1.5	1.5	3.0
		Adjusted Residual	-1.7	1.7	
Total		Count	100	102	202
		Expected Count	100.0	102.0	202.0

Appendix 6. 3: FC East adjusted residual values for retouched pieces length classes per raw materials.

Length class * Raw materials crosstabulation					
			Raw materials		Total
			Lava	Metamorphic	
Length class	20-39 mm	Count	100	65	165
		Expected Count	82.5	82.5	165.0
		Adjusted Residual	6.5	-6.5	
	40-59 mm	Count	0	29	29
		Expected Count	14.5	14.5	29.0
		Adjusted Residual	-5.8	5.8	
	60-79 mm	Count	0	6	6
		Expected Count	3.0	3.0	6.0
		Adjusted Residual	-2.5	2.5	
Total		Count	100	100	200
		Expected Count	100.0	100.0	200.0

Appendix 6. 1: FC East adjusted residual values for retouched pieces' dorsal cortex per raw materials.

Dorsal cortex * Raw material Crosstabulation					
			Raw material		Total
			Lava	Metamorphic	
Dorsal cortex	Cortex <50%	Count	0	25	25
		Expected Count	12.5	12.5	25.0
		Adjusted Residual	-5.3	5.3	
	Cortex >50%	Count	50	6	56
		Expected Count	28.0	28.0	56.0
		Adjusted Residual	6.9	-6.9	
	Non-cortical	Count	50	69	119
		Expected Count	59.5	59.5	119.0
		Adjusted Residual	-2.7	2.7	
Total		Count	100	100	200
		Expected Count	100.0	100.0	200.0

Appendix 8

Appendix 8. 1: WK site adjusted residual values for core reduction types per raw materials.

Adjusted residuals of WK core exploitation strategies - raw material					
			Raw Material Group		Total
			Lava	Metamorphic	
Core exploitation	Discoid	Count	40	38	78
		Expected Count	39.0	39.0	78.0
		Adjusted Residual	.3	-.3	
	Multifacial	Count	47	50	97
		Expected Count	48.5	48.5	97.0
		Adjusted Residual	-.4	.4	
	Polyhedron	Count	0	4	4
		Expected Count	2.0	2.0	4.0
		Adjusted Residual	-2.0	2.0	
	Test core	Count	13	4	17
		Expected Count	8.5	8.5	17.0
		Adjusted Residual	2.3	-2.3	
	Unifacial Simple P	Count	0	4	4
		Expected Count	2.0	2.0	4.0
		Adjusted Residual	-2.0	2.0	
Total		Count	100	100	200
		Expected Count	100.0	100.0	200.0

Appendix 9

Appendix 9. 1: Adjusted residual values for length classes of flakes – comparisons between experimental (Model) and Archaeological (HWKEE) materials – Quartzite (Bold values indicate significant differences explained in the main body of this document).

Adjusted residuals of quartzite flake length classes					
			Context		Total
			HWKEE	Model	
Length Classes	<20 mm	Count	19	8	27
		Expected Count	13.9	13.1	27.0
		Adjusted Residual	2.1	-2.1	
	20-39 mm	Count	68	31	99
		Expected Count	51.0	48.0	99.0
		Adjusted Residual	4.9	-4.9	
	40-59 mm	Count	10	35	45
		Expected Count	23.2	21.8	45.0
		Adjusted Residual	-4.5	4.5	
	60-79 mm	Count	2	20	22
		Expected Count	11.3	10.7	22.0
		Adjusted Residual	-4.2	4.2	
	80–99 mm	Count	1	0	1
		Expected Count	.5	.5	1.0
		Adjusted Residual	1.0	-1.0	
Total		Count	100	94	194
		Expected Count	100.0	94.0	194.0

Appendix 9. 2: Adjusted residual values for length classes of flakes – comparisons between experimental (Model) and Archaeological (EF-HR) – Lava

Adjusted residuals of lava flake length classes					
			Context		Total
			EFHR	Model	
Length Classes	<20 mm	Count	0	9	9
		Expected Count	4.5	4.5	9.0
		Adjusted Residual	-3.1	3.1	
	20-39 mm	Count	60	34	94
		Expected Count	46.8	47.2	94.0
		Adjusted Residual	3.8	-3.8	
	40-59 mm	Count	31	32	63
		Expected Count	31.3	31.7	63.0
		Adjusted Residual	-.1	.1	
	60-79 mm	Count	7	25	32
		Expected Count	15.9	16.1	32.0
		Adjusted Residual	-3.4	3.4	
	80–99 mm	Count	1	0	1
		Expected Count	.5	.5	1.0
		Adjusted Residual	1.0	-1.0	
Total		Count	99	100	199
		Expected Count	99.0	100.0	199.0

Appendix 9. 3: Adjusted residual values for length classes of flakes – comparisons between experimental (Model) and Archaeological (EF-HR) – Quartzite

Adjusted residuals of quartzite flake length classes					
			Context		
			EFHR	Model	
Length Classes	<20 mm	Count	6	8	14
		Expected Count	7.2	6.8	14.0
		Adjusted Residual	-.7	.7	
	20-39 mm	Count	76	31	107
		Expected Count	55.2	51.8	107.0
		Adjusted Residual	6.0	-6.0	
	40-59 mm	Count	18	35	53
		Expected Count	27.3	25.7	53.0
		Adjusted Residual	-3.0	3.0	
	60-79 mm	Count	0	20	20
		Expected Count	10.3	9.7	20.0
		Adjusted Residual	-4.9	4.9	
Total		Count	100	94	194
		Expected Count	100.0	94.0	194.0

Appendix 9. 4: Adjusted residual values for length classes of flakes – comparisons between experimental (Model) and Archaeological (EF-HR) – Chert

Adjusted residuals of chert flake length classes					
			Context		Total
			EFHR	Model	
Length_Range	<20 mm	Count	20	12	32
		Expected Count	16.0	16.0	32.0
		Adjusted Residual	1.5	-1.5	
	20-39 mm	Count	80	45	125
		Expected Count	62.5	62.5	125.0
		Adjusted Residual	5.1	-5.1	
	40-59 mm	Count	0	35	35
		Expected Count	17.5	17.5	35.0
		Adjusted Residual	-6.5	6.5	
	60-79 mm	Count	0	8	8
		Expected Count	4.0	4.0	8.0
		Adjusted Residual	-2.9	2.9	
Total		Count	100	100	200
		Expected Count	100.0	100.0	200.0

Appendix 9. 5: Adjusted residual values for dorsal cortex of flakes – comparisons between experimental (Model) and Archaeological (HWKEE) – Quartzite

Dorsal Cortex					
			Context		Total
			HWKEE	Model	
Dorsal Cortex	<50	Count	21	32	53
		Expected Count	26.6	26.4	53.0
		Adjusted Residual	-1.8	1.8	
	>50	Count	8	31	39
		Expected Count	19.6	19.4	39.0
		Adjusted Residual	-4.1	4.1	
	0	Count	69	26	95
		Expected Count	47.7	47.3	95.0
		Adjusted Residual	6.0	-6.0	
	100	Count	2	10	12
		Expected Count	6.0	6.0	12.0
		Adjusted Residual	-2.4	2.4	
Total		Count	100	99	199
		Expected Count	100.0	99.0	199.0

Appendix 9. 6: Adjusted residual values for dorsal cortex of flakes – comparisons between experimental (Model) and Archaeological (HWKEE) – Chert

Dorsal Cortex					
			Context		Total
			HWKEE	Model	
Dorsal Cortex	<50	Count	23	50	73
		Expected Count	36.3	36.7	73.0
		Adjusted Residual	-3.9	3.9	
	>50	Count	12	23	35
		Expected Count	17.4	17.6	35.0
		Adjusted Residual	-2.0	2.0	
	0	Count	59	18	77
		Expected Count	38.3	38.7	77.0
		Adjusted Residual	6.0	-6.0	
	100	Count	5	9	14
		Expected Count	7.0	7.0	14.0
		Adjusted Residual	-1.1	1.1	
Total		Count	99	100	199
		Expected Count	99.0	100.0	199.0

Appendix 9. 7: Adjusted residual values for dorsal cortex of flakes – comparisons between experimental (Model) and Archaeological (EF-HR) – Quartzite

Dorsal_Cortex					
			Context		
			EFHR	Model	
Dorsal_Cortex	<50	Count	27	32	59
		Expected Count	29.6	29.4	59.0
		Adjusted Residual	-.8	.8	
	>50	Count	6	31	37
		Expected Count	18.6	18.4	37.0
		Adjusted Residual	-4.6	4.6	
	0	Count	67	26	93
		Expected Count	46.7	46.3	93.0
		Adjusted Residual	5.8	-5.8	
	100	Count	0	10	10
		Expected Count	5.0	5.0	10.0
		Adjusted Residual	-3.3	3.3	
Total		Count	100	99	199
		Expected Count	100.0	99.0	199.0

Appendix 9. 8: Adjusted residual values for dorsal cortex of flakes – comparisons between experimental (Model) and Archaeological (EF-HR) – Chert

Dorsal_Cortex					
			Context		Total
			EFHR	Model	
Dorsal_Cortex	<50	Count	40	50	90
		Expected Count	45.0	45.0	90.0
		Adjusted Residual	-1.4	1.4	
	>50	Count	0	23	23
		Expected Count	11.5	11.5	23.0
		Adjusted Residual	-5.1	5.1	
	0	Count	40	18	58
		Expected Count	29.0	29.0	58.0
		Adjusted Residual	3.4	-3.4	
	100	Count	20	9	29
		Expected Count	14.5	14.5	29.0
		Adjusted Residual	2.2	-2.2	
Total		Count	100	100	200
		Expected Count	100.0	100.0	200.0

Appendix 9. 9: Adjusted residual values for Toth's flake types – comparisons between experimental (Model) and Archaeological (HWKEE) materials – Lava

Toth's Flake Types					
			Context		Total
			HWKEE	Model	
Toth's Flake Types	I	Count	13	6	19
		Expected Count	9.5	9.5	19.0
		Adjusted Residual	1.7	-1.7	
	II	Count	28	9	37
		Expected Count	18.4	18.6	37.0
		Adjusted Residual	3.5	-3.5	
	III	Count	10	30	40
		Expected Count	19.9	20.1	40.0
		Adjusted Residual	-3.5	3.5	
	IV	Count	6	6	12
		Expected Count	6.0	6.0	12.0
		Adjusted Residual	.0	.0	
	V	Count	28	38	66
		Expected Count	32.8	33.2	66.0
		Adjusted Residual	-1.5	1.5	
	VI	Count	14	11	25
		Expected Count	12.4	12.6	25.0
		Adjusted Residual	.7	-.7	
Total		Count	99	100	199
		Expected Count	99.0	100.0	199.0

Appendix 9. 10: Adjusted residual values for Toth's flake types – comparisons between experimental (Model) and Archaeological (HWKEE) materials – Quartzite.

Toth's Flake Types					
			Context		Total
			HWKEE	Model	
Toth's Flake Types	I	Count	1	7	8
		Expected Count	4.0	4.0	8.0
		Adjusted Residual	-2.2	2.2	
	II	Count	8	25	33
		Expected Count	16.4	16.6	33.0
		Adjusted Residual	-3.2	3.2	
	III	Count	13	20	33
		Expected Count	16.4	16.6	33.0
		Adjusted Residual	-1.3	1.3	
	IV	Count	1	3	4
		Expected Count	2.0	2.0	4.0
		Adjusted Residual	-1.0	1.0	
	V	Count	21	32	53
		Expected Count	26.4	26.6	53.0
		Adjusted Residual	-1.7	1.7	
	VI	Count	56	14	70
		Expected Count	34.8	35.2	70.0
		Adjusted Residual	6.3	-6.3	
Total		Count	100	101	201
		Expected Count	100.0	101.0	201.0

Appendix 9. 11: Adjusted residual values for Toth's flake types – comparisons between experimental (Model) and Archaeological (HWKEE) materials – Chert

Toth's Flake Types					
			Context		Total
			HWKEE	Model	
Toth's Flake Types	I	Count	2	7	9
		Expected Count	4.5	4.5	9.0
		Adjusted Residual	-1.7	1.7	
	II	Count	17	14	31
		Expected Count	15.3	15.7	31.0
		Adjusted Residual	.6	-.6	
	III	Count	0	2	2
		Expected Count	1.0	1.0	2.0
		Adjusted Residual	-1.4	1.4	
	IV	Count	7	3	10
		Expected Count	5.0	5.0	10.0
		Adjusted Residual	1.3	-1.3	
	V	Count	60	43	103
		Expected Count	51.0	52.0	103.0
		Adjusted Residual	2.5	-2.5	
	VI	Count	14	33	47
		Expected Count	23.3	23.7	47.0
		Adjusted Residual	-3.1	3.1	
Total		Count	100	102	202
		Expected Count	100.0	102.0	202.0

Appendix 9. 12: Adjusted residual values for Toth's flake types – comparisons between experimental (Model) and Archaeological (EF-HR) materials – Lava

Toth's Flake Types					
			Context		Total
			EFHR	Model	
Toth's Flake Types	I	Count	3	6	9
		Expected Count	4.5	4.5	9.0
		Adjusted Residual	-1.0	1.0	
	II	Count	10	9	19
		Expected Count	9.5	9.5	19.0
		Adjusted Residual	.2	-.2	
	III	Count	7	30	37
		Expected Count	18.5	18.5	37.0
		Adjusted Residual	-4.2	4.2	
	IV	Count	7	6	13
		Expected Count	6.5	6.5	13.0
		Adjusted Residual	.3	-.3	
	V	Count	36	38	74
		Expected Count	37.0	37.0	74.0
		Adjusted Residual	-.3	.3	
	VI	Count	37	11	48
		Expected Count	24.0	24.0	48.0
		Adjusted Residual	4.3	-4.3	
Total		Count	100	100	200
		Expected Count	100.0	100.0	200.0

Appendix 9. 13: Adjusted residual values for Toth's flake types – comparisons between experimental (Model) and Archaeological (EF-HR) materials – Quartzite

Toth's Flake Types					
			Context		Total
			EFHR	Model	
Toth's Flake Types	I	Count	0	7	7
		Expected Count	3.5	3.5	7.0
		Adjusted Residual	-2.7	2.7	
	II	Count	9	25	34
		Expected Count	17.0	17.0	34.0
		Adjusted Residual	-3.0	3.0	
	III	Count	0	20	20
		Expected Count	10.0	10.0	20.0
		Adjusted Residual	-4.7	4.7	
	IV	Count	0	3	3
		Expected Count	1.5	1.5	3.0
		Adjusted Residual	-1.7	1.7	
	V	Count	26	32	58
		Expected Count	29.0	29.0	58.0
		Adjusted Residual	-.9	.9	
	VI	Count	66	14	80
		Expected Count	40.0	40.0	80.0
		Adjusted Residual	7.5	-7.5	
Total		Count	101	101	202
		Expected Count	101.0	101.0	202.0

Appendix 9. 14: Adjusted residual values for Toth's flake types – comparisons between experimental (Model) and Archaeological (EF-HR) materials – Chert

Toth's Flake Types					
			Context		Total
			EFHR	Model	
Toth's Flake Types	I	Count	20	7	27
		Expected Count	13.4	13.6	27.0
		Adjusted Residual	2.7	-2.7	
	II	Count	20	14	34
		Expected Count	16.8	17.2	34.0
		Adjusted Residual	1.2	-1.2	
	III	Count	0	2	2
		Expected Count	1.0	1.0	2.0
		Adjusted Residual	-1.4	1.4	
	IV	Count	0	3	3
		Expected Count	1.5	1.5	3.0
		Adjusted Residual	-1.7	1.7	
	V	Count	20	43	63
		Expected Count	31.2	31.8	63.0
		Adjusted Residual	-3.4	3.4	
	VI	Count	40	33	73
		Expected Count	36.1	36.9	73.0
		Adjusted Residual	1.1	-1.1	
Total		Count	100	102	202
		Expected Count	100.0	102.0	202.0

