

**UNIVERSITY OF NAIROBI**  
**DEPARTMENT OF HISTORY AND ARCHAEOLOGY**

**PALAEOENVIRONMENTAL RECONSTRUCTION OF HOLOCENE VEGETATION  
IN EAST TURKANA, KENYA**

**BY**

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## DECLARATION

This project paper is my original work and has not been presented for the award of a degree in any other university.

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## APPROVAL

This project paper has been submitted for examination with our approval as university supervisors

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## **DEDICATION**

This work is dedicated to

My late father Mashaka Katambo Mwinshehe May your soul continue to rest in peace, in our  
hearts you live forever

My mother Pili Said Mandwanga for her support and prayers and

My daughter Ifrah Katambo

## ABSTRACT

This study demonstrates the importance of phytolith proxy in reconstructing vegetation history and understanding human and climate impact on vegetation changes. Phytoliths are plant silica that preserves for a long period of time, even if plants are dead. The study was conducted in two regions, Ileret and Karari in East Turkana. The main objective of this study was to understand how vegetation cover changes and the key drivers contributing to these changes. The study specifically aimed to understand the correlation between phytolith assemblages and the above-ground vegetation cover and to explain the impact of humans and climate on vegetation cover changes. The study was guided by two theories, cultural ecology and climate variability theory. Plant species from inside and outside (transects) abandoned bomas were identified, tallied and recorded to understand the plant diversity and abundance. Soil samples were collected from recently abandoned *bomas* and from different unoccupied habitats (riverine, grasslands, bushlands, and shrublands). Also, dung (donkeys, sheep, goat, and cattle) was collected from inside the boma to determine their biased phytolith input against outside boma. In addition, sediment samples were collected from Early and Mid-Holocene sites to compare and reconstruct the vegetation history between the modern landscape and the Holocene period. Little is known about how human and climate variability influenced the vegetation cover in the region. The vegetation was classified as woody, grasslands, or mixed. Phytoliths were categorised as grass short-cell phytoliths, herbaceous phytoliths, and woody dicot phytoliths. This classification was based on the International Code of Nomenclature and available literature. The phytoliths data were plotted in R-script for vegetation data, and modern phytoliths from dung and soil. Fossil phytoliths were plotted in TILIA diagrams to understand the vegetation change between the Early and Mid-Holocene period. This study results indicate that phytoliths from current soil samples correlate with the above-ground vegetation composition. In reconstructing palaeoenvironment through phytolith analysis indicated that vegetation cover is dominated by herbs and grasses. Phytolith indices like the Aridity index indicate arid conditions in modern and Holocene landscapes while Dicotyledon versus Poaceae suggests herbaceous grassland mixed with woody. The modern and fossil phytoliths can accurately predict past vegetation cover, especially in classifying different habitats such as grasslands, wooded grasslands, and wooded vegetation.

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## LIST OF ABBREVIATIONS

Iph: Aridity Index

D/P<sup>o</sup>: Dicotyledon versus Poaceae

GAA: Glacial Acetic Acid

HCL: Hydrochloric Acid

SPT: Sodium Polytungstate Solution

dH<sub>2</sub>O: Distilled water

GSSC: Grass short silica cell

Kyr: A thousand years ago

μl: Microlitre



# CHAPTER ONE

## INTRODUCTION

### 1.1 Introduction

The Holocene period was a time of dramatic climatic change in East Africa, shifting from wetter conditions during the Early period (ca. 9 ka – 6 ka) to drier conditions during the Middle Holocene (ca. 6 ka – 4 ka). The drying trend continued through the late Holocene, especially between ca. 4 ka and 2 ka to the present (Ashley et al. 2011; Garcin et al. 2012).

In East Africa, climatic changes influenced vegetation cover, densities, and diversity by extension, affecting food and water resources for both human and animal populations. Additionally, soil moisture and precipitation have been identified as the key factors affecting past vegetation cover (Ashley et al., 2011; Kinyanjui, 2013; Mohammed et al., 1996). During the dry Mid-Holocene period, Oxygen isotopes (O16/O18) data suggest the presence of freshwater springs on the landscape (Ashley et al., 2011). On the other hand, archaeological findings indicate changes in subsistence from reliance on fish and other lake resources. Caprine remains in the archaeological record (Ndiema, 2010; Ndiema et al., 2011) support the presence of bone harpoons and numerous itch faunal remains during the Early-Mid Holocene to dependence on domesticated animals during the late Holocene.

Evidence of the impact of Holocene climatic variability on the paleoenvironments, landscapes, and land use has been preserved in both geological and archaeological records (Ashley et al., 2011; Ndiema et al., 2011). Paleobotanical study in the region showed that vegetation cover and structure changed in response to climatic variability, changing from wooded dominated vegetation cover during the Early Holocene to open grasslands towards the late Holocene when climates became increasingly dry (Kinyanjui, 2018). Different proxies have been used recently to reconstruct paleolandscape in Africa, including pollen, stable isotopes, and phytoliths. Due to the lack of and poor preservation of organic plant remains, especially pollen, inorganic plant signatures such as phytoliths present a significant opportunity to reconstruct past vegetation cover and structure.

Phytoliths are silica plant cells formed when silica is deposited around cells or within cells and form cell replicas or cast through the transpiration process (Piperno 1988; 2006). These silica cells

are preserved in the soil when the plant dies and decomposes, turning into essential plant microfossils that can be studied to reconstruct vegetation history even after the actual vegetation is long gone (Albert et al., 2006; 2012; 2014, Fredlund and Tieszen 1994; Piperno 1988; 2006). The paleo-ethnobotanical interpretation of phytolith relies on comparing ancient types with morphotypes extracted from living reference collections (Mercarder et al., 2009; 2011).

Phytolith research worldwide began in the 19<sup>th</sup> C classified into four stages (Piperno 2006). The first stage from 1835 to 1895, when German scientists and microbiologists observed siliceous bodies in soil samples named them *Phytolitharian*, a Greek word that means “plant stones.” For the first time, a phytolith classification system was developed. In the second phase, from 1895 to 1936, researchers started to identify silica bodies from wheat, barley, and millet in ancient pottery and ash heaps in sites from Europe and Turkey (Piperno, 2006). The third phase, 1955 to 1975, was characterized by scientists from different disciplines such as soil scientists, ecologists, agronomists, and botanists engaging in phytolith studies (Piperno, 2006).

Modern plant phytoliths were investigated during this phase, and the phytolith classification system developed by Twiss et al. (1969) described grass subfamilies. This classification system is used widely by researchers like Kinyanjui (2018), Novello, et al., (2017). The last phase, 1978 to the present, has seen more archaeologists and paleobotanists concerned with paleoenvironmental studies to reconstruct past vegetation cover, for example, in Ethiopia, Tanzania. In Tanzania, Olduvai, and adjacent sites like the Serengeti, Lake Eyasi, and Lake Manyara, phytoliths have helped reconstruct paleoenvironments, especially the presence of freshwater resources on the paleolandscapes (Albert and Bamford, 2012; 2014, Ashley et al., 2011, Albert et al., 2006).

Grass phytoliths are particularly important in reconstructing African vegetation cover because of their ability to identify grass beyond the family level to subfamily, making it possible to classify grass phytolith to their ecological affiliations (Twiss, 1998, Esteban et al., 2017).

In the Koobi Fora region, only a single study has used phytoliths analyses to reconstruct past vegetation cover during the Pleistocene and Holocene periods (Kinyanjui, 2018). The study aimed to understand the temporal vegetation dynamics. Kinyanjui (2018) explained that vegetation variation noted from Early Holocene to Late Holocene from mosaic environment to arid environment comparable to modern-day savanna grassland. Concluded that Holocene vegetation

changes were the result of climatic change controlled by moisture or hydrological availability. However, the data collected was a low resolution due to the scope of the research. Kinyanjui (2018) does not explain how human activities contribute to the vegetation changes. Therefore, this study seeks to build on the existing phytolith data and increase the temporal and spatial resolution, emphasizing Holocene sites and modern pastoralist homesteads in the East Turkana basin. The Dassanech community homesteads in this study used to understand how pastoralist activities contribute to the vegetation changes especially in Koobi Fora, East Turkana.

Modern Koobi Fora vegetation cover and structure are entirely dynamic, caused not only by overgrazing but also by the nomadism nature of the pastoralists (Observations and oral literature). They move across the landscape following the availability of greener pastures and water sources, operating on both all-year-round base camps (*foras*) and seasonal fly/satellite camps (*Bomas*) (Kinyanjui et al., *in prep*). Once the bomas are abandoned, new herbaceous species colonize the area, especially within cattle sheds due to the high concentration of uric acid and nitrogen from livestock dung and urine. Eventually, the bomas host a high concentration of herbaceous species which grow across the fence, some on shades and others boma enclosures (Kinyanjui et al., *in prep*). Species abundance and diversity differ between occupied areas (abandoned boma) and unoccupied areas (outside the boma). Species diversity also varies due to water chemistry, soil structure, and sediment composition. The time frame of the abandonment of bomas is a crucial factor explaining the variation of the vegetation cover-diversity, abundance, and density. The longer the boma has been abandoned, the denser the succeeding vegetation cover, the shorter the time of the abandonment, the less or no vegetation cover noted on these enclosures.

The modern data will determine the extent to which phytolith data can be used to identify land-use patterns. In contrast, the fossil data will determine how vegetation cover has changed through the Holocene period, understanding how climate variability influences this change. Modern and Holocene data helped to determine vegetation change from Early to Mid-Holocene to modern landscape.

## **1.2 Statement of the problem**

In tropical Africa, climate dynamics dictate how plant species/communities are distributed across the landscape and their diversity and densities (White, 1983). Soil moisture and rainfall have been

identified as valuable factors impacting the vegetation cover on ancient landscapes (Mohammed et al., 1996; Ashley et al., 2011; Kinyanjui, 2018).

Human activities such as fire, domestication of animals, and farming impact vegetation cover either by destroying or hindering the growth of various plant species such as trees/shrubs (Dimbleby, G. W., cited in Thames and Hudson, 1969).

The vegetation cover at Koobi Fora landscape indicates an intense change driven by a combination of climatic change and human activities. Other sites such as Olduvai, Laetoli, Lake Eyasi, Awash, Manyara, where more phytolith studies have been carried out, have mainly focused on Plio-Pleistocene and Pleistocene period. However, little is known for the Koobi Fora, especially during the Holocene period (Kinyanjui, 2018). The study conducted by Kinyanjui (2018) for the Late Pleistocene to Holocene in Koobi Fora discussed the climate variability impact on the vegetation change. More so, the effect of climate variability on the nomadic pastoralists is poorly documented at Koobi Fora for the Holocene settlements.

It is evident that pastoralism activities impact the modern vegetation in Koobi Fora. The differential Nitrogen input from the dung and urine decomposes, adding to the soil nutrients in the cattle enclosures creating micro-habitats characterized by abundance and diversity of certain plant species and reduction or absence of other species.

Phytolith assemblage analysis provides evidence on modern and ancient environmental transformation due to human activities and climate variability impacting the environment.

From this study, the following research questions arise:

- 1 Does modern vegetation cover correlate with the modern phytolith data?
- 2 How did vegetation cover change in the Koobi Fora region during the Holocene?
- 3 What were the key drivers of these changes?

### **1.3 Goal of the study**

The main goal is to understand how vegetation cover changes and the key drivers contributing to these changes during the Holocene period in East Turkana.

### **1.4 Specific objectives**

- 1 To explain the correlation between phytolith assemblages and the above-ground vegetation cover.
- 2 To assess vegetation cover changes in Koobi Fora between the modern and Holocene environment
- 3 To explain the impact of humans and climate on vegetation cover changes during the Holocene period.

### **1.5 Research hypothesis**

- 1 Phytolith data correlates with modern vegetation cover of Koobi Fora.
- 2 There has been a significant variation of vegetation cover in Koobi Fora during the Holocene
- 3 Humans were the key drivers to vegetation change than climate in Koobi Fora

### **1.6 Justification research**

Studies have been conducted whose primary concern has been paleoecological reconstruction in different sites in Africa. In East Africa and specifically in Tanzania, sites like Olduvai, Laetoli, Serengeti, Manyara, and Lake Eyasi have had palaeoecological reconstructions studies using phytolith proxy. However, little is known about the Holocene vegetation cover, the impact of climate variability, and the changing human adaptation strategies, especially with domestication on the vegetation cover. Kinyanjui's (2018) study concluded that vegetation cover changed in response to the Holocene climatic variability with a subtle indication of human activities-oriented impacts

This study seeks to build on the previous research by sampling more Holocene sites, reconstructing vegetation history using phytoliths and microcharcoal, and studying present-day abandoned bomas

to understand the role of humans and livestock in changing vegetation cover. Phytolith and micro-charcoal analyses will help to establish the relationship between human ecology and changing climatic conditions at Koobi Fora.

### **1.7 Scope and Limitations**

Vegetation studies using phytoliths and charcoal data have presented a great opportunity to undertake vegetation studies in the Koobi Fora region. Phytolith studies have been incorporated to answer different questions in Africa. The application of phytolith studies in various disciplines focused on fossil or modern or combined assemblages to identify parent plant species. However, the question of the production of homogenous morphotypes by plants of different species redundancy and different phytolith morphotypes by a single plant species-multiplicity have not been entirely addressed (Piperno, 2006).

Research undertaken in different regions across space and through time improved and standardized phytolith methods to minimize the gap between the advantage and limitations of phytoliths studies.

This research conducted within the Koobi Fora East Turkana, where phytolith samples from abandoned bomas from inside and outside and Holocene sites were collected. The Holocene data of Koobi Fora will be compared with other paleoenvironmental studies in East Africa, especially from neighboring paleo-basins, to determine and interpret the region's long-term environmental changes and possible modifications of paleolandscapes. This study will add quantitatively and qualitatively to the existing standardized methods and interpretation of the phytolith datasets.

## 1.8 Definition of operative terms

**Phytoliths** are biosilica plants' microfossils resulting from silica deposition in plant cells (Piperno 1988, 2008). These silica cells are deposited in the soil and become important plant micro-fossils (Albert et al., 2012, 2014, Piperno 1988, 2008). In this study, phytolith has been used as a proxy that reconstructs the paleovegetation because it is well preserved in soil and helps determine plant species that existed in an environment for an extended period.

**Centrifugation** is a procedure which use centrifugal forces to separate heavy materials. This is whereby uniform sediment is placed in a vial and centrifuged for 3000rpm/5minutes or 5000rpm/10minutes to remove unwanted materials (Katz et al., 2010). This study's centrifugation of phytolith samples will help eliminate unwanted soil elements and obtain the silica fraction consisting of phytoliths.

**Sonication** is the procedure conducted before the centrifugation of samples assigned to cavitation in the solvent; this process includes bubbles nucleation, growing, and collapse in a liquid, operated by the passage of the ultrasonic waves (Katz et al., 2010)

**Paleoenvironment** Is the ancient environment conserved in the rock record (Kenedy 1998). This study refers to the settings during the Holocene period and beyond. Phytolith is a proxy of paleobotany which is a function of paleoenvironments.

**Paleoecology** is the study that helps scientists understand fossil organisms interact with their ancient environment (Peteet 1999). It includes the time interval of life's existence on Earth. It unveils natural features of ancient histories, such as climate vegetation.

**Micro-charcoal** is charred material, widely used in reconstructing the fire history which was impacted by the climate and vegetation changes of the past (Zuo et al., 2021). Micro-charcoal identification is essential because of its present valuable data on the presence of wood or grass fuels of ancient man. Is carbon hence cannot be affected by organism decomposition.

**Bomas** are homesteads made by pastoralists and abandoned bomas are uninhabited sites which left by the herders communities.

## **CHAPTER TWO**

### **LITERATURE REVIEW**

#### **2.1 Introduction**

This chapter gives an account of the literature review and theoretical framework. The literature review is divided into three sections. The first section explains the background study of phytoliths and how different scholars have used phytoliths to reconstruct the Holocene environment. The second section explains how phytoliths and charcoal can explain the impacts of human activities on vegetation changes. The third section, defines phytoliths identification, classification, and counting. The last section of the theoretical framework presents two theories. The cultural ecology theory, explains how environment influences cultural change and adaptation by humans. Climate variability theory explains how climate contributes to vegetation changes.

#### **2.2 Background study of Phytoliths**

Phytoliths, plants' silica, formed due to silica deposition in plants cells. They can either be deposited around cells or within cells, forming cell replicas or casts through transpiration. These silica cells are deposited in the soils when the plant dies and decays. Phytolith studies have been used worldwide to reconstruct past ecological environments such as forested or grass-dominated habitats (Strömberg, 2004; 2007). Phytolith studies have been applied in the following three main areas first, to determine plant remains in fossil records by studying particular phytolith morphotypes. Secondly, to understand their accuracy in predicting vegetation and, by extension, climatic changes. Lastly, phytoliths has been used establish how depositional and post-depositional processes affect phytolith preservation status (Esteban et al., 2017). Phytoliths are a valuable tool in reconstructing past local vegetation because phytoliths are deposited in the sites near the original plant and do not experience aerial transportation (Pearsall, 2000).

Phytoliths production is influenced by various factors, including climatic conditions under which plants grow and mature, soil chemistry, soil water, plant development stage, and taxonomic relationship of the plant (Piperno, 2006). Dicotyledon plants produce fewer phytoliths, while monocotyledons produce numerous (Piperno, 2006).



In America, archaeobotanists analyzed phytoliths as independent representatives of the prehistory of plant use, domestication, and habitat and compared phytolith production and morphology in a wide range of plant taxa (Piperno, 2006). In North America, phytolith studies have helped reconstruct paleoenvironments and identify particular plant groups such as deciduous and coniferous tree species (Fredlund and Tieszen, 1997, Piperno, 2006). In Europe, phytolith analysis has been used in reconstructing early-to-late Miocene vegetation history (grassland vs. forest) in Greece and in reconstructing grass-dominated habitats in Turkey during the Cenozoic (Strömberg et al., 2004, 2007).

In Africa, phytolith research of palms, sedges, and woody eudicots is commonplace. However, in paleoenvironment studies using phytolith proxy, more emphasis has been put on grass species since they show different shapes associated with differences in paleovegetation (Bamford et al., 2006, Esteban et al., 2016, Mercader et al., 2010). Researchers have been using different proxies to reconstruct past vegetation changes in the composition of C<sub>3</sub> in contrast to C<sub>4</sub> grasses in vegetation. The fossil pollen assemblages cannot determine the C<sub>3</sub> and C<sub>4</sub> grass's contributions because grass (Poaceae) species usually produce pollen grains with morphological similarities (Bremond et al., 2008).

Phytoliths help approximate past vegetation's C<sub>3</sub> and C<sub>4</sub> grasses proportions. Phytoliths are valuable in quantitative indices of paleoclimates in paleoecology because grass phytoliths can distinguish C<sub>4</sub> grasses from C<sub>3</sub> grasses and determine their distribution fractions helping researchers understand paleoclimates such as moisture/rainfall and temperature rises (Bremond et al., 2008). The phytolith assemblages can provide information on past plant communities and vegetation structures (Stromberg, 2003). The distribution of grasses, trees, and shrub composition may provide information on closed or open habitats (Bredmond et al., 2005a).

Grasses are the active silica accumulator and produce numerous distinguishable phytoliths that help identify beyond the family level (Twiss et al., 1969, Marcader et al., 2010). Grass (Poaceae) species are divided into five subfamilies. Phytoliths assemblages reflect well the relative proportions of three grass subfamilies, each of which is adapted to different environmental settings (Alexandre et al., 1997, Albert et al., 2006, Bredmond et al., 2008). The first subfamily is Pooideae grasses which use C<sub>3</sub> photosynthesis and often grow at high elevations and high latitudes. Second,

Panicoideae grasses usually use C<sub>4</sub> photosynthesis and are commonly found in wet environments of low elevation and low latitudes.

In Africa, 21% of the Panicoideae grasses subfamily mainly grow under tropical forest canopies and use C<sub>3</sub> photosynthesis. Third Chloridoideae grasses use C<sub>4</sub> photosynthesis, commonly dominating dry environments at low elevations and low latitudes. The remaining two grass subfamilies, Bambusoideae grasses and most Arundinoideae grasses are everywhere and use C<sub>3</sub> photosynthesis (Bredmond et al., 2008). For example, the Chloridoideae in high quantity produces saddle morphotype, by a few taxa of the Bambusoideae (C<sub>3</sub> genera) and Arundinoideae, which are primarily C<sub>3</sub> species. The dumbbells (Bilobates) and cross morphotypes are highly produced but are not exclusive to the Panicoideae. The Chloridoideae, Arundinoideae, Bambusoideae, and Stipa, produce the dumbbells and cross in low quantity (Alexander, 1997).

Phytoliths are essential tools in grass systematics. In reconstructing vegetation, history phytoliths are more accurate than pollen. Pollen and phytolith differ in preservation; phytoliths can withstand high temperatures, for example, 800<sup>0</sup>C to 1200<sup>0</sup> C, and preserve well in the soil for a long time (Piperno, 2006). Variable silica content within species is assumed to associate mainly with local climate and soil conditions. PH, iron, and aluminum oxide affect dissolved silica preservation (Piperno, 1988, 2006). *In-situ* phytolith data is assumed to be produced directly by plants in large quantities and varies from site to site (Piperno, 2006).

Recent phytolith studies have included macrobotanical data composed of silicified macro remains of wood, leaves, roots, and silicified fruits (Bamford, 2005, Albert and Bamford, 2012). Phytolith analysis is essential in determining domesticated crops in contrast to wild crops in archaeological sites (Pearsall 200), recognizing and reconstructing vegetation structure (Bremond et al., 2008), and determining the climate influence in the past (Fredlund and Tieszen, 1997).

In Olduvai Gorge, studies conducted using pollen micro remains, carbon isotopes, and faunal remains have provided evidence of the past environment and vegetation for the Plio-Pleistocene period (Albert et al., 2014). The result indicated vegetation shifts in Olduvai Gorge from wooded vegetation cover during middle and lower Bed I. More vegetation by uppermost Bed I to woodland mosaic in lower Bed II influenced by the highly saline-alkaline lake conditions. Olduvai Gorge provides strong evidence of the palaeoecological and paleoenvironmental data, which present

vegetation history composed of pieces of woods, leaves, roots, and silicified fruits (Albert and Bamford, 2012; Albert et al., 2014) and pollen micro remains and phytoliths (Albert and Bamford et al., 2014).

Silica microremains (phytoliths) have been applied by researchers to reconstruct African vegetation history (Alexander et al., 1997) for the Holocene period (Barboni et al., 1999, Albert et al., 2014) and focused on the ecological features of the grass leaves (Albert et al., 2014). Phytolith can differentiate C<sub>3</sub> grassland from C<sub>4</sub> grasslands and further distinguish between C<sub>4</sub> grasslands dominated by C<sub>4</sub> warm, humid climate grasses (subfamily grasses Panicoideae) and those dominated by warm, dry climate grasses (subfamily Chloridoideae) (Murungi et al., 2016).

Studies conducted using pollen in East Africa have presented natural vegetation evidence during the early Holocene and natural and human impact during the late Holocene (Murungi et al., 2016). Archaeologically, phytoliths have helped identify plants used by prehistoric people and aided in distinguishing between those used by people and those that are natural accumulations and representing past vegetation (Mercader et al., 2009).

A multiproxy data from all vegetation species obtained from paleontological sites of Laetoli, Olduvai, Peninj, and other East African phytolith assemblages presented evidence of some similarities between past and present-day vegetation at the regional scale (Barboni et al., (2014). The paleobotanical analysis of phytoliths depends on comparing ancient types with morphotypes extracted from modern soil and vegetation (Mercader et al., 2009; Mercader et al., 2012).

A similar study conducted by Esteban et al. (2017) on the south coast of South Africa analyzes modern soil phytoliths related to contemporary vegetation composition (plant communities). The goal was to assess the accuracy of phytolith data reflecting vegetation cover, strengthening phytolith's ability to interpret phytolith data in reconstructing paleovegetation of the Pinnacle point and south coast sites in South Africa.

