A Spatial Approach to Phytolith Analysis for the Detection of Interior and Exterior Spaces at Songo Mnara, Tanzania

Volume 1 of 2

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PhD

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Archaeology

May 2017

Abstract

This thesis reports on phytolith research in and around a domestic structure at the Swahili stonetown of Songo Mnara, Tanzania, elucidating the use of space at the site on a micro-scale through the development of a methodology for intra-site sampling, and the refinement of a phytolith extraction methodology for tropical environments.

This project forms part of a broader programme of excavation at Songo Mnara aimed at exploring use of space within a Swahili stonetown occupied between the late 14th-16th centuries AD. Songo Mnara was part of a network of stonetowns engaged in Indian Ocean trade along the coast of East Africa. The town plan comprises extensive architecture, including stone-built houses and wattle and daub structures of broadly contemporary date. The site's relatively short occupation sequence and its simple stratigraphy make it ideal for spatial analysis.

This thesis, employing a phytolith extraction methodology contextualised through a review of current practice, reports on an intensive sampling strategy focused on a wattle and daub house, and opportunistic sampling of external areas and stone built structures. This is one of the most comprehensive spatial studies of an archaeological structure to date. In addition, the thesis develops an ethnographic reference collection, and a methodology for recovery of phytoliths in tropical environments.

Preservation of phytoliths was variable, with significant local challenges including higher pH and a sandy sediment matrix. It was, however, possible to distinguish between interior and exterior spaces, and to identify certain plant-based activity areas. Discussion of these results is framed within a comprehensive assessment of visibility and potential of phytolith analysis in this environment, considering that production of diagnostic phytoliths and subsequent deposition into the domestic contexts explored, may be limited.

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Acknowledgements

For Alexander, who is my greatest achievement.

To Paul, without whose encouragement and support I would never have embarked on and completed this journey, save for the evenings, late nights, weekends and holidays sacrificed. Without the support of my parents, Sean and Joan McParland, it would not have been possible to begin this process.

Above all, I am grateful to Dr Stephanie Wynne-Jones for providing me with this opportunity, for her supervision and support throughout the process and all of her efforts on my behalf.

This thesis was undertaken as part of the Songo Mnara Urban Landscape Project, directed by Dr Stephanie Wynne-Jones and Dr Jeffrey Fleisher. I am grateful to the Arts and Humanities Research Council for their generous funding, which has made this research possible and to the National Science Foundation.

I wish to thank Dr Jeffrey Fleisher for the opportunity to participate in the project and his support in the field. I am indebted to Dr Sarah Walshaw and Dr Federica Sulas for their support and their supervision in the field and during post-excavation. Matthew von Tersche provided unending laboratory support and guidance.

I would like to thank the Antiquities Division, Ministry of Natural Resources and Tourism, United Republic of Tanzania and the Ministry of Mining United Republic of Tanzania, for granting permission to export soil samples to the laboratory at the University of York; in particular, R. Bugumba of the Antiquities Division Kilwa office and M. Mgusi of the Antiquities Division.

I would also like to extend my thanks to Dr Tom Fitton, who excavated Trench 32 and to the Songo Mnara project team from the 2013 excavation season.

Thanks are also due to my colleagues in the Department of Archaeology and BioArCh, University of York and at Historic England, who offered words of encouragement and support at every turn. In particular, Dr Jim Williams, who supported completion of this thesis by generously covering a period of extended leave.

Those who require my gratitude are too numerous to thank, but I am forever grateful.

Authors Declaration

I declare that this thesis is a presentation of original work, and that I am the sole author. This work has not previously been presented for an award at this, or any other University. All sources are acknowledged as References.

1. Introduction

1.1 Background to the project

Recent excavations at Songo Mnara, Tanzania, provided the opportunity to test a methodology for the detection of plant-based activity areas within ephemeral structures through phytolith analysis, considered alongside geochemical analysis and archaeobotanical analysis. Systematic spatial sampling has more commonly been used for geochemical analysis, although the application of systematic sampling for phytolith analysis has recently been used for ethnographic structures (Rondelli *et al.* 2014; Ruiz-Pérez *et al.* 2014). This thesis presents a case study from a single ephemeral wattle and daub structure, which features simple stratigraphy and a well-defined occupation surface, an ideal context in which to assess the efficacy of intensive sampling for the identification of spatial variation through phytolith analysis.