Appendix 9. 15: Adjusted residual values for length class of cores – comparisons between experimental (Model) and Archaeological (HWKEE) – Lava

Length Class					
			Context		Total
			HWKEE	Model	
Length Class	>100mm	Count	11	60	71
		Expected Count	33.8	37.2	71.0
		Adjusted Residual	-6.8	6.8	
	60-79 mm	Count	44	20	64
		Expected Count	30.5	33.5	64.0
		Adjusted Residual	4.1	-4.1	
	80–99 mm	Count	36	20	56
		Expected Count	26.7	29.3	56.0
		Adjusted Residual	3.0	-3.0	
Total		Count	91	100	191
		Expected Count	91.0	100.0	191.0

Appendix 9. 16: Adjusted residual values for length class of cores – comparisons between experimental (Model) and Archaeological (HWKEE) – Quartzite

Length Class					
			Context		Total
			HWKEE	Model	
Length Class	>100mm	Count	5	53	58
		Expected Count	26.3	31.7	58.0
		Adjusted Residual	-6.8	6.8	
	40-59 mm	Count	38	7	45
		Expected Count	20.4	24.6	45.0
		Adjusted Residual	6.1	-6.1	
	60-79 mm	Count	25	13	38
		Expected Count	17.2	20.8	38.0
		Adjusted Residual	2.8	-2.8	
	80–99 mm	Count	15	27	42
		Expected Count	19.0	23.0	42.0
		Adjusted Residual	-1.4	1.4	
Total		Count	83	100	183
		Expected Count	83.0	100.0	183.0

Appendix 9. 17: Adjusted residual values for length class of cores – comparisons between experimental (Model) and Archaeological (HWKEE) – Chert

Length Class					
			Context		Total
			HWKEE	Model	
Length Class	>100mm	Count	0	53	53
		Expected Count	17.7	35.3	53.0
		Adjusted Residual	-6.4	6.4	
	40-59 mm	Count	40	29	69
		Expected Count	23.0	46.0	69.0
		Adjusted Residual	5.9	-5.9	
	60-79 mm	Count	10	6	16
		Expected Count	5.3	10.7	16.0
		Adjusted Residual	2.6	-2.6	
	80–99 mm	Count	0	12	12
		Expected Count	4.0	8.0	12.0
		Adjusted Residual	-2.6	2.6	
Total		Count	50	100	150
		Expected Count	50.0	100.0	150.0

Appendix 9. 18: Adjusted residual values for length class of cores – comparisons between experimental (Model) and Archaeological (EF-HR) – Lava

Length Class					
			Context		Total
			EF-HR	Model	
Length Class	>100mm	Count	13	60	73
		Expected Count	34.2	38.8	73.0
		Adjusted Residual	-6.3	6.3	
	60-79 mm	Count	35	20	55
		Expected Count	25.7	29.3	55.0
		Adjusted Residual	3.0	-3.0	
	80-99 mm	Count	40	20	60
		Expected Count	28.1	31.9	60.0
		Adjusted Residual	3.7	-3.7	
Total		Count	88	100	188
		Expected Count	88.0	100.0	188.0

Appendix 9. 19: Adjusted residual values for length class of cores – comparisons between experimental (Model) and Archaeological (EF-HR) – Quartzite

Length Class					
			Context		Total
			EF-HR	Model	
Length Class	>100mm	Count	7	53	60
		Expected Count	26.9	33.1	60.0
		Adjusted Residual	-6.3	6.3	
	40-59 mm	Count	21	7	28
		Expected Count	12.5	15.5	28.0
		Adjusted Residual	3.5	-3.5	
	60-79 mm	Count	39	13	52
		Expected Count	23.3	28.7	52.0
		Adjusted Residual	5.2	-5.2	
	80–99 mm	Count	14	27	41
		Expected Count	18.3	22.7	41.0
		Adjusted Residual	-1.6	1.6	
Total		Count	81	100	181
		Expected Count	81.0	100.0	181.0

Appendix 9. 20: Adjusted residual values for weight range of cores – comparisons between experimental (Model) and Archaeological (HWKEE) – Lava

Weight Range						
			Context			
			HWKEE	Model		
Weight Range	<50 g	Count	1	0	1	
		Expected Count	.5	.5	1.0	
		Adjusted Residual	1.0	-1.0		
	>800 g	Count	4	33	37	
		Expected Count	18.6	18.4	37.0	
		Adjusted Residual	-5.3	5.3		
	101-200 g	Count	21	33	54	
		Expected Count	27.1	26.9	54.0	
		Adjusted Residual	-2.0	2.0		
	201-400 g	Count	43	33	76	
		Expected Count	38.2	37.8	76.0	
		Adjusted Residual	1.4	-1.4		
	401-800 g	Count	27	0	27	
		Expected Count	13.6	13.4	27.0	
		Adjusted Residual	5.6	-5.6		
	50-100 g	Count	4	0	4	
		Expected Count	2.0	2.0	4.0	
		Adjusted Residual	2.0	-2.0		
	Total		Count	100	99	199
			Expected Count	100.0	99.0	199.0

Appendix 9. 21: Adjusted residual values for weight range of cores – comparisons between experimental (Model) and Archaeological (HWKEE) – Quartzite

Weight Range					
			Context		
			HWKEE	Model	
Weight Range	<50 g	Count	23	0	23
		Expected Count	11.6	11.4	23.0
		Adjusted Residual	5.1	-5.1	
	101-200 g	Count	23	29	52
		Expected Count	26.1	25.9	52.0
		Adjusted Residual	-1.0	1.0	
	201-400 g	Count	21	57	78
		Expected Count	39.2	38.8	78.0
		Adjusted Residual	-5.3	5.3	
	401-800 g	Count	13	14	27
		Expected Count	13.6	13.4	27.0
		Adjusted Residual	-.2	.2	
	50-100 g	Count	17	0	17
		Expected Count	8.5	8.5	17.0
		Adjusted Residual	4.3	-4.3	
	801-1600 g	Count	4	0	4
		Expected Count	2.0	2.0	4.0
		Adjusted Residual	2.0	-2.0	
Total		Count	101	100	201
		Expected Count	101.0	100.0	201.0

Appendix 9. 22: Adjusted residual values for weight range of cores – comparisons between experimental (Model) and Archaeological (HWKEE) – Chert

Weight Range					
			Context		Total
			HWKEE	Model	
Weight Range	<50 g	Count	65	56	121
		Expected Count	60.5	60.5	121.0
		Adjusted Residual	1.3	-1.3	
	101-200 g	Count	10	0	10
		Expected Count	5.0	5.0	10.0
		Adjusted Residual	3.2	-3.2	
	201-400 g	Count	5	11	16
		Expected Count	8.0	8.0	16.0
		Adjusted Residual	-1.6	1.6	
	50-100 g	Count	20	33	53
		Expected Count	26.5	26.5	53.0
		Adjusted Residual	-2.1	2.1	
Total		Count	100	100	200
		Expected Count	100.0	100.0	200.0

Appendix 9. 23: Adjusted residual values for weight range of cores – comparisons between experimental (Model) and Archaeological (EF-HR) – Lava

Weight Range					
			Context		Total
			EF-HR	Model	
Weight Range	<50 g	Count	1	0	1
		Expected Count	.5	.5	1.0
		Adjusted Residual	1.0	-1.0	
	>800 g	Count	8	33	41
		Expected Count	20.3	20.7	41.0
		Adjusted Residual	-4.3	4.3	
	101-200 g	Count	11	33	44
		Expected Count	21.8	22.2	44.0
		Adjusted Residual	-3.7	3.7	
	201-400 g	Count	39	33	72
		Expected Count	35.6	36.4	72.0
		Adjusted Residual	1.0	-1.0	
	401-800 g	Count	34	0	34
		Expected Count	16.8	17.2	34.0
		Adjusted Residual	6.5	-6.5	
	50-100 g	Count	4	0	4
		Expected Count	2.0	2.0	4.0
		Adjusted Residual	2.0	-2.0	
Total		Count	97	99	196
		Expected Count	97.0	99.0	196.0

Appendix 9. 24: Adjusted residual values for weight range of cores – comparisons between experimental (Model) and Archaeological (EF-HR) – Quartzite

Weight Range					
			Context		Total
			EF-HR	Model	
Weight Range	<50 g	Count	21	0	21
		Expected Count	10.4	10.6	21.0
		Adjusted Residual	4.9	-4.9	
	101-200 g	Count	14	29	43
		Expected Count	21.3	21.7	43.0
		Adjusted Residual	-2.5	2.5	
	201-400 g	Count	21	57	78
		Expected Count	38.6	39.4	78.0
		Adjusted Residual	-5.1	5.1	
	401-800 g	Count	21	14	35
		Expected Count	17.3	17.7	35.0
		Adjusted Residual	1.4	-1.4	
	50-100 g	Count	14	0	14
		Expected Count	6.9	7.1	14.0
		Adjusted Residual	3.9	-3.9	
	801-1600 g	Count	7	0	7
		Expected Count	3.5	3.5	7.0
		Adjusted Residual	2.7	-2.7	
Total		Count	98	100	198
		Expected Count	98.0	100.0	198.0

Appendix 9. 25: Adjusted residual values for cortex of cores – comparisons between experimental (Model) and Archaeological (HWKEE) – Chert

Cortex Coverage					
			Context		Total
			HWKEE	Model	
Cortex Coverage	Cortex <50%	Count	55	75	130
		Expected Count	65.0	65.0	130.0
		Adjusted Residual	-3.0	3.0	
	Cortex >50%	Count	40	25	65
		Expected Count	32.5	32.5	65.0
		Adjusted Residual	2.3	-2.3	
	Non-cortical	Count	5	0	5
		Expected Count	2.5	2.5	5.0
		Adjusted Residual	2.3	-2.3	
Total		Count	100	100	200
		Expected Count	100.0	100.0	200.0

Appendix 9. 26: Adjusted residual values for cortex of cores – comparisons between experimental (Model) and Archaeological (EF-HR) – Quartzite

Cortex Coverage					
			Context		Total
			EF-HR	Model	
Cortex Coverage	Cortex <50%	Count	41	100	141
		Expected Count	70.5	70.5	141.0
		Adjusted Residual	-9.1	9.1	
	Cortex >50%	Count	26	0	26
		Expected Count	13.0	13.0	26.0
		Adjusted Residual	5.5	-5.5	
	Non-cortical	Count	33	0	33
		Expected Count	16.5	16.5	33.0
		Adjusted Residual	6.3	-6.3	
Total		Count	100	100	200
		Expected Count	100.0	100.0	200.0

Appendix 9. 27: Adjusted residual values for scar counts of cores – comparisons between experimental (Model) and Archaeological (HWKEE) – Lava

Scar Counts					
			Context		Total
			HWKEE	Model	
Scar Counts	>9 scars	Count	2	67	69
		Expected Count	34.7	34.3	69.0
		Adjusted Residual	-9.7	9.7	
	1-3 scars	Count	52	0	52
		Expected Count	26.1	25.9	52.0
		Adjusted Residual	8.3	-8.3	
	4-6 scars	Count	33	33	66
		Expected Count	33.2	32.8	66.0
		Adjusted Residual	.0	.0	
	7-9 scars	Count	14	0	14
		Expected Count	7.0	7.0	14.0
		Adjusted Residual	3.9	-3.9	
Total		Count	101	100	201
		Expected Count	101.0	100.0	201.0

Appendix 9. 28: Adjusted residual values for scar counts of cores – comparisons between experimental (Model) and Archaeological (EF-HR) – Lava

Number_of_scars * Context Crosstabulation					
			Context		Total
			EF-HR	Model	
Number_of_scars	>9 scars	Count	6	67	73
		Expected Count	36.5	36.5	73.0
		Adjusted Residual	-9.0	9.0	
	1-3 scars	Count	30	0	30
		Expected Count	15.0	15.0	30.0
		Adjusted Residual	5.9	-5.9	
	4-6 scars	Count	51	33	84
		Expected Count	42.0	42.0	84.0
		Adjusted Residual	2.6	-2.6	
	7-9 scars	Count	13	0	13
		Expected Count	6.5	6.5	13.0
		Adjusted Residual	3.7	-3.7	
Total		Count	100	100	200
		Expected Count	100.0	100.0	200.0

Appendix 9. 29: Adjusted residual values for length classes of flakes – comparisons between experimental (Model) and Archaeological (FC East, JK2, and WK) – Basalt

Length class * Site Crosstabulation							
			Site				Total
			Experimental	FC East	JK2	WK	
Length class	20-39 mm	Count	38	44	26	22	130
		Expected Count	32.9	32.3	32.6	32.3	130.0
		Adjusted Residual	1.3	2.9	-1.6	-2.5	
	40-59 mm	Count	35	22	43	44	144
		Expected Count	36.5	35.7	36.1	35.7	144.0
		Adjusted Residual	-.3	-3.3	1.7	2.0	
	60-79 mm	Count	28	33	22	33	116
		Expected Count	29.4	28.8	29.1	28.8	116.0
		Adjusted Residual	-.3	1.1	-1.8	1.1	
	80-99 mm	Count	0	0	9	0	9
		Expected Count	2.3	2.2	2.3	2.2	9.0
		Adjusted Residual	-1.8	-1.7	5.2	-1.7	
Total		Count	101	99	100	99	399
		Expected Count	101.0	99.0	100.0	99.0	399.0

Appendix 9. 30: Adjusted residual values for length classes of flakes – comparisons between experimental (Model) and Archaeological (FC East, JK West, JK2, and WK) – Quartzite

Length_class * Site Crosstabulation								
			Site					Total
			Experimental	FC East	JK West	JK2	WK	
Length_class	100-119 mm	Count	1	0	0	0	0	1
		Expected Count	.2	.2	.2	.2	.2	1.0
		Adjusted Residual	2.0	-.5	-.5	-.5	-.5	
	20-39 mm	Count	34	76	80	79	93	362
		Expected Count	73.0	72.3	72.3	72.3	72.3	362.0
		Adjusted Residual	-9.7	.9	1.9	1.7	5.2	
	40-59 mm	Count	38	21	18	18	6	101
		Expected Count	20.4	20.2	20.2	20.2	20.2	101.0
		Adjusted Residual	4.9	.2	-.6	-.6	-3.9	
	60-79 mm	Count	22	3	2	3	1	31
		Expected Count	6.2	6.2	6.2	6.2	6.2	31.0
		Adjusted Residual	7.3	-1.5	-1.9	-1.5	-2.4	
	80-99 mm	Count	6	0	0	0	0	6
		Expected Count	1.2	1.2	1.2	1.2	1.2	6.0
		Adjusted Residual	4.9	-1.2	-1.2	-1.2	-1.2	
Total		Count	101	100	100	100	100	501
		Expected Count	101.0	100.0	100.0	100.0	100.0	501.0

Appendix 9. 31: Adjusted residual values for flake dorsal cortex – comparisons between experimental (Model) and Archaeological (FC East, JK2, and WK) – Basalt