Several studies have shown the importance of understanding phytolith production, reference collections, and the correlation between phytoliths from modern surfaces (Mercader et al., 2009; 2011; 2012). Although an extensive bibliography exists on phytolith-based environmental Reconstruction for Olduvai, Laetoli, Lake Eyasi in Tanzania (Albert et al., 2006, Albert and

Bamford, 2012, Barboni et al., 2010) and other sites in Kenya such as Olorgoissaille (Kinyanjui, 2012) there is scarce information for Koobi Fora northern Kenya.

This study will provide vegetation structure details, human behavioral adaptability, and, by extension, infer the general trend of Holocene climate change in Koobi Fora.

### **2.3 Phytoliths and Charcoal**

Phytolith and charcoal data are essential for reconstructing the paleoenvironment, and both may indicate vegetation changes and human activities. Charcoal dispersal, transportation, and deposition help to understand phytolith dispersal (Fredlund and Tieszen, 1994) by providing vital information on fire regimes (wood vs. grass) in a locality (Warrock, 1998). It may represent the ages along with the depth of the soil profile (Bremond et al., 2017).

Human activities such as the domestication of animals affect modern soil and vegetation cover and structure (Bamford et al., 2014). Human activities and their effects on the vegetation change during the last two millennia have been recorded in East African high altitude mountains, for example, Mt. Kenya and little-researched Virunga volcanoes (Murungi et al., 2016). Emphasis has been pointed to more durable microscopic phytolith silica bodies.

Pastoral activities influence the modern vegetation cover in Koobi Fora. The differential Nitrogen input from the dung and urine decomposes adding to the soil nutrients in the cattle enclosures creating micro-habitats characterized by abundance and diversity of certain plant species and reduction and absence of other species.

Phytolith analysis helps understand human variability, paleosols, and culturally influenced factors on change of soil profile. In addition, to how humans contribute to the paleoenvironment and present environment (Barczi, 2003).

Evidence of human impacts and vegetation changes during the late Holocene has been presented by charcoal and pollen data in montane sites of southwestern Uganda (Murungi et al., 2016).

## 2.4. Phytolith Identification, Classification, and Counting

Phytoliths are classified according to their morphological features and/or their taxonomic affiliations. Twiss et al. (1969) proposed a phytoliths morphology associated with grass taxonomy classifying phytoliths. The phytoliths morphology precipitated in short cells of the mature leave epidermis are incorporated with other epidermis features in species and genera identification. This can be identified in three grass subfamilies: Panicoideae, Festcoideae, and Chloridoideae. General classification mainly follows the published International Code of phytolith Nomenclature (Madella et al., 2005, Neuman et al., 2019)

Other published studies on specific morphotypes or plant taxa are used. These include palms (Albert et al., 2014), sedges (Albert et al., 2006), grasses (Twiss et al., 1969, Twiss, 1992, Alexander et al., 1997, Rasouw, 2009, Stromberg, 2003). In addition, other studies that document various phytolith morphologies and systematics as modern references to assist in the identification and interpretation of fossil assemblage include (Bremond et al., 2005; Neumann et al., 2009; Novello et al., 2012, Novello and Barboni, 2015).

They are classified into two broad categories: diagnostic and non-diagnostic morphotypes. Diagnostic morphotypes are silica cells with unique shapes and sizes, and they usually occur in specific vegetation taxa. The plants that produce diagnostic morphotypes are grasses, palms, and sedges. Non-diagnostic phytolith morphotypes lack taxonomic characteristics (Albert et al., 1999). Their occurrence is controlled by environmental variables where the parent plants developed (Piperno, 1988). According to Piperno (2006), these morphotypes are wavy and smooth elongates, trichomes and bulliforms. Morphotypes have been allocated in different categories, such that Trichrome has been earmarked with angiosperms and bulliforms to grasses (Piperno, 2006). The morphotypes can also be assigned with graminoids.

The non-diagnostic morphotypes have been included in this study because they help understand environmental variables and different habitats. Morphotypes like bulliforms are good indicators of grasslands and high moisture (Rovner, 1983).

Phytoliths fall under different size categories varying between 2 and 800um. While processing and extracting phytoliths, this fact should be considered to ensure the recovery of all size-class

phytoliths (Stromberg, 2004; Albert et al., 2006; Piperno, 2001)

Grasses form identifiable morphotypes that help reconstruct vegetation history in Africa even after a plant is long gone. Grasses accumulate high silica in a plant and preserve well in soil for a long time. Different studies have identified grass-specific morphotypes distinguishing the subfamilies (Piperno, 2006). The grass phytoliths that are considered to distinguish grass subfamilies, according to Madella et al. (2005), are,

- Pooideae C<sub>3</sub> are rondels (pyramidal rondel), conical rondel, and keeled rondels types.
- Panicoideae are symmetrical and asymmetrical bilobates (dumbbells), cross-shaped and polylobate.
- Chloridoideae are saddles shape

The categories help further identify the subfamilies and distinguish Aristidoideae grasses (Piperno, 2006). The grass silica short cells identification does not always depend on the taxonomic attribution; it also depends on the region studied. Barboni and Bredmond (2007) illustrated that rondel morphotypes are affiliated with Pooideae C<sub>3</sub> grasses in temperate areas. In tropical Africa, rondels are associated with Pooideae in high altitudes and with C<sub>4</sub> grasses, especially Chloridoideae C<sub>4</sub> short grassland in low altitudes.

In African paleobotany, counting phytolith morphotypes to attain authentic ecological inferences has been debatable, and essential debate has developed (Barboni et al., 2007). Some researchers count up to 200 Poaceae short cell types irrespective of how many other phytoliths categories may be present (e.g., Stromberg 2009).

In this study, grass short cell phytoliths were counted up to 250 because of the nature of the site due to the feeding habit of the domesticated animals (cattle, sheep, goats, and donkeys). The domestic animals feed on grass, and the urine and dung act as nutrients on the soil, which generate vegetation, especially grass. Dung from cattle, donkeys, camels, goats, and sheep were processed. The aim was to determine the above phytoliths assemblage and the dung correlation. Unfortunately, this case did not apply to fossil samples because some did not have enough grass phytoliths concentration for identification and interpretation.

## **2.5. Theoretical framework**

### **2.5.1. Cultural Ecology Theory**

The theory explains how environmental factors influence human cultural beliefs and practices and their ecosystem (Steward, 1995). The approach was proposed in the 1930s and 1940s by Julian Steward. The theory also explains the multilineal evolution concept that societies develop at different times depending on the availability of the resources in their environment (Steward, 1995). When there is environmental disturbance due to climate change, humans migrate and search for new resources (Maslin, 2014). It has been the case in Turkana, where the lack of water sources and pastures for the livestock forces the Dassanech community to move from one place to another, searching for pasture.

This theory helps understand how nomadic human activities (Dassanech culture), moving from one place to another searching for pasture, contribute to vegetation change. Humans have been the most significant engineers of landscape cover change (Ellis et al., 2013; Kaplan et al., 2011). When the Dassanech moves, the abandoned bomas especially in cattle enclosures, the dung decomposes with the soil and is a nutrient hot spot for plant growth.

In this study, cultural ecology theory answers the question of human-environment interaction aspects and fails to answer the question of climate changes impact on vegetation changes. Considering the use of two theories is essential to explain the impact of climate on the landscape. The second to answer the question is climate variability theory. The climate variability theory addresses the issue of climate change impact. It explains the role of temperature and rainfall in changing and/or sustaining vegetation cover. In addition, it helps to understand how climate change affects the Dassanech life in Koobi Fora.

### **2.5.2. Climate Variability Theory**

The proponent of this theory is Richard Potts, and the theory was first applied in the 1960s to explain the role of climate variability in evolution history. The theory suggests human evolution was a response to climates changing rapidly and extremely rather than progressively. In addition, the variability theory emphasizes vegetation reconstruction, regional hydrology, landscape, and animal communities over a long-time frame.

Scholars applied this theory to different topics, such as the impact of climate on the vegetation cover. Understanding the timing when vegetation changes in response to climate variabilities such as increased rainfall, temperature, and carbon dioxide (CO<sub>2</sub>) is vital. The climate contributes directly or indirectly to ecosystem processes and is perpendicular to land cover changes due to anthropogenic activities involving a multiplex combination of biogeochemical and biogeophysical activities (Gaillard et al., 2018). They indicate how the land cover changes over time.

This theory help to interpret the environment (temperature and rainfall) on the growth of plant species, abundance, and diversity of the species inside and outside abandoned bomas. The theory helps understand the climate impact on the Koobi Fora landscape.



## CHAPTER THREE

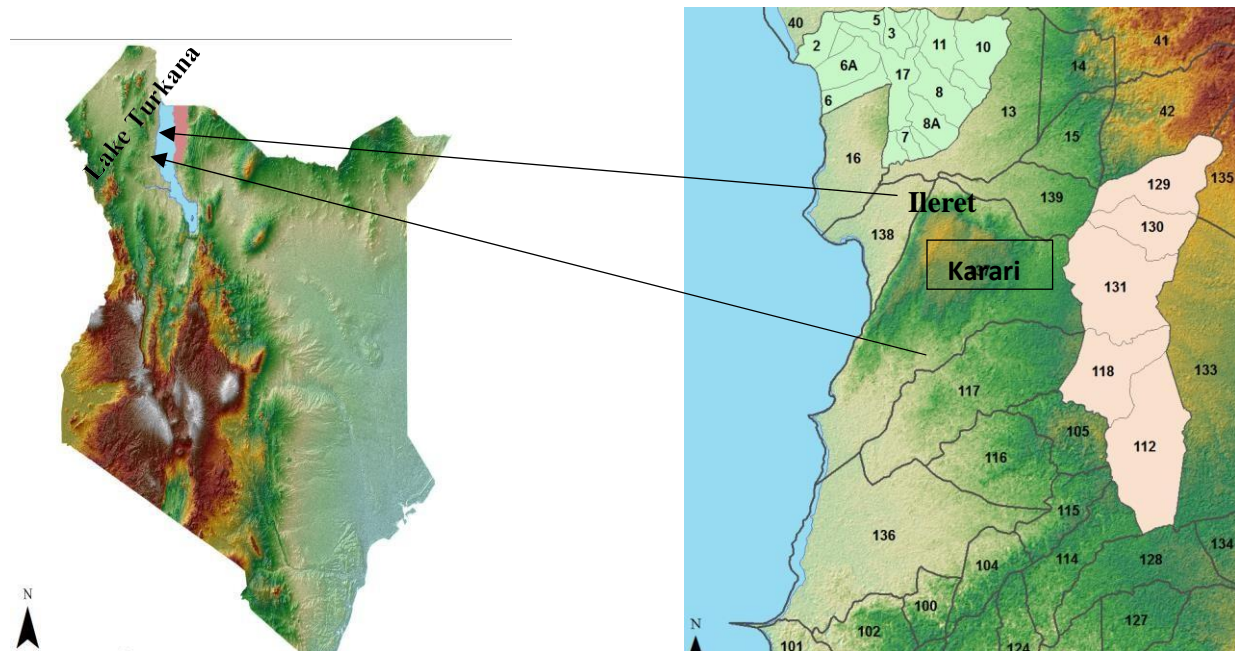
### THE STUDY SITES

#### 3.1. Introduction

This chapter begins by giving a history on the location of the study sites. It also describes climate and vegetation. The area is characterised by dry climatic conditions. It receives minimal rains per year. Vegetation cover is dominated by herbaceous grassland. Geology and archaeological sites in the research area are also discussed.

##### 3.1.1 Location

Koobi Fora is located in the Northern part of the Kenya rift valley at 3°N, 36°E in Marsabit County. The area extends from Kenya to the Ethiopian border (Ileret) to Alia Bay in the south. It lies within the Sibiloi National Park that was gazetted in the 1970s. The samples were collected from Karari and Ileret.



**Figure 2.3:1 Map showing Lake Turkana Basin location and sampling sites (adapted from Google and modified by author)**

### 3.1.2 Climate and vegetation

The Koobi Fora climatic condition is semi-arid, and the mean annual rainfall at the site is ~130 - ~150mm. The region is predominantly hot, with the mean temperature at ~37°C - ~27°C, and the soil temperature at 25cm depth is ~37°C (Yuretich and Cerling, 1983). The long precipitation season falls between March and May, and between September and November is the shorter period (Mbaluka and Brown, 2016). The highest peak of the rainfall season at season falls in April and November (Mbaluka and Brown, 2016). The rapid climate fluctuation causes droughts in the basin, affecting the wild and domesticated animals' death (Kinyanjui, 2018).

In much of Lake Turkana basin, about 83% is covered with *Acacia-Commiphora* grassland and shrublands, comprising herbaceous vegetation and semi-desert grasslands with perennial and annual bushes, riverine forest, woodlands, and semi-desert shrublands (Berthelme, 1985).

Mbaluka and Brown (2016) explain that the current vegetation structure indicates that the Koobi Fora basin is covered by distinctive flora diversification controlled by the soil/rock type, topography, and drainage system.

Perennial grasslands cover the Koobi Fora site along the lakeside: *Indigofera spinosa*, *Dusperma longcalyx*, *Barleria spp.*, *Sporobolus spicatus*, and annual grasslands *Aristida mutabilis*. *Commiphora sp.* *Euphorbia cuneata*, *Acacia recifiens*, *Cadaba rotundifolia*, and *Salvadora persica* shrublands mostly dominate on alluvium and outcrops outlooks (Mbaluka and Brown, 2016). The shrublands are primarily dominant in the north of the Koobi Fora region, especially Ileret

The herbaceous vegetation cover comprises *Aloe sp*, *Barleria sp*, *Sansveria sp*, and C4 grasslands. The riverine and woodlands of the site are mostly linked with the seasonal ponds and semi-permanent river channels known as *laggas*. They are dominated by species like *Hyphaene compressa*, *Acacia elatior*, *Ziziphus mauritiaum*, *Cordia sinensis*, *Lawsonia inermis*, *Terminalia spinosa*, *Acacia tortilis*, and *Grewia fallax* (Mbaluka and Brown, 2016).

### 3.1.3 Geology

On the northern side of the Lake Turkana basin, three (3) significant geological chronologies are found. The geological chronologies are Shungura, Mursi, and Usno Formations. The Nachukui Formation in the western part and the Koobi Fora Formation in the northern part of the present-day Lake Turkana (Brown and Feibel, 1986). All these Formations are members of the Omo Group, which contains paleontological from the Pliocene epoch and archaeological record that dates back 2.4 million years ago.

The Koobi Fora Formation comprises eight members, from Pliocene to Pleistocene, which can easily be differentiated by volcanic tephra with unique chemical conformation (Brown and Feibel, 1986). Koobi Fora Formation is geographically branched into three subregions, the northern part is Ileret, the central is Koobi Fora, and Allia Bay is the southern part. The Formation dates back from 4.3 to 0.6 million years ago with 560m overall thickness.

The five (5) older members are Pliocene members: Lonyumun, Moiti, Lokochot, Tul Bor, and Burgi, and younger members are three from Pleistocene members KBS, Okote, and Chari. The Koobi Fora Formation unconformities tuff can be seen within two members: the Burgi member, which is divided into upper, and lower, and the Chari member. The Formation overlies unconformably in fault contact with Miocene and Pliocene volcanic rocks and associated sediments and is disconformably overlain by the Holocene Galana Boi beds (Gathogo and Brown, 2006).

The Holocene Galana Boi Formation comprises lacustrine and shoreline deposits characterized by diatomaceous siltstones, sand, mollusk, and fish remains. Kinyanjui (2018) carried out the first paleoenvironment study using phytolith proxy analysis from the Galana Boi Formation. This pioneering study confirmed that phytoliths are well preserved in these sediments.

The phytolith samples collected from Galana Boi deposits were analyzed along with the modern samples from abandoned bomas. Phytolith data from the ancient samples will help understand how vegetation changed during the Holocene period and the role of humans and climate in this change. Samples from the abandoned bomas will help understand the impact of animal domestication on the landscape

### 3.2 Sites

This section explains all the sites sampled in Koobi Fora, East Turkana. A total of thirteen abandoned bomas, three Holocene sites were studied. Abandoned bomas were selected according to the year of abandonment and their settings such as in riparian environment. The Holocene sites were sampled by observing the profiles to collect soil samples.

#### 3.2.1 Abandoned bomas

Bomas are homesteads made by herding communities, and dung accumulations in livestock enclosures can leave lasting signatures on landscapes. The herders homesteads referred are those abandoned by Dassanech community residing in Karari and Ilerete in East Turkana. In Karare, Area 117 (four bomas) and Area 129 (three bomas) were counted. Modern samples were collected from inside and outside abandoned bomas, domesticated animal dung, pest control, fire pit, depositional area, and homogenous samples.

Table 2.3:1 Abandoned bomas details and the years abandoned from Ileret and Karari

<b>SITE</b>		<b>BOMA</b>	<b>COORDINATES</b>	<b>YEAR ABANDONED</b>
<b>ILLERET</b>				
Area 8		Boma 1a	37N 0197275N 0474075E 444m	3 years
		Boma 1b	37N 0197450N 0474042E 442m	3 years
El-Kimere	Flat Plain	Boma 2c	37N 0194612N 0464777E 377m	10 years
		Boma 2d	37N 0195292N 0465060E 374m	10 years
River Loborana		Boma 3e	37N 0206390N 0480171E 437m	8 years

		boma 3f	37N 0206507E 0480302N 442m	1 year
<b>KARARI</b>				
Area 117	Flat Plain	Boma Ka	37N 0206228N 0453232E 462m	2 years
		Boma Kb	37N 0206217N 0453055E 464m	5 years
		Boma Kc	37N 0207343N 04531102E 474m	3 years
	Flat Plain	Boma Kd	37N 0208805E 0454113N 492m	10 years
Area 129		Boma Ke	37N 0216092N 0463204E 555m	2 years
		Boma Ke (b)	37N 0216085N 0463118E 555m	5 years
		Boma Kf	37N 0214859N 0460607E 559m	5 years

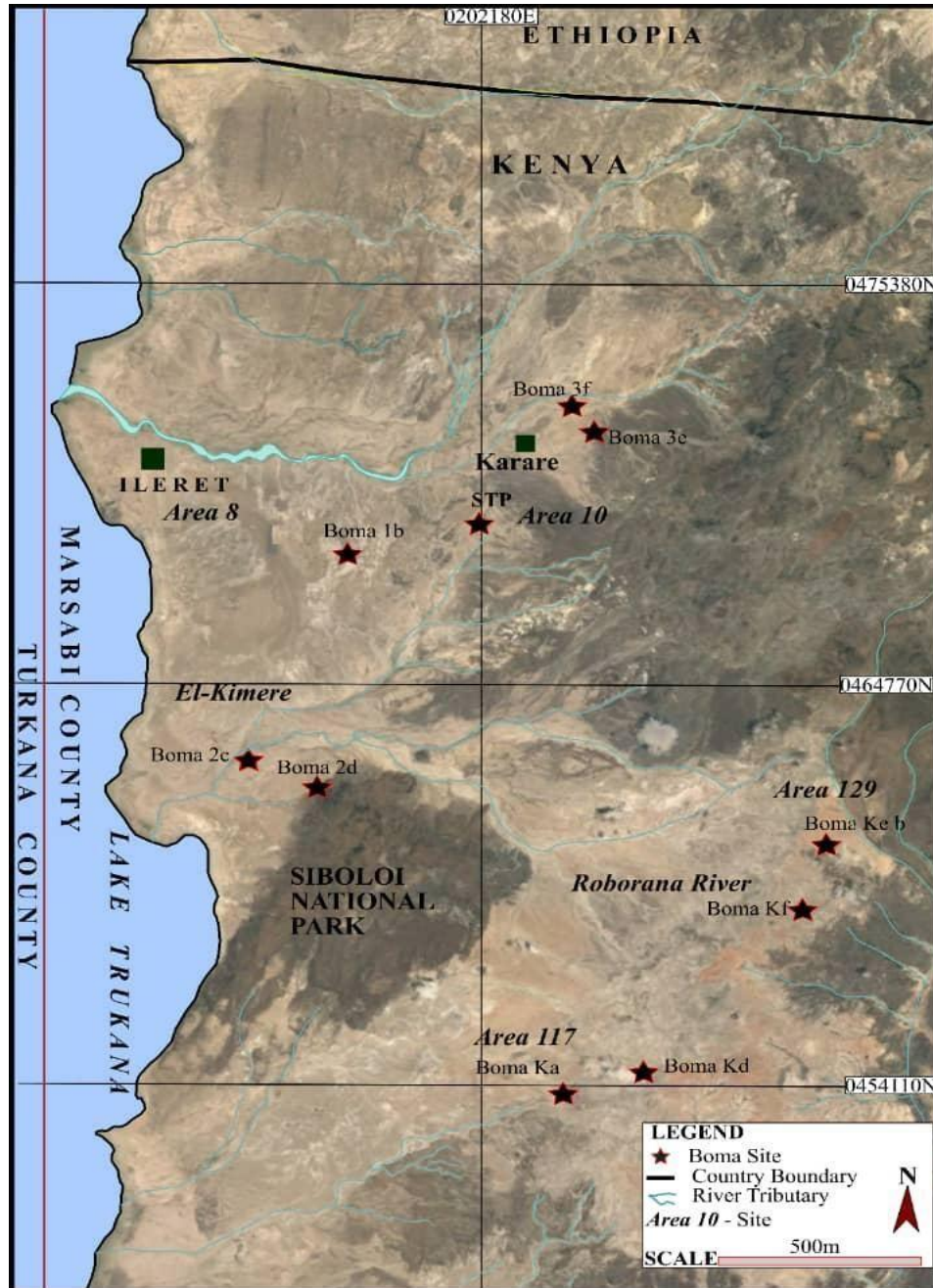


Figure 2.3:2 Map showing the location of the sites (abandoned bomas and Holocene sites). (Adopted from Google Earth and modified by author)



**Plate 3:1** Showing the boma where Dassanech people reside with the domesticated animals



**Plate 3:2** Inside boma *Tribulus sp.* started to dominate after the Dassanech people abandoned the boma

### **3.2.2. FxJj108**

The site is located in area 117 in Karari and is found within the Holocene Galana Boi deposit. The site is an early Holocene site with a high lake stand (80M above the current lake level) dated approximately 9.6kyr to 6kyr (Kinyanjui, 2018). There are no available dates for this site. Researchers have correlated the date of the site with other sites with similar lithostratigraphic sequences and archaeological records.

Three phytolith samples were collected from the excavated square in 2018 (37N 0204613N 0453870E 459m) by the Holocene team led by Dr. Emmanuel Ndiema. The depth of the square was a half-meter (50cm) down. The soil profile described and recorded the inclusions of materials such as small roots bones across the whole profile.

### **3.2.3. FwJj 25W**

The site is located in Area 10 within the Holocene Galana Boi deposits. The OSL dates conducted indicate that the FwJj25W site dated to 4Kyr BP. It contains cultural transition evidence from the early to mid-Holocene period. The evidence from archaeology and geology indicate the existence of two occupations; fisher-gatherers during the high lake stand and a later Pastoral-Neolithic occupation (Ashley et al., 2011).

### **3.2.4. Lowasera A**

The site is located on an old Lake Turkana shoreline, and it is 6.7km from the current shore (Phillipson, 1977). Lowasera A is found at the end of the southern part of the site, where the beach deposits lie against the Precambrian gneiss outcrop, which is protected mainly from subsequent erosion. The site indicates evidence of prehistoric occupation, abundant chipped stone artifacts, potsherds, shell beads, and spiky bone harpoon head remains. Also, evidence of human skeletal and faunal, mostly fish remains found in Lowasera.

The soil samples were collected from Unit 11 as described by Phillipson, 1977. The maximum thickness of Unit 11 is 50cm. Lithologically, it is grey diatomaceous silt, moderately humic with an interbedded concentration of molluscs. The slightly humic amount indicates that it was lying in the shallow end of the lake. It is suggested that the water level began to decrease during that time



## **CHAPTER FOUR**

### **METHODOLOGY**

#### **4.1. Introduction**

The phytolith samples from modern soil, ancient sediment, and domesticated animals were collected from thirteen (13) abandoned bomas in Ileret and Karari to reconstruct Holocene vegetation data. Vegetations were identified, tallied, and quantified from inside and outside abandoned bomas. Modern soil samples were collected from inside and outside depending on the number of years of abandonment and locations (inland, riparian, flat plain). Domesticated animal dung and fossil sediment from Areas 10 and 117 were collected.