This PhD research was undertaken as part of the Songo Mnara Urban Landscape Project, drawing on data from excavations across the site, particularly the archaeobotanical assemblages and the geochemical assemblages (Walshaw 2018; Sulas Unpublished Data). Fieldwork at Songo Mnara ran on a biennial basis from 2009 to 2016 and included excavations across the site which focussed on domestic coral and lime architecture, ritual and monumental structures including the Necropolis and Mosques, wattle and daub structures and open spaces (Fleisher and Wynne-Jones 2010; 2011; 2013a; 2013b). The phytolith results and sampling strategy, which are the subject of this thesis, were part of the 2013 field season, during which stone structures and wattle and daub structures were excavated, along with associated sampling across the open areas (Fleisher and Wynne-Jones 2013b).

This thesis focuses specifically on the phytolith signatures to explore and elucidate use of space within an ephemeral wattle and daub structure, but it forms part of a broader project which sought to investigate intra-site patterning revealing the use of space through day to day activities within the stonetown, considering the difference in use of space between public and private settings, including religious architecture, cemeteries, and open spaces, and domestic strutures, contextualising and elucidating social identity through domestic activities and material culture (Fleisher and Wynne-Jones 2010).

The project sought to define specific material practices related to the constitution of social identities within the stonetown through domestic activity and ritual or commemorative practices within cemeteries and open areas in the centre of the domestic setting, identifying public practices and private practices, their specific location within the settlement, and within individual structures (Fleisher and Wynne-Jones 2010; 2013). The investigation of a structure at microscale for the identification of activity areas within ephemeral structures, is further discussed in Chapter 8.

1.2 Rationale

In East Africa, archaeobotanical sampling has only recently been used routinely, and a relative paucity of archaeobotanical evidence is often attributed to the greater effect of taphonomic processes in tropical environments, impacting on the preservation and recovery of charred plant remains (Hather 1994; Young 1999). Yet, archaeobotanical sampling of Swahili domestic contexts on Pemba Island, Zanzibar, and at Songo Mnara, presented the most comprehensive archaeobotanical study of Swahili plant use to date; identifying rural and urban subsistence and plant procurement strategies, and highlighting the value of archaeobotanical sampling within these contexts (Walshaw 2005; Walshaw 2010; Walshaw 2018).

The application of Phytolith analysis within tropical African contexts is an emerging technique and has the potential to inform our understanding of plant-based activities, including domestic and craft uses, in contexts which lack the preservation conditions to preserve charred plant remains, or for the identification of activities which may not be subject to processes which would induce charring. Archaeobotanical sampling of contexts within both wattle and daub and stone structures at Songo Mnara provided an important comparative assemblage to the spatial phytolith assemblage, the results of which are discussed briefly in Chapter 8.

Phytolith analysis as part of a multi-proxy approach may help to broaden our understanding of the use of plant materials for subsistence or craft within Swahili domestic contexts. Phytolith identification affords visibility to non-food plant remains unlikely to be subject to charring; plant-based research on a micro-scale affords the ability to undertake systematic high intensity sampling for plant remains, facilitatating the reconstruction of activity areas across occupation surfaces, delineating use of space within ephemeral structures. The approach is particularly valuable for the identification

of interior and exterior spaces. There may be intra-structural variation in Phytoliths with the assemblage differing between rooms, and ethnographic studies have demonstrated that areas within structures may differ substantially; for example 'public' rooms such as store rooms may have more phytoliths due to a lack of floor covering, increased trampling of organic material or less 'cleaning' and resurfacing (Milek 2012; Shahack-Gross et al. 2004; Tsartsidou et al. 2008). Structures with clearly defined boundaries and internal divisions immediately highlight a difference in space within the structure, yet more ephemeral daub structures may lack clearly defined boundaries or internal divisions; in both cases the application of high resolution systematic sampling has the potential to provide comparable and complementary data for spatial analysis. The history of phytolith analysis in sub-Saharan Africa is discussed in detail in Chapter 2 (2.5), highlighting the unique methodological contribution of this thesis.

1.3 Songo Mnara

Songo Mnara occupies the north-western tip of an island in the Kilwa archipelago, on the southern coast of Tanzania (Figure 1). The archipelago features a numberof Swahili sites known as 'stonetowns', which include stonehouses, wattle and daub structures, mosques and tombs, including one of the most prominent towns within the Swahili world, Kilwa Kisiwani (Chittick 1974; Horton and Middleton 2000; Fleisher *et al.* 2015). Kilwa Kisiwani was a key town in the Swahili trade network trading 'Gold, ivory, ambergris, iron, timber and slaves' for 'fine silks and fabrics or glazed and decorated ceramics' (Wynne-Jones 2007, 368). These key trading towns, with their stone architecture, were part of a wider settlement pattern which included wattle and daub architecture alongside coral and lime 'stone' architecture and a farming and fishing population (Wynne-Jones 2007).