Dorsal cortex * Site Crosstabulation							
			Site				Total
			Experimental	FC East	JK2	WK	
Dorsal cortex	Cortex<50%	Count	28	0	26	44	98
		Expected Count	24.7	24.5	24.5	24.3	98.0
		Adjusted Residual	.9	-6.6	.4	5.3	
	Cortex>50%	Count	28	11	26	11	76
		Expected Count	19.2	19.0	19.0	18.8	76.0
		Adjusted Residual	2.6	-2.4	2.1	-2.3	
	Cortical	Count	13	67	39	11	130
		Expected Count	32.8	32.5	32.5	32.2	130.0
		Adjusted Residual	-4.9	8.5	1.6	-5.2	
	Non-cortical	Count	32	22	9	33	96
		Expected Count	24.2	24.0	24.0	23.8	96.0
		Adjusted Residual	2.1	-.5	-4.1	2.5	
Total		Count	101	100	100	99	400
		Expected Count	101.0	100.0	100.0	99.0	400.0

Appendix 9. 32: Adjusted residual values for flake dorsal cortex – comparisons between experimental (Model) and Archaeological (FC East, JK West, JK2, and WK) – Quartzite

Dorsal cortex * Site Crosstabulation								
			Site					Total
			Experimental	FC East	JK West	JK2	WK	
Dorsal cortex	Cortex<50%	Count	32	28	28	31	22	141
		Expected Count	28.0	28.3	28.3	28.3	28.3	141.0
		Adjusted Residual	1.0	-.1	-.1	.7	-1.6	
	Cortex>50%	Count	31	8	21	29	21	110
		Expected Count	21.8	22.0	22.0	22.0	22.0	110.0
		Adjusted Residual	2.5	-3.8	-.3	1.9	-.3	
	Cortical	Count	10	0	2	3	0	15
		Expected Count	3.0	3.0	3.0	3.0	3.0	15.0
		Adjusted Residual	4.6	-2.0	-.7	.0	-2.0	
	Non-cortical	Count	26	64	49	37	57	233
		Expected Count	46.2	46.7	46.7	46.7	46.7	233.0
		Adjusted Residual	-4.6	3.9	.5	-2.2	2.3	
Total		Count	99	100	100	100	100	499
		Expected Count	99.0	100.0	100.0	100.0	100.0	499.0

Appendix 9. 33: Adjusted residual values for Toth's flake categories – comparisons between experimental (Model) and Archaeological (FC East, JK2, and WK) – Basalt

Toth flake * Site Crosstabulation							
			Site				Total
			Experiment	FC East	JK2	WK	
Toth flake	I	Count	6	44	30	11	91
		Expected Count	22.8	22.6	22.8	22.8	91.0
		Adjusted Residual	-4.6	5.9	2.0	-3.3	
	II	Count	9	0	9	0	18
		Expected Count	4.5	4.5	4.5	4.5	18.0
		Adjusted Residual	2.5	-2.5	2.5	-2.5	
	III	Count	30	0	0	0	30
		Expected Count	7.5	7.4	7.5	7.5	30.0
		Adjusted Residual	9.8	-3.3	-3.3	-3.3	
	IV	Count	6	22	9	0	37
		Expected Count	9.3	9.2	9.3	9.3	37.0
		Adjusted Residual	-1.3	5.1	-.1	-3.7	
	V	Count	38	11	43	56	148
		Expected Count	37.1	36.7	37.1	37.1	148.0
		Adjusted Residual	.2	-6.2	1.4	4.5	
	VI	Count	11	22	9	33	75
		Expected Count	18.8	18.6	18.8	18.8	75.0
		Adjusted Residual	-2.3	1.0	-2.9	4.2	
Total		Count	100	99	100	100	399
		Expected Count	100.0	99.0	100.0	100.0	399.0

Appendix 9. 34: Adjusted residual values for Toth's flake categories – comparisons between experimental (Model) and Archaeological (FC East, JK2, and WK) – Quartzite

Toth flake * Site Crosstabulation							
			Site				Total
			Experimental	FC East	JK2	WK	
Toth flake	I	Count	7	0	2	0	9
		Expected Count	2.3	2.2	2.2	2.2	9.0
		Adjusted Residual	3.7	-1.7	-.2	-1.7	
	II	Count	25	7	8	9	49
		Expected Count	12.3	12.2	12.2	12.2	49.0
		Adjusted Residual	4.4	-1.8	-1.5	-1.1	
	III	Count	20	8	5	11	44
		Expected Count	11.1	11.0	11.0	11.0	44.0
		Adjusted Residual	3.3	-1.1	-2.2	.0	
	IV	Count	3	0	2	0	5
		Expected Count	1.3	1.2	1.2	1.2	5.0
		Adjusted Residual	1.8	-1.3	.8	-1.3	
	V	Count	32	28	52	36	148
		Expected Count	37.3	36.9	36.9	36.9	148.0
		Adjusted Residual	-1.3	-2.1	3.6	-.2	
	VI	Count	14	57	31	44	146
		Expected Count	36.8	36.4	36.4	36.4	146.0
		Adjusted Residual	-5.4	4.9	-1.3	1.8	
Total		Count	101	100	100	100	401
		Expected Count	101.0	100.0	100.0	100.0	401.0

Appendix 9. 35: Adjusted residual values for core length class – comparisons between experimental (Model) and Archaeological (FC East, JK West, JK2, and WK) – Basalt

Length class * Site Crosstabulation								
			Site					Total
			Experimental	FC East	JK West	JK2	WK	
Length class	100-119 mm	Count	40	0	0	9	0	49
		Expected Count	9.8	9.8	9.8	9.7	9.7	49.0
		Adjusted Residual	11.3	-3.7	-3.7	-.3	-3.7	
	140-159 mm	Count	20	0	0	0	0	20
		Expected Count	4.0	4.0	4.0	4.0	4.0	20.0
		Adjusted Residual	9.1	-2.3	-2.3	-2.3	-2.3	
	160-179 mm	Count	0	0	0	3	0	3
		Expected Count	.6	.6	.6	.6	.6	3.0
		Adjusted Residual	-.9	-.9	-.9	3.5	-.9	
	20-39 mm	Count	0	0	0	9	0	9
		Expected Count	1.8	1.8	1.8	1.8	1.8	9.0
		Adjusted Residual	-1.5	-1.5	-1.5	6.1	-1.5	
	40-59 mm	Count	0	0	0	39	33	72
		Expected Count	14.5	14.5	14.5	14.3	14.3	72.0
		Adjusted Residual	-4.6	-4.6	-4.6	7.9	6.0	
	60-79 mm	Count	20	50	100	24	33	227
		Expected Count	45.6	45.6	45.6	45.1	45.1	227.0
		Adjusted Residual	-5.7	1.0	12.2	-4.8	-2.7	
	80-99 mm	Count	20	50	0	15	33	118
		Expected Count	23.7	23.7	23.7	23.5	23.5	118.0
		Adjusted Residual	-1.0	6.9	-6.2	-2.2	2.5	
Total		Count	100	100	100	99	99	498
		Expected Count	100.0	100.0	100.0	99.0	99.0	498.0

Appendix 9. 36: Adjusted residual values for core length class – comparisons between experimental (Model) and Archaeological (FC East, JK West, JK2, and WK) – Quartzite

Length class * Site Crosstabulation							
			Site				Total
			Experimental	FC East	JK2	WK	
Length class	100-119 mm	Count	53	8	6	0	67
		Expected Count	16.7	16.5	16.9	16.9	67.0
		Adjusted Residual	11.2	-2.7	-3.4	-5.2	
	120-139 mm	Count	0	8	2	0	10
		Expected Count	2.5	2.5	2.5	2.5	10.0
		Adjusted Residual	-1.8	4.1	-.4	-1.9	
	20-39 mm	Count	0	39	9	0	48
		Expected Count	12.0	11.9	12.1	12.1	48.0
		Adjusted Residual	-4.3	9.7	-1.1	-4.3	
	40-59 mm	Count	7	18	44	62	131
		Expected Count	32.7	32.3	33.0	33.0	131.0
		Adjusted Residual	-6.3	-3.5	2.7	7.1	
	60-79 mm	Count	13	13	26	31	83
		Expected Count	20.7	20.5	20.9	20.9	83.0
		Adjusted Residual	-2.2	-2.1	1.4	2.9	
	80-99 mm	Count	27	13	14	8	62
		Expected Count	15.5	15.3	15.6	15.6	62.0
		Adjusted Residual	3.7	-.7	-.5	-2.4	
Total		Count	100	99	101	101	401
		Expected Count	100.0	99.0	101.0	101.0	401.0

Appendix 9. 37: Adjusted residual values for core weight class – comparisons between experimental (Model) and Archaeological (FC East, JK West, JK2, and WK) – Basalt

Weight class * Site Crosstabulation								
			Site					Total
			Experimental	FC East	JK West	JK2	WK	
Weight class	>800 g	Count	33	0	0	9	0	42
		Expected Count	8.4	8.5	8.5	8.4	8.4	42.0
		Adjusted Residual	9.9	-3.4	-3.4	.3	-3.4	
	101-200 g	Count	33	0	100	18	44	195
		Expected Count	38.8	39.2	39.2	38.8	38.8	195.0
		Adjusted Residual	-1.3	-9.0	13.9	-4.8	1.2	
	201-400 g	Count	33	100	0	39	33	205
		Expected Count	40.8	41.2	41.2	40.8	40.8	205.0
		Adjusted Residual	-1.8	13.4	-9.4	-.4	-1.8	
	401-800 g	Count	0	0	0	27	22	49
		Expected Count	9.8	9.9	9.9	9.8	9.8	49.0
		Adjusted Residual	-3.7	-3.7	-3.7	6.5	4.6	
	50-100 g	Count	0	0	0	6	0	6
		Expected Count	1.2	1.2	1.2	1.2	1.2	6.0
		Adjusted Residual	-1.2	-1.2	-1.2	4.9	-1.2	
Total		Count	99	100	100	99	99	497
		Expected Count	99.0	100.0	100.0	99.0	99.0	497.0

Appendix 9. 38: Adjusted residual values for core weight class – comparisons between experimental (Model) and Archaeological (FC East, JK West, JK2, and WK) – Quartzite

Weight class * Site Crosstabulation								
			Site					Total
			Experimental	FC East	JK West	JK2	WK	
Weight class	<50 g	Count	0	45	23	19	0	87
		Expected Count	17.4	17.5	17.4	17.4	17.4	87.0
		Adjusted Residual	-5.1	8.1	1.7	.5	-5.1	
	>800 g	Count	0	8	0	2	0	10
		Expected Count	2.0	2.0	2.0	2.0	2.0	10.0
		Adjusted Residual	-1.6	4.8	-1.6	.0	-1.6	
	101-200 g	Count	29	8	28	19	46	130
		Expected Count	25.9	26.2	25.9	25.9	25.9	130.0
		Adjusted Residual	.8	-4.6	.5	-1.8	5.1	
	201-400 g	Count	57	11	20	21	23	132
		Expected Count	26.3	26.6	26.3	26.3	26.3	132.0
		Adjusted Residual	7.8	-3.9	-1.6	-1.4	-.8	
	401-800 g	Count	14	21	16	11	0	62
		Expected Count	12.4	12.5	12.4	12.4	12.4	62.0
		Adjusted Residual	.6	2.9	1.2	-.5	-4.2	
	50-100 g	Count	0	8	13	28	31	80
		Expected Count	16.0	16.1	16.0	16.0	16.0	80.0
		Adjusted Residual	-4.9	-2.5	-.9	3.7	4.6	
Total		Count	100	101	100	100	100	501
		Expected Count	100.0	101.0	100.0	100.0	100.0	501.0

Appendix 9. 39: Adjusted residual values for core cortex coverage – comparisons between experimental (Model) and Archaeological (FC East, JK West, JK2, and WK) – Basalt

Cortex coverage * Site Crosstabulation								
			Site					Total
			Experimental	FC East	JK West	JK2	WK	
Cortex coverage	Cortex <50%	Count	33	50	100	18	44	245
		Expected Count	49.0	49.0	49.0	49.0	49.0	245.0
		Adjusted Residual	-3.6	.2	11.4	-6.9	-1.1	
	Cortex >50%	Count	67	50	0	82	56	255
		Expected Count	51.0	51.0	51.0	51.0	51.0	255.0
		Adjusted Residual	3.6	-.2	-11.4	6.9	1.1	
Total		Count	100	100	100	100	100	500
		Expected Count	100.0	100.0	100.0	100.0	100.0	500.0

Appendix 9. 40: Adjusted residual values for core cortex coverage – comparisons between experimental (Model) and Archaeological (FC East, JK West, JK2, and WK) – Quartzite

Cortex coverage * Site Crosstabulation								
			Site					Total
			Experimental	FC East	JK West	JK2	WK	
Cortex coverage	Cortex <50%	Count	86	53	70	63	77	349
		Expected Count	69.8	69.8	69.8	69.8	69.8	349.0
		Adjusted Residual	3.9	-4.1	.0	-1.7	1.8	
	Cortex >50%	Count	0	21	30	37	19	107
		Expected Count	21.4	21.4	21.4	21.4	21.4	107.0
		Adjusted Residual	-5.8	-.1	2.3	4.3	-.7	
	Non-cortical	Count	14	26	0	0	4	44
		Expected Count	8.8	8.8	8.8	8.8	8.8	44.0
		Adjusted Residual	2.1	6.8	-3.5	-3.5	-1.9	
Total		Count	100	100	100	100	100	500
		Expected Count	100.0	100.0	100.0	100.0	100.0	500.0

Appendix 9. 41: Adjusted residual values for core flake scars – comparisons between experimental (Model) and Archaeological (FC East, JK West, JK2, and WK) – Basalt

Core_flake_scar * Site Crosstabulation								
			Site					Total
			Experimental	FC East	JK West	JK2	WK	
Core_flake_scar	>9 scars	Count	67	0	100	3	0	170
		Expected Count	34.0	34.0	34.0	34.0	34.0	170.0
		Adjusted Residual	7.8	-8.0	15.6	-7.3	-8.0	
	1-3 scars	Count	0	50	0	67	67	184
		Expected Count	36.8	36.8	36.8	36.8	36.8	184.0
		Adjusted Residual	-8.5	3.1	-8.5	7.0	7.0	
	4-6 scars	Count	33	50	0	18	22	123
		Expected Count	24.6	24.6	24.6	24.6	24.6	123.0
		Adjusted Residual	2.2	6.6	-6.4	-1.7	-.7	
	7-9 scars	Count	0	0	0	12	11	23
		Expected Count	4.6	4.6	4.6	4.6	4.6	23.0
		Adjusted Residual	-2.5	-2.5	-2.5	3.9	3.4	
Total		Count	100	100	100	100	100	500
		Expected Count	100.0	100.0	100.0	100.0	100.0	500.0

Appendix 9. 42: Adjusted residual values for core flake scars – comparisons between experimental (Model) and Archaeological (FC East, JK West, JK2, and WK) – Quartzite

Core_flake_scar * Site Crosstabulation								
			Site					Total
			Experimental	FC East	JK West	JK2	WK	
Core_flake_scar	>9 scars	Count	0	8	16	2	0	26
		Expected Count	5.2	5.2	5.2	5.2	5.2	26.0
		Adjusted Residual	-2.6	1.4	5.4	-1.6	-2.6	
	1-3 scars	Count	43	29	23	36	46	177
		Expected Count	35.7	35.3	35.3	35.3	35.3	177.0
		Adjusted Residual	1.7	-1.5	-2.9	.2	2.5	
	4-6 scars	Count	29	55	38	51	50	223
		Expected Count	45.0	44.5	44.5	44.5	44.5	223.0
		Adjusted Residual	-3.6	2.4	-1.5	1.5	1.2	
	7-9 scars	Count	29	8	23	11	4	75
		Expected Count	15.1	15.0	15.0	15.0	15.0	75.0
		Adjusted Residual	4.3	-2.2	2.5	-1.2	-3.4	
Total		Count	101	100	100	100	100	501
		Expected Count	101.0	100.0	100.0	100.0	100.0	501.0

Appendix 10

Appendix 10. 1: Adjusted residuals values for technological categories – comparisons between FC East, JK West, JK2, and WK – All raw materials.