##### **4.1.1. Vegetation data**

Plant species from thirteen (13) abandoned bomas and their surroundings, six (6) from Ileret, and seven (7) from Karari in different settings (inland, flat plain, and riparian environments) were identified, tallied, and recorded. In transects outside bomas, a plot of 100 by 100 meters was established to locate and count species within the plot.

##### **4.1.2. Modern soil**

Twenty (20) modern soils from inside and outside abandoned bomas were collected. The soil samples were collected from inside abandoned bomas and outside about 0.5km away to avoid contamination. To understand their fire regime, the soil samples were collected in different locations, such as inside bomas from fire pits and pest control areas. In depositional and homogenous samples were collected from both inside and outside. The modern samples were taken from inside and outside bomas to determine the correlation between vegetation cover and soil sediment.

Table 4:2 Abandoned bomas where modern soil and dung samples were collected from inside and outside abandoned bomas.

SITE	BOMA	COORDINATES	BARCODES	COLLECTED		SAMPLE#	
				AREA			
Area 8	Boma 1a	37N 0197275E 0474075N 444m	1251007	Fire pit		I1	
				1251008	Cattle enclosure		I2
				1251009	Homogeneous sample		I3
				1251012	Pest control/ashes		I4
				1251013	Outside boma (1a and 1b)		I5
El-Kimere	Flat Plain Boma 2c	37N 0194612E 0464777N 377m	1251016	Depositional area (inside)		I6	
				1251017	River side/ Quad 1 (outside)		I7
				1251019	Near Quad 4 (Cow dung)		I8
River Loborana	Boma 3e  boma 3f	37N 0206390E 0480171N 437m  37N 0206507E 0480302N 442m	1251022	Depositional area (inside)		I38	
				1251023	Homogeneous sample (inside)		I9
				1251024	Outside		I10

	Flat		37N 0206228E			
Area 117	Plain	Boma Ka	0453232N 462m	1251026	Fire pit (inside)	K13
				1251027	Homogeneous (inside)	K14
					Cattle enclosure	
				1251028	(inside)	K15
				1251029	Outside	K16
			37N 0206217E			
		Boma Kb	0453055N 464m	1251032	Donkey dung sample	K18
				1251033	Goat dung sample	K17
			37N 0207343E			
		Boma Kc	04531102N 474m	1251035	Outside	K19
				1251036	Inside	K20
			37N 0216092E			
Area 129		Boma Ke	0463204N 555m	1251038	Inside	K21
				1251040	Outside	K46
		Boma Ke	37N 0216085E		Phytolith sample	
		(b)	0463118N 555m	1251041	(Solanum incanum)	K22
					Phytolith sample(	
				1251042	Amaranthus)	K23
					Phytolith sample	
				1251043	(Grasses)	K24

### 4.1.3. Dung

Three (3) dung samples from cattle, sheep/goats, and donkeys were collected to infer modern plant communities at this locality. The cattle dung and urine accumulation inside pastoral homesteads develop distinctive vegetation patterns, which make it easy to allocate where the settlement was located.

### 4.1.4. Fossil soil samples

A total of nine (8) fossil samples were collected from Ileret and Karari in FxJj 108, FwJj 25W, and Lowasera considering the layers observed.

Dr. Rahab Kinyanjui collected the three (3) fossil samples from FwJj 25W in 2011.

Table 4:3 Lithographic details of the Holocene samples collected from Ileret FwJj25W site.

<b>Lithology</b>	<b>Sample#</b>	<b>GPS Coordinates</b>	<b>Collected at</b>
Sandy layer below the CaCo <sub>3</sub> layer	I12	37N 0199406N 0474228E 446m	FwJj25W
The silty layer above the CaCo <sub>3</sub> layer	I39	37N 0199406N 0474228E 446m	FwJj25W
From the square, most Easterly	I40	37N 0199406N 0474228E 446m	FwJj25W

In Karare, three (3) samples were collected from Area 117 (FxJj 108) the total depth was 50cm (1/2m).

Table 4:4 Lithographic details of the Holocene samples collected from Karari area 117 (FxJj108) and the point samples collected

<b>Lithology</b>	<b>Sample#</b>	<b>Coordinates</b>	<b>Collected at</b>
0-10cm-sand silt			
10-34cm-Fine sand	K48	37N 0204613N 0453870E 459m	17-22cm depth-6cm width
34-40cm-coarse sand	K49	37N 0204613N 0453870E 459m	34-40cm depth-5cm width
40-50cm- compact sediment	K50	37N 0204613N 0453870E 459m	42-50cm depth-6cm width



**Plate 4:3** Showing the image of a test pit from Area 117 (FxJj 108) site

Lowasera, two (2) samples were collected from geological unit 11 as described by Phillipson, 1977.

**Table 4:5** Lithological details of the Early Holocene site from Lowasera A.

<b>Lithology</b>	<b>Sample#</b>	<b>GPS Coordinates</b>	<b>Collected at</b>
Tuff with shells 22cm depth	L51	37N 0246307N 0324801E 441m	12cm depth, and 2cm width
Silty sand/diatomaceous	L52	37N 0246307N 0324801E 441m	12cm depth and 2cm width

## **4.2. Data processing**

The modern soil, dung, and fossil sediment samples collected from abandoned bomas and excavation were processed using a rapid procedure (Katz et al., 2010).

The samples were equally weighted at 10mg and placed in a 2ml vial. Hydrochloric acid (HCL) of 50 $\mu$ l was added to each sample to dissolve carbonate minerals and carbonated hydroxylapatite. 50 $\mu$ l Potassium Hydroxide pellets were added to remove organic materials. After adding each acid, samples were put in hot water for 10minutes to fasten the process and centrifuged at 3000rpm for 5minutes. The supernatant was decanted and washed twice with distilled water (dH<sub>2</sub>O) and centrifuged at 3000rpm for 5minutes to remove the remaining acids. 50 $\mu$ l of Sodium Polytungstate Solution (SPT) was added for the heavy liquid floatation process and centrifuged at 3000rpm for 5minutes. The floatation fraction was transferred to different vials and washed twice with distilled water to remove the salt.

Then 50 $\mu$ l of Glacial Acetic Acid (GAA) was added to neutralize water and remaining acids before adding the Acetolysis mixture. The Acetolysis mixture was added to each sample to dissolve cellulose, hemicellulose, and chitin. Acetolysis mixture cleans pollen to see the morphological characteristics. The mix in samples was washed, centrifuged at 3000rpm for 5minutes, and decanted. Glacial Acetic Acid (GAA) was added again to neutralize the Acetolysis mixture to prevent the reaction when mixed with other acids or water.

The aim of these detailed lab procedures is to get the final residue which contain phytolith assemblages.

## **4.3. Phytoliths microscopic analysis**

The final solutions of each sample, approximately 1mg, were mounted on 22mm x 22mm frosted microscopic slides. The solutions were mounted using Entellan mounting media and covered with 11mm x 11mm cover slips.

Phytolith counting was done vertically across the slide using Zeiss Axioskop at 40x magnifications. In each slide 250, Poaceae short cell types were counted because of the nature of the sites studied. In counting very small-sized phytolith fragments, included and multi-celled

phytoliths were counted as one or the number of individual cells within the multicellular structure. For slides with few morphotypes second slide was mounted to get the 250 grass silica short cells (GSSC). The image of morphotypes observed was captured using a phone camera.

#### **4.3.1. Phytoliths morphological classification**

Phytoliths in this study were identified according to their morphotype categories and taxonomic affiliation (parent plant species). The general morphological classification of phytoliths follows the published International Code of phytolith Nomenclature (Madella et al., 2005, Neuman et al., 2019). For this study, specific plant taxa published studies are considered, such as Palms (Albert et al., 2014), sedges (Albert et al., 2006), and grasses (Twiss et al., 1969, Twiss, 1992, Alexander et al., 1997, Rasouw, 2009, Stromberg, 2003). In addition, other studies focused on East-Central Africa as modern references and vegetation reconstruction include (Bremond et al., 2005; Neumann et al., 2009; Novello et al., 2012, Novello and Barboni, 2015). Local modern reference collections include (Kinyanjui, 2013: 2018).

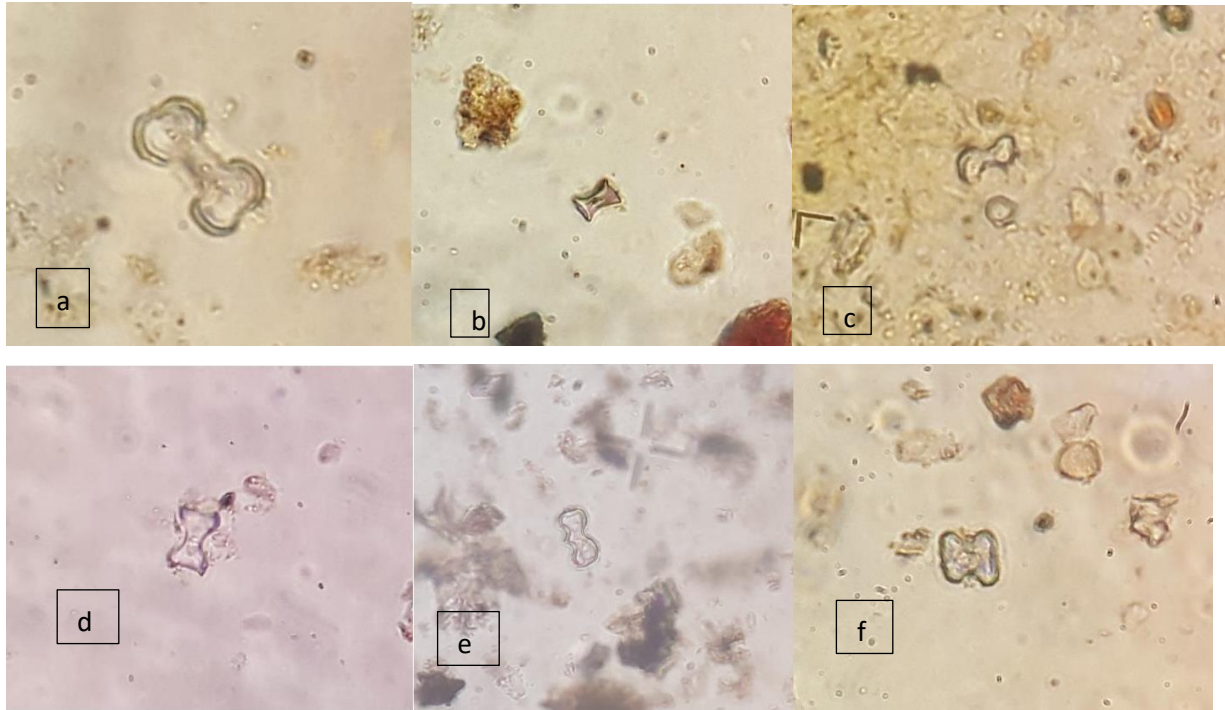
Grass family identification has been emphasized since East African vegetation cover grass is more dominant. Geographically grass subfamilies are highly affected by climatic conditions such as temperature, precipitation, and altitudinal gradient, which provides information on past climate and ecology (Twiss et al., 1969, Twiss, 1992, Alexandre et al., 1997, Barboni et al., 2007, Bremond et al., 2008). The grass subfamilies identified in this study include Pooideae, Panicoideae, Chloridoideae, and Aristidoideae.

#### **4.3.2. Grass short cell phytoliths**

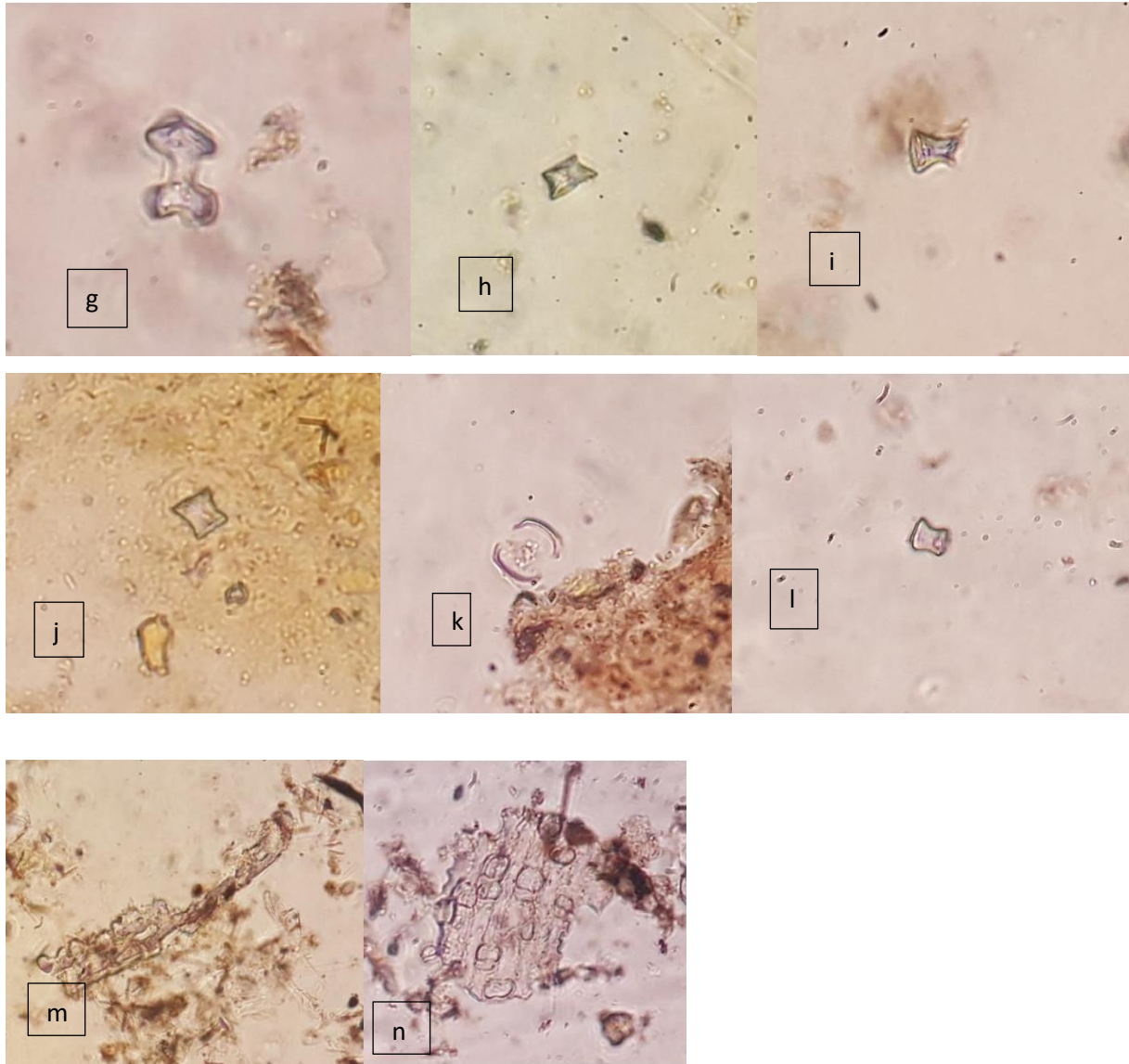
Silica cells from grass leaf epidermal cells include bilobate, polylobate, saddle, cross/quadrilobates, and rondels (Twiss et al., 1969, Piperno, 2006, Bremond et al., 2008, Rossouw, 2009, Mercader 2010). The short silica cells help to differentiate between C<sub>3</sub> and C<sub>4</sub> grass and are good indicators of the climatic condition and plant habitat (Rossouw, 2009). The percentage of grass short cells produced in the grass can determine the C<sub>3</sub> and C<sub>4</sub> dominance (Bremond et al., 2008). In addition, the ratio between short grass cells and non-grass phytoliths can determine the relative dominance of grasslands against wood vegetation (Bremond, 2005a).



Bulliforms are found in most grasses but are non-diagnostic morphotypes of any grass subfamily. Researchers suggested that bulliforms are a helpful indicator of grasses growing in high humid habitats, and therefore their ratio within an assemblage indicates high precipitation (Piperno, 2006).

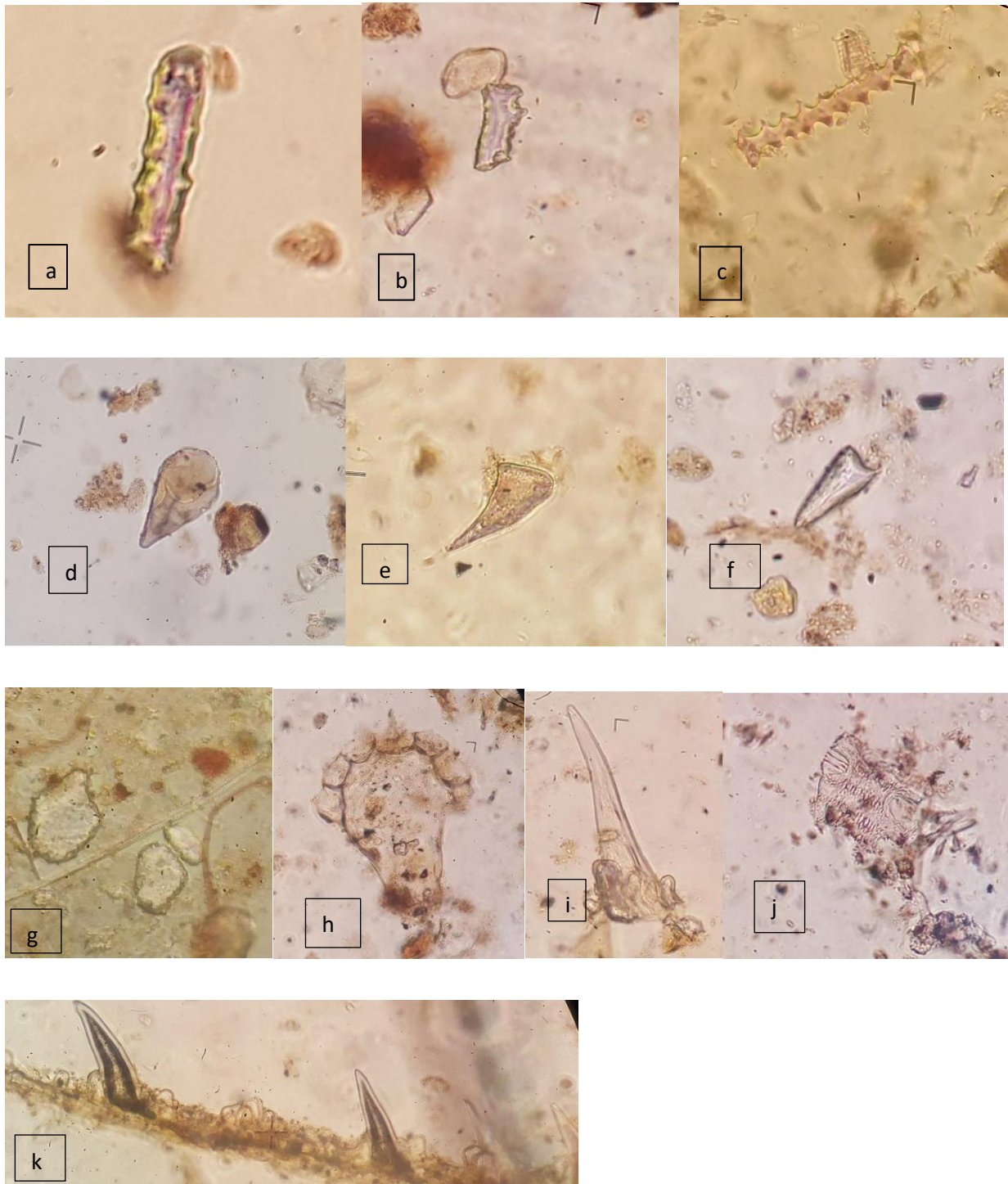


**Plate 4:4 (a).** a-d) Bilobates, e) Polylobate, f) Cross



**Plate 4:4(b).** g) Cross, h-i) Rondels, j-l) Saddles, m-n) Epidermal cells, m) Bilobate epidermal, n) Saddle epidermal

**Non-diagnostic grass phytoliths**



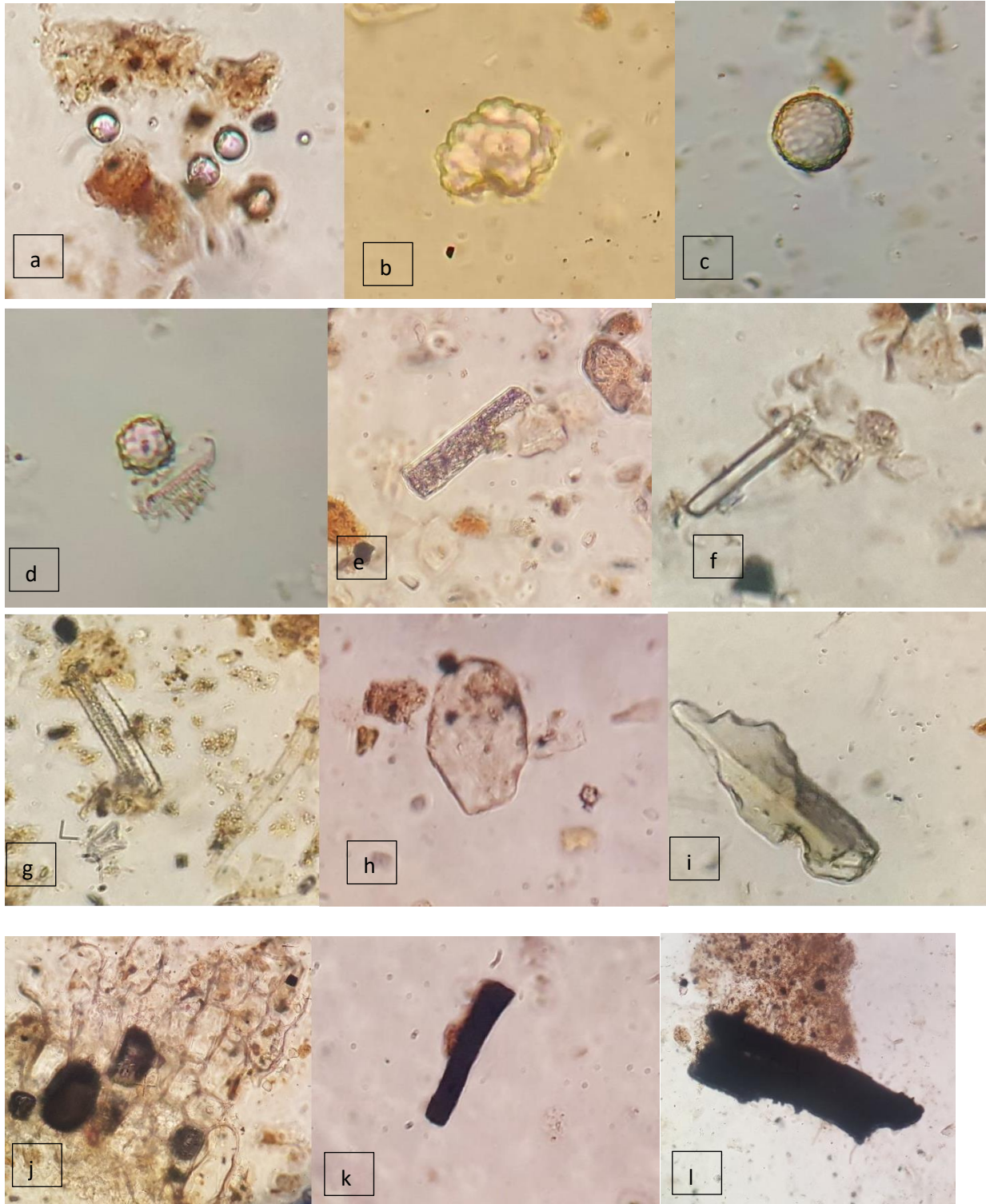
**Plate 4:5** a-c) Elongate echinate, d-e) Trichomes, f) Scutiform, g-h) Bulliforms, i) Hair cell, j) Elongate echinate epidermal, k) Grass trichome epidermal

### **4.3.3. Forest/wood indicators**

These morphotypes are treachery element of xylem (tracheids), sclerenchyma tissue (sclereids), globular granulate, globular psilate (Spheroid psilate), decorated blocky (Piperno, 2006, Mercader, 2009) stomatal cells, trichome and hair bases (Mercader et al., 2010). These morphotypes are found in woody dicotyledons. They are linked with closed habitats and help to determine moist climates (Piperno, 2006). In addition, these morphotypes have less taxonomic importance and are primarily redundant across taxa (Piperno, 2006, Mercader, 2009). The ratio of these morphotypes in the fossil assemblages is significant in interpreting the woody elements in the vegetation structure (Mercader, 2009, Albert et al., 2006). The above morphotypes help determine vegetation change between open grasslands in contrast to closed wooded habitats and their related climatic condition (Barboni et al., 2007, Mercader, 2010).