It is likely that Songo Mnara was related to Kilwa Kisiwani, although there is no clear understanding of the relationship between the towns, compounded by the paucity of historical references to Songo Mnara and, more generally, this part of the East African Coast (Freeman-Grenville 1962; Wynne-Jones 2016; Wynne-Jones and Fleisher 2016, 352). The relationship is perhaps implied by the establishment and rapid construction of the town on Songo Mnara during the late 14th century; a period during which there was also a focus of stonehouse construction at Kilwa Kisiwani and it is possible that Songo Mnara may have stemmed from the urban expansion of Kilwa Kisiwani into the archipelago (Wynne-Jones 2016). This may be further supported by the way in which

not only the establishment but also subsequent decline of Songo Manra follows the same pattern of activity as Kilwa Kisiwani, which rapidly declined after subjugation by the Portuguese in the eary 16th century AD (Wynne-Jones 2013,765). It is noteable that whislt the decline at Kilwa Kisiwani was a gradual one, at Songo Mnara there was a more immediate 'abandonment'of the settlement in the early 16th century AD (Wynne-Jones 2013, 765). The structures at Songo Mnara present a unique opportunity to understand the use of the settlement and individual spaces within a relatively short occupation phase, lasting only 100 years from the late 14th to the early 16th centuries AD through well-preserved occupation surfaces and surrounding spaces, which have been minimally impacted by later activity (Wynne-Jones 2013, 765).

The stonetowns at Kilwa and Songo Mnara were part of the final stages of development of a network of stonetowns along the coast of East Africa, with a focus on trading with the Indian Ocean rim. Urban developments began in the 8th and 9th centuries AD and at Kilwa, declined from the early 16th century AD. Songo Mnara was established late, at the peak of coral and lime construction on Kilwa Kisiwani, in the late 14th century AD, prior to this, coral and lime had largely been reserved for the construction of religious and monumental structures incluing mosques and tombs and by the establishment of Songo Mnara; despite a short occupation, more than forty coral and lime built houses and five mosques were constructed, as well as wattle and daub structures, enclosed within a town wall (Wynne-Jones 2013, 759; 763).

Excavations at other coastal Swahili sites, including Shanga in the Lamu archipelago of northern Kenya (Horton 1996), revealed a pattern of urban growth from early sites built of wattle and daub to dense urban settlements of stone architecture (coral and lime mortar) by the second millennium AD, yet wattle and daub architecture continued alongside the shift to stone architecture (Horton 1996). Historically, wattle and daub houses have been in the majority and stonehouses would have been built by the 'elite' residents (Wynne-Jones and Fleisher 2016, 352).. Stonetowns have traditionally been the focus of archaeological excavation including Kilwa Kisiwani (Chittick 1974), Manda (Chittick 1984) and Shanga (Horton 1996; Wynne-Jones 2007, 371-372); yet few wattle and daub houses have been excavated on the coast (LaViolette and Fleisher 2009; Fleisher and LaViolette 1999; Horton 1996). The survival of wattle and daub architecture appears to be dependent on burning, where the daub has been burnt or vitrified presenting a hard clay cap. Excavation at Songo Mnara is significant as a town

established between the 14th and 16th centuries AD has not previously been the focus of of excavation, which has tended to concentrate on the earliest periods of coastal occupation (e.g. Horton 1996; LaViolette and Fleisher 2009). There are also no similar examples of wattle and daub architecture from such a discrete period, likely because the identification of discrete watte and daub structures can be challenging due to specific preservation conditions required (La Violette and Fleisher 2009).

As discussed, in common with settlements along the East African coast, it is likely that the early occupation of Kilwa would have been based on wattle and daub architecture, although excavations focused on the later coral and lime architecture and the early development of the site is poorly understood (Chittick 1964).