Technological category							
			Site				Total
			FC East	JK West	JK2	WK	
Technological category	Cores	Count	21	22	17	22	82
		Expected Count	20.5	20.5	20.5	20.5	82.0
		Adjusted Residual	.1	.4	-1.0	.4	
	Flakes	Count	70	52	59	54	235
		Expected Count	58.8	58.8	58.8	58.8	235.0
		Adjusted Residual	2.6	-1.6	.1	-1.1	
	Retouched Pieces	Count	9	26	24	24	83
		Expected Count	20.8	20.8	20.8	20.8	83.0
		Adjusted Residual	-3.3	1.5	.9	.9	
Total		Count	100	100	100	100	400
		Expected Count	100.0	100.0	100.0	100.0	400.0

Appendix 10. 2: Adjusted residuals values for length class of cores – comparisons between FC East, JK West, JK2, and WK – Basalt.

Length class – Core - Basalt							
			Site				Total
			FC East	JK West	JK2	WK	
Length class	100-119 mm	Count	0	0	15	0	15
		Expected Count	3.8	3.8	3.7	3.7	15.0
		Adjusted Residual	-2.3	-2.3	6.9	-2.3	
	120-139 mm	Count	0	0	9	0	9
		Expected Count	2.3	2.3	2.2	2.2	9.0
		Adjusted Residual	-1.8	-1.8	5.3	-1.7	
	180-199 mm	Count	0	0	3	0	3
		Expected Count	.8	.8	.7	.7	3.0
		Adjusted Residual	-1.0	-1.0	3.0	-1.0	
	40-59 mm	Count	0	0	9	33	42
		Expected Count	10.6	10.6	10.4	10.4	42.0
		Adjusted Residual	-4.0	-4.0	-.5	8.5	
	60-79 mm	Count	50	100	39	33	222
		Expected Count	55.8	55.8	55.2	55.2	222.0
		Adjusted Residual	-1.3	10.3	-3.8	-5.2	
	80-99 mm	Count	50	0	24	33	107
		Expected Count	26.9	26.9	26.6	26.6	107.0
		Adjusted Residual	6.0	-7.0	-.7	1.7	
Total		Count	100	100	99	99	398
		Expected Count	100.0	100.0	99.0	99.0	398.0

Appendix 10. 3: Adjusted residuals values for length class of cores – comparisons between FC East, JK West, JK2, and WK – Quartzite.

Length class – Core - Quartzite							
			Site				Total
			FC East	JK West	JK2	WK	
Length class	100-119 mm	Count	8	1	6	0	15
		Expected Count	3.7	3.7	3.8	3.8	15.0
		Adjusted Residual	2.6	-1.7	1.3	-2.3	
	120-139 mm	Count	8	3	2	0	13
		Expected Count	3.2	3.2	3.3	3.3	13.0
		Adjusted Residual	3.1	-.1	-.8	-2.1	
	20-39 mm	Count	39	16	9	0	64
		Expected Count	15.8	15.8	16.2	16.2	64.0
		Adjusted Residual	7.3	.1	-2.2	-5.1	
	40-59 mm	Count	18	36	44	62	160
		Expected Count	39.6	39.6	40.4	40.4	160.0
		Adjusted Residual	-5.1	-.9	.8	5.1	
	60-79 mm	Count	13	26	26	31	96
		Expected Count	23.8	23.8	24.2	24.2	96.0
		Adjusted Residual	-2.9	.6	.5	1.8	
	80-99 mm	Count	13	17	14	8	52
		Expected Count	12.9	12.9	13.1	13.1	52.0
		Adjusted Residual	.0	1.4	.3	-1.8	
Total		Count	99	99	101	101	400
		Expected Count	99.0	99.0	101.0	101.0	400.0

Appendix 10. 4: Adjusted residuals values for length class of cores – comparisons between JK West, JK2, and WK – Phonolite.

Length class – Core - Phonolite						
			Site			Total
			JK West	JK2	WK	
Length class	100-119 mm	Count	0	13	0	13
		Expected Count	4.3	4.3	4.3	13.0
		Adjusted Residual	-2.6	5.2	-2.6	
	40-59 mm	Count	0	13	0	13
		Expected Count	4.3	4.3	4.3	13.0
		Adjusted Residual	-2.6	5.2	-2.6	
	40-59 mm	Count	60	0	33	93
		Expected Count	31.0	31.0	31.0	93.0
		Adjusted Residual	7.7	-8.2	.5	
	60-79 mm	Count	20	27	67	114
		Expected Count	38.0	38.0	38.0	114.0
		Adjusted Residual	-4.5	-2.8	7.3	
	80-99 mm	Count	20	47	0	67
		Expected Count	22.3	22.3	22.3	67.0
		Adjusted Residual	-.7	7.3	-6.6	
Total		Count	100	100	100	300
		Expected Count	100.0	100.0	100.0	300.0

Appendix 10. 5: Adjusted residuals values for length class of cores – comparisons between JK West, JK2, and WK – Trachyte.

Length class – Core - Trachyte						
			Site			
			JK West	JK2	WK	
Length class	100-119 mm	Count	8	20	0	28
		Expected Count	9.3	9.3	9.3	28.0
		Adjusted Residual	-.6	4.5	-3.9	
	180-199 mm	Count	8	0	0	8
		Expected Count	2.7	2.7	2.7	8.0
		Adjusted Residual	4.1	-2.0	-2.0	
	40-59 mm	Count	15	0	0	15
		Expected Count	5.0	5.0	5.0	15.0
		Adjusted Residual	5.6	-2.8	-2.8	
	60-79 mm	Count	38	40	100	178
		Expected Count	59.3	59.3	59.3	178.0
		Adjusted Residual	-5.3	-4.8	10.1	
	80-99 mm	Count	31	40	0	71
		Expected Count	23.7	23.7	23.7	71.0
		Adjusted Residual	2.1	4.7	-6.8	
Total		Count	100	100	100	300
		Expected Count	100.0	100.0	100.0	300.0

Appendix 10. 6: Adjusted residuals values for width class of cores – comparisons between FC East, JK West, JK2, and WK – Basalt.

Width class – Core - Basalt							
			Site				Total
			FC East	JK West	JK2	WK	
Width class	100-119 mm	Count	0	0	6	0	6
		Expected Count	1.5	1.5	1.5	1.5	6.0
		Adjusted Residual	-1.4	-1.4	4.3	-1.4	
	40-59 mm	Count	50	100	39	33	222
		Expected Count	55.6	55.6	55.1	55.6	222.0
		Adjusted Residual	-1.3	10.3	-3.8	-5.3	
	60-79 mm	Count	50	0	36	67	153
		Expected Count	38.3	38.3	38.0	38.3	153.0
		Adjusted Residual	2.8	-9.1	-.5	6.8	
	80-99 mm	Count	0	0	18	0	18
		Expected Count	4.5	4.5	4.5	4.5	18.0
		Adjusted Residual	-2.5	-2.5	7.6	-2.5	
Total		Count	100	100	99	100	399
		Expected Count	100.0	100.0	99.0	100.0	399.0

Appendix 10. 7: Adjusted residuals values for width class of cores – comparisons between FC East, JK West, JK2, and WK – Quartzite.

Width class – Core - Quartzite							
			Site				Total
			FC East	JK West	JK2	WK	
Width class	<20 mm	Count	8	0	0	0	8
		Expected Count	2.0	2.0	2.0	2.0	8.0
		Adjusted Residual	4.9	-1.6	-1.7	-1.6	
	100-119 mm	Count	8	0	1	0	9
		Expected Count	2.3	2.2	2.3	2.3	9.0
		Adjusted Residual	4.5	-1.7	-1.0	-1.8	
	20-39 mm	Count	39	29	35	4	107
		Expected Count	26.8	26.5	27.0	26.8	107.0
		Adjusted Residual	3.2	.7	2.1	-5.9	
	40-59 mm	Count	16	43	37	77	173
		Expected Count	43.3	42.8	43.7	43.3	173.0
		Adjusted Residual	-6.4	.0	-1.6	7.9	
	60-79 mm	Count	24	23	22	19	88
		Expected Count	22.0	21.8	22.2	22.0	88.0
		Adjusted Residual	.6	.3	-.1	-.8	
	80-99 mm	Count	5	4	6	0	15
		Expected Count	3.8	3.7	3.8	3.8	15.0
		Adjusted Residual	.8	.2	1.3	-2.3	
Total		Count	100	99	101	100	400
		Expected Count	100.0	99.0	101.0	100.0	400.0

Appendix 10. 8: Adjusted residuals values for width class of cores – comparisons between JK West, JK2, and WK – Phonolite.

Width class – Core - Phonolite						
			Site			Total
			JK West	JK2	WK	
Width class	20-39 mm	Count	60	7	0	67
		Expected Count	22.3	22.5	22.3	67.0
		Adjusted Residual	11.1	-4.5	-6.5	
	40-59 mm	Count	20	27	100	147
		Expected Count	48.8	49.3	48.8	147.0
		Adjusted Residual	-7.1	-5.5	12.5	
	60-79 mm	Count	20	40	0	60
		Expected Count	19.9	20.1	19.9	60.0
		Adjusted Residual	.0	6.1	-6.1	
	80-99 mm	Count	0	27	0	27
		Expected Count	9.0	9.1	9.0	27.0
		Adjusted Residual	-3.8	7.7	-3.8	
Total		Count	100	101	100	301
		Expected Count	100.0	101.0	100.0	301.0

Appendix 10. 9: Adjusted residuals values for width class of cores – comparisons between JK West, JK2, and WK – Trachyte.

Width class – Core - Trachyte						
			Site			Total
			JK West	JK2	WK	
Width class	100-119 mm	Count	15	8	0	23
		Expected Count	7.6	7.7	7.6	23.0
		Adjusted Residual	3.4	.1	-3.5	
	20-39 mm	Count	8	0	0	8
		Expected Count	2.7	2.7	2.7	8.0
		Adjusted Residual	4.1	-2.0	-2.0	
	40-59 mm	Count	15	31	33	79
		Expected Count	26.2	26.5	26.2	79.0
		Adjusted Residual	-3.1	1.2	1.9	
	60-79 mm	Count	62	62	67	191
		Expected Count	63.5	64.1	63.5	191.0
		Adjusted Residual	-.4	-.5	.9	
Total		Count	100	101	100	301
		Expected Count	100.0	101.0	100.0	301.0

Appendix 10. 10: Adjusted residuals values for weight class of cores – comparisons between FC East, JK West, JK2, and WK – Basalt.

Weight class – Core - Basalt							
			Site				Total
			FC East	JK West	JK2	WK	
Weight class	>800 g	Count	0	0	9	0	9
		Expected Count	2.3	2.3	2.2	2.2	9.0
		Adjusted Residual	-1.8	-1.8	5.3	-1.7	
	101-200 g	Count	0	100	18	44	162
		Expected Count	40.7	40.7	40.3	40.3	162.0
		Adjusted Residual	-9.6	13.9	-5.3	.9	
	201-400 g	Count	100	0	39	33	172
		Expected Count	43.2	43.2	42.8	42.8	172.0
		Adjusted Residual	13.2	-10.1	-.9	-2.3	
	401-800 g	Count	0	0	27	22	49
		Expected Count	12.3	12.3	12.2	12.2	49.0
		Adjusted Residual	-4.3	-4.3	5.2	3.5	
	50-100 g	Count	0	0	6	0	6
		Expected Count	1.5	1.5	1.5	1.5	6.0
		Adjusted Residual	-1.4	-1.4	4.3	-1.4	
Total		Count	100	100	99	99	398
		Expected Count	100.0	100.0	99.0	99.0	398.0

Appendix 10. 11: Adjusted residuals values for weight class of cores – comparisons between FC East, JK West, JK2, and WK – Quartzite.

Weight class – Core - Quartzite							
			Site				
			FC East	JK West	JK2	WK	
Weight class	<50 g	Count	45	23	19	0	87
		Expected Count	21.9	21.7	21.7	21.7	87.0
		Adjusted Residual	6.4	.4	-.8	-6.1	
	>800 g	Count	8	0	2	0	10
		Expected Count	2.5	2.5	2.5	2.5	10.0
		Adjusted Residual	4.0	-1.8	-.4	-1.8	
	101-200 g	Count	8	28	19	46	101
		Expected Count	25.4	25.2	25.2	25.2	101.0
		Adjusted Residual	-4.6	.7	-1.6	5.5	
	201-400 g	Count	11	20	21	23	75
		Expected Count	18.9	18.7	18.7	18.7	75.0
		Adjusted Residual	-2.3	.4	.7	1.3	
	401-800 g	Count	21	16	11	0	48
		Expected Count	12.1	12.0	12.0	12.0	48.0
		Adjusted Residual	3.2	1.4	-.3	-4.3	
	50-100 g	Count	8	13	28	31	80
		Expected Count	20.1	20.0	20.0	20.0	80.0
		Adjusted Residual	-3.5	-2.0	2.3	3.2	
Total		Count	101	100	100	100	401
		Expected Count	101.0	100.0	100.0	100.0	401.0

Appendix 10. 12: Adjusted residuals values for weight class of cores – comparisons between JK West, JK2, and WK – Phonolite.

Weight class – Core - Phonolite						
			Site			Total
			JK West	JK2	WK	
Weight class	<50 g	Count	40	0	0	40
		Expected Count	13.4	13.3	13.3	40.0
		Adjusted Residual	9.6	-4.8	-4.8	
	101-200 g	Count	0	13	33	46
		Expected Count	15.4	15.3	15.3	46.0
		Adjusted Residual	-5.2	-.8	6.0	
	201-400 g	Count	20	40	33	93
		Expected Count	31.2	30.9	30.9	93.0
		Adjusted Residual	-3.0	2.4	.6	
	401-800 g	Count	20	33	0	53
		Expected Count	17.8	17.6	17.6	53.0
		Adjusted Residual	.7	5.0	-5.7	
	50-100 g	Count	20	13	33	66
		Expected Count	22.1	21.9	21.9	66.0
		Adjusted Residual	-.6	-2.6	3.3	
Total		Count	100	99	99	298
		Expected Count	100.0	99.0	99.0	298.0

Appendix 10. 13: Adjusted residuals values for weight class of cores – comparisons between JK West, JK2, and WK – Trachyte.

Weight class – Core - Trachyte						
			Site			Total
			JK West	JK2	WK	
Weight class	<50 g	Count	8	0	0	8
		Expected Count	2.7	2.7	2.7	8.0
		Adjusted Residual	4.0	-2.0	-2.0	
	>800 g	Count	15	0	0	15
		Expected Count	5.0	5.0	5.0	15.0
		Adjusted Residual	5.6	-2.8	-2.8	
	101-200 g	Count	31	15	0	46
		Expected Count	15.4	15.3	15.3	46.0
		Adjusted Residual	5.3	-.1	-5.2	
	201-400 g	Count	38	54	33	125
		Expected Count	41.9	41.5	41.5	125.0
		Adjusted Residual	-1.0	3.1	-2.1	
	401-800 g	Count	8	15	33	56
		Expected Count	18.8	18.6	18.6	56.0
		Adjusted Residual	-3.4	-1.1	4.5	
	50-100 g	Count	0	15	33	48
		Expected Count	16.1	15.9	15.9	48.0
		Adjusted Residual	-5.4	-.3	5.7	
Total		Count	100	99	99	298
		Expected Count	100.0	99.0	99.0	298.0

Appendix 10. 14: Adjusted residuals values for cortex coverage of cores – comparisons between FC East, JK West, JK2, and WK – Basalt.