### **4.3.4. Herbaceous and non- grass taxa**

These morphotypes are morphologically similar to wood dicots morphotypes. These morphotypes are globular (spheroid) psilate, ellipsoid forms, epidermal appendages, and others. Despite being poor phytoliths, producers with phytoliths are mostly restricted to fruits and seeds (Piperno, 2006). They are incorporated in the analysis and discussed under the woody and herbaceous taxa categories (Kinyanjui, 2018).



**Plate 4:6** a-d) Spheroid bodies, a) Spheroid psilate, b) Spheroid verrucate, c) Spheroid ornate, d) Spheroid echinate (Palm type), e-f) Elongates, g) Tracheid, h) Block, i) Sclereid j) Honey comb, k-l) Charcoal

#### 4.3.5. Cyperaceae (Sedge)

The morphotypes are categorized as achenes and hat-shaped (papillae) in the sedge (Piperno, 2006). Sedges produce distinctive conical-shaped phytoliths that can easily be distinguished from other similar shapes produced in other plants (Piperno, 2006). Achene morphotypes are silicified achene cells produced in Cyperaceae inflorescence (Piperno, 2006). Sedges form useful elements of secondary vegetation that are mainly correlated with human interaction in the archaeological record. In palaeoecological records are related to wetlands and swampy habitats (Stromberg, 2003).



**Plate 4:7 a) Achene, b) Sedge, c) Hat-shapes/Papillae (adopted from Kinyanjui, 2018)**

#### Non vegetation assemblages observed



**Plate 4:8 a-d) Diatom sponges**

**Table 4:6** Modern phytolith reference collections table (adopted from Kinyanjui 2018 and modified by author).

Grass short silica cells			
Categories	Morphological description	Figure no.	References
<b>1. Bilobate</b> also known as dumbbells) Descriptions based on the outline of the lobes and length of the connecting shank)	Grass silica short cells with two distinct lobes connected with a shank. (Twiss <i>et al.</i> , 1969; Mulholland, 1989).	<b>Fig 4:4, (a-d)</b>	Twiss <i>et al.</i> , 1969; Twiss, 1992; Madella <i>et al.</i> , 2005; Stromberg, 2003; Rossouw, 2009; Mercader <i>et al.</i> , 2010.
a) Bilobate convex outer margin short shank (BCXSS) c.f. BI-7	Bilobate with rounded lobes connected with a short shank. <20µm.		Piperno and Pearsall, 1998; Stromberg, 2003; Fahmy, 2008; Mercader <i>et al.</i> , 2010.
b) Bilobate convex outer margin long shank (BCXLS) c.f. BI-5	Bilobate with rounded outer lobes connected with long shank >20µm.		Stromberg, 2003; Piperno, 2006; Fahmy, 2008; Mercader <i>et al.</i> , 2010.
c) Bilobate concave outer margin short Shank (BCCSS)c.f. BI-7	Bilobate with caved lobes connected with short shank <20µm.		Stromberg, 2003; Piperno, 2006; Fahmy, 2008; Barboni and Bremond, 2009; Mercader <i>et al.</i> , 2010.
d) Bilobate concave outer margin long Shank (BCCLS) c.f. BI-6	Bilobate with caved lobes connected with long shank >20µm		Stromberg, 2003; Fahmy, 2008; Barboni and Bremond 2009; Mercader <i>et al.</i> , 2010.
e) Bilobate flattened outer margin short shank (BFSS)c.f. BI-1, BI-6	Bilobate with outer margins squared, shank<20 µm		Stromberg, 2003; Piperno and Pearsall, 1998; Fahmy, 2008; Mercader <i>et al.</i> , 2010.
f) Bilobate flattened outer margin long Shank (BFLS) c. f. BI-6	Bilobates with outer margin squared with shank >20µm		Piperno and Pearsall, 1998; Stromberg, 2003; Fahmy, 2008; Mercader <i>et al.</i> , 2010.
g) Bilobate Panicoid type c.f. BI-8	Symmetrical bilobate with outer margin concave wide Shank <20µm		Stromberg, 2003; Piperno, 2006; Fahmy, 2008; Mercader <i>et al.</i> , 2010.
<b>2. Saddles (SAD)</b> Chloridoideae	Grass short silica cells with two opposite convex edges and two straight or concave edges	<b>Fig, 4:4, (j-l)</b>	Twiss <i>et al.</i> , 1969; Mulholland, 1989; Piperno and Pearsall, 1998; Stromberg, 2003;

	(Twiss <i>et al.</i> , 1969; Mulholland, 1989).		Madella <i>et al.</i> , 2005; Rossouw, 2009.
a) Saddle long (SADL) Arundinoideae (e.g., <i>Phragmites</i> sp.) BI-14	Saddles with long convex edges. Described as bilobate category (Stromberg, 2003)		Stromberg, 2003; Barboni and Bremond, 2009; Rossouw, 2009; Mercader <i>et al.</i> , 2010.
b) Saddle ovate (SADO) Aristidoideae (e.g. <i>Aristida</i> spp)	Rondels rounded /rounds (Piperno and Pearsall, 1998; Mercader <i>et al.</i> , 2010). Described as symmetry B bilobate (Stromberg, 2003)		(Piperno and Pearsall, 1998; Mercader <i>et al.</i> , 2010)Stromberg, 2003; Barboni and Bremond, 2009; Mercader <i>et al.</i> , 2010, Kinyanjui, 2013
c) Saddle squat (SADS) c.f.BI-15 Arundinoideae (e.g. in <i>Phragmites</i> sp.)	Saddles with short convex edges. Described as collapsed saddle (Stromberg, 2003, Piperno 2009)		Stromberg, 2003; Piperno, 2009; Barboni and Bremond, 2009; Rossouw, 2009; Mercader <i>et al.</i> , 2010.
d) Saddle plateau (SADp) c.f. BI-15 Chloridoideae (e.g., in <i>Eragrostis</i> sp.)	Saddle with side notches and much longer.		Twiss <i>et al.</i> , 1969; Stromberg 2003; Barboni and Bremond, 2009; Mercader <i>et al.</i> , 2010.
<b>3. Cross/quadra-lobate (QCR) c.f CR4-2, 6</b> Panicoideae (e.g., in <i>Melinis</i> spp., <i>Coelarichis</i> spp.)	Grass short silica cell with four lobates, symmetrical or asymmetrical (Twiss <i>et al.</i> , 1969; Mulholland and Rapp, 1992)	<b>Fig, 4:4, (f-g)</b>	Twiss <i>et al.</i> , 1969; Mulholland and Rapp, 1992; Piperno and Pearsall, 1998; Stromberg, 2003; Madella <i>et al.</i> , 2005; Barboni and Bremond, 2009; Mercader <i>et al.</i> , 2010; Kinyanjui, 2013.
<b>4. Polylobate (PLY) c.f. PO</b> Panicoideae e.g. <i>Panicum</i> sp.	Grass short silica cell with more than two lobes	<b>Fig, 4:4, (e)</b>	Twiss <i>et al.</i> , 1969; Stromberg, 2003; Madella <i>et al.</i> , 2005; Mercader, 2009; Kinyanjui, 2013.
<b>5. Rondels (ROND) cf. KR; keeled rondel</b>	Grass silica short cells with conical, keeled, and pyramidal forms, described in Twiss <i>et al.</i> (1969).	<b>Fig, 4:4, (h-i)</b>	Twiss <i>et al.</i> , 1969; Twiss, 1992; Fredlund and Tieszen, 1994; Stromberg, 2003; Madella <i>et al.</i> , 2005.
<b>6. Towers (TW) c.f. BI-3-4</b>	Variants of rondel categories; Stromberg, (2003); variants of trapeziforms in Bremond <i>et al.</i> , (2008); Rossouw, (2009).		Stromberg, 2003; Bremond <i>et al.</i> , 2008; Rossouw, 2009; Mercader <i>et al.</i> , 2010; Kinyanjui, 2013.



a) Tower horned (TWH) c.f. BI-4 Panicoideae (e. g. <i>Hyparrhenia</i> sp.)	Rondels with apex ends in one or two outward apices/ top truncated. Described as bilobate variant” in Stromberg (2003); “saddle variant 1” (Rossouw, 2009); “rondel” (Neumann et al., 2009).		Stromberg 2003; Barboni and Bremond, 2009; Mercader <i>et al.</i> , 2010.
b) Tower wide (TWD) BI-10-11	Rondel elliptical base/ tall body with tapering/flat apex; its base is at least three times wider than the apex. Described as “conical rondel” (Stromberg, 2003); “reniform” (Rossouw, 2009).		Stromberg, 2003; Barboni and Bremond, 2009; Mercader <i>et al.</i> , 2010; Kinyanjui, 2013.
<b>7. Trapeziforms sinuate/elongate/tabular crenate (TABCRE)</b> (Panicoideae, e.g., <i>Oplismenus</i> sp., Chloridoideae . e.g., <i>Cynodon</i> sp.)	Elongate body with trapezoidal cross-section and wavy edges. Described as crenate in Stromberg (2003); trapeziform polylobate (Rossouw, 2009); “trapezoid sinuate” (Neumann et al., 2009).	<b>Fig, 4:5 (a-c)</b> <b>Fig, 4:6, (e-f)</b>	Stromberg, 2003; Rossouw, 2009; Barboni and Bremond, 2009; Neumann et al., 2009; Mercader <i>et al.</i> , 2010; Kinyanjui, 2013.
<b>8. Bulliforms</b>	Epidermal cells located in mesophyll are usually three-dimensional, highly silicified, and are associated with moisture storage in the plant leaf. Also called-fan- shaped cells in some studies.	<b>Fig, 4:5, (g-h)</b>	Pearsall and Dinan, 1992; Piperno, 2006 P. 74 fig 3,9d.
<b>Non-Grass morphotypes (Dicot Morphotypes)</b>			
<b>9. Tracheid elements (TRCH)</b>	Silicified vein-sheath cells	<b>Fig 4:6, (g)</b>	Fahn, 1990; Albert, 1999; Piperno, 2006; Albert et al., 2009; Neumann et al., 2009; Novello et al., 2012.
<b>10. Sclereids (SCLD)</b>	Tracheary elements and other related silicified cells (Stromberg, 2003)	<b>Fig 4:6, (i)</b>	Piperno, 2006
<b>11. Globular morphotypes</b>	Also identified as spheroids in various publications	<b>Fig, 4:6, (a-d)</b>	Stromberg, 2003; Mercader <i>et al.</i> , 2000; Madella <i>et al.</i> , 2005; Albert et al., 2009; Barboni and Bremond, 2009; Neumann et al.,

			2009; Novello et al., 2012,
a) Globular psilate (GBHS)	Globular, smooth/sub-smooth surface.		Albert, 1999; Madella <i>et al.</i> , 2005.
b) Globular echinate (GBHEC)	Globular, with spikes/pricks		Albert <i>et al.</i> , 2009; Barboni and Bremond, 2009, Novello and Barboni, 2015.
c) Globular granulate (GBHESC)	Globular, with a granular surface		Albert, 1999; Piperno, 2006.
d) Globular verrucate (GBHEVE)	Globular, rough irregular surface.		Albert, 1999; Madella <i>et al.</i> , 2005; Piperno, 2006; Neumann et al., 2009.
<b>Non-grass morphotypes (Herbaceous and non-grass taxa)</b>			
<b>12. Ellipsoids/Oblong</b>	Longer than broad and with nearly parallel side		Albert, 1999; Madella <i>et al.</i> , 2005; Albert et al., 2009.
a) Ellipsoid psilate (ELLPS)	Ellipsoid with a smooth surface		Albert, 1999; Madella <i>et al.</i> , 2005.
b) Ellipsoid scabrate (ELLSC)	Ellipsoid with a granular surface		Albert, 1999; Madella <i>et al.</i> , 2005.
c) Ellipsoid verrucate (ELLVE)	Ellipsoid with rough, irregular surface		Albert, 1999; Madella <i>et al.</i> , 2005.
<b>13. Honeycomb Assemblages</b>	Net-like-connected cells in situ. Categorized as “spherical and sub-spherical bodies” (Stromberg, 2003).	<b>Fig, 4:6, (j)</b>	Bozarth 1992; Albert, 1999; Madella <i>et al.</i> , 2005.
a) Honeycomb elongates (HYE)	Network of elongated silica cells		Albert, 1999; Madella <i>et al.</i> , 2005.
b) Honeycomb globular (HYGB)	Network of circular/semi-circular cells. Described as “verrucate silica” (Stromberg, 2003).		Albert, 1999; Madella <i>et al.</i> , 2005; Kinyanjui, 2103.
<b>14. Silica skeletons (SC)</b>	Silicified sections of epidermal cells		Bozarth, 1992; Rosen 1992; Albert, 1999.
<b>15. Irregular forms (IRRF)</b>	Silica cells with no defined shape/don't belong to any of the above categories		Albert, 1999; Stromberg, 2003; Madella <i>et al.</i> , 2005.
a) Irregular verrucate (IRRVE)	Irregular forms with rough surfaces		Albert, 1999; Madella <i>et al.</i> , 2005.

b) Irregular scabrate (IRRSC)	Irregular forms with granulate surface		Albert, 1999; Madella <i>et al.</i> , 2005.
<b>16. Epidermal appendages</b>		<b>Fig, 4:4 (m-n), Fig, 4:5, (j-k)</b>	Albert, 1999v
<b>17. Epidermal appendages</b>	Silicified mesophyll, epidermal & Parenchyma cells		Albert, 1999; Piperno, 2005.
a) Hair base (HB)	Silicified mesophyll cells with a radial outline		Albert, 1999; Mercader <i>et al.</i> , 2009.
b) Hair (HR)	Silicified elongated outgrowths from mesophyll	<b>Fig 4:5, (i)</b>	Albert, 1999; Mercader <i>et al.</i> , 2009.
c) Stomata (STMT)	Intercellular guard & subsidiary cells		Mercader <i>et al.</i> , 2009
<b>18. Parallelepiped (P)</b>	Tabular body with opposite sides parallel to each other		Madella <i>et al.</i> , 2005.
a) Parallelepiped thin crenate (PPTCR)	With psilate texture and scalloped edges		Albert, 1999; Madella <i>et al.</i> , 2005; Mercader <i>et al.</i> , 2010.
b) Parallelepiped verrucate (PPVE)	With rough, irregular surface		Albert, 1999; Madella <i>et al.</i> , 2005; Mercader <i>et al.</i> , 2010.
c) Parallelepiped dendritic (PPDT)	With finely branched processes		Albert, 1999; Madella <i>et al.</i> , 2005; Mercader <i>et al.</i> , 2010.
d) Parallelepiped thin psilate (PPTP)	With smooth surface, width<length		Albert, 1999; Madella <i>et al.</i> , 2005; Mercader <i>et al.</i> , 2010.
e) Parallelepiped blocky psilate (PPBP)	With smooth surface, width >length		Albert, 1999; Madella <i>et al.</i> , 2005; Mercader <i>et al.</i> , 2010
f) Parallelepiped blocky scabrate (PPBS)	With granular surface, width>length		Albert, 1999; Madella <i>et al.</i> , 2005; Mercader <i>et al.</i> , 2010.
g) Parallelepiped facetated (PPFC)	With scalloped edges		Albert, 1999; Mercader <i>et al.</i> , 2010.

<b>19. Cyperaceae phytoliths</b>			
a) Papillae (PAPL)	Hat-shaped silica bodies in sedges.		Ollendorf, 1992; Novello et al., 2012; Piperno, 2006; Mercader et al., 2010; Kinyanjui, 2013.
b) Achene (ACHN)	Cone-shaped silica bodies in sedges.		Ollendorf, 1992; Piperno, 2006; Mercader et al., 2010; Kinyanjui, 2013

#### **4.4. Data analysis**

##### **4.4.1. R-Script and TILIA software**

The vegetation data and modern phytolith from soil and dung were plotted using R-Script. The plant species tallied were presented in R-Script to determine the species abundance and diversity. The diagrams shows all plant species from inside and outside abandoned boma. Modern phytolith from dung and soil identified were counted and data plotted in R-Script diagrams showing assemblage from inside and outside bomas.

Identified fossil phytolith data were plotted in a TILIA diagram. The diagram composed of assemblages identified from each level within a geological profile versus the depth. The differences in percentage of vegetation types indicated the vegetation changes through time.

##### **4.4.2. Phytoliths indices**

This method is applied to understand vegetation types described by phytolith data such as grass dominance subfamily and woody dicots density and their association with climatic conditions such as temperature (Bremond et al., 2008). Two phytolith indices have been applied to this study, the aridity index (I<sub>ph</sub>) and tree cover density index (Dicotyledon versus Poaceae index) (D/P<sup>0</sup>). The phytolith indices of phytolith types with taxonomic significance were calculated.

#### **4.4.2.1. Aridity index (Iph)**

The Iph index refers to the ratio of Chloridoideae (saddle) to the sum of Chloridoideae and Panicoideae (saddle, bilobate, cross, polylobate) short cell phytoliths types. This index helps determine the short C<sub>4</sub> grasses and tall C<sub>4</sub> grasses that give information about aridity-humidity habitats at low altitudes (Bremond et al., 2008).

$$\text{Iph} = (\text{Chloridoideae}) / (\text{Chloridoideae} + \text{Panicoideae}) \times 100$$

When Iph is high, close to one suggests an arid climate, while a low index close to zero suggests a humid condition (Bremond et al., 2008).

#### **4.4.2.2. Dicotyledon versus Poaceae index (D/P<sup>0</sup>)**

This index helps indicate tree cover density for tropical areas of low altitude (Bremond, 2008). The D/P<sup>0</sup> index is the percentage of phytoliths diagnostic of tropical woody dicots versus short cell phytoliths diagnostic of grasses (Bremond, 2008). This index is calculated as follows;

$$\text{D/P}^0 = \frac{\text{Globular granulate (Spheroid echinate + spheroid ornate + spheroid verrucate)}}{\text{Bilobate + Saddle + Rondel + Crosses/Quadralobates + Polylobate short cells}}$$

When D/P<sup>0</sup> indices are high, close to one suggests close-forest vegetation with grass dominance (Bremond et al., 2008).

### **4.5. Summary**

This chapter gives detailed information of the methods used to collect data for both above-ground vegetation, modern soil, cattle's dung, and fossil soil samples for phytoliths analysis for this study. Also, it included field methods and laboratory works in processing and identifying phytolith assemblages. The results of this data collected in this chapter are presented in the following chapter.

## CHAPTER FIVE

### RESEARCH FINDINGS AND DISCUSSION

#### 5.1. Introduction

This chapter explains on the modern plant species counted to determine abundance and diversity and, phytolith data from both livestock dung (used as modern vegetation analogue) and surface soils. The soil phytoliths were extracted from 13 abandoned bomas and 3 Holocene sites (Early- and Mid-Holocene). More than a hundred different phytolith morphotypes from dungs and soil were identified and counted.

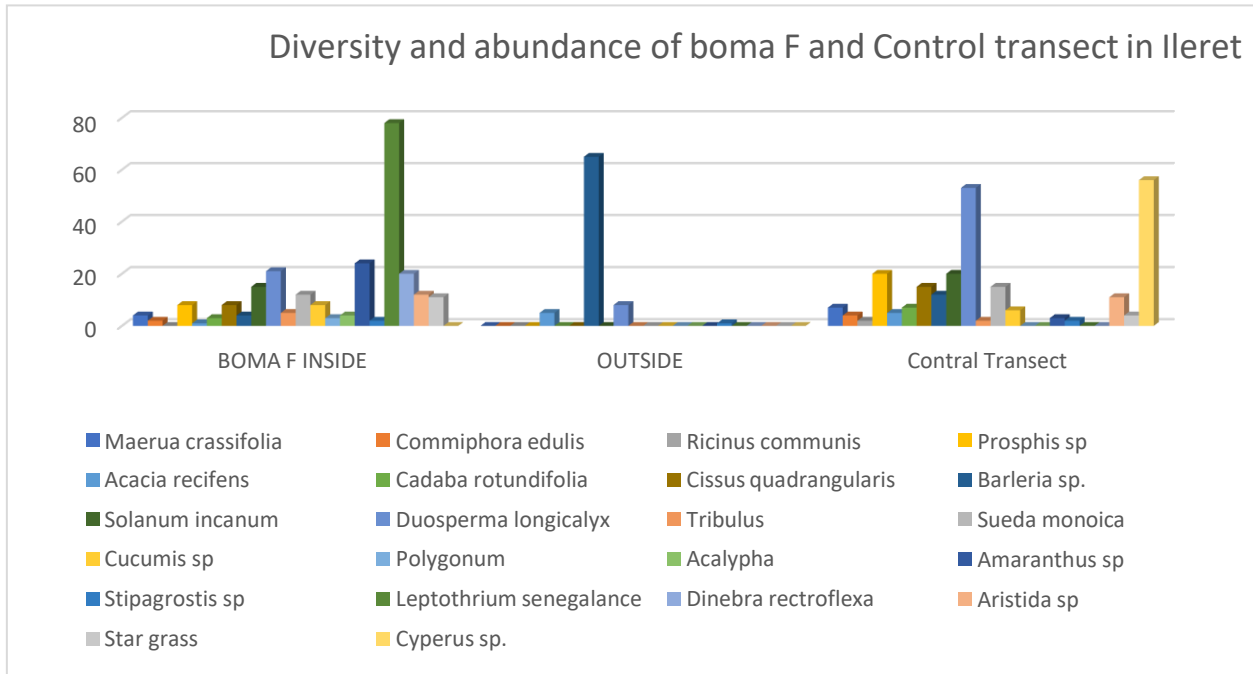
The vegetation data presented here include more than 30 plant species and more than 8000 occurrences /abundance. A total of 3 livestock dung samples, 20 surface soil samples from inside and outside abandoned bomas and 9 fossil soil from Holocene sites.

Phytolith assemblages from soil gives information on the above-ground plant communities and are useful to archaeologists in reconstructing paleovegetation and by extension, paleoenvironments. To interpret phytolith data accurately the correlation of plant communities above the ground and phytolith assemblages is important. This study correlates the above ground vegetation with the soil phytoliths collected from abandoned pastoralists' bomas in different settings and, phytoliths variation across the modern landscape.

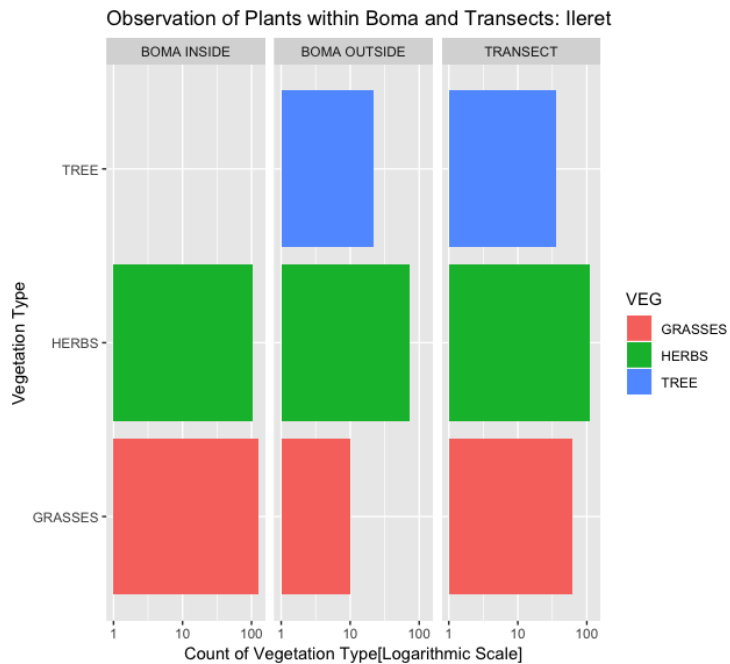
In addition, this chapter explains discuss the phytoliths data from both Ileret and Karari localities, east of Lake Turkana. The discussions include modern vegetation data, phytoliths data from dung, moden soil and fossil phytoliths assemblages. The results of phytoliths indices are discussed here.