1.3.1 Archaeological Background

Songo Mnara, an island with relatively thin *terra rossa* soils, was occupied for a relatively short time, established during the late 14th century, occupied during the 15th century, and abandoned very early in the 16th century (Fleisher and Wynne-Jones 2009; 2011; 2013; Sulas and Madella 2012). The town occupies a sandy area in the north west of the island, though there are areas to the immediate south of the stonetown which today support agriculture in the terra rossa soils (Fleisher and Sulas 2015; Sulas and Madella 2012; Pollard 2008). The 'open areas' of the site today, which contain the wattle and daub structures, are now subject to Coconut palm (*Cocos nucifera*) plantation, which is likely to have had a significant affect on the local vegetation dynamics and the preservation of phytoliths within the occupation horizons (Baker pers. comm. 2013).

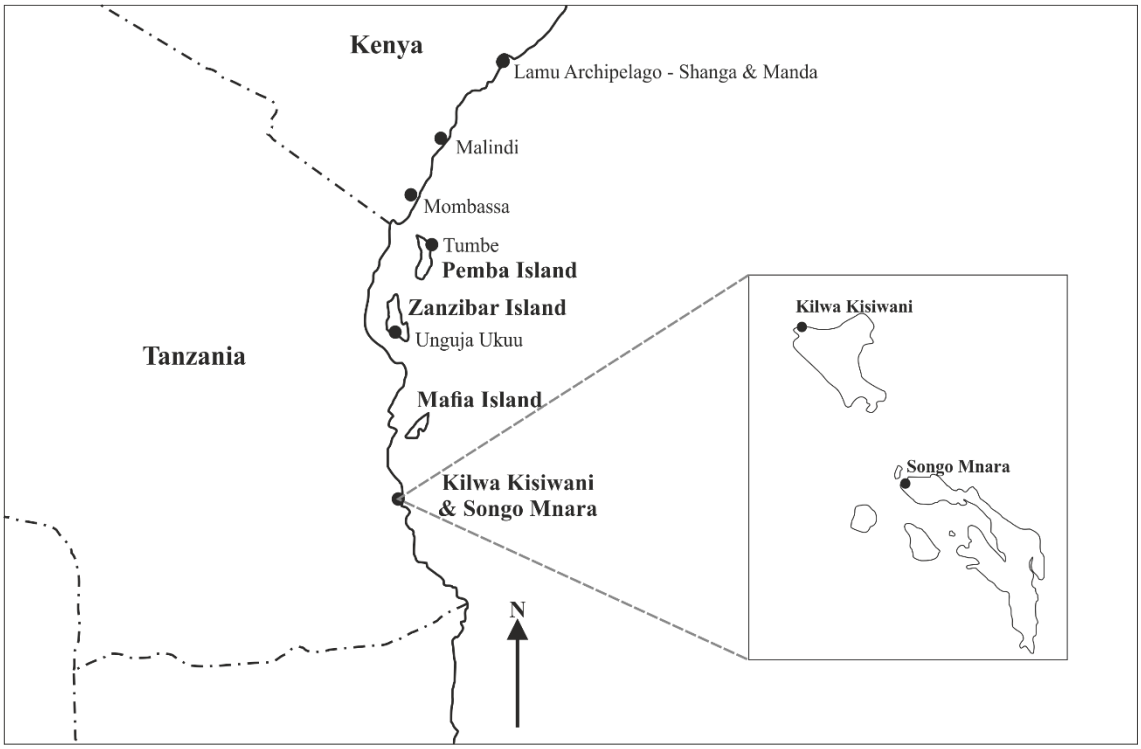


Figure 1: The location of Songo Mnara on the eastern coast of Africa, and in the Kilwa archipelago (inset)

At Songo Mnara, a programme of survey and excavation aimed to understand the use of space within the town (Wynne-Jones and Fleisher 2010, 2011). A multi-proxy approach was employed to develop an understanding of life within the town, in a domestic context, a public context and a ritual context, Methods including magnetometry and EM geophysical survey (Welham et al. 2014), open area excavations, and a programme of test-pitting and sampling for geochemical analysis, phytoliths, and charred plant remains within internal and external spaces were used to layer our understanding from the specific to the broader settlement (Sulas and Madella 2012; Fleisher 2014; Wynne-Jones 2013; Walshaw 2008).