Core cortex coverage - Basalt							
			Site				Total
			FC East	JK West	JK2	WK	
Core cortex	<50%	Count	50	100	18	44	212
		Expected Count	53.0	53.0	53.0	53.0	212.0
		Adjusted Residual	-.7	10.9	-8.1	-2.1	
	>50%	Count	50	0	82	56	188
		Expected Count	47.0	47.0	47.0	47.0	188.0
		Adjusted Residual	.7	-10.9	8.1	2.1	
Total		Count	100	100	100	100	400
		Expected Count	100.0	100.0	100.0	100.0	400.0

Appendix 10. 15: Adjusted residuals values for cortex coverage of cores – comparisons between FC East, JK West, JK2, and WK – Quartzite.

Core cortex coverage - Quartzite							
			Site				Total
			FC East	JK West	JK2	WK	
Core cortex	Cortex <50%	Count	53	70	63	77	263
		Expected Count	65.8	65.8	65.8	65.8	263.0
		Adjusted Residual	-3.1	1.0	-.7	2.7	
	Cortex >50%	Count	21	30	37	19	107
		Expected Count	26.8	26.8	26.8	26.8	107.0
		Adjusted Residual	-1.5	.8	2.7	-2.0	
	Non-cortical	Count	26	0	0	4	30
		Expected Count	7.5	7.5	7.5	7.5	30.0
		Adjusted Residual	8.1	-3.3	-3.3	-1.5	
Total		Count	100	100	100	100	400
		Expected Count	100.0	100.0	100.0	100.0	400.0

Appendix 10. 16: Adjusted residuals values for cortex coverage of cores – comparisons between JK West, JK2, and WK – Phonolite.

Core cortex coverage - Phonolite						
			Site			Total
			JK West	JK2	WK	
Core cortex	Cortex <50%	Count	60	40	33	133
		Expected Count	44.5	44.5	44.0	133.0
		Adjusted Residual	3.8	-1.1	-2.7	
	Cortex >50%	Count	0	60	33	93
		Expected Count	31.1	31.1	30.8	93.0
		Adjusted Residual	-8.2	7.7	.6	
	Non-cortical	Count	40	0	33	73
		Expected Count	24.4	24.4	24.2	73.0
		Adjusted Residual	4.4	-7.0	2.5	
Total		Count	100	100	99	299
		Expected Count	100.0	100.0	99.0	299.0

Appendix 10. 17: Adjusted residuals values for cortex coverage of cores – comparisons between JK West, JK2, and WK – Trachyte.

Core cortex coverage - Trachyte						
			Site			Total
			JK West	JK2	WK	
Core cortex	Cortex <50%	Count	31	31	100	162
		Expected Count	54.2	54.2	53.6	162.0
		Adjusted Residual	-5.7	-5.7	11.4	
	Cortex >50%	Count	62	62	0	124
		Expected Count	41.5	41.5	41.1	124.0
		Adjusted Residual	5.1	5.1	-10.2	
	Non-cortical	Count	8	8	0	16
		Expected Count	5.4	5.4	5.3	16.0
		Adjusted Residual	1.4	1.4	-2.9	
Total		Count	101	101	100	302
		Expected Count	101.0	101.0	100.0	302.0

Appendix 10. 18: Adjusted residuals values for number of flake scars on cores – comparisons between FC East, JK West, JK2, and WK – Basalt.

Core flake scars - Basalt							
			Site				Total
			FC East	JK West	JK2	WK	
Core_flake_scars	>9 scars	Count	0	100	3	0	103
		Expected Count	25.8	25.8	25.8	25.8	103.0
		Adjusted Residual	-6.8	19.6	-6.0	-6.8	
	1-3 scars	Count	50	0	67	67	184
		Expected Count	46.0	46.0	46.0	46.0	184.0
		Adjusted Residual	.9	-10.7	4.9	4.9	
	4-6 scars	Count	50	0	18	22	90
		Expected Count	22.5	22.5	22.5	22.5	90.0
		Adjusted Residual	7.6	-6.2	-1.2	-.1	
	7-9 scars	Count	0	0	12	11	23
		Expected Count	5.8	5.8	5.8	5.8	23.0
		Adjusted Residual	-2.9	-2.9	3.1	2.6	
Total		Count	100	100	100	100	400
		Expected Count	100.0	100.0	100.0	100.0	400.0

Appendix 10. 19: Adjusted residuals values for number of flake scars on cores – comparisons between FC East, JK West, JK2, and WK – Quartzite.

Core flake scars - Quartzite							
			Site				Total
			FC East	JK West	JK2	WK	
Core_flake_scars	>9 scars	Count	8	16	2	0	26
		Expected Count	6.5	6.5	6.5	6.5	26.0
		Adjusted Residual	.7	4.4	-2.1	-3.0	
	1-3 scars	Count	29	23	36	46	134
		Expected Count	33.5	33.5	33.5	33.5	134.0
		Adjusted Residual	-1.1	-2.6	.6	3.1	
	4-6 scars	Count	55	38	51	50	194
		Expected Count	48.5	48.5	48.5	48.5	194.0
		Adjusted Residual	1.5	-2.4	.6	.3	
	7-9 scars	Count	8	23	11	4	46
		Expected Count	11.5	11.5	11.5	11.5	46.0
		Adjusted Residual	-1.3	4.2	-.2	-2.7	
Total		Count	100	100	100	100	400
		Expected Count	100.0	100.0	100.0	100.0	400.0

Appendix 10. 20: Adjusted residuals values for number of flake scars on cores – comparisons between JK West, JK2, and WK – Phonolite.

Core flake scars - Phonolite						
			Site			Total
			JK West	JK2	WK	
Core_flake_scars	>9 scars	Count	20	7	0	27
		Expected Count	9.0	9.1	9.0	27.0
		Adjusted Residual	4.7	-.9	-3.8	
	1-3 scars	Count	20	60	100	180
		Expected Count	59.8	60.4	59.8	180.0
		Adjusted Residual	-9.9	-.1	10.0	
	4-6 scars	Count	20	27	0	47
		Expected Count	15.6	15.8	15.6	47.0
		Adjusted Residual	1.5	3.8	-5.3	
	7-9 scars	Count	40	7	0	47
		Expected Count	15.6	15.8	15.6	47.0
		Adjusted Residual	8.2	-2.9	-5.3	
Total		Count	100	101	100	301
		Expected Count	100.0	101.0	100.0	301.0

Appendix 10. 21: Adjusted residuals values for number of flake scars on cores – comparisons between JK West, JK2, and WK – Trachyte.

Core flake scars - Trachyte						
			Site			Total
			JK West	JK2	WK	
Core_flake_scars	>9 scars	Count	31	8	0	39
		Expected Count	13.0	13.0	12.9	39.0
		Adjusted Residual	6.5	-1.8	-4.7	
	1-3 scars	Count	31	38	33	102
		Expected Count	34.1	34.1	33.8	102.0
		Adjusted Residual	-.8	1.0	-.2	
	4-6 scars	Count	23	46	33	102
		Expected Count	34.1	34.1	33.8	102.0
		Adjusted Residual	-2.9	3.1	-.2	
	7-9 scars	Count	15	8	33	56
		Expected Count	18.7	18.7	18.5	56.0
		Adjusted Residual	-1.2	-3.4	4.6	
Total		Count	100	100	99	299
		Expected Count	100.0	100.0	99.0	299.0

Appendix 10. 22: Adjusted residuals values for flaking scheme on cores – comparisons between FC East, JK West, JK2, and WK – Basalt.

Core flaking scheme - Basalt							
			Site				Total
			FC East	JK West	JK2	WK	
Flaking scheme	BALP	Count	50	0	9	0	59
		Expected Count	14.8	14.8	14.6	14.8	59.0
		Adjusted Residual	11.5	-4.8	-1.8	-4.8	
	BSP	Count	0	0	15	0	15
		Expected Count	3.8	3.8	3.7	3.8	15.0
		Adjusted Residual	-2.3	-2.3	6.9	-2.3	
	DISC	Count	0	0	3	22	25
		Expected Count	6.3	6.3	6.2	6.3	25.0
		Adjusted Residual	-3.0	-3.0	-1.5	7.5	
	MLT	Count	0	100	6	67	173
		Expected Count	43.4	43.4	42.9	43.4	173.0
		Adjusted Residual	-10.1	13.2	-8.6	5.5	
	TC	Count	0	0	45	11	56
		Expected Count	14.0	14.0	13.9	14.0	56.0
		Adjusted Residual	-4.7	-4.7	10.4	-1.0	
	UAB1	Count	0	0	3	0	3
		Expected Count	.8	.8	.7	.8	3.0
		Adjusted Residual	-1.0	-1.0	3.0	-1.0	
	UAU1	Count	50	0	3	0	53
		Expected Count	13.3	13.3	13.2	13.3	53.0
		Adjusted Residual	12.5	-4.5	-3.5	-4.5	
	UAU2	Count	0	0	3	0	3
		Expected Count	.8	.8	.7	.8	3.0
		Adjusted Residual	-1.0	-1.0	3.0	-1.0	
	USP	Count	0	0	12	0	12
		Expected Count	3.0	3.0	3.0	3.0	12.0
		Adjusted Residual	-2.0	-2.0	6.1	-2.0	
Total		Count	100	100	99	100	399
		Expected Count	100.0	100.0	99.0	100.0	399.0

Appendix 10. 23: Adjusted residuals values for flaking techniques on cores – comparisons between FC East, JK West, JK2, and WK – Quartzite.

Core flaking scheme - Quartzite							
			Site				Total
			FC East	JK West	JK2	WK	
Flaking scheme	BALP	Count	21	4	4	0	29
		Expected Count	7.4	7.1	7.3	7.2	29.0
		Adjusted Residual	6.0	-1.4	-1.5	-3.2	
	BALT	Count	11	0	4	0	15
		Expected Count	3.8	3.7	3.8	3.7	15.0
		Adjusted Residual	4.3	-2.2	.1	-2.3	
	BAP	Count	0	0	2	0	2
		Expected Count	.5	.5	.5	.5	2.0
		Adjusted Residual	-.8	-.8	2.4	-.8	
	BP	Count	0	1	2	0	3
		Expected Count	.8	.7	.8	.7	3.0
		Adjusted Residual	-1.0	.4	1.7	-1.0	
	BSP	Count	3	7	7	0	17
		Expected Count	4.4	4.1	4.3	4.2	17.0
		Adjusted Residual	-.8	1.6	1.6	-2.4	
	DISC	Count	11	16	4	38	69
		Expected Count	17.7	16.8	17.3	17.2	69.0
		Adjusted Residual	-2.0	-.3	-4.1	6.4	
	MLT	Count	24	43	40	50	157
		Expected Count	40.2	38.3	39.4	39.1	157.0
		Adjusted Residual	-3.8	1.1	.1	2.6	
	POL	Count	0	4	1	4	9
		Expected Count	2.3	2.2	2.3	2.2	9.0
		Adjusted Residual	-1.8	1.4	-1.0	1.4	
	TC	Count	11	7	9	4	31
		Expected Count	7.9	7.6	7.8	7.7	31.0
		Adjusted Residual	1.3	-.2	.5	-1.6	
	UAB1	Count	3	4	6	0	13
		Expected Count	3.3	3.2	3.3	3.2	13.0
		Adjusted Residual	-.2	.5	1.8	-2.1	
	UAU1	Count	0	6	7	0	13
		Expected Count	3.3	3.2	3.3	3.2	13.0
		Adjusted Residual	-2.2	1.9	2.4	-2.1	
	UAU2	Count	3	6	4	0	13
		Expected Count	3.3	3.2	3.3	3.2	13.0
		Adjusted Residual	-.2	1.9	.5	-2.1	
	UAUT	Count	13	0	6	0	19
		Expected Count	4.9	4.6	4.8	4.7	19.0
		Adjusted Residual	4.4	-2.5	.7	-2.6	
	USP	Count	0	0	3	4	7
		Expected Count	1.8	1.7	1.8	1.7	7.0
		Adjusted Residual	-1.6	-1.5	1.1	2.0	

	USP2	Count	3	0	2	0	5
		Expected Count	1.3	1.2	1.3	1.2	5.0
		Adjusted Residual	1.8	-1.3	.8	-1.3	
Total		Count	103	98	101	100	402
		Expected Count	103.0	98.0	101.0	100.0	402.0

Appendix 10. 24: Adjusted residuals values for flaking scheme on cores – comparisons between JK West, JK2, and WK – Phonolite.

Core flaking scheme - Phonolite						
			Site			Total
			JK West	JK2	WK	
Flaking scheme	BALT	Count	0	7	0	7
		Expected Count	2.3	2.3	2.3	7.0
		Adjusted Residual	-1.9	3.8	-1.9	
	BSP	Count	0	13	0	13
		Expected Count	4.3	4.3	4.3	13.0
		Adjusted Residual	-2.6	5.2	-2.6	
	DISC	Count	0	7	33	40
		Expected Count	13.4	13.4	13.2	40.0
		Adjusted Residual	-4.8	-2.3	7.1	
	MLT	Count	60	33	33	126
		Expected Count	42.1	42.1	41.7	126.0
		Adjusted Residual	4.4	-2.3	-2.2	
	POL	Count	20	0	0	20
		Expected Count	6.7	6.7	6.6	20.0
		Adjusted Residual	6.5	-3.3	-3.3	
	TC	Count	20	27	33	80
		Expected Count	26.8	26.8	26.5	80.0
		Adjusted Residual	-1.9	.1	1.8	
	UAB1	Count	0	13	0	13
		Expected Count	4.3	4.3	4.3	13.0
		Adjusted Residual	-2.6	5.2	-2.6	
Total		Count	100	100	99	299
		Expected Count	100.0	100.0	99.0	299.0

Appendix 10. 25: Adjusted residuals values for flaking scheme on cores – comparisons between JK West, JK2, and WK – Trachyte.

Core flaking scheme - Trachyte						
			Site			
			JK West	JK2	WK	
Flaking scheme	BALP	Count	15	8	0	23
		Expected Count	7.7	7.7	7.6	23.0
		Adjusted Residual	3.4	.1	-3.5	
	BAP	Count	0	8	0	8
		Expected Count	2.7	2.7	2.6	8.0
		Adjusted Residual	-2.0	4.0	-2.0	
	BHC	Count	8	0	0	8
		Expected Count	2.7	2.7	2.6	8.0
		Adjusted Residual	4.0	-2.0	-2.0	
	BSP	Count	23	31	0	54
		Expected Count	18.1	18.1	17.9	54.0
		Adjusted Residual	1.6	4.1	-5.7	
	DISC	Count	8	8	100	116
		Expected Count	38.8	38.8	38.4	116.0
		Adjusted Residual	-7.7	-7.7	15.5	
	TC	Count	31	38	0	69
		Expected Count	23.1	23.1	22.8	69.0
		Adjusted Residual	2.3	4.3	-6.7	
	UAU1	Count	8	0	0	8
		Expected Count	2.7	2.7	2.6	8.0
		Adjusted Residual	4.0	-2.0	-2.0	
	UAU2	Count	8	0	0	8
		Expected Count	2.7	2.7	2.6	8.0
		Adjusted Residual	4.0	-2.0	-2.0	
	UAUT	Count	0	8	0	8
		Expected Count	2.7	2.7	2.6	8.0
		Adjusted Residual	-2.0	4.0	-2.0	
Total		Count	101	101	100	302
		Expected Count	101.0	101.0	100.0	302.0

Appendix 10. 26: Adjusted residuals values for flake length – comparisons between FC East, JK West, JK2, and WK – Basalt.