## 5.2 Vegetation data

### 5.2.1. Ileret:



**Fig. 5:3** Species abundance and diversity of boma F and control transect in Ileret

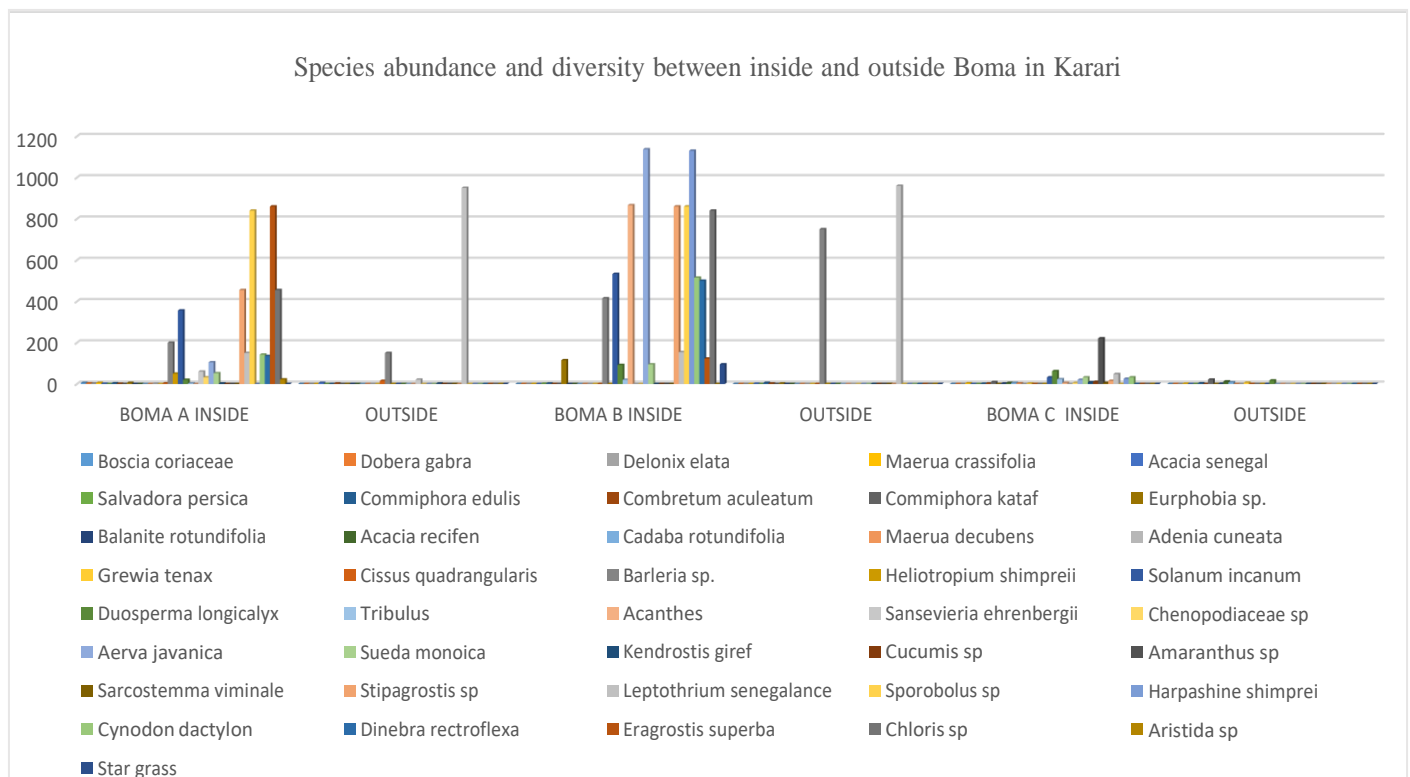


**Fig. 5:4** Vegetation observed Inside and Transect (Outside) boma

Species abundance in boma F (N=245) and Control Transect (N=244). Boma F (Fig 5:3) have a high species diversity of 70.1% of the total record while the control site (Fig 5:3), sampled from a riparian habitat has a diversity of 74.1% (N=27 species). Boma F *Leptrothrium senegalance* 31%, *Amaranthus* 10% have high abundance respectively of the total occurrence (N=104).

Control transect have high species diversity *Cyperus sp.* 26.8%, *Duesperma longicalyx* 23.9%, *Solanum sp.*10% (Plate 5:4) and *Prospis sp* (Mathenge) 10% respectively of the total abundance (N=146). Both boma F and Control Transect some species lead in abundance but occurring with less than 10%. It is worth noting the presence of *Prosopis juliflora* and *Ricinus communis* (castor oil) since they are associated with human disturbance.

### 5.2.2. Karari:



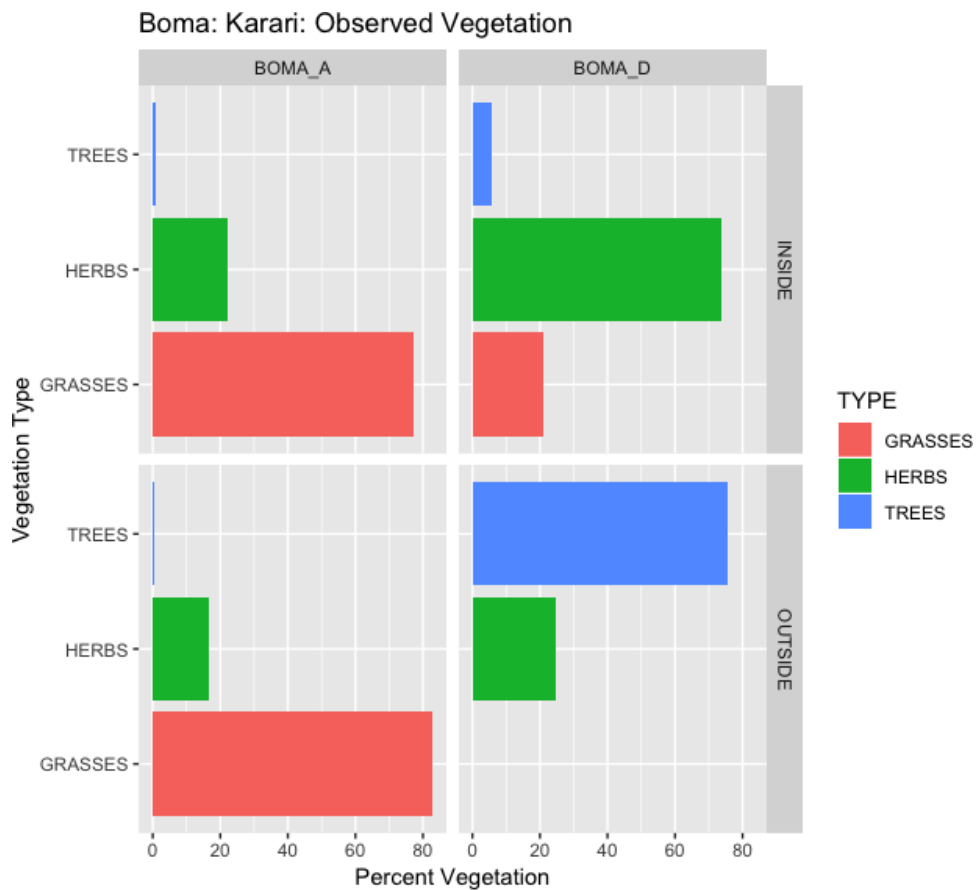
**Fig. 5:5** Showing species abundance and diversity of three bomas (A, B, & C), for the inside versus their immediate surroundings.

Boma C has the highest diversity with 27 different plant species while Bomas A and B have almost equal species diversity at 21 and 24 plant species. In boma C, *Amaranthus sp.*, *Duospermum*

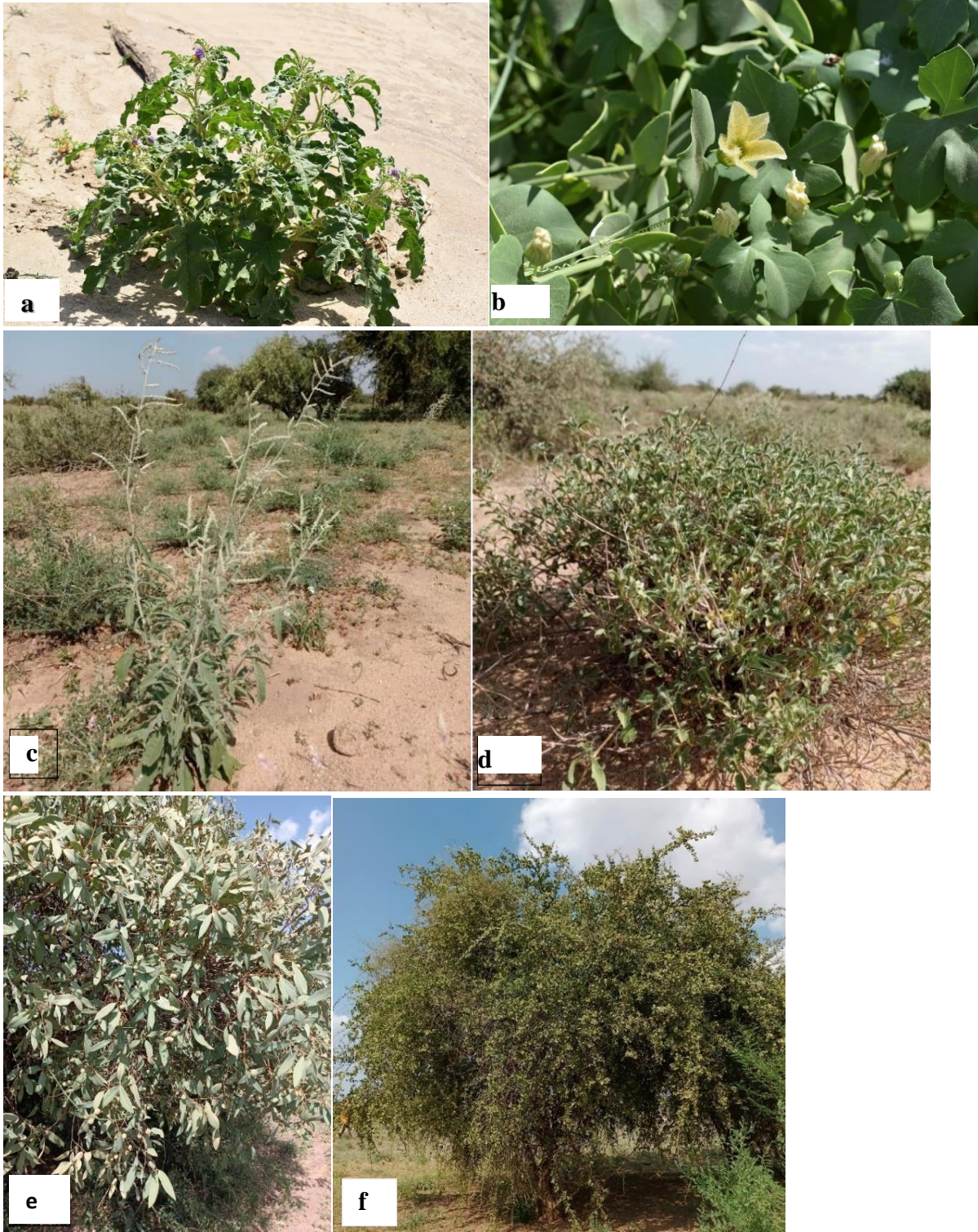


*longicalyx* and *Sueda Monoica* (photo3) have the highest abundance with 38%, 11% and 6% respectively of the total occurrence (N=575 plant species). Although Boma A and B have almost equal plant diversity, boma B has more abundance (N= 8353) compared to Boma C (N=3968).

In Boma A, *Sporobolus sp*, *Duosperma longicalyx*, *Kedrotis gijef* and *Sueda monoica* are the most abundant occurring at 19%, 18%, 10% and 10% respectively. In Boma B, similar species lead in abundance but with less than 10% occurrence. *Sporobolus* grasses are the most prominent in both bomas at >19%.

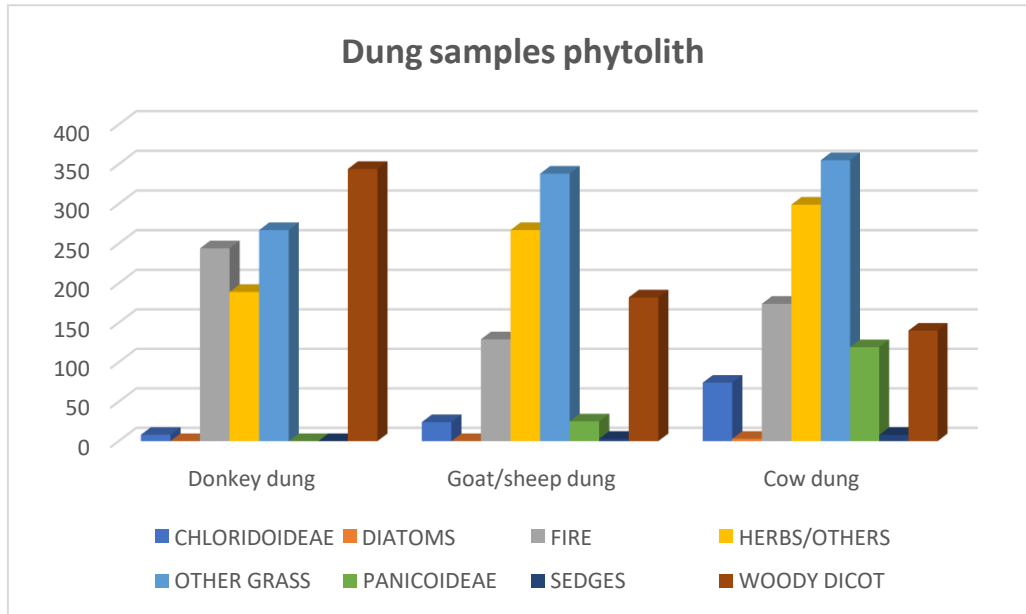


**Fig. 5:6** Showing vegetation structure in Karari between Inside and Outside abandoned bomas



**Plate 5:4** a) *Solanum incanum*, b) *Cucumis* sp. c) *Aerva javanica* , d) *Duosperma longicalyx*, e) *Cadaba fruticosa*, f) *Bilanite rotudifolia*

### 5.3. Dung phytoliths data



**Fig. 5:7** Plant categories identified by phytoliths analysed from the dung samples

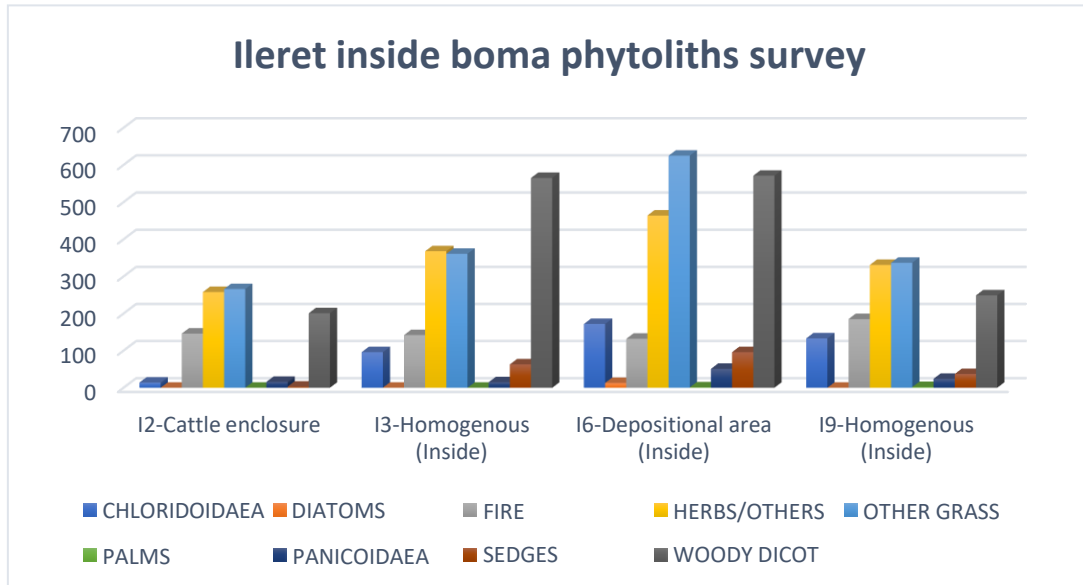
Donkey dung sample consist of unexpectedly high percentage of phytoliths derived from woody dicots at 13% compared to other dung such as goat at 7% and 5% for cow. This is most likely could be explained by the feeding habit of donkey, they are intensive grazers and more often dig through the soils for grass roots hence ingesting soil phytoliths in the process. Such that phytolith assemblage from dung resembles that of soil samples. Grass phytoliths accounts for 13% from goat/sheep and cow and 10% from donkey. Herbs/others at 11% from cow, 10% goat/sheep and 7% from donkey.

Panicoideae grass are absent in the donkey' assemblage while Chloridoideae grasses are very low. Goat/sheep dung sample shows 1% of Panicoideae and Chloridoideae grasses compont while Cow dung sample shows presence of Panicoideae grass at 5% and 3% of Chloridoideae grass.

Sedges are very low in goat/sheep and cow dung while is absent to donkey dung sample. Palms are absent while diatoms are present at very low percent. Microcharcoal presence is very high from the donkey dung 6% of all charcoal observed compared to other dung samples.

## 5.4. Soil phytoliths data from Inside and Outside abandoned bomas

### 5.4.1. Ileret

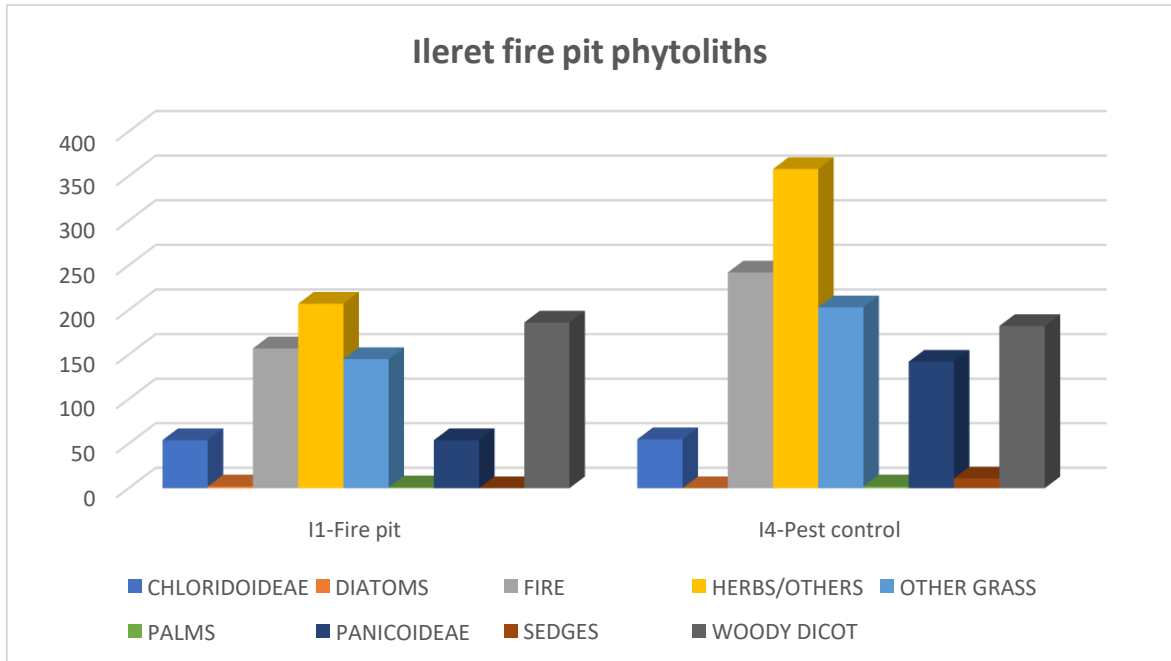


**Fig. 5:8** Phytoliths data from Inside abandoned bomas in Ileret

Samples collected indicate that other grasses, herbs/others and woody dicot have high proportion ranging from 4% to 12%. Other grasses have high percentage of 12% especially on the depositional area, 6% to 7% from homogenous samples and 5% from cattle enclosure samples. Samples collected from Homogenous and depositional area also indicate high percentage of wood dicot morphotypes at 11%.

Herbs/others range from 5% to 9%, shows high at 9% from the depositional area followed by 6%, 7% from homogenous samples. The samples from cattle enclosure grass phytoliths range from 0-5% because the bomas were recently abandoned and low distribution of the plant species.

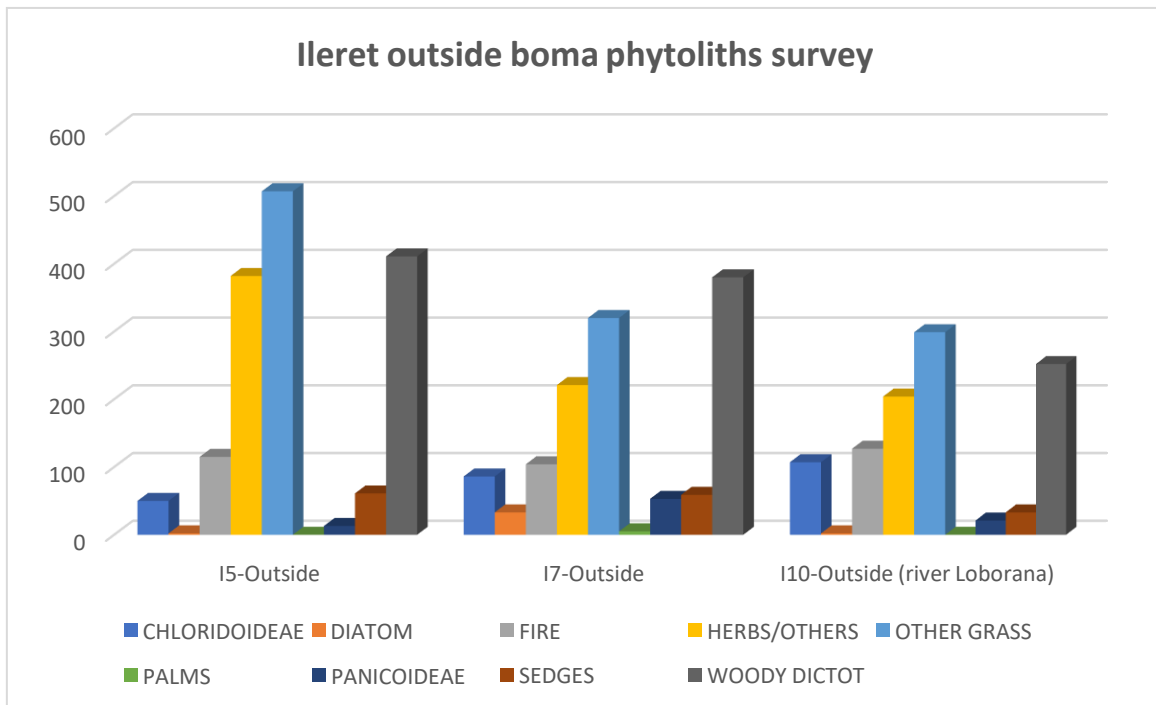
Chloridoideae grass is high from other samples ranging from 2% to 3% compared to cattle enclosure. Panicoideae grass inside bomas in Ileret is very low compared to other samples and it shows 1% from the depositional area. Presence of diatoms, and microcharcoal as high as 3%. Palms and sedges are very low, but sedges appears 2% from depositional area samples.



**Fig. 5:9** Phytoliths data from fire pit and pest control inside abandoned bomas

Herbs/others morphotypes dominate by 18% on the pest control and 10% from fire pit. Other grass in fire pit is 7% and it is increasing to 10% in pest control. Woody dicot morphotypes have higher proportion of 9% in both settings. Materials indicating fire such as microcharcoal and burnt morphotypes account for 8% to 12% on the area.