This included the excavation of a range of coral and lime architecture domestic structures, wattle and daub structures, open areas and ritucal and commemorative spaces. Excavation of the Central Mosque in 2011, revealed its situation on a midden deposit raising it above the immediate topography, and featured a plaster floor with water tanks located at the southern entrance (Fleisher and Wynne-Jones 2013). The wooden roof was supported by a substantial post-pad and post (Fleisher and Wynne-Jones 2013a, 29; 31). Excavation of the Western Mosque revealed that the mosque had two phases of construction, the initial phase comprised two rooms; the subsequent phase

was related to construction of the town wall, and there is evidence for repair of the structure (Fleisher and Wynne-Jones 2013b, 27). Excavation of the Necropolis in 2009 provided the first evidence for memorialisation within the stone town, with deposits of coins, pottery and quartz pebbles (Fleisher and Wynne-Jones 2011, 60). Fourteen burials were excavated during the 2011 field season, and these provided evidence for memorialisation long after internment (Fleisher and Wynne-Jones 2013a, 32).The excavation of a well within an open area between coral and lime stonehouses and a Mosque revealed through the artefactual assemblage that these functional spaces also had a strongly social element (Fleisher and Wynne-Jones 2011).

The excavation of several examples of relatively short-lived late 14th-early 15th century Swahili stonehouses at Songo Mnara, constructed of coral and lime architecture revealed that as for the Mosques, the houses were constructed on raised platforms, with underlying made ground, perhaps to facilitate the entrance via staircases, or to facilitate the construction of the sunken courtyards (Wynne-Jones 2012, 759; Wynne-Jones 2013, 764).

Excavation within houses 23 and 44 revealed a range of internal activities including food production and spinning – evidenced through the presence of spindlewhorls, jiko fragments, and the presence of food debris in association with and an area of burning which may indicate the location of hearths (Fleisher and Wynne-Jones 2010, 60). Internal rooms featured plaster floors, and in some cases, floors of beaten earth (Fleisher and Wynne-Jones 2010; 2013). Evidence within in House 31 suggests that the burning of lime was undertaken internally for repairs for the plaster floor; similarly an area of lime production was identified in an open area between houses 47 and 48 (Fleisher and Wynne-Jones 2013, 26).

Wattle and daub structures were identified within the stone-built townscape, between stonehouses and in what were assumed to be open areas associated with the stonetown. A programme of test-pitting and EM geophysical survey were able to identify and confirm the presence of burnt daub *in situ*, which overlay floor platforms (Fleisher and Wynne-Jones 2011; Fleisher 2014; Welham et al. 2014).This facilitated the targeting of an open area trench over two wattle and daub structures, one of which, Trench 32, is the subject of this thesis. The results from the analysis of the wattle and daub structure are the focus of Chapters 7 and 8.

Wattle and Daub Structures

The smaller daub structure towards the southern part of the site, Trenches 31 and 35, was defined by the spread of daub and a compact earth floor silty sand deposit which formed a floor platform, a single structural post hole with a post pad of ceramic was dug into the natural beach sand (Fleisher and Wynne-Jones 2013b, 21-22). Three almost complete pots were concentrated at the eastern limits of the structure; however, the limits of the structure were not well defined and were ephemeral (Fleisher and Wynne-Jones 2013b, 22). An assemblage of artefacts was identified in association with the compacted earthen floor surface, including local and imported pottery, glass and shell beads, coins and iron objects; a quantity of glass beads and coins were concentrated around the post hole (Clarke pers. comm.; Fleisher and Wynne-Jones 2013b). Though the structure was sampled spatially for phytolith analysis, it was felt following excavation, that the structure had a less clearly defined floor surface than that of Trench 32, and that where preserved, this had been impacted by bioturbation from roots. Trench 32, discussed below, was much less impacted by intrusion of roots.

A second wattle and daub structure was excavated contiguously, and though both structures were selected for phytolith sampling, the structure within Trench 32 had a strongly domestic character as implied by the artefact assemblage in the field. The wattle and daub structure discussed here within Trench 32 featured clear evidence of domestic occupation, with a finds and ceramic assemblage comparable with that of the stonehouses (Fleisher and Wynne-Jones 2013b; Wynne-Jones 2013). This included personal items such as a kohl stick, a copper disc and a crystal bead, as well as local and imported pottery, a large quantity of glass and shell beads, iron and copper items and coins, some of which had been trampled into the working domestic floor surface (Fleisher and Wynne-Jones 2013b). Post-abandonment, the area appears to have been reused for craft production of aragonite beads (Fleisher and Wynne-Jones 2013b). A layer of collapsed and burned daub was identified, which covered a compact trampled silt/sand floor surface (Figure 2). Concentrations of daub at the limits of the floor surface were interpreted as ‘walls’ and it was evident from clear wattle impressions upon the daub fragments, that the daub was evidently pressed around the wooden structure. (Fleisher and Wynne-Jones 2013b). The occupation of the structure and the post-abandonment activity appear to have taken place during the 15th century AD (Fleisher and Wynne-Jones 2013b). It is not possible to establish a more detailed

chronology due to a reliance of artefact typology for dating (Fleisher and Wynne-Jones 2013). Archaeologically, there was little internal differentiation of features, due to the ephemerality of the structure. The primary deposit contained a number of posthole features related to the establishment of the structure, which were cut into the white sand and overlain by the floor surface and a concentration of daub (Fleisher and Wynne-Jones 2013b). At the lowest level, some posthole features appeared to be present, cut into the white sand, but these had not been visible at a higher level (Figure 2)