Length class - Basalt						
			Site			Total
			FC East	JK2	WK	
Length class	20-39 mm	Count	44	26	22	92
		Expected Count	30.6	30.9	30.6	92.0
		Adjusted Residual	3.6	-1.3	-2.3	
	40-59 mm	Count	22	43	44	109
		Expected Count	36.2	36.6	36.2	109.0
		Adjusted Residual	-3.6	1.6	2.0	
	60-79 mm	Count	33	22	33	88
		Expected Count	29.2	29.5	29.2	88.0
		Adjusted Residual	1.0	-2.0	1.0	
	80-99 mm	Count	0	9	0	9
		Expected Count	3.0	3.0	3.0	9.0
		Adjusted Residual	-2.1	4.3	-2.1	
Total		Count	99	100	99	298
		Expected Count	99.0	100.0	99.0	298.0

Appendix 10. 27: Adjusted residuals values for flake length – comparisons between FC East, JK West, JK2, and WK – Quartzite.

Length class - Quartzite							
			Site				Total
			FC East	JK West	JK2	WK	
Length class	20-39 mm	Count	76	80	79	93	328
		Expected Count	82.0	82.0	82.0	82.0	328.0
		Adjusted Residual	-1.8	-.6	-.9	3.3	
	40-59 mm	Count	21	18	18	6	63
		Expected Count	15.8	15.8	15.8	15.8	63.0
		Adjusted Residual	1.7	.7	.7	-3.1	
	60-79 mm	Count	3	2	3	1	9
		Expected Count	2.3	2.3	2.3	2.3	9.0
		Adjusted Residual	.6	-.2	.6	-1.0	
Total		Count	100	100	100	100	400
		Expected Count	100.0	100.0	100.0	100.0	400.0

Appendix 10. 28: Adjusted residuals values for flake length – comparisons between FC East, JK West, JK2, and WK – Phonolite.

Length class - Phonolite							
			Site				Total
			FC East	JK West	JK2	WK	
Length class	100-119 mm	Count	0	0	7	0	7
		Expected Count	1.8	1.8	1.8	1.8	7.0
		Adjusted Residual	-1.5	-1.5	4.6	-1.5	
	20-39 mm	Count	0	100	20	0	120
		Expected Count	30.0	30.0	30.0	30.0	120.0
		Adjusted Residual	-7.6	17.6	-2.5	-7.6	
	40-59 mm	Count	100	0	53	100	253
		Expected Count	63.2	63.2	63.2	63.2	253.0
		Adjusted Residual	8.8	-15.1	-2.5	8.8	
	60-79 mm	Count	0	0	20	0	20
		Expected Count	5.0	5.0	5.0	5.0	20.0
		Adjusted Residual	-2.6	-2.6	7.9	-2.6	
Total		Count	100	100	100	100	400
		Expected Count	100.0	100.0	100.0	100.0	400.0

Appendix 10. 29: Adjusted residuals values for flake length – comparisons between FC East, JK West, JK2, and WK – Trachyte.

Length class - Trachyte						
			Site			Total
			JK West	JK2	WK	
Length class	20-39 mm	Count	50	24	20	94
		Expected Count	31.3	31.3	31.3	94.0
		Adjusted Residual	4.9	-1.9	-3.0	
	40-59 mm	Count	0	40	80	120
		Expected Count	40.0	40.0	40.0	120.0
		Adjusted Residual	-10.0	.0	10.0	
	60-79 mm	Count	50	32	0	82
		Expected Count	27.3	27.3	27.3	82.0
		Adjusted Residual	6.2	1.3	-7.5	
	80-99 mm	Count	0	4	0	4
		Expected Count	1.3	1.3	1.3	4.0
		Adjusted Residual	-1.4	2.8	-1.4	
Total		Count	100	100	100	300
		Expected Count	100.0	100.0	100.0	300.0

Appendix 10. 30: Adjusted residuals values for flake width class – comparisons between JK West, JK2, and WK – Basalt.

Width class - Basalt						
			Site			Total
			FC East	JK2	WK	
Width class	< 20 mm	Count	0	9	0	9
		Expected Count	3.0	3.0	3.0	9.0
		Adjusted Residual	-2.2	4.3	-2.2	
	20-39 mm	Count	67	39	78	184
		Expected Count	61.3	61.3	61.3	184.0
		Adjusted Residual	1.4	-5.6	4.2	
	40-59 mm	Count	22	48	22	92
		Expected Count	30.7	30.7	30.7	92.0
		Adjusted Residual	-2.3	4.6	-2.3	
	60-79 mm	Count	11	4	0	15
		Expected Count	5.0	5.0	5.0	15.0
		Adjusted Residual	3.4	-.6	-2.8	
Total		Count	100	100	100	300
		Expected Count	100.0	100.0	100.0	300.0

Appendix 10. 31: Adjusted residuals values for flake width class – comparisons between FC East, JK West, JK2, and WK – Quartzite.

Width class - Quartzite							
			Site				Total
			FC East	JK West	JK2	WK	
Width class	<20 mm	Count	22	35	30	36	123
		Expected Count	30.7	31.0	30.7	30.7	123.0
		Adjusted Residual	-2.2	1.0	-.2	1.3	
	20-39 mm	Count	67	61	65	62	255
		Expected Count	63.6	64.2	63.6	63.6	255.0
		Adjusted Residual	.8	-.8	.3	-.4	
	40-49 mm	Count	0	4	0	0	4
		Expected Count	1.0	1.0	1.0	1.0	4.0
		Adjusted Residual	-1.2	3.5	-1.2	-1.2	
	40-59 mm	Count	11	0	5	2	18
		Expected Count	4.5	4.5	4.5	4.5	18.0
		Adjusted Residual	3.6	-2.5	.3	-1.4	
	60-79 mm	Count	0	1	0	0	1
		Expected Count	.2	.3	.2	.2	1.0
		Adjusted Residual	-.6	1.7	-.6	-.6	
Total		Count	100	101	100	100	401
		Expected Count	100.0	101.0	100.0	100.0	401.0

Appendix 10. 32: Adjusted residuals values for flake width class – comparisons between FC East, JK West, JK2, and WK – Phonolite.

Width class - Phonolite							
			Site				Total
			FC East	JK West	JK2	WK	
Width class	<20 mm	Count	0	20	0	0	20
		Expected Count	5.0	5.0	5.0	5.0	20.0
		Adjusted Residual	-2.6	7.9	-2.6	-2.6	
	20-39 mm	Count	100	80	67	100	347
		Expected Count	86.8	86.8	86.8	86.8	347.0
		Adjusted Residual	4.5	-2.3	-6.7	4.5	
	40-59 mm	Count	0	0	33	0	33
		Expected Count	8.3	8.3	8.3	8.3	33.0
		Adjusted Residual	-3.5	-3.5	10.4	-3.5	
Total		Count	100	100	100	100	400
		Expected Count	100.0	100.0	100.0	100.0	400.0

Appendix 10. 33: Adjusted residuals values for flake width class – comparisons between JK West, JK2, and WK – Trachyte.

Width class - Trachyte						
			Site			Total
			JK West	JK2	WK	
Width class	<20 mm	Count	0	4	0	4
		Expected Count	1.3	1.3	1.3	4.0
		Adjusted Residual	-1.4	2.8	-1.4	
	20-39 mm	Count	50	44	80	174
		Expected Count	58.0	58.0	58.0	174.0
		Adjusted Residual	-2.0	-3.5	5.5	
	40-49 mm	Count	50	48	20	118
		Expected Count	39.3	39.3	39.3	118.0
		Adjusted Residual	2.7	2.2	-4.8	
	60-79 mm	Count	0	4	0	4
		Expected Count	1.3	1.3	1.3	4.0
		Adjusted Residual	-1.4	2.8	-1.4	
Total		Count	100	100	100	300
		Expected Count	100.0	100.0	100.0	300.0

Appendix 10. 34: Adjusted residuals values for flake weight class – comparisons between FC East, JK2, and WK – Basalt.

Weight class - Basalt						
			Site			Total
			FC East	JK2	WK	
Weight class	<20 g	Count	56	30	44	130
		Expected Count	43.5	43.5	43.0	130.0
		Adjusted Residual	3.1	-3.3	.2	
	>100 g	Count	33	22	0	55
		Expected Count	18.4	18.4	18.2	55.0
		Adjusted Residual	4.6	1.1	-5.8	
	20-40 g	Count	11	26	33	70
		Expected Count	23.4	23.4	23.2	70.0
		Adjusted Residual	-3.6	.7	2.9	
	41-60 g	Count	0	13	22	35
		Expected Count	11.7	11.7	11.6	35.0
		Adjusted Residual	-4.5	.5	4.0	
	61-80 g	Count	0	9	0	9
		Expected Count	3.0	3.0	3.0	9.0
		Adjusted Residual	-2.2	4.3	-2.1	
Total		Count	100	100	99	299
		Expected Count	100.0	100.0	99.0	299.0

Appendix 10. 35: Adjusted residuals values for flake weight class – comparisons between FC East, JK West, JK2, and WK – Quartzite.

Weight class - Quartzite							
			Site				Total
			FC East	JK West	JK2	WK	
Weight class	<20 g	Count	80	87	78	93	338
		Expected Count	84.1	84.9	84.9	84.1	338.0
		Adjusted Residual	-1.3	.7	-2.2	2.8	
	>100 g	Count	0	0	1	0	1
		Expected Count	.2	.3	.3	.2	1.0
		Adjusted Residual	-.6	-.6	1.7	-.6	
	20-40 g	Count	12	10	16	6	44
		Expected Count	10.9	11.1	11.1	10.9	44.0
		Adjusted Residual	.4	-.4	1.8	-1.8	
	41-60 g	Count	5	2	4	1	12
		Expected Count	3.0	3.0	3.0	3.0	12.0
		Adjusted Residual	1.4	-.7	.7	-1.3	
	61-80 g	Count	3	1	1	0	5
		Expected Count	1.2	1.3	1.3	1.2	5.0
		Adjusted Residual	1.8	-.3	-.3	-1.3	
	81-100 g	Count	0	1	1	0	2
		Expected Count	.5	.5	.5	.5	2.0
		Adjusted Residual	-.8	.8	.8	-.8	
Total		Count	100	101	101	100	402
		Expected Count	100.0	101.0	101.0	100.0	402.0

Appendix 10. 36: Adjusted residuals values for flake weight class – comparisons between FC East, JK West, JK2, and WK – Phonolite.

Weight class - Phonolite							
			Site				Total
			FC East	JK West	JK2	WK	
Weight class	<20 g	Count	100	100	27	50	277
		Expected Count	69.1	69.1	69.8	69.1	277.0
		Adjusted Residual	7.7	7.7	-10.6	-4.8	
	>100 g	Count	0	0	7	0	7
		Expected Count	1.7	1.7	1.8	1.7	7.0
		Adjusted Residual	-1.5	-1.5	4.6	-1.5	
	20-40 g	Count	0	0	40	50	90
		Expected Count	22.4	22.4	22.7	22.4	90.0
		Adjusted Residual	-6.2	-6.2	4.8	7.6	
	41-60 g	Count	0	0	20	0	20
		Expected Count	5.0	5.0	5.0	5.0	20.0
		Adjusted Residual	-2.6	-2.6	7.9	-2.6	
	81-100 g	Count	0	0	7	0	7
		Expected Count	1.7	1.7	1.8	1.7	7.0
		Adjusted Residual	-1.5	-1.5	4.6	-1.5	
Total		Count	100	100	101	100	401
		Expected Count	100.0	100.0	101.0	100.0	401.0

Appendix 10. 37: Adjusted residuals values for flake weight class – comparisons between JK West, JK2, and WK – Trachyte.

Weight class - Trachyte						
			Site			Total
			JK West	JK2	WK	
Weight class	<20 g	Count	50	32	40	122
		Expected Count	40.7	40.7	40.7	122.0
		Adjusted Residual	2.3	-2.2	-.2	
	>100 g	Count	0	28	0	28
		Expected Count	9.3	9.3	9.3	28.0
		Adjusted Residual	-3.9	7.9	-3.9	
	20-40 g	Count	50	24	60	134
		Expected Count	44.7	44.7	44.7	134.0
		Adjusted Residual	1.3	-5.1	3.8	
	41-60 g	Count	0	12	0	12
		Expected Count	4.0	4.0	4.0	12.0
		Adjusted Residual	-2.5	5.0	-2.5	
	81-100 g	Count	0	4	0	4
		Expected Count	1.3	1.3	1.3	4.0
		Adjusted Residual	-1.4	2.8	-1.4	
Total		Count	100	100	100	300
		Expected Count	100.0	100.0	100.0	300.0

Appendix 10. 38: Adjusted residuals values for dorsal cortex on flakes – comparisons between FC East, JK West, JK2, and WK – Basalt.

Dorsal cortex - Basalt						
			Site			Total
			FC East	JK2	WK	
Dorsal cortex	Cortex <50%	Count	0	26	44	70
		Expected Count	23.4	23.4	23.2	70.0
		Adjusted Residual	-6.8	.7	6.0	
	Cortex >50%	Count	11	26	11	48
		Expected Count	16.1	16.1	15.9	48.0
		Adjusted Residual	-1.7	3.3	-1.6	
	Cortex 100%	Count	67	39	11	117
		Expected Count	39.1	39.1	38.7	117.0
		Adjusted Residual	7.0	.0	-7.0	
	Non-cortical	Count	22	9	33	64
		Expected Count	21.4	21.4	21.2	64.0
		Adjusted Residual	.2	-3.7	3.5	
Total		Count	100	100	99	299
		Expected Count	100.0	100.0	99.0	299.0

Appendix 10. 39: Adjusted residuals values for dorsal cortex on flakes – comparisons between FC East, JK West, JK2, and WK – Quartzite.

Dorsal cortex - Quartzite							
			Site				Total
			FC East	JK West	JK2	WK	
Dorsal cortex	Cortex <50%	Count	28	28	31	22	109
		Expected Count	27.3	27.3	27.3	27.3	109.0
		Adjusted Residual	.2	.2	1.0	-1.4	
	Cortex >50%	Count	8	21	29	21	79
		Expected Count	19.8	19.8	19.8	19.8	79.0
		Adjusted Residual	-3.4	.4	2.7	.4	
	Cortex 100%	Count	0	2	3	0	5
		Expected Count	1.3	1.3	1.3	1.3	5.0
		Adjusted Residual	-1.3	.8	1.8	-1.3	
	Non-cortical	Count	64	49	37	57	207
		Expected Count	51.7	51.7	51.7	51.7	207.0
		Adjusted Residual	2.8	-.6	-3.4	1.2	
Total		Count	100	100	100	100	400
		Expected Count	100.0	100.0	100.0	100.0	400.0

Appendix 10. 40: Adjusted residuals values for dorsal cortex on flakes – comparisons between FC East, JK West, JK2, and WK – Phonolite.