Panicoideae grasses are more prominent in the pest control setting by 7% than fire pit which is 3%. Chloridoideae grasses have similar proportion of 3% from fire pit and pest control. Other grass percentage is very high (18%) on pest control compared to fire pit (17%). Other materials observed in a very low occurrence such sedges, palms and diatoms to both samples.

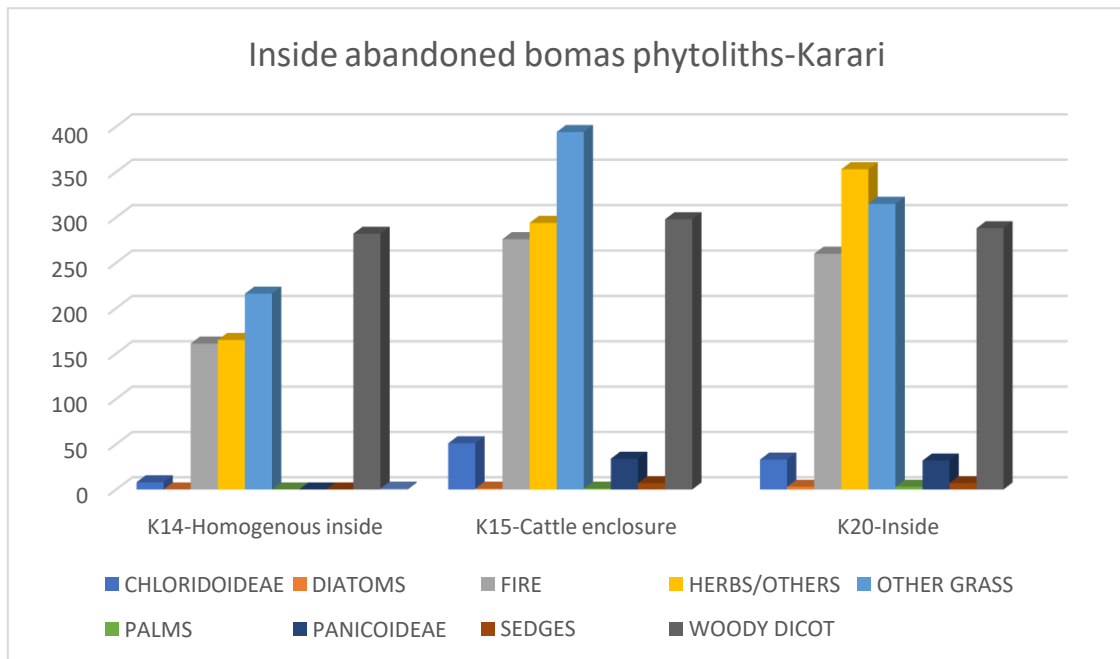


**Fig. 5:10** Phytoliths data from outside abandoned bomas phytoliths data

The samples have high proportions of other grass, herbs/others and woody dicot. The high proportions of other grass range from 9% to 15%. The woody dicot have higher percentage from inside bomas at Ileret ranging from 12%, 11% and 7% in the riparian settings. Herbs/others category ranges from 6% to 11%.

Chloridoideae and Panicoideae observed are in low percentage, such that Chloridoideae from inside bomas range from 1% to 2% while in riverine setting (river Loborana) dominated in 3%. Panicoideae proportion range from 0 to 2% in the inside and 1% in the riverine.r. In addition, phytolith data indicate the presence of sedges, palms in low percentage such as palms in 0.1%.

### 5.4.2. KARARI: Inside and Outside phytoliths results

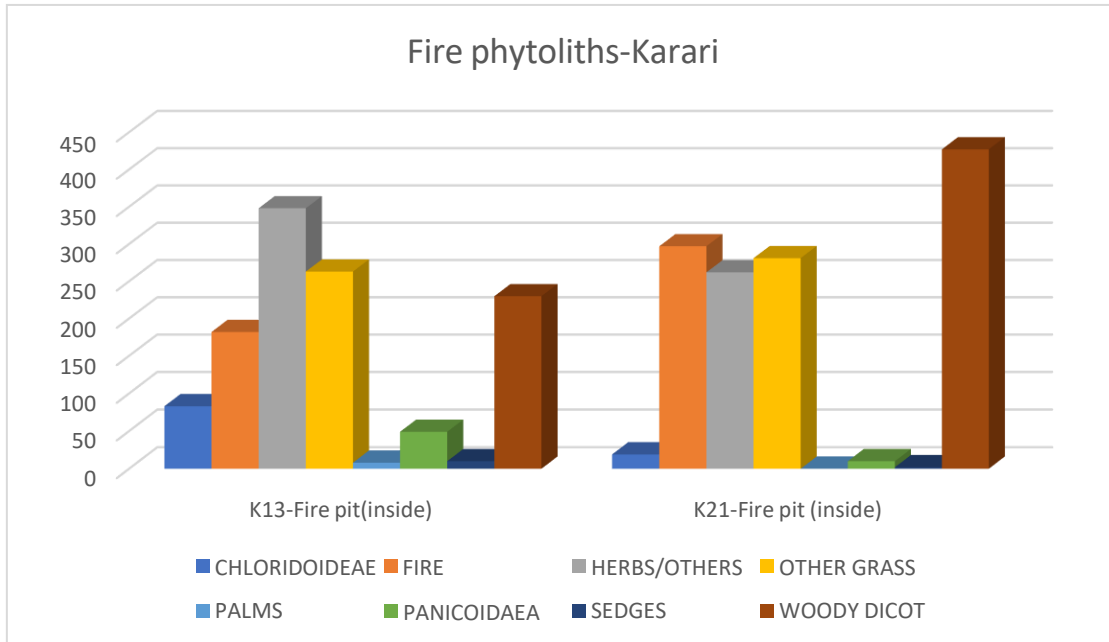


**Fig. 5:11** Phytoliths data from inside abandoned bomas

Samples collected from cattle enclosure shows that other grass dominates at 14%, herbs/others at 11% with the same proportion of wood taxa. In other samples such as Homogenous and K20 which was collected inside indicate other grass phytoliths are higher as 8% and 11%.

The K20 sample is dominated by herbs/others at 13%, other grass 11%, and wood dicot at 10%. The Homogenous sample has the high percent of other grass 8%, and herbs/others 6% while wood taxa have the lowest percent.

Chloridoideae and Panicoideae grasses are present in both samples with 1% to 2% occurrence from cattle enclosure and K20-inside samples while homogenous samples shows that these grasses are rare at Palms, sedges and diatoms are also rarely present.

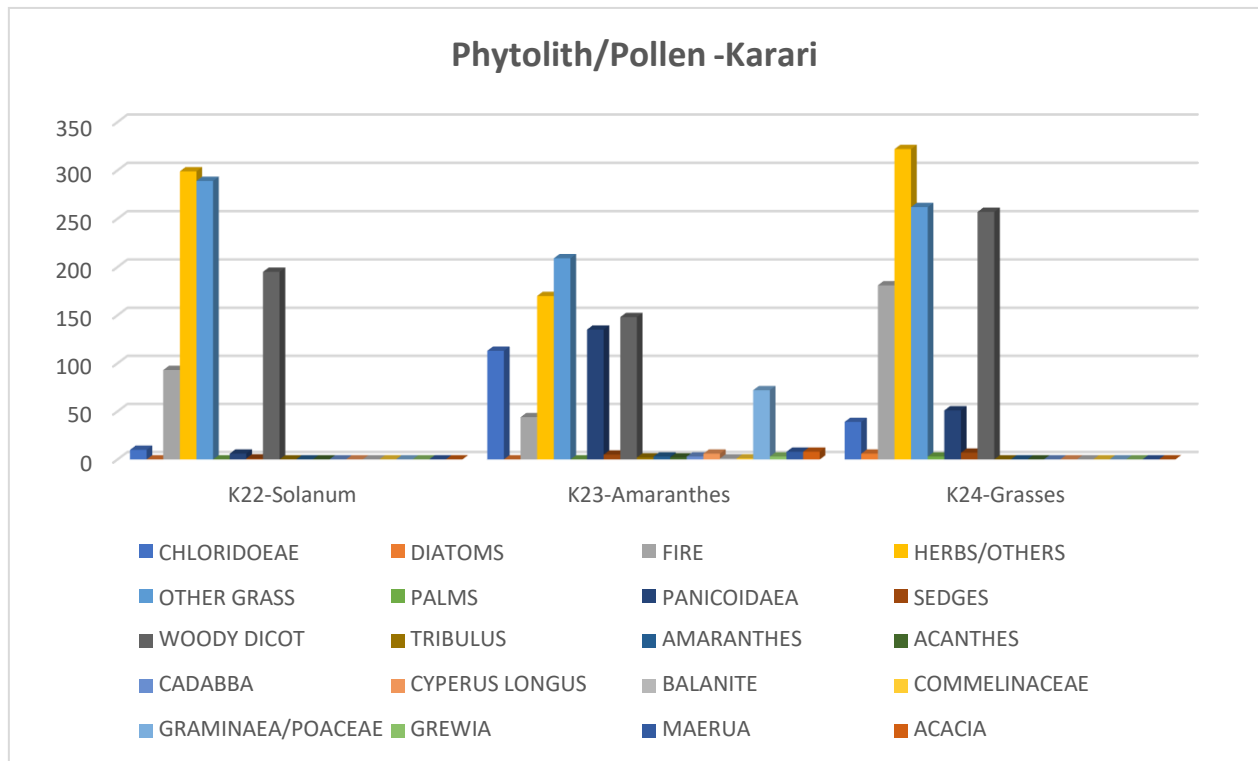


**Fig. 5:12 Phytoliths data from fire pits in abandoned bomas**

In this region samples collected from the fire pit inside the boma consist of higher woody morphotypes ranging from 12% to 21%. Herbs/others range from 13% to 14% in both the fire pit samples while sedges and palms are very low in both samples.

Chloridoideagrass morphotypes are present at 1% to 4% while Panicoideae grass phytoliths are present between 1% and 2%. The other grass taxa are high at 13% and 14% .





**Fig. 5:13 Phytoliths and Pollen data from inside abandoned boma**

Inside this boma the vegetations were divided into 3 section, Solanum, Amaranthus and Grasses. The samples were collected from each section to understand the correlation of the above vegetation and the phytoliths. The results of the phytoliths indicate that herbs/others dominated at 12% from Solanum, 7% from Amaranthus and 13% from grasses vegetation side.

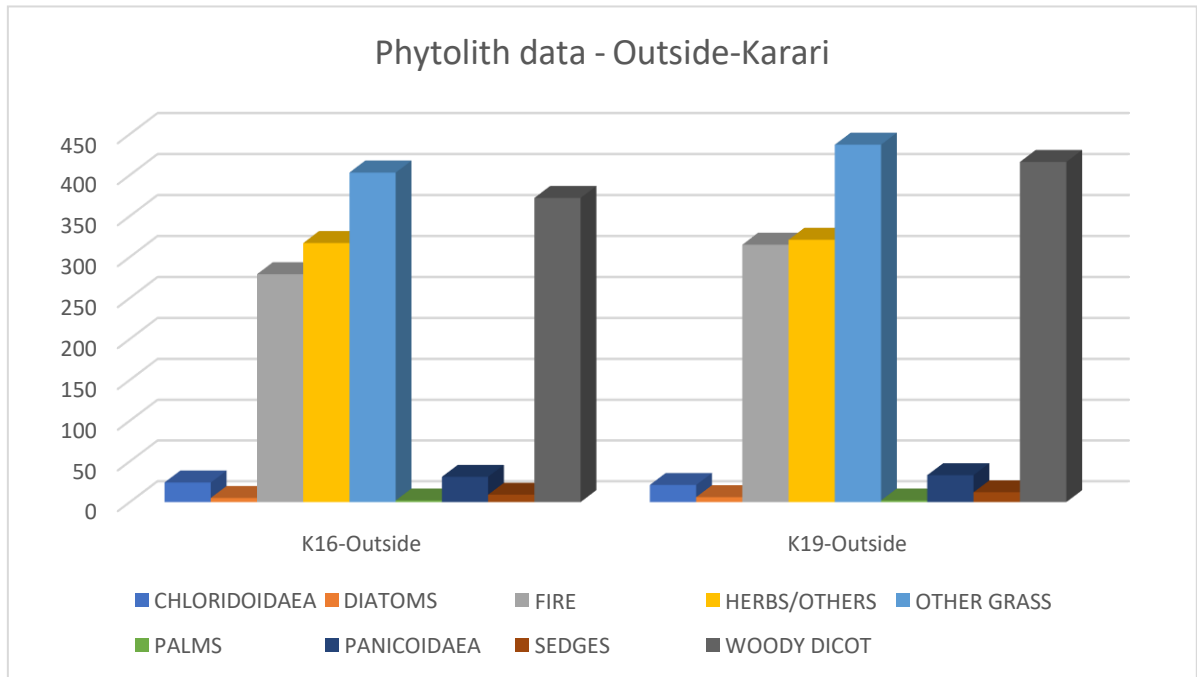
Other grass phytoliths accounts for 11%, Solanum, 8% -Amaranthus and other grasses, for 10%. Woody dicot , account for 8%, 6% and 10%. Sedges and palms are present with the lowest percent.

Panicoideae and Chloridoideae C<sub>4</sub> grasses, range from >5%. The Panicoideae grasses lead in dominance of 5% on the Amaranthus side while Chloridoideae grasses have 4%. On the grasses side both have low dominance of 2% and lowest on the Solanum side.

Microcharcoal data of all observed on the slides suggest that on the Solanum has 29%, Amaranthus 14% and 57% on the grasses side.

In addition, The following pollen grains were observed on the Amaranthus side; Amaranthus 3%, Balanite 1%, Maerua 7%, Acacia 7%, Commelinaceae 1%, Cadaba 3%, Grewia 3%, Cyperus

longus 6%, Acranthes 2%, Tribulus 2%, and Graminaeae/Poaceae 66%. The percentage add up to all pollen observed.

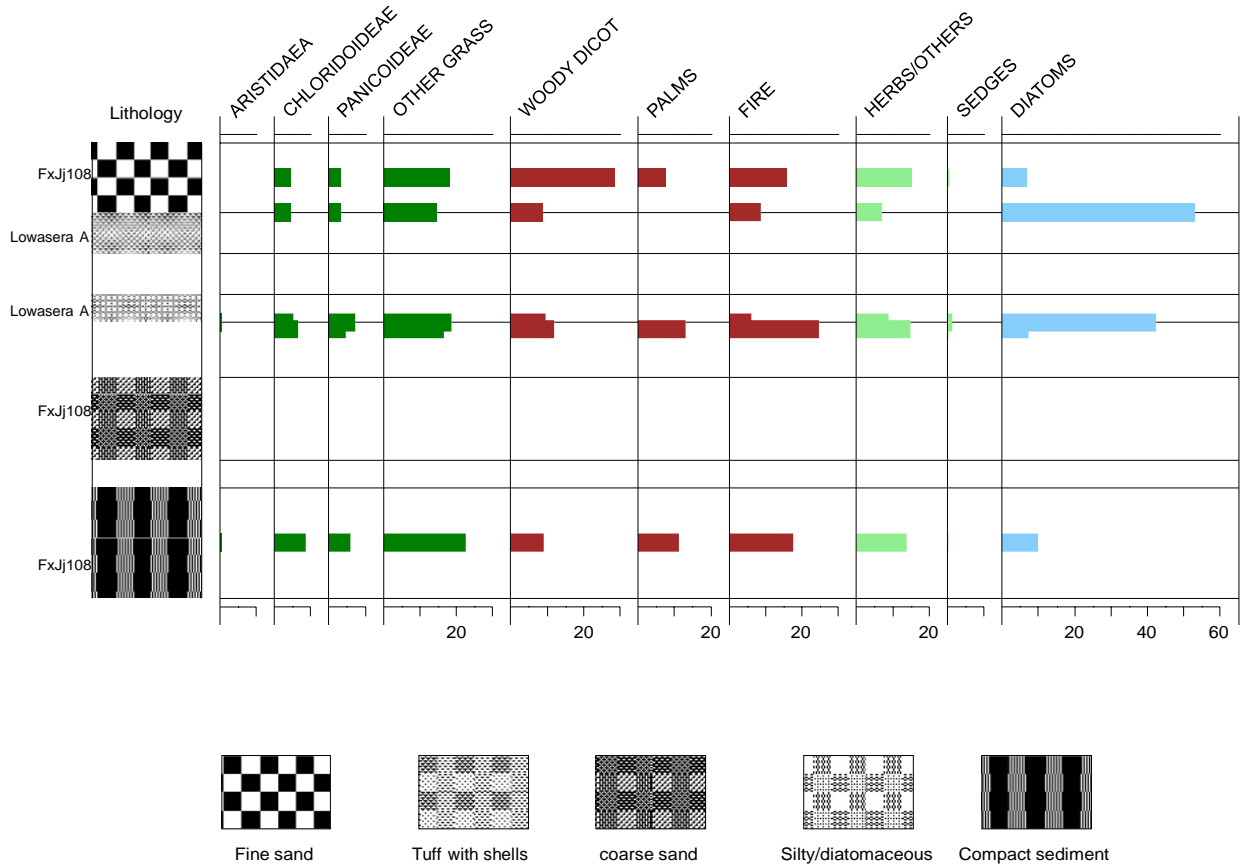


**Fig. 5:14 Phytoliths data from Outside abandoned bomas**

The outside abandoned boma samples indicate high dominance of woody dicot at 16% and 17%. Other grass have high component of 17% and 18% while herbs/others at 13%. Chloridoideae and Panicoideae grasses have similar dominance of 1% to all samples. Sedges, palms and diatoms are very low. Microcharcoal are present.

## 5.5. Fossil samples from excavation

### 5.5.1. Early Holocene



**Fig. 5:15** Shows phytolith data analysed from the Early Holocene sites in Lowasera A and Karari (FxJj108) in Area 117. Samples are not arranged in a chronological order but following sites. The vertical stratigraphy 22cm to 30cm represent Lowasera A. At the top from 17cm to 22cm, 34cm to 50 represent FxJj108 in Karari.

#### Area 117 (FxJj108)

Samples collected indicate that the fine sand at depths from 17cm to 22cm have higher proportion of woody taxa of 29%, other grass 18% and herbs/others at 15%. The proportion of woody decrease downwards in the coarser sand (34cm to 40cm) at 12%, while other grass and herbs/others have the same proportion ranging from 15% to 17%. In the compact sediment layer woody phytoliths decreases to 9% while other grass increases to 23% and herbs/others have low proportion of 14%.

Chloridoideae and Panicoideae grass have high proportion at the bottom in compact soil (40-50cm). While Chloridoideae grass has 9% at compact soil, the proportion decreases at the coarser sands to 7% and decreased further towards the top in fine sand to 4%. Panicoideae grass have 6% at the bottom in compact soil, 5% at the coarse sand and decreases to 3% towards the top layer of the fine sand.

Palms are present in high proportion from compact sediment at the bottom and coarse sand ranging from 11% to 13% but decreases at the fine sand layer to 7%. Aristidoideae grasses are present at the bottom layer at 1% while sedges at the top layer at 1%.

Diatoms have a proportion of 10% in compact sediment, and 7% to coarse and fine sand layer. Microcharcoal and burnt phytoliths observed indicating fire have proportion of 18% in compact sediment, 25% at the coarse sand and decreased to 16% at the top layer.

### **Lowasera A**

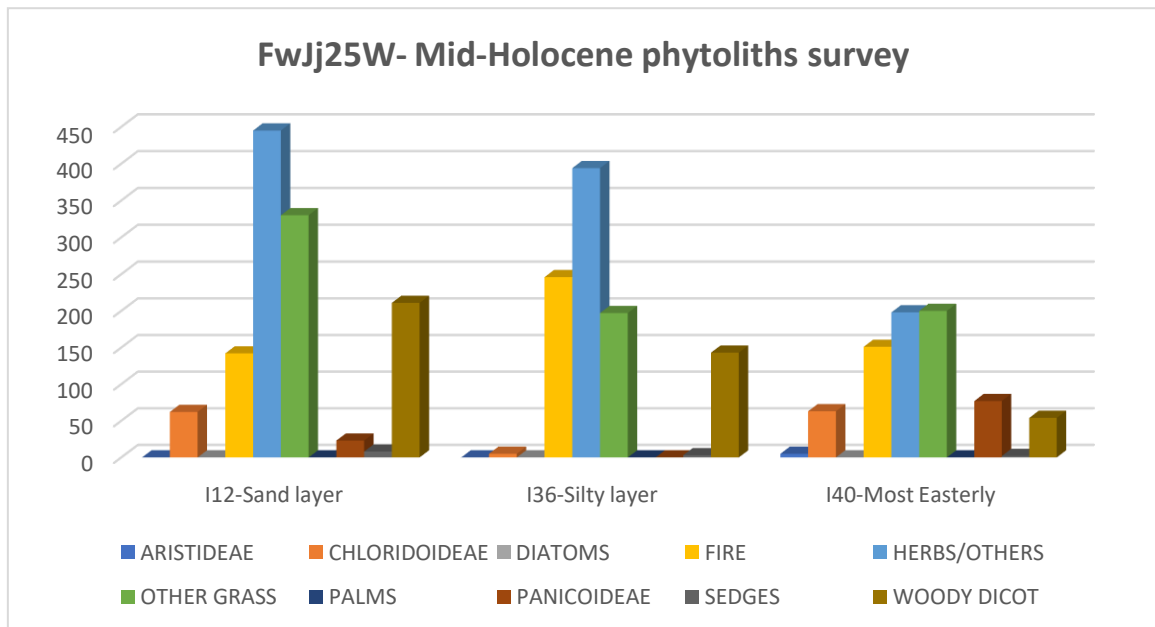
The silty diatomaceous layer have high proportion of 15% of other grass, 10% of woody taxa and 9% of herbs/others. These morphotypes decreases at the bottom layer of tuff with shells at 15% other grass, 9% woody dicot and 7% herbs/others.

Panicoideae grass has the proportion of 7% at the silty diatomaceous and decreased to 3% in tuff with shells. Chloridoideae have 5% at the silty diatomaceous which decreases in the tuff with snail shells layer to 4%.

Aristidoideae accounts for 0.4% at the bottom layer of silty diatomaceous but absent at the top sand layer. Palms are absent in both layers while sedges are present at 1% in the silty diatomaceous layer. Microcharcoal and burnt morphotypes account for 6% at the bottom and 9% at the top layer.

Diatoms and sponge spicules have the highest proportion than phytoliths of 53% at the top layer and 42% at the silty diatomaceous layer.

### 5.5.2: Mid-Holocene sites



**Fig. 5:16** Showing FwJj25W Mid-Holocene site phytoliths data

The sand layer consist high proportion of herbs/others 36%, other grasses 27% and woody dicot 17%. Silty layer has 40% of herbs/others, 20% of other grass and 14% of woody dicot. The sample from more easterly shows high proportion of other grass 27%, herbs/others 26% and woody dicot decreased to 7%. Diatoms and palms are absent on both layers. Sedges have the lowest proportion of 1% at the sand layer, 0.3 at the silty layer and 0.2 at the most easterly layer.

Aristidoieae grasses are present at 1% on the most easterly layer while it is absent to other layers. Chloridoideae grasses accounts for 8% in the most easterly side while Panicoideae grass have 10%. In Sand layer Chloridoideae 5% while the Panicoideae grass have 2%. In the silty layer Panicoideae grass are absent while Chloridoideae dominate with 1%.

Microcharcoal and burnt phytoliths have 25% at the silty sand, 20% at the most Easterly and 12% at the sand layer.