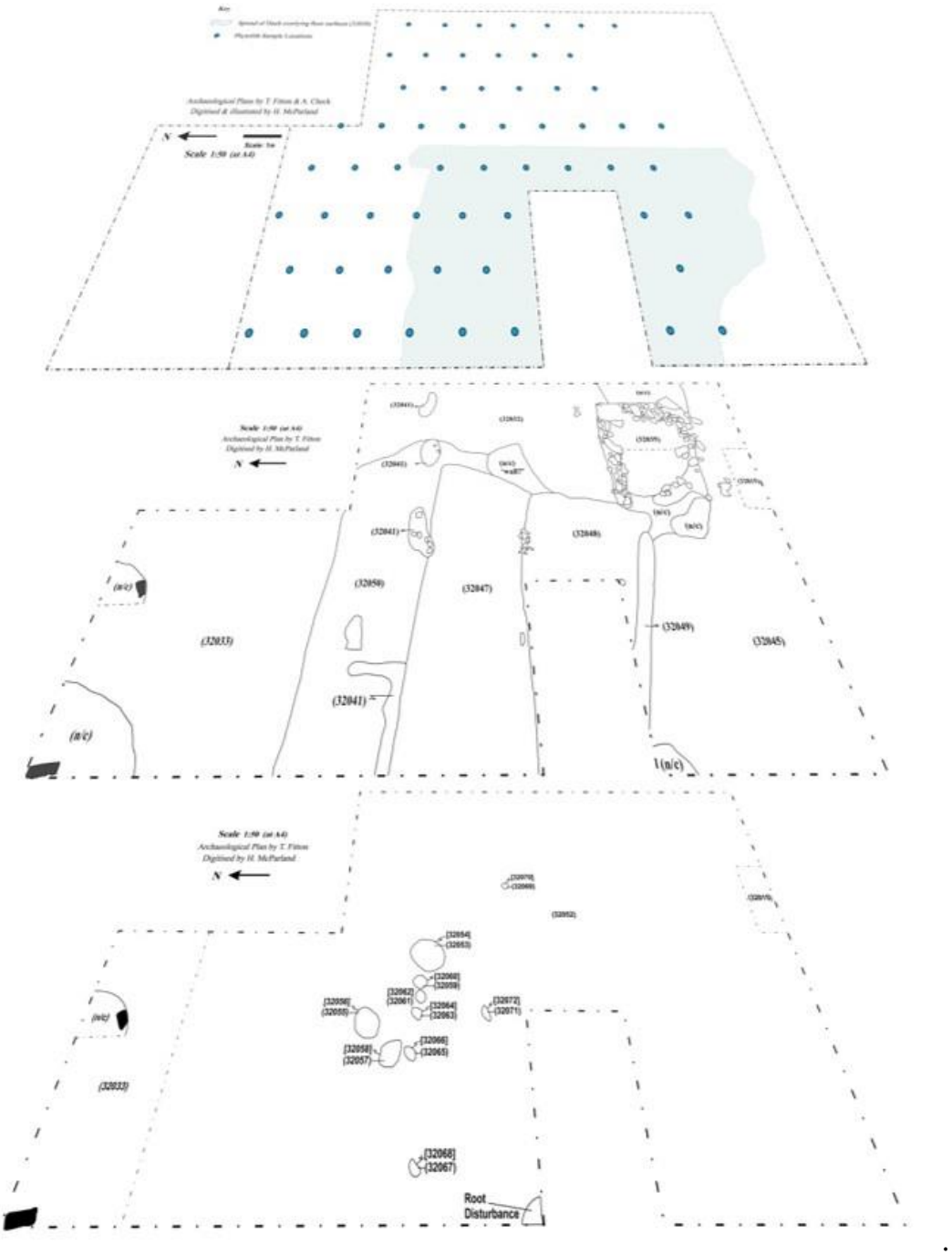


Figure 2: The location of phytolith samples taken from Trench 32, overlain