Dorsal cortex - Phonolite							
			Site				Total
			FC East	JK West	JK2	WK	
Dorsal cortex	Cortex <50%	Count	50	40	33	0	123
		Expected Count	30.8	30.8	30.8	30.8	123.0
		Adjusted Residual	4.8	2.3	.6	-7.7	
	Cortex >50%	Count	50	0	47	0	97
		Expected Count	24.3	24.3	24.3	24.3	97.0
		Adjusted Residual	6.9	-6.5	6.1	-6.5	
	Cortex 100%	Count	0	0	7	50	57
		Expected Count	14.2	14.2	14.2	14.2	57.0
		Adjusted Residual	-4.7	-4.7	-2.4	11.8	
	Non-cortical	Count	0	60	13	50	123
		Expected Count	30.8	30.8	30.8	30.8	123.0
		Adjusted Residual	-7.7	7.3	-4.4	4.8	
Total		Count	100	100	100	100	400
		Expected Count	100.0	100.0	100.0	100.0	400.0

Appendix 10. 41: Adjusted residuals values for dorsal cortex on flakes – comparisons between JK West, JK2, and WK – Trachyte.

Dorsal cortex - Trachyte						
			Site			Total
			JK West	JK2	WK	
Dorsal cortex	Cortex <50%	Count	50	20	40	110
		Expected Count	36.7	36.7	36.7	110.0
		Adjusted Residual	3.4	-4.2	.8	
	Cortex >50%	Count	0	20	20	40
		Expected Count	13.3	13.3	13.3	40.0
		Adjusted Residual	-4.8	2.4	2.4	
	Cortex 100%	Count	0	36	20	56
		Expected Count	18.7	18.7	18.7	56.0
		Adjusted Residual	-5.9	5.4	.4	
	Non-cortical	Count	50	24	20	94
		Expected Count	31.3	31.3	31.3	94.0
		Adjusted Residual	4.9	-1.9	-3.0	
Total		Count	100	100	100	300

	Expected Count	100.0	100.0	100.0	300.0

Appendix 10. 42: Adjusted residuals values for Toth's flake types – comparisons between FC East, JK2, and WK – Basalt.

Toth flake type - Basalt						
			Site			Total
			FC East	JK2	WK	
Toth flake type	I	Count	44	30	11	85
		Expected Count	28.1	28.4	28.4	85.0
		Adjusted Residual	4.3	.4	-4.7	
	II	Count	0	9	0	9
		Expected Count	3.0	3.0	3.0	9.0
		Adjusted Residual	-2.1	4.3	-2.2	
	IV	Count	22	9	0	31
		Expected Count	10.3	10.4	10.4	31.0
		Adjusted Residual	4.7	-.6	-4.2	
	V	Count	11	43	56	110
		Expected Count	36.4	36.8	36.8	110.0
		Adjusted Residual	-6.5	1.6	4.9	
	VI	Count	22	9	33	64
		Expected Count	21.2	21.4	21.4	64.0
		Adjusted Residual	.2	-3.7	3.5	
Total		Count	99	100	100	299
		Expected Count	99.0	100.0	100.0	299.0

Appendix 10. 43: Adjusted residuals values for Toth's flake types – comparisons between FC East, JK West, JK2, and WK – Quartzite

Toth flake type - Quartzite							
			Site				
			FC East	JK West	JK2	WK	
Toth flake type	I	Count	0	2	2	0	4
		Expected Count	1.0	1.0	1.0	1.0	4.0
		Adjusted Residual	-1.2	1.2	1.2	-1.2	
	II	Count	7	5	8	9	29
		Expected Count	7.2	7.2	7.2	7.2	29.0
		Adjusted Residual	-.1	-1.0	.3	.8	
	III	Count	8	8	5	11	32
		Expected Count	8.0	8.0	8.0	8.0	32.0
		Adjusted Residual	.0	.0	-1.3	1.3	
	IV	Count	0	0	2	0	2
		Expected Count	.5	.5	.5	.5	2.0
		Adjusted Residual	-.8	-.8	2.5	-.8	
	V	Count	28	42	52	36	158
		Expected Count	39.5	39.5	39.5	39.5	158.0
		Adjusted Residual	-2.7	.6	3.0	-.8	
	VI	Count	57	43	31	44	175
		Expected Count	43.8	43.8	43.8	43.8	175.0
		Adjusted Residual	3.1	-.2	-3.0	.1	
Total		Count	100	100	100	100	400
		Expected Count	100.0	100.0	100.0	100.0	400.0

Appendix 10. 44: Adjusted residuals values for Toth's flake types – comparisons between FC East, JK West, JK2, and WK – Phonolite.

Toth flake type - Phonolite							
			Site				
			FC East	JK West	JK2	WK	
Toth flake type	II	Count	50	0	20	0	70
		Expected Count	17.5	17.5	17.6	17.5	70.0
		Adjusted Residual	9.9	-5.3	.7	-5.3	
	III	Count	0	0	7	0	7
		Expected Count	1.7	1.7	1.8	1.7	7.0
		Adjusted Residual	-1.5	-1.5	4.6	-1.5	
	IV	Count	0	0	7	50	57
		Expected Count	14.2	14.2	14.4	14.2	57.0
		Adjusted Residual	-4.7	-4.7	-2.4	11.8	
	V	Count	50	40	60	0	150
		Expected Count	37.4	37.4	37.8	37.4	150.0
		Adjusted Residual	3.0	.6	5.3	-8.9	
	VI	Count	0	60	7	50	117
		Expected Count	29.2	29.2	29.5	29.2	117.0
		Adjusted Residual	-7.4	7.8	-5.7	5.3	
Total		Count	100	100	101	100	401
		Expected Count	100.0	100.0	101.0	100.0	401.0

Appendix 10. 45: Adjusted residuals values for Toth's flake types – comparisons between JK West, JK2, and WK – Trachyte.

Toth flake type - Trachyte						
			Site			Total
			JK West	JK2	WK	
Toth flake type	I	Count	0	24	20	44
		Expected Count	14.7	14.7	14.7	44.0
		Adjusted Residual	-5.1	3.2	1.8	
	II	Count	0	8	0	8
		Expected Count	2.7	2.7	2.7	8.0
		Adjusted Residual	-2.0	4.1	-2.0	
	IV	Count	0	12	0	12
		Expected Count	4.0	4.0	4.0	12.0
		Adjusted Residual	-2.5	5.0	-2.5	
	V	Count	50	32	60	142
		Expected Count	47.3	47.3	47.3	142.0
		Adjusted Residual	.7	-3.8	3.1	
	VI	Count	50	24	20	94
		Expected Count	31.3	31.3	31.3	94.0
		Adjusted Residual	4.9	-1.9	-3.0	
Total		Count	100	100	100	300
		Expected Count	100.0	100.0	100.0	300.0

Appendix 10. 46: Adjusted residuals values for flake striking platform facet – comparisons between FC East, JK2, and WK – Basalt.

Striking platform - Basalt						
			Site			Total
			FC East	JK2	WK	
Striking platform	Bifaceted	Count	0	0	22	22
		Expected Count	7.3	7.4	7.3	22.0
		Adjusted Residual	-3.4	-3.5	6.9	
	Multifaceted	Count	11	0	22	33
		Expected Count	11.0	11.1	11.0	33.0
		Adjusted Residual	.0	-4.3	4.3	
	Non-faceted	Count	44	35	11	90
		Expected Count	29.9	30.2	29.9	90.0
		Adjusted Residual	3.8	1.3	-5.1	
	Unifaceted	Count	44	65	44	153
		Expected Count	50.8	51.3	50.8	153.0
		Adjusted Residual	-1.7	3.4	-1.7	
Total		Count	99	100	99	298
		Expected Count	99.0	100.0	99.0	298.0

Appendix 10. 47: Adjusted residuals values for flake striking platform facet – comparisons between FC East, JK West, JK2, and WK – Quartzite.

Striking platform - Quartzite							
			Site				Total
			FC East	JK West	JK2	WK	
Striking_platfrom	Bifaceted	Count	3	3	2	2	10
		Expected Count	2.5	2.5	2.5	2.5	10.0
		Adjusted Residual	.4	.4	-.4	-.4	
	Multifaceted	Count	0	2	0	0	2
		Expected Count	.5	.5	.5	.5	2.0
		Adjusted Residual	-.8	2.5	-.8	-.8	
	Non-faceted	Count	13	17	16	25	71
		Expected Count	17.8	17.8	17.8	17.6	71.0
		Adjusted Residual	-1.4	-.2	-.5	2.2	
	Unifaceted	Count	84	78	82	72	316
		Expected Count	79.2	79.2	79.2	78.4	316.0
		Adjusted Residual	1.4	-.3	.8	-1.8	

Total	Count	100	100	100	99	399
	Expected Count	100.0	100.0	100.0	99.0	399.0

Appendix 10. 48: Adjusted residuals values for flake striking platform facet – comparisons between FC East, JK West, JK2, and WK – Phonolite.

Striking platform - Phonolite							
			Site				Total
			FC East	JK West	JK2	WK	
Striking platform	Bifaceted	Count	0	20	0	0	20
		Expected Count	5.0	5.0	5.0	5.0	20.0
		Adjusted Residual	-2.6	7.9	-2.6	-2.6	
	Non-faceted	Count	50	0	27	0	77
		Expected Count	19.3	19.3	19.3	19.3	77.0
		Adjusted Residual	9.0	-5.6	2.3	-5.6	
	Unifaceted	Count	50	80	73	100	303
		Expected Count	75.8	75.8	75.8	75.8	303.0
		Adjusted Residual	-6.9	1.1	-.7	6.5	
Total		Count	100	100	100	100	400
		Expected Count	100.0	100.0	100.0	100.0	400.0

Appendix 10. 49: Adjusted residuals values for flake striking platform facet – comparisons between JK West, JK2, and WK – Trachyte.

Striking platform - Trachyte						
			Site			Total
			JK West	JK2	WK	
Striking platform	Non-faceted	Count	0	32	0	32
		Expected Count	10.7	10.7	10.7	32.0
		Adjusted Residual	-4.2	8.5	-4.2	
	Unifaceted	Count	100	68	100	268
		Expected Count	89.3	89.3	89.3	268.0
		Adjusted Residual	4.2	-8.5	4.2	
Total		Count	100	100	100	300
		Expected Count	100.0	100.0	100.0	300.0

Appendix 10. 50: Adjusted residuals values for retouched pieces length class – comparisons between JK West, JK2, and WK – Basalt.

Length class - Basalt						
			Site			Total
			JK West	JK2	WK	
Length class	20-39 mm	Count	100	22	0	122
		Expected Count	40.8	40.4	40.8	122.0
		Adjusted Residual	14.8	-4.6	-10.2	
	40-59 mm	Count	0	44	86	130
		Expected Count	43.5	43.0	43.5	130.0
		Adjusted Residual	-10.8	.2	10.5	
	60-79 mm	Count	0	22	14	36
		Expected Count	12.0	11.9	12.0	36.0
		Adjusted Residual	-4.5	3.8	.7	
	80-99 mm	Count	0	11	0	11
		Expected Count	3.7	3.6	3.7	11.0
		Adjusted Residual	-2.4	4.8	-2.4	
Total		Count	100	99	100	299
		Expected Count	100.0	99.0	100.0	299.0

Appendix 10. 51: Adjusted residuals values for retouched pieces length class – comparisons between FC East, JK West, JK2, and WK – Quartzite.

Length class - Quartzite							
			Site				Total
			FC East	JK West	JK2	WK	
Length class	20-39 mm	Count	65	72	78	85	300
		Expected Count	75.0	75.0	75.0	75.0	300.0
		Adjusted Residual	-2.7	-.8	.8	2.7	
	40-59 mm	Count	29	25	21	15	90
		Expected Count	22.5	22.5	22.5	22.5	90.0
		Adjusted Residual	1.8	.7	-.4	-2.1	
	60-79 mm	Count	6	3	1	0	10
		Expected Count	2.5	2.5	2.5	2.5	10.0
		Adjusted Residual	2.6	.4	-1.1	-1.8	
Total		Count	100	100	100	100	400
		Expected Count	100.0	100.0	100.0	100.0	400.0

Appendix 10. 52: Adjusted residuals values for retouched pieces length class – comparisons between FC East, JK West, JK2, and WK – Phonolite.

Length class - Phonolite							
			Site				Total
			FC East	JK West	JK2	WK	
Length class	20-39 mm	Count	100	39	33	0	172
		Expected Count	43.0	43.4	42.6	43.0	172.0
		Adjusted Residual	13.3	-1.0	-2.2	-10.0	
	40-59 mm	Count	0	56	44	100	200
		Expected Count	50.0	50.5	49.5	50.0	200.0
		Adjusted Residual	-11.5	1.3	-1.3	11.5	
	60-79 mm	Count	0	6	11	0	17
		Expected Count	4.3	4.3	4.2	4.3	17.0
		Adjusted Residual	-2.4	1.0	3.9	-2.4	
	80-99 mm	Count	0	0	11	0	11
		Expected Count	2.8	2.8	2.7	2.8	11.0
		Adjusted Residual	-1.9	-2.0	5.9	-1.9	
Total		Count	100	101	99	100	400
		Expected Count	100.0	101.0	99.0	100.0	400.0

Appendix 10. 53: Adjusted residuals values for retouched pieces length class – comparisons between JK West, JK2, and WK – Trachyte.

Length class – Trachyte						
			Site			Total
			JK West	JK2	WK	
Length class	20-39 mm	Count	25	46	38	109
		Expected Count	36.3	36.0	36.7	109.0
		Adjusted Residual	-2.9	2.6	.3	
	40-59 mm	Count	0	38	63	101
		Expected Count	33.7	33.3	34.0	101.0
		Adjusted Residual	-8.7	1.2	7.5	
	60-79 mm	Count	50	15	0	65
		Expected Count	21.7	21.5	21.9	65.0
		Adjusted Residual	8.4	-1.9	-6.5	
	80-99 mm	Count	25	0	0	25
		Expected Count	8.3	8.3	8.4	25.0
		Adjusted Residual	7.4	-3.7	-3.7	
Total		Count	100	99	101	300
		Expected Count	100.0	99.0	101.0	300.0

Appendix 10. 54: Adjusted residuals values for retouched pieces width class – comparisons between JK West, JK2, and WK – Basalt.

Width class - Basalt						
			Site			Total
			JK West	JK2	WK	
Width class	<20 mm	Count	0	11	0	11
		Expected Count	3.7	3.6	3.7	11.0
		Adjusted Residual	-2.4	4.8	-2.4	
	20-39 mm	Count	100	33	57	190
		Expected Count	63.5	62.9	63.5	190.0
		Adjusted Residual	9.3	-7.6	-1.7	
	40-59 mm	Count	0	44	43	87
		Expected Count	29.1	28.8	29.1	87.0
		Adjusted Residual	-7.9	4.1	3.8	
	60-79 mm	Count	0	11	0	11
		Expected Count	3.7	3.6	3.7	11.0
		Adjusted Residual	-2.4	4.8	-2.4	
Total		Count	100	99	100	299
		Expected Count	100.0	99.0	100.0	299.0

Appendix 10. 55: Adjusted residuals values for retouched pieces width class – comparisons between FC East, JK West, JK2, and WK – Quartzite.