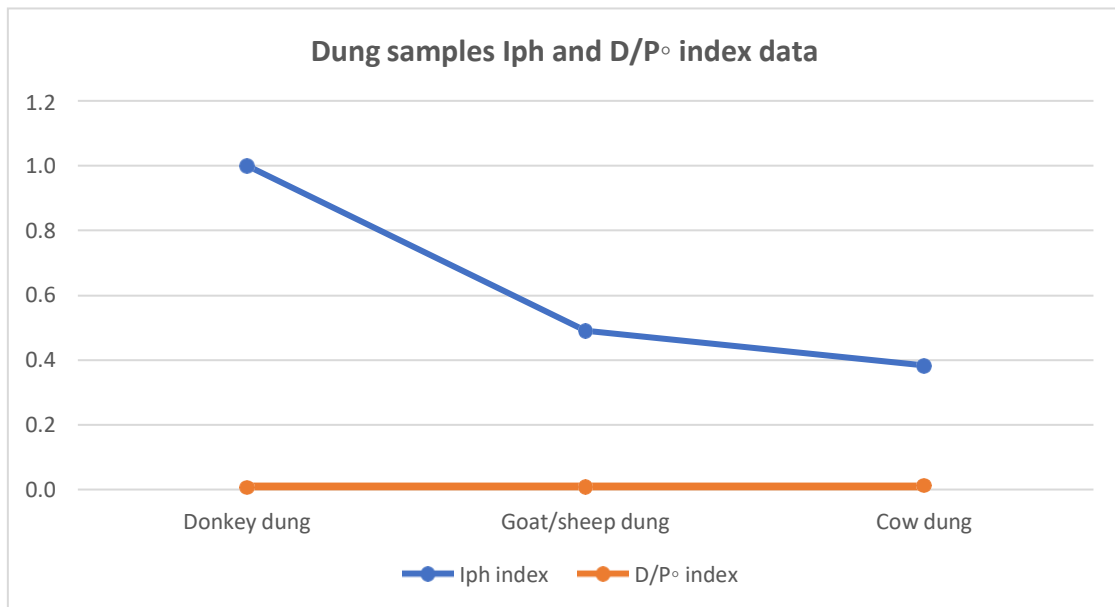
## 5.6. Data Analysis

### 5.6.1. Phytoliths indices

This section report the results of the two phytoliths indices:- Aridity index (Iph)index and woody cover index (D/P<sup>o</sup>) from Ileret and Karari region.

### 5.6.2. Aridity Index (Iph) and Dicotyledon versus Poaceae from Inside and Outside bomas

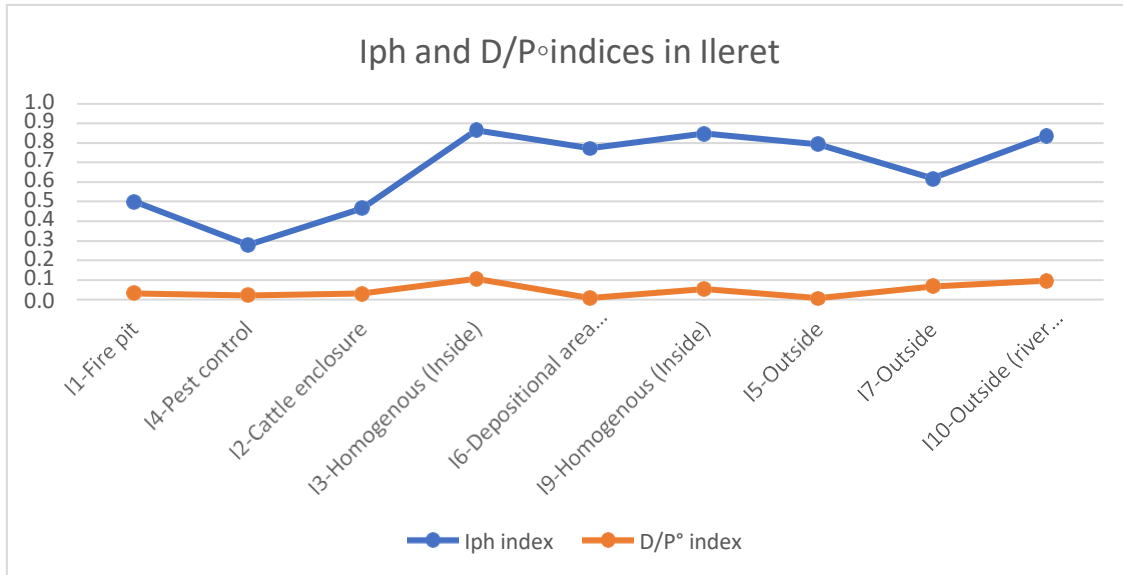
#### Ileret



**Figure 5:17** Aridity Index (Iph) and Dicotyledon versus Poaceae from donkey, goat/sheep and cow dung

Iph index – Both dung samples show high dominance of Chloridoideae grass. The donkey dung indicate higher input of Chloridoideae phytoliths dominance than cow and goat/sheep dung.

D/P<sup>o</sup> - All dung samples indicate low woody phytoliths with relatively value of 0.



**Fig. 5:18** Aridity and Dicotyledon versus Poaceae results in Ileret between Inside and Outside abandoned bomas

Iph index in the figure above indicates the biomass burnt fire pit 1 consisting of higher component of Chloridoideae grasses than in the biomass burnt for pest control. Most likely the pest control fire was burnt after a rainy season which had more Panicoideae phytoliths in the dung while the Fire pit one was burnt during a drier season.

D/P-Woody phytoliths are relatively low, probably the boma in question was for grazers, either sheep, cows or donkeys but very few goats (browsers).

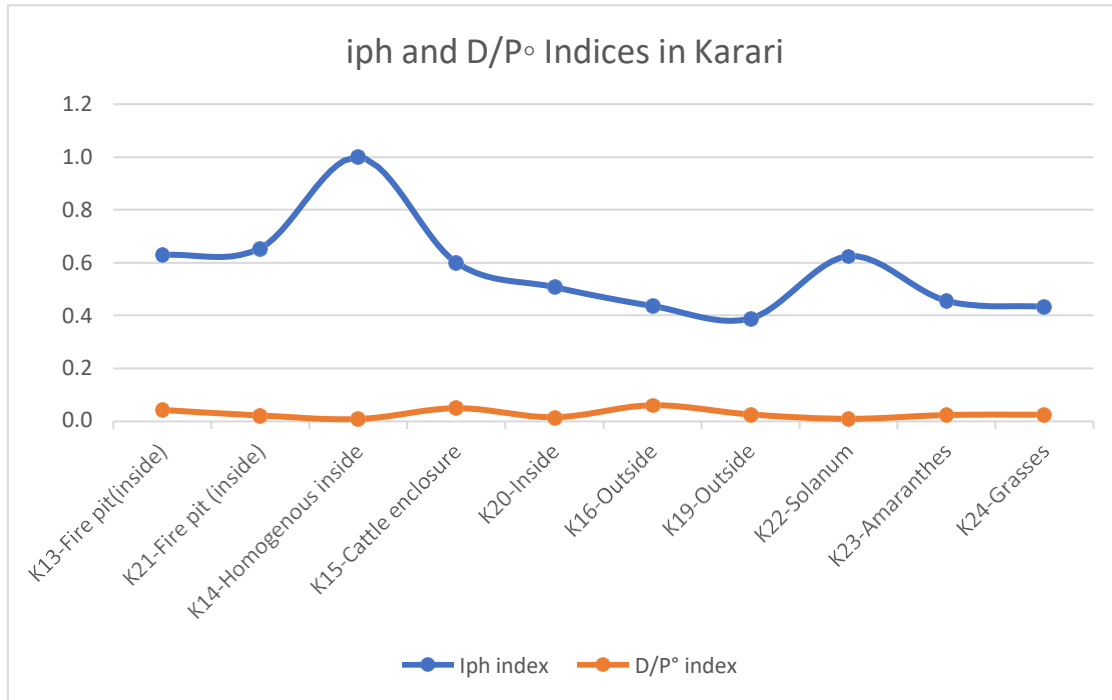
Iph- The inside samples have higher component of Chloridoideae grasses than the cattle enclosures. The cattle enclosure has more input from far brought in by livestock while the other samples

D/P- Woody phytoliths are low across all samples, meaning this is open grasslands.

Iph- The samples from outside shows higher component of Chloridoideae grasses in two samples, one riparian setting (river Loborana) and I5 from inland boma than the other outside sample from inland bomas.

D/P – Woody phytoliths are relatively low across the samples from outside

## Karari



**Fig. 5:19** Aridity and Dicotyledon indices between Inside and Outside abandoned bomas in Karari

Iph index - indicates the biomass burnt fire pit 2 has higher dominance of Chloridoid grasses than in the biomass fire pit 1.

Iph- Inside samples indicate homogenous samples has high component of Chloridoideae grass than other two samples.

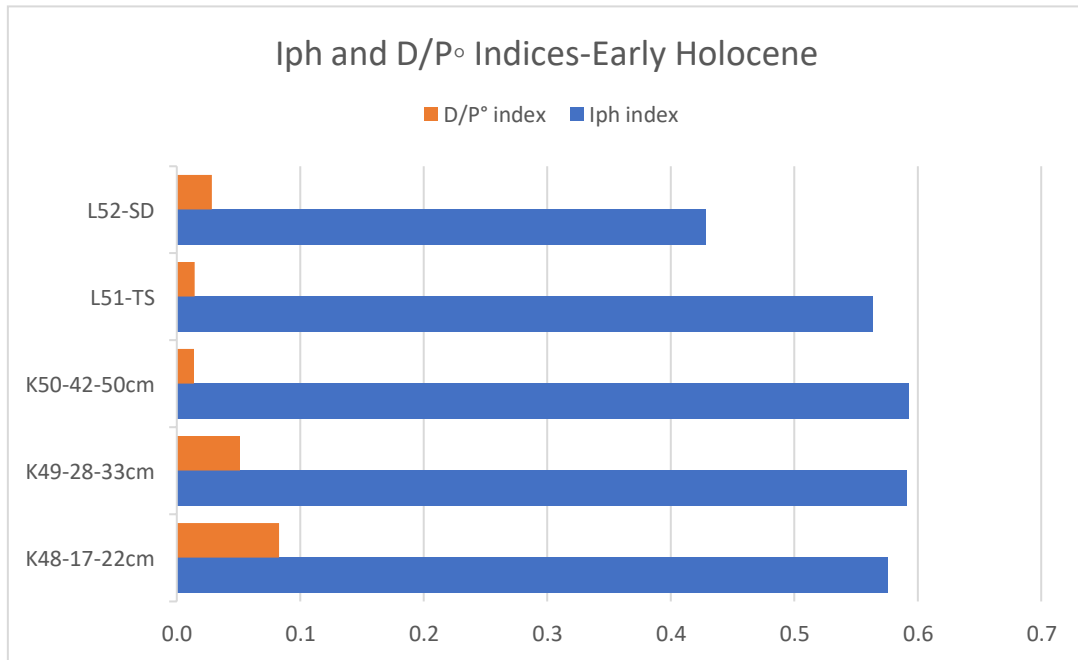
D/P°- Both samples from fire pits and inside boma indicate low woody phytoliths suggesting open grassland.

Iph- One sample from outside K16 indicate higher dominance of the Chloridoid phytoliths than the other sample.

Iph- Samples collected from the vegetation side especially on the Solanum and Amaranthus indicate high component of Chloridoideae phytoliths than on the Amaranthus and Solanum side which have relative similar representation.



### 5.6.3. Aridity Index (Iph) and Dicotyledon versus Poaceae from Early and Mid-Holocene sites



**Fig. 5:20** Aridity and Dicotyledon versus Poaceae results of Early Holocene

#### **FxJj108 from Area 117**

All samples indicate high aridity and low woody taxa

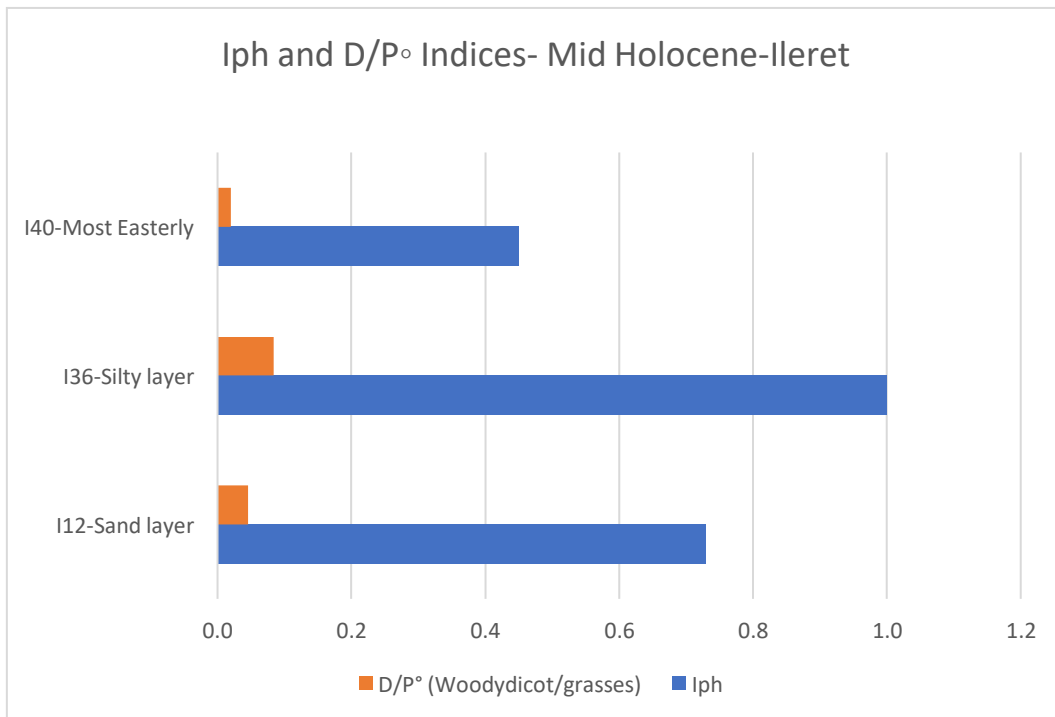
Iph- All samples indicate higher presence of Chloridoideae phytoliths. The first top layer sample show low Iph index, indicating low input of Chloridoideae phytoliths while the second and third layer samples has relatively higher Chloridoideae grasses

D/P- Grass phytolith component is higher than woody component on both layers.

#### **Lowasera A**

Iph- in both layers indicate higher component of Chloridoid grass. The first layer of Tuff silty shows that Chloridoideae phytoliths have high dominance than the second layer of silty/diatomaceous.

D/P- Woody phytolith is low on both layers indicating open grassland.



**Fig. 5:21** Aridity and Dicotyledon versus Poaceae indices results of Mid-Holocene

Iph- All samples indicate higher presence of Chloridoideae phytoliths.

The first two samples show high Iph index, indicating higher input of Chloridoideae phytoliths while the 3<sup>rd</sup> sample has relatively low Chloridoideae grasses.

D/P- Grass phytolith component is higher than woody component. Meaning all samples represent a vegetation structure dominated by open grasslands.

All the samples of Early and Mid Holocene indicate high aridity and more grass phytoliths.

## **5.7. DISCUSSION**

### **5.7.1. Vegetation data**

In Ileret, similar vegetation structure prevails. Herbaceous grasslands are the most prominent within boma F, control transect and Flood plain with >28% occurrence in all boma while woody vegetation is prominent in unoccupied site, consistent with the phytolith data figure 11 and 13. While assessing the vegetation structure between bomas, herbaceous grasslands are the most prominent within bomas with >40% occurrence in all Bomas while woody vegetation is prominent within the unoccupied sites in Karari.

### **5.7.2. Dung phytoliths samples**

The Dung data was collected in East Turkana in various locations in Ileret and Karari. High short grass phytolith concentration have been observed from cow, goat and sheep dung >13% compared to donkey dung 10%. Donkey dung have a high concentration of woody phytoliths >13% compared to other livestock >5%. The phytoliths concentration on the dung and soil are the result of the diet based on livestock and availability of water to solvate phytoliths morphotypes.

Dung from grazers during humid seasons have higher grass phytoliths concentration compared to dung of the same grazers during dry seasons (Shahack-Gross et al., 2003). During the drier seasons results show low grass phytoliths concentration since the main available plant species are shrubs and woody species and grazers tend to browse instead. Woody and shrubs species tends to produce low phytoliths in general and, this decreases further during dry conditions compared to grasses. During dry seasons the dungs are preserved better (Shahack-Gross et al., 2003) while during wet seasons the dung disintegrates releasing nutrients and humus back to the soils. This is evident in the abandoned bomas.

The results indicate that grass phytoliths present in livestock dung correlate with the phytoliths concentration in the surface soil samples within bomas than outside bomas. The relationship suggests that pastoralist activities contribute to the vegetation cover in East Turkana.

### **5.7.3. Modern soil assemblages**

Archaeologists have been using soil phytoliths assemblages to reconstruct palaeoenvironments since they are reliable plants' fossils. However, to fully understand and determine vegetation cover and structure based on phytolith data, one requires local and regional understanding of the relationship between modern vegetation cover and below-ground phytolith assemblage, coupled with environmental factors. Interpretation depends on the correlation between vegetation species with phytoliths assemblages as well as their distribution on the landscape.

Phytolith data shows that other grass phytoliths and herbs occur in high proportion of >40% on the landscape. Panicoideae and Chloridoideae C<sub>4</sub> grasses morphotypes are lowly produced with the high proportional of >15%. Aristidoideae grass are very rare on the modern sample to both Karari and Ileret.

Microscopic charcoal observed indicated that the pastoralists use wood as a source of fuel since the wood dicot phytoliths observed in >20% from fire pits than from the pest control side samples. The grass presence on the fire pit indicate that maybe the Dassanech used grass or herbs to generate fire. Burnt phytoliths observed most are woody derived, which correlates with the microcharcoal observed. Samples collected from pest control show more burnt grass phytoliths than woody. Diatoms observed in low percentage, and most are fresh water from the recent rains. Palms phytoliths are present but rare.

Outside and inside bomas samples indicate herbaceous grassland environment. Comparing the phytoliths results from modern soil provides information on vegetation changes in East Turkana with a significant of influence from human activities especially pastoralism. Phytolith data are consistent with the above-ground vegetation data.

### **5.7.4. Fossil phytoliths data**

Fossil phytolith assemblages from Early and Mid-Holocene were identified and classified to vegetation communities they represented in order to interpret vegetation cover dynamics and, by extension associated climates.

#### **5.7.4.1. Early Holocene phytoliths assemblages**

The sites studied that represents this period are FxJj108 form Area 117 in Karari and Lowasera A from the end of the southern part of the site.

##### **A). FxJj108-Area 117**

The site is dominated by mixed wooded grasslands. Phytolith assemblage from this site consist of woody and herbaceous phytolith morphotypes indicating that the vegetation structure in Early Holocene was a mixed wooded grasslands. However, the landscape was largely dominated by C<sub>4</sub> grasslands with >29% followed by herbs/others morphotypes at >15%. Woody derived phytoliths such as palm trees are present in all levels indicating an mixed wooded grasslands environment. Aristidoideae C<sub>4</sub> grasses are commonly associated with very arid and disturbed/shallow soils. Their morphotypes are rare throughout the FwJj108 sequence, an indication that the site was not extremely arid/dry. The presence of diatom sponges indicates a shallow water environment throughout the Early Holocene sequence. This is further supported by the presence of palms in all the layers indicating the presence of freshwater sources or high water tables at the site (Albert et al., 2009).

Throughout the sequence, vegetation cover dynamics are observed especially between the top fine sandy layer and the bottom compact soil layer. The bottom layer has a high component of short grass cells including Panicoideae and Chloridoideae >15% compared to the top layer <7%. This suggests that vegetation cover shifted to less grassland with a few Panicoideae and Chloridoideae with rare Aristidoideae. Further, indicating a more arid environments at the bottom and less arid at the top.

##### **B). Lowasera A**

The site vegetation structure is mixed wooded grasslands. The site is more open with scattered *Acacia sp.* trees.

In the silty diatomaceous layer, short grass phytoliths dominate by over 12% indicating the layer represents grassy environments. Vegetation shift is noted in the top layer of silty tuff by <7% from more short grass cells dominance from silty diatomaceous layer to less short grass cells dominance.

Phytolith assemblage is dominated by short grass cell phytoliths indicating grasslands dominated vegetation structure. In both layer Chloridoideae and Panicoideae grasses dominated by >29% and herbs with 16% while woody taxa are present throughout the layer by >9%. This conclude that the landscape was an open environment with scattered trees.

Notably, Aristidoideae grasses are rare in both layers with few occurrences on the bottom layer of silty diatomaceous layer. The samples have higher components of diatoms that indicate a high-water table or the existence of a freshwater source. These diatoms include *Flagilaria sp.*, *Gophonema, sp.*, *Naviculasp.*, *Stephanodiscuss sp.*, and others are the most widespread and common freshwater indicators.

The phytolith analysis, therefore suggested that during the Early Holocene vegetation cover was dominated by grasslands with woody taxa scattered.

#### **5.7.4.2. Mid-Holocene phytoliths assemblages**

##### **A). FwJj25W**

The site suggested to date to 4000 BP (Ndiema, 2011). The Mid Holocene phytolith data at this site is dominated by short grass cells. Chloridoideae and Panicoideae C<sub>4</sub> grass have high component of >18% in the most easterly side while decreasing to 7% on the sandy layer. In the silty layer Panicoideae C<sub>4</sub> grasses are absent while Chloridoideae account for 1%. The decreasing trend of C<sub>4</sub> grasses from the high dominance in most easterly layer to lowly dominance in silty layer indicates vegetation shifts during Mid-Holocene period. The rarity in Aristidoideae grasses noted during this period on the most easterly layer and absent to other two layers. This suggests that during Mid-Holocene the environment was dry.

Microcharcoal concentration indicates fire activities and burnt vegetation in the area. Low microcharcoal concentration with a small number of particles during Mid-Holocene are associated by low number of fires. Woody morphotypes suggest that the vegetation cover was mixed wooded grassland. Diatoms and sedges are good indicators of wet environment but during Mid-Holocene diatoms were absent and sedges occurred in low proportion throughout the layer.

The data indicates that the vegetation cover was mixed grassy woodlands. However, vegetation changes are noted on the decrease of C<sub>4</sub> grass during Mid-Holocene.

### **5.7.5. Phytoliths Indices**

To determine the vegetation structure and environmental change in East Turkana, two phytoliths indices were used to interpret vegetation cover change on modern landscapes within and outside modern abandoned bomas and , Early to Mid-Holocene landscapes Results are presented below;

#### **5.7.5.1. Aridity Index (Iph)**

The dung samples indicate high aridity ranging from 0.4 to 1.0 value. Donkey dung indicates a high aridity value of 1.0 showing higher dominance of Chloridoideae grasses. The aridity of the inside abandoned bomas indicated high aridity ranging from 0.5 to 1.0 value. Two samples were exceptional having an high value of aridity >0.5. I3-Homogenous collected from Ileret has aridity value of 0.8. K14-Homogenous from Karari has a high value of aridity 1.0 indicating high component of Chloridoideae grasses.

Fire pit samples indicate high aridity value of 0.5 while pest control indicate low aridity. This suggest phytolith component in the fire pits consist of more Chloridoideae-derived phytoliths compared to those in pest control fires. I4-Pest control have low aridity value of 0.3. Most likely the pest control fire was burnt after a rainy season which had more Panicoideae phytoliths in the dung while the fire pit one was burnt during a drier season. Fire pit phytoliths assemblage reflect local vegetation while pest control phytoliths are from extra-local or regional input brought in by livestock from grazing sources.

Two samples from outside indicated relatively high aridity value of 0.8 one from riparian settings while one sample has high aridity of 0.6 from bomas that is not in riparian environment. The inside samples have a higher component of Chloridoideae grasses than the cattle enclosures because cattle enclosure has more input from far brought in by livestock from outside grazing fields. Phytolith data suggests that Mid-Holocene period was more arid compared to Early Holocene period which was more humid. Samples K48, 49, 50 from Karari and L51 from Lowasera A consist of grassier morphotypes, open grasslands during Early Holocene. This is further indicated by Iph relatively high value of 0.6. Mid-Holocene samples shows high aridity value ranging from 0.5 to

1.0. Sample I36 collected from silty layer in Ileret indicate high aridity value of 1.0 showing higher input of Chloridoideae grass.

#### **5.7.5.2. Dicotyledon versus Poaceae (D/P<sup>o</sup>)**

The cow, sheep/goat and donkey dung have low component of the woody taxa with relatively low value. Livestock dungs were used as a modern phytoliths analog to interpret the domestication activities impact on the vegetation changes.

The samples collected inside and from their immediate transect show expected results. In all bomas in Karari and Ileret woody phytoliths component are very low especially inside, probably the boma in question was for grazers, either sheep, cows or donkeys but very few goats (browsers). Low woody taxa suggests that the vegetation cover is open grasslands.

All samples from Early Holocene and Mid-Holocene indicate high aridity and low woody taxa components. Early Holocene samples on the bottom and middle layer shows lowest concentration of woody while the upper layer woody taxa increased. Mid-Holocene shows low woody taxa throughout layers. The data suggest that Early and Mid-Holocene environment was characterised by open grasslands.

### **5.8. Summary**

In this chapter presented the results of the data collected and discussed the vegetation data, phytoliths data from modern soil from inside and outside bomas, dung samples and fossil assemblages from Holocene sites. The morphotypes from both samples shows a significant associations. In addition, it discusses the significance of the results in the interpretation of the palaeoenvironments. The following chapter is concluding this research and future directions of the study.



## CHAPTER SIX

### CONCLUSIONS AND RECOMMENDATIONS

#### 6.1. CONCLUSION

The first objective of this study was to explain the correlation between the phytoliths assemblages and above-ground vegetation cover. This study showed a general correlation between phytolith assemblages and the above-ground vegetation cover. However, vegetation data in bomas shows that grass and herbs have more abundant than woody species, which were more abundant on unoccupied land. Phytolith data complemented the vegetation data by having a similar trend. Both phytolith and vegetation data of all bomas inside and outside indicate an herbaceous grassland habitat with scattered shrubs.

The second objective was to assess the vegetation changes. Assessment of the changes in vegetation cover in Koobi Fora, the data indicate that there has been a significant variation of vegetation cover in Koobi Fora during the Holocene. Vegetation cover during the Early and Mid-Holocene comprised mainly of C<sub>4</sub> short Chloridoideae grasses, which thrive in arid conditions, and a small proportion of C<sub>4</sub> Panicoideae tall grasses that thrive under moist conditions. There is a significant occurrence of palms, indicating the presence of wetland/swampy habitats during the Early Holocene. Aristidoideae grasses, which are indicators of shallow or disturbed soils in extremely arid conditions, are only noted in a few Holocene samples; this is an indication that although the environments were arid, there was little or no soil disturbance/ degradation.

The last objective of the study was to explain the impact of humans and climate on the vegetation cover changes. Modern phytolith and vegetation data address the issue of the role of humans and climate in shaping the vegetation cover of the Koobi Fora. Over the years, the Dasannech population has been increasing, hence the livestock population. The community has been moving seasonally across the landscape to ensure grazing lands are used during the right season and are not overgrazed. They have “mapped” pastures for dry and rainy seasons for grazing purposes. This sociocultural practice has significantly influenced the dynamics in vegetation cover, particularly within designated Boma areas/plots. This impact is mainly due to differential Nitrogen input from the dung that decomposes, adding to the soil nutrients in the cattle enclosures, thereby creating

microhabitats characterized by abundance and diversity of herbaceous species and reduction and/or absence of other species. During the rainy season, different plant species can easily be observed compared to the dry seasons.

The microscopic charcoal and burnt phytoliths provide insights into using fire on landscapes. The analysis of microcharcoal in archaeological settings gives information on the use of firewood and fuel management and the related adaptability of societies over time (Marquer et al., 2020). The high abundance of microcharcoal on the samples from the inside indicates that the dassanech people were using wood for fuel. During the Early and Mid-Holocene, the low microcharcoal components resulted from human activities.

The aridity index suggests that dry conditions have prevailed in East Turkana since the late Holocene to modern landscapes. . D/P° index is essential to understand tree cover density in modern and fossil samples. The D/P° index suggested herbaceous grassland with scattered tree components during the Holocene period as well as in the modern landscape.

Therefore, the study conclude that phytoliths assemblages correlates with the above-ground vegetation. Human activities, especially the domestication of animals and climate, have positively impacted the vegetation changes in East Turkana. The results of phytoliths and microcharcoal in this research support that the vegetation cover in East Turkana is Herbaceous grassland with a mix of few trees. Lastly, the trend of the results indicates that phytolith data can be used to identify past archaeological occupations, especially when coupled with charcoal data.

## **6.2. RECOMMENDATIONS**

This study explores the impact of pastoralist activities and climate on the vegetation cover change in abandoned bomas. To increase sample size and robustness, longitudinal study should be conducted. The future sampling strategies should include more dung samples in dry and wet seasons to obtain a more accurate dung phytolith assemblages representation during all seasons. The future direction should aim to understand the livestock's feeding habits in different seasons. This will help to determine grass composition in dung for all seasons.

In addition, incorporate soil chemistry, pollen, and charcoal datasets. Soil chemistry is a useful proxy in reconstructing human activities' impact on the soil, determining activities within sites and site boundaries, and its related stratigraphy. When such studies are applied to Holocene sites it will be possible to determine anthropogenic horizons coupled with charcoal data. It will give information on whether human or naturally induced fires are responsible for the change. Soil chemistry will assist in determining fertilizer levels and manure accumulation that facilitate plant species abundance and diversity.

Although the Holocene sample size is small due to the short time frame of this study, future research should increase the sample size and include dates of the sites to understand the continued vegetation dynamics throughout the Holocene period to present

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## APPENDICES

### Appendix I: List of vegetation species identified and counted from inside and outside abandoned bomas

SPECIES	37N 021033E 0456230N; Elev 455m		37N 0207360E 0453099N; Elv 471m		37N 0216084E 0463225N; Elv 455m	
TREES	BOMA A INSIDE	OUTSIDE	BOMA B INSIDE	OUTSIDE	BOMA C INSIDE	OUTSIDE
Boscia coriacea	5	0	0	0	0	0
Dobera gabra	3	0	0	0	0	0
Delonix elata	2	0	0	0	0	0
Maerua crassifolia	5	0	0	0	3	1
Acacia senegal	1	5	0	1	0	0
Salvadora persica	0	0	1	0	0	0
Commiphora edulis	3	0	2	5	1	3
Combretum aculeatum	1	2	0	2	2	0
Commiphora kataf	0	0	0	0	9	21
Eurphobia sp.	5	0	115	2	0	0
Balanite rotundifolia	0	0	0	0	2	1
Acacia recifen	0	0	0	0	5	12
Cadaba rotundifolia	0	0	0	0	5	8
Maerua decubens	0	0	0	0	3	0
Adenia cuneata	1	0	0	0	0	0
Grewia tenax	0	0	0	0	2	6
<b>TOTAL Trees</b>	<b>26</b>	<b>7</b>	<b>118</b>	<b>10</b>	<b>32</b>	<b>52</b>
<b>HERBS</b>						
Cissus quadrangularis	3	15	0	0	0	0
Barleria sp.	200	150	415	750	0	0
Heliotropium shimpreii	50	0	0	0	0	0
Solanum incanum	356	0	533	0	32	0
Duosperma longicalyx	20	0	92	0	62	17
Tribulus	3	0	20	0	23	0
Acanthes	0	0	866	0	5	0
Sansevieria ehrenbergii	60	21	0	0	0	0
Chenopodiaceae sp	32	0	0	0	5	0
Aerva javanica	105	0	1137	0	20	0
Sueda monoica	52	0	95	0	32	0
Kendrostis giref	2	2	0	0	8	0
Cucumis sp	0	0	0	0	10	0
Amaranthus sp	0	0	0	0	221	0
Sarcostemma viminale	0	0	0	0	5	0
<b>TOTAL Herbs</b>	<b>883</b>	<b>188</b>	<b>3158</b>	<b>750</b>	<b>423</b>	<b>17</b>
<b>GRASSES</b>						
Stipagrostis sp	455	0	860	0	15	0
Leptothrium senegalance	150	950	154	960	48	0
Sporobolus sp	840	0	860	0	0	0
Harpashine shimprei	0	0	1130	0	25	0
Cynodon dactylon	142	0	515	0	32	0
Dinebra rectroflexa	135	0	500	0	0	0
Eragrostis superba	860	0	123	0	0	0
Chloris sp	455	0	840	0	0	0
Aristida sp	22	0	0	0	0	0
Star grass	0	0	95	0	0	0
<b>TOTAL Grasses</b>	<b>3059</b>	<b>950</b>	<b>5077</b>	<b>960</b>	<b>120</b>	<b>0</b>

<b>SPECIES</b>	<b>37N 0197295 0474086N</b>		<b>37N 0194612E 0464771N; Elv 374m</b>
<b>TREES</b>	<b>BOMA F INSIDE</b>	<b>OUTSIDE</b>	<b>Contral Transect</b>
Maerua crassifolia	4	0	7
Commiphora edulis	2	0	4
Ricinus communis	0	0	2
Prosphis sp	8	0	20
Acacia recifens	1	5	5
Cadaba rotundifolia	3	0	7
<b>TOTAL Trees</b>	<b>18</b>	<b>5</b>	<b>45</b>
<b>HERBS</b>			
Cissus quadrangularis	8	0	15
Barleria sp.	4	65	12
Solanum incanum	15	0	20
Duosperma longicalyx	21	8	53
Tribulus	5	0	2
Sueda monoica	12	0	15
Cucumis sp	8	0	6
Polygonum	3	0	0
Acalypha	4	0	0
Amaranthus sp	24	0	3
<b>TOTAL Herbs</b>	<b>104</b>	<b>73</b>	<b>126</b>
<b>GRASSES</b>			
Stipagrostis sp	2	1	2
Leptothrium senegalance	78	0	0
Dinebra retroflexa	20	0	0
Aristida sp	12	0	11
Star grass	11	0	4
Cyperus sp.	0	0	56
<b>TOTAL Grasses</b>	<b>123</b>	<b>1</b>	<b>73</b>

**Appendix II: List of phytolith assemblages counted on the inside and outside abandoned bomas and dung samples**

MORPHOTYPE	12-Cattle enclosure	11-Fire pit	13-Homogenous (Inside)	14-Pest control	15-Outside	16-Depositional area (Inside)	17-Outside	18-Cow dung	19-Homogenous (Inside)	110-Outside (r
Sedge	0	0	58	11	61	83	50	5	28	26
Bilobate	13	49	15	102	9	49	44	87	20	16
Rondel	146	50	120	95	149	218	157	178	222	126
Saddle	14	54	96	54	50	172	86	69	130	107
Burnt	36	93	77	189	88	92	69	36	161	81
Cross	3	4	0	32	4	1	4	20	4	5
Epidermal (scl)	0	0	0	0	0	0	2	0	0	0
Verrucate sphere	6	24	90	7	7	8	82	11	123	73
Polygonal	2	6	12	17	30	53	9	1	5	9
Trichome	90	63	111	84	195	214	115	87	93	113
Epidermal (elongate)	11	0	3	7	0	0	2	14	6	0
Spheroid ornate	9	8	50	9	4	7	31	7	26	41
Elongate	105	112	123	194	173	247	164	131	108	74
Seclereid	51	51	170	30	152	166	98	36	32	42
Bullform	17	17	115	8	147	193	30	10	8	50
Spheroid echinate	4	16	13	6	24	11	37	8	15	13
polyhedral	2	1	7	0	18	28	8	0	0	0
Spheroid psilate	91	95	220	112	197	210	52	104	186	124
Blocky	86	55	162	53	124	240	71	40	16	52
Pollen	0	4	0	0	0	0	2	0	0	1
Weathered	31	34	71	16	18	68	28	0	23	14
Hat-shaped	0	0	4	0	0	13	7	3	4	7
Elongate echinate	5	6	4	2	0	0	15	10	4	1
Diatom	0	2	0	0	2	13	33	3	0	2
Elongate (scl type)	4	5	17	0	14	9	21	0	0	0
Elongate sinuate	0	0	2	0	0	0	3	0	0	0
Palm	0	1	0	2	0	1	5	0	2	0
Subspheroid	0	18	33	16	7	18	9	8	18	13
Charcoal	110	64	65	53	27	40	35	138	24	46
Dendritic	0	0	0	0	0	0	1	0	0	0
Epidermal	42	0	22	43	12	7	2	52	31	6
Spores	2	1	12	2	9	4	4	5	5	13
Epidermal (sedge)	0	0	1	0	0	0	2	0	5	0
Tracheid	15	0	9	28	31	31	12	23	14	8
Epidermal (rondel)	1	0	1	0	0	0	0	6	0	0
Scutiform	7	9	10	7	16	0	0	23	10	9
Polylobate	0	0	0	2	0	1	0	6	0	0
Parenchymatous/mesophyll bodies	3	0	0	3	0	0	0	2	0	0
Elongate (multiple)	0	0	0	6	0	0	0	0	0	0
Epidermal (saddle)	0	0	0	1	0	0	0	5	3	0
Faceted blocky	4	0	0	0	0	0	0	2	0	0
Epidermal (tranc)	2	0	0	0	0	0	0	4	0	1
Cytolith	6	0	0	0	0	0	0	7	0	0
Epidermal (spheroid)	16	2	0	5	0	0	0	6	0	0
Achene	3	0	0	0	0	0	0	0	0	0
Trichome grass epidermal	0	0	0	0	0	0	0	4	0	0
Trichome grass	0	0	0	0	0	0	0	17	0	0
Stomata	0	0	0	0	0	0	0	3	0	0
Trichome epidermal	0	0	0	0	0	0	0	6	0	0
Bilobate epidermal	0	1	0	6	0	0	0	6	0	0
Quadrilateral (Achinete) epidermal	0	0	0	11	0	0	0	0	0	0

MORPHOTYPE	K13-Fire pit (inside)	K14-Homogenous inside	K15-Cattle enclosure	K16-Outside	K17-Donkey dung	K18-Goat/sheep dung	K19-Outside	K20-Inside	K21-Fire pit (inside)
Sedge	9	0	6	6	0	0	5	4	2
Bilobate	44	0	33	23	0	18	23	27	9
Rondel	123	110	206	178	0	206	216	186	117
Saddle	83	8	51	24	0	24	21	33	19
Burnt	81	14	88	96	0	27	108	80	105
Cross	3	0	1	8	0	4	7	4	1
Epidermal (sphere)	4	0	0	0	0	10	0	0	0
Verrucate sphere	83	14	59	20	0	11	25	16	11
Polgonal	1	3	9	4	0	1	6	3	2
Trichome	70	44	99	126	0	90	143	72	77
Epidermal (elongate)	3	9	0	0	0	0	0	0	0
Spheroid ornate	17	2	24	28	0	4	13	6	7
Elongate	133	97	151	171	0	104	193	189	113
Seclereid	18	57	39	80	0	37	96	69	88
Bullform	43	49	70	73	0	26	43	34	67
Spheroid echinate	17	3	5	5	0	7	17	11	13
polyhedral	1	1	7	1	0	0	1	0	0
Spheroid psilate	207	56	143	139	0	146	117	158	123
Blocky	52	186	113	162	0	80	170	126	222
Pollen	0	0	2	1	0	2	16	3	4
Weathered	13	0	20	51	0	0	26	19	32
Hat-shaped	1	0	0	3	0	3	7	3	0
Elongate echinate	19	0	12	9	0	5	14	3	8
Diatom	1	0	1	5	0	0	6	3	0
Elongate (scl type)	0	7	4	12	0	0	24	8	17
Elongate sinuate	0	0	0	0	0	0	0	0	0
Palm	8	0	1	2	0	0	2	3	0
Subspheroid	28	0	31	33	0	28	32	34	52
Charcoal	101	147	188	183	0	102	207	180	192
Dendritic	2	0	0	0	0	0	0	0	0
Epidermal	8	11	0	6	0	17	11	6	26
Spores	8	6	1	0	0	15	4	5	2
Epidermal (sedge)	0	0	0	0	0	0	0	0	0
Trancheid	7	9	7	20	0	4	32	15	0
Epidermal (rondel)	0	0	1	0	0	0	0	0	0
Scutiform	3	2	6	17	0	11	21	20	12
Polylobate	1	0	0	0	0	1	3	1	0
Parenchymatous/mesophyll bodies	0	1	0	1	0	0	0	0	0
Elongate (multiple)	0	0	0	0	0	0	0	0	0
Epidermal (saddle)	0	0	0	0	0	0	0	0	0
Faceted blocky	2	0	0	7	0	0	0	0	15
Epidermal (tranc)	0	0	0	0	0	0	0	0	0
Epidermal (bilobate)	1	0	0	0	0	0	0	0	0
Achene	0	0	1	0	0	0	0	0	0
Trichome infill	0	2	0	0	0	0	0	0	0
Long achinate epidermal	0	0	0	0	0	0	0	0	0
Stomata	0	0	0	0	0	0	0	0	0



### Appendix III: Phytolith assemblages counted on the samples collected on the vegetation

MORPHOTYPE	K22-Solanum	K23-Amaranthites	K24-Grasses
Sedge	1	4	5
Bilobate	3	89	38
Rondel	163	130	131
Saddle	10	110	38
Burnt	21	20	10
Cross	3	37	10
Epidermal (sphere)	0	0	6
Verrucate sphere	11	9	20
Polygonal	3	0	2
Trichome	56	51	62
Epidermal (elongate)	5	2	7
Spheroid ornate	3	11	9
Elongate	67	58	159
Seclereid	33	28	51
Bullform	38	19	41
Spheroid echinate	16	28	14
polyhedral	0	0	1
Spheroid psilate	176	57	98
Blocky	85	46	103
Pollen	4	49	0
Weathered	58	0	22
Hat-shaped	0	0	2
Elongate echinate	5	9	19
Diatom	0	0	6
Elongate (scl type)	0	0	18
Elongate sinuate	0	0	0
Palm	0	0	3
Subspheroid	42	20	11
Charcoal	72	24	171
Dendritic	0	0	0
Epidermal	63	34	32
Spores	8	170	19
Epidermal (sedge)	0	0	0
Tracheid	2	3	10
Epidermal (rondel)	0	0	0
Scutiform	15	15	31
Polylobate	0	8	2
Parenchymatous/mesophyll bodies	0	0	3
Elongate (multiple)	0	0	0
Epidermal (saddle)	0	3	1
Faceted blocky	0	3	12
Epidermal (tranc)	0	0	0
Epidermal (bilobate)	0	1	1
Achene	0	1	0
Trichome infill	0	0	0
Long achinate epidermal	0	0	1
Stomata	0	4	0
Tribulus	0	2	0
Amaranthes	0	3	0
Acanthes	0	2	0
Cadabba	0	3	0
Cyperus longus	0	6	0
Balanite	0	1	0
Commelinaceae	0	1	0
Graminaea/Poaceae	0	72	0
Grewia	0	3	0
Maerua	0	8	0
Acacia	0	8	0

## Appendix IV: Phytolith assemblages counted on the fossil soil samples

MORPHOTYPE	112-Sand layer	136-Silty layer	140-Most Easterly
Sedge	8	0	2
Bilobate	18	0	52
Rondel	128	118	129
Saddle	62	5	61
Burnt	61	48	22
Cross	5	0	22
Epidermal (scl)	0	0	0
Verrucate sphere	32	19	10
Polygonal	8	1	1
Trichome	119	55	43
Epidermal (elongate)	0	0	2
Spheroid ornate	19	17	7
Elongate	199	144	98
Seclereid	93	67	19
Bullform	57	24	11
Spheroid echinate	14	9	6
polyhedral	2	0	0
Spheroid psilate	84	50	27
Blocky	156	162	63
Pollen	1	0	0
Weathered	66	13	11
Hat-shaped	0	3	0
Elongate echinate	11	0	5
Diatom	0	0	0
Elongate (scl type)	6	13	0
Elongate sinuate	0	0	0
Palm	0	0	0
Subspheroid	21	13	8
Charcoal	81	198	129
Dendritic	0	0	0
Epidermal	6	38	10
Spores	0	0	15
Epidermal (sedge)	0	0	0
Trancheid	8	4	3
Epidermal (rondel)	0	0	0
Scutiform	15	0	10
Polylobate	0	0	3
Parenchymatous/mesophyll bodies	0	0	0
Elongate (multiple)	0	0	0
Epidermal (saddle)	0	0	0
Faceted blocky	8	0	0
Epidermal (tranc)	0	0	0
Cytolith	0	0	0
Epidermal (spheroid)	0	0	0
Achene	0	0	0
Trichome grass epidermal	0	0	0
Trichome grass	0	0	0
Stomata	0	0	0
Trichome epidermal	0	0	0
Bilobate epidermal	0	0	0
Quadrilateral (Achinat) epidermal	0	0	0
Collapsed saddle	0	0	2
Aristida bilobate	0	0	5

MORPHOTYPE	K48-17-22cm	K49-28-33cm	K50-42-50cm
Sedge	3	3	3
Bilobate	28	35	37
Rondel	103	121	149
Saddle	57	78	83
Burnt	82	68	64
Cross	14	10	15
Epidermal (sphere)	0	0	0
Verrucate sphere	19	2	5
Polygonal	0	3	0
Trichome	69	35	45
Epidermal (elongate)	0	0	0
Spheroid ornate	28	17	5
Elongate	122	143	97
Seclereid	63	25	23
Bullform	45	26	9
Spheroid echinate	31	23	7
polyhedral	8	1	0
Spheroid psilate	33	23	20
Blocky	192	68	32
Pollen (Cucurbitaceae)	0	0	1
Weathered	31	44	49
Hat-shaped	4	0	0
Elongate echinate	14	10	11
Diatom	88	88	95
Elongate (scl type)	16	0	0
Elongate sinuate	0	0	0
Palm	98	157	106
Subspheroid	4	0	10
Charcoal	124	225	105
Dendritic	0	0	0
Epidermal	44	12	11
Spores	1	0	0
Trancheid	5	2	5
Scutiform	8	7	2
Polylobate	0	9	5
Parenchymatous/mesophyll bodies	0	0	2
Echinate subsphere	10	0	0
Aristida bilobate	0	0	5



**Appendix V: Summary of phytolith assemblages, diatoms and pollen observed and their categories**

MORPHOTYPE	SPECIES CATEGORY
Saddle	CHLORIDOIDEAE
Epidermal (saddle)	CHLORIDOIDEAE
Burnt	FIRE
Charcoal	FIRE
FIRE	
Elongate	HERBS/OTHERS
Spheroid psilate	HERBS/OTHERS
Elongate sinuate	HERBS/OTHERS
Epidermal	HERBS/OTHERS
Parenchymatous/mesophyll	HERBS/OTHERS
Elongate (multiple)	HERBS/OTHERS
Cytolith	HERBS/OTHERS
Rondel	OTHER GRASS
Trichome	OTHER GRASS
Epidermal (elongate)	OTHER GRASS
Bullform	OTHER GRASS
Elongate echinate	OTHER GRASS
Dendritic	OTHER GRASS
Epidermal (rondel)	OTHER GRASS
Scutiform	OTHER GRASS
Palm	PALMS
Bilobate	PANICOIDEAE
Cross	PANICOIDEAE
Polylobate	PANICOIDEAE
Sedge	SEDGES
Hat-shaped	SEDGES
Epidermal (sedge)	SEDGES
Epidermal (scl)	WOODY DICOT
Verrucate sphere	WOODY DICOT
Polygonal	WOODY DICOT
Spheroid ornate	WOODY DICOT
Seclereid	WOODY DICOT
Spheroid echinate	WOODY DICOT
polyhedral	WOODY DICOT
Blocky	WOODY DICOT
Elongate (scl type)	WOODY DICOT
Subspheroid	WOODY DICOT
Trancheid	WOODY DICOT
Faceted blocky	WOODY DICOT
Epidermal (tranc)	WOODY DICOT
<b>DIATOMS</b>	
Aulacoseira	AULACOSEIRA
Canicula	CANICULA
Cymbella	CYMBELLA
Diatoma	DIATOMA
Eutonia	EUTONIA
Fragilaria	FRAGILARIA
Gomophonema	GOMOPHONEMA
Melosira	MELOSIRA
Meridian circular	MERIDIAN CIRCULAR
Nitzschia	NITZSCHIA
Rhoicospheria	RHOICOSPHERIA
<b>POLLEN</b>	
Amaranthes	AMARANTHES
Acanthes	ACANTHES
Cadabba	CADABBA
Cyperus longus	CYPERUS LONGUS
Balanite	BALANITE
Commelinaceae	COMMELINACEAE
Graminaea/poaceae	GRAMINAE/POACEA
Grewia	GREWIA
Maerua	MAERUA
Acacia	ACACIA