Width class - Quartzite							
			Site				Total
			FC East	JK West	JK2	WK	
Width class	<20 mm	Count	6	28	19	15	68
		Expected Count	17.0	17.0	17.0	17.0	68.0
		Adjusted Residual	-3.4	3.4	.6	-.6	
	20-39 mm	Count	82	64	78	81	305
		Expected Count	76.3	76.3	76.3	76.3	305.0
		Adjusted Residual	1.6	-3.3	.5	1.3	
	40-59 mm	Count	12	8	3	4	27
		Expected Count	6.8	6.8	6.8	6.8	27.0
		Adjusted Residual	2.4	.6	-1.7	-1.3	
Total		Count	100	100	100	100	400
		Expected Count	100.0	100.0	100.0	100.0	400.0

Appendix 10. 56: Adjusted residuals values for retouched pieces width class – comparisons between FC East, JK West, JK2, and WK – Phonolite.

Width class - Phonolite							
			Site				Total
			FC East	JK West	JK2	WK	
Width class	<20 mm	Count	0	6	22	0	28
		Expected Count	7.0	7.1	7.0	7.0	28.0
		Adjusted Residual	-3.2	-.5	6.8	-3.2	
	20-39 mm	Count	100	89	56	100	345
		Expected Count	86.0	86.9	86.0	86.0	345.0
		Adjusted Residual	4.7	.7	-10.0	4.7	
	40-59 mm	Count	0	6	22	0	28
		Expected Count	7.0	7.1	7.0	7.0	28.0
		Adjusted Residual	-3.2	-.5	6.8	-3.2	
Total		Count	100	101	100	100	401
		Expected Count	100.0	101.0	100.0	100.0	401.0

Appendix 10. 57: Adjusted residuals values for retouched pieces width class – comparisons between JK West, JK2, and WK – Trachyte.

Width class - Trachyte						
			Site			Total
			JK West	JK2	WK	
Width class	<20 mm	Count	0	23	0	23
		Expected Count	7.7	7.7	7.7	23.0
		Adjusted Residual	-3.5	7.1	-3.5	
	20-39 mm	Count	25	46	75	146
		Expected Count	48.7	48.7	48.7	146.0
		Adjusted Residual	-5.8	-.7	6.5	
	40-59 mm	Count	50	31	25	106
		Expected Count	35.3	35.3	35.3	106.0
		Adjusted Residual	3.8	-1.1	-2.6	
	60-79 mm	Count	25	0	0	25
		Expected Count	8.3	8.3	8.3	25.0
		Adjusted Residual	7.4	-3.7	-3.7	
Total		Count	100	100	100	300
		Expected Count	100.0	100.0	100.0	300.0

Appendix 10. 58: Adjusted residuals values for retouched pieces weight class – comparisons between JK West, JK2, and WK – Basalt.

Weight class - Basalt						
			Site			Total
			JK West	JK2	WK	
Weight class	1-9 g	Count	100	25	0	125
		Expected Count	41.5	42.4	41.1	125.0
		Adjusted Residual	14.5	-4.3	-10.2	
	10-19 g	Count	0	13	14	27
		Expected Count	9.0	9.1	8.9	27.0
		Adjusted Residual	-3.8	1.6	2.2	
	20-29 g	Count	0	25	71	96
		Expected Count	31.9	32.5	31.6	96.0
		Adjusted Residual	-8.4	-2.0	10.4	
	30-39 g	Count	0	13	0	13
		Expected Count	4.3	4.4	4.3	13.0
		Adjusted Residual	-2.6	5.1	-2.6	
	50-59 g	Count	0	13	14	27
		Expected Count	9.0	9.1	8.9	27.0
		Adjusted Residual	-3.8	1.6	2.2	
	60-69 g	Count	0	13	0	13
		Expected Count	4.3	4.4	4.3	13.0
		Adjusted Residual	-2.6	5.1	-2.6	

Total	Count	100	102	99	301
	Expected Count	100.0	102.0	99.0	301.0

Appendix 10. 59: Adjusted residuals values for retouched pieces weight class – comparisons between FC East, JK West, JK2, and WK – Quartzite.

Weight class – Quartzite							
			Site				Total
			FC East	JK West	JK2	WK	
Weight class	1-9 g	Count	47	58	49	59	213
		Expected Count	53.9	53.4	52.3	53.4	213.0
		Adjusted Residual	-1.6	1.1	-.8	1.3	
	10-19 g	Count	18	25	33	22	98
		Expected Count	24.8	24.6	24.1	24.6	98.0
		Adjusted Residual	-1.8	.1	2.4	-.7	
	20-29 g	Count	6	5	10	11	32
		Expected Count	8.1	8.0	7.9	8.0	32.0
		Adjusted Residual	-.9	-1.3	.9	1.3	
	30-39 g	Count	18	7	4	4	33
		Expected Count	8.4	8.3	8.1	8.3	33.0
		Adjusted Residual	4.0	-.5	-1.7	-1.8	
	40-49 g	Count	6	1	1	4	12
		Expected Count	3.0	3.0	2.9	3.0	12.0
		Adjusted Residual	2.0	-1.4	-1.3	.7	
	50-59 g	Count	0	1	1	0	2
		Expected Count	.5	.5	.5	.5	2.0
		Adjusted Residual	-.8	.8	.8	-.8	
	60-69 g	Count	0	3	0	0	3
		Expected Count	.8	.8	.7	.8	3.0
		Adjusted Residual	-1.0	3.0	-1.0	-1.0	
	70-79 g	Count	6	0	0	0	6
		Expected Count	1.5	1.5	1.5	1.5	6.0
		Adjusted Residual	4.2	-1.4	-1.4	-1.4	
Total		Count	101	100	98	100	399
		Expected Count	101.0	100.0	98.0	100.0	399.0

Appendix 10. 60: Adjusted residuals values for retouched pieces weight class – comparisons between FC East, JK West, JK2, and WK – Phonolite.

Weight class - Phonolite							
			Site				Total
			FC East	JK West	JK2	WK	
Weight class	1-9 g	Count	100	0	33	0	133
		Expected Count	33.3	33.3	33.0	33.3	133.0
		Adjusted Residual	16.3	-8.2	.0	-8.2	
	10-19 g	Count	0	0	0	100	100
		Expected Count	25.1	25.1	24.8	25.1	100.0
		Adjusted Residual	-6.7	-6.7	-6.6	20.0	
	20-29 g	Count	0	0	22	0	22
		Expected Count	5.5	5.5	5.5	5.5	22.0
		Adjusted Residual	-2.8	-2.8	8.4	-2.8	
	30-39 g	Count	0	0	33	0	33
		Expected Count	8.3	8.3	8.2	8.3	33.0
		Adjusted Residual	-3.5	-3.5	10.4	-3.5	
	40-49 g	Count	0	100	0	0	100
		Expected Count	25.1	25.1	24.8	25.1	100.0
		Adjusted Residual	-6.7	20.0	-6.6	-6.7	
	90-99 g	Count	0	0	11	0	11
		Expected Count	2.8	2.8	2.7	2.8	11.0
		Adjusted Residual	-1.9	-1.9	5.9	-1.9	
Total		Count	100	100	99	100	399
		Expected Count	100.0	100.0	99.0	100.0	399.0

Appendix 10. 61: Adjusted residuals values for retouched pieces weight class – comparisons between JK West, JK2, and WK – Trachyte.

Weight class - Trachyte						
			Site			Total
			JK West	JK2	WK	
Weight class	>100 g	Count	0	8	0	8
		Expected Count	2.7	2.7	2.7	8.0
		Adjusted Residual	-2.0	4.1	-2.0	
	1-9 g	Count	25	46	0	71
		Expected Count	23.6	23.6	23.8	71.0
		Adjusted Residual	.4	6.5	-6.9	
	10-19 g	Count	0	8	50	58
		Expected Count	19.3	19.3	19.5	58.0
		Adjusted Residual	-6.0	-3.5	9.5	
	20-29 g	Count	0	15	38	53
		Expected Count	17.6	17.6	17.8	53.0
		Adjusted Residual	-5.7	-.8	6.5	
	30-39 g	Count	0	8	13	21
		Expected Count	7.0	7.0	7.0	21.0
		Adjusted Residual	-3.4	.5	2.9	
	50-59 g	Count	0	15	0	15
		Expected Count	5.0	5.0	5.0	15.0
		Adjusted Residual	-2.8	5.6	-2.8	
	70-79 g	Count	25	0	0	25
		Expected Count	8.3	8.3	8.4	25.0
		Adjusted Residual	7.4	-3.7	-3.7	
	80-89 g	Count	25	0	0	25
		Expected Count	8.3	8.3	8.4	25.0
		Adjusted Residual	7.4	-3.7	-3.7	
	90-99 g	Count	25	0	0	25
		Expected Count	8.3	8.3	8.4	25.0
		Adjusted Residual	7.4	-3.7	-3.7	
Total		Count	100	100	101	301
		Expected Count	100.0	100.0	101.0	301.0

Appendix 10. 62: Adjusted residuals values for retouch pieces type – comparisons between FC East, JK2, and WK – Basalt.

Retouch type - Basalt						
			Site			Total
			JK West	JK2	WK	
Retouch type	Denticulate	Count	0	22	14	36
		Expected Count	12.0	12.0	12.0	36.0
		Adjusted Residual	-4.5	3.8	.8	
	Notch	Count	100	78	57	235
		Expected Count	78.3	78.3	78.3	235.0
		Adjusted Residual	6.4	-.1	-6.3	
	Sidescraper	Count	0	0	29	29
		Expected Count	9.7	9.7	9.7	29.0
		Adjusted Residual	-4.0	-4.0	8.0	
Total		Count	100	100	100	300
		Expected Count	100.0	100.0	100.0	300.0

Appendix 10. 63: Adjusted residuals values for retouch pieces type – comparisons between FC East, JK West, JK2, and WK – Quartzite.

Retouch type - Quartzite							
			Site				Total
			FC East	JK West	JK2	WK	
Retouch type	Denticulate	Count	47	25	27	22	121
		Expected Count	30.3	30.3	30.3	30.3	121.0
		Adjusted Residual	4.2	-1.3	-.8	-2.1	
	Notch	Count	29	64	69	74	236
		Expected Count	59.0	59.0	59.0	59.0	236.0
		Adjusted Residual	-7.0	1.2	2.3	3.5	
	Sidescraper	Count	24	11	4	4	43
		Expected Count	10.8	10.8	10.8	10.8	43.0
		Adjusted Residual	4.9	.1	-2.5	-2.5	
Total		Count	100	100	100	100	400
		Expected Count	100.0	100.0	100.0	100.0	400.0

Appendix 10. 64: Adjusted residuals values for retouch pieces type – comparisons between FC East, JK West, JK2, and WK – Phonolite.

Retouch type - Phonolite							
			Site				Total
			FC East	JK West	JK2	WK	
Retouch type	Denticulate	Count	100	28	33	50	211
		Expected Count	52.6	53.1	52.6	52.6	211.0
		Adjusted Residual	11.0	-5.8	-4.5	-.6	
	Notch	Count	0	67	67	25	159
		Expected Count	39.7	40.0	39.7	39.7	159.0
		Adjusted Residual	-9.4	6.3	6.5	-3.5	
	Sidescraper	Count	0	6	0	25	31
		Expected Count	7.7	7.8	7.7	7.7	31.0
		Adjusted Residual	-3.3	-.8	-3.3	7.5	
Total		Count	100	101	100	100	401
		Expected Count	100.0	101.0	100.0	100.0	401.0

Appendix 10. 65: Adjusted residuals values for retouch pieces type – comparisons between JK West, JK2, and WK – Trachyte.

Retouch type- Trachyte						
			Site			Total
			JK West	JK2	WK	
Retouch type	Denticulate	Count	50	38	38	126
		Expected Count	41.9	41.9	42.3	126.0
		Adjusted Residual	2.0	-1.0	-1.1	
	Notch	Count	50	62	50	162
		Expected Count	53.8	53.8	54.4	162.0
		Adjusted Residual	-.9	2.0	-1.1	
	Sidescraper	Count	0	0	13	13
		Expected Count	4.3	4.3	4.4	13.0
		Adjusted Residual	-2.6	-2.6	5.2	
Total		Count	100	100	101	301
		Expected Count	100.0	100.0	101.0	301.0

Appendix 10. 66: Adjusted residuals values for retouch pieces dorsal cortex – comparisons between FC East, JK2, and WK – Basalt.

Dorsal cortex - Basalt						
			Site			Total
			JK West	JK2	WK	
Dorsal cortex	Cortex <50%	Count	100	67	43	210
		Expected Count	69.8	69.8	70.5	210.0
		Adjusted Residual	8.1	-.7	-7.3	
	Cortex >50%	Count	0	22	29	51
		Expected Count	16.9	16.9	17.1	51.0
		Adjusted Residual	-5.5	1.6	3.9	
	Non-cortical	Count	0	11	29	40
		Expected Count	13.3	13.3	13.4	40.0
		Adjusted Residual	-4.8	-.8	5.6	
Total		Count	100	100	101	301
		Expected Count	100.0	100.0	101.0	301.0

Appendix 10. 67: Adjusted residuals values for retouch pieces dorsal cortex – comparisons between FC East, JK West, JK2, and WK – Quartzite.

Dorsal cortex - Quartzite							
			Site				Total
			FC East	JK West	JK2	WK	
Dorsal cortex	Cortex <50%	Count	24	18	29	30	101
		Expected Count	25.4	24.9	25.2	25.4	101.0
		Adjusted Residual	-.4	-1.9	1.0	1.2	
	Cortex >50%	Count	12	13	28	30	83
		Expected Count	20.9	20.5	20.7	20.9	83.0
		Adjusted Residual	-2.5	-2.1	2.1	2.6	
	Cortical	Count	0	0	2	4	6
		Expected Count	1.5	1.5	1.5	1.5	6.0
		Adjusted Residual	-1.4	-1.4	.5	2.4	
	Non-cortical	Count	65	68	41	37	211
		Expected Count	53.1	52.1	52.6	53.1	211.0
		Adjusted Residual	2.7	3.7	-2.7	-3.7	
Total		Count	101	99	100	101	401
		Expected Count	101.0	99.0	100.0	101.0	401.0

Appendix 10. 68: Adjusted residuals values for retouch pieces dorsal cortex – comparisons between FC East, JK West, JK2, and WK – Phonolite.

Dorsal cortex - Phonolite							
			Site				Total
			FC East	JK West	JK2	WK	
Dorsal cortex	Cortex <50%	Count	0	11	44	0	55
		Expected Count	13.8	13.8	13.6	13.8	55.0
		Adjusted Residual	-4.6	-.9	10.2	-4.6	
	Cortex >50%	Count	0	11	33	25	69
		Expected Count	17.3	17.3	17.1	17.3	69.0
		Adjusted Residual	-5.3	-1.9	4.9	2.4	
	Non-cortical	Count	100	78	22	75	275
		Expected Count	68.9	68.9	68.2	68.9	275.0
		Adjusted Residual	7.8	2.3	-11.6	1.5	
Total		Count	100	100	99	100	399
		Expected Count	100.0	100.0	99.0	100.0	399.0

Appendix 10. 69: Adjusted residuals values for retouch pieces dorsal cortex – comparisons between JK West, JK2, and WK – Trachyte.

Dorsal cortex - Trachyte						
			Site			Total
			JK West	JK2	WK	
Dorsal cortex	Cortex <50%	Count	25	46	38	109
		Expected Count	36.2	36.2	36.6	109.0
		Adjusted Residual	-2.9	2.5	.4	
	Cortex >50%	Count	0	46	25	71
		Expected Count	23.6	23.6	23.8	71.0
		Adjusted Residual	-6.8	6.5	.3	
	Non-cortical	Count	75	8	38	121
		Expected Count	40.2	40.2	40.6	121.0
		Adjusted Residual	8.7	-8.0	-.6	
Total		Count	100	100	101	301
		Expected Count	100.0	100.0	101.0	301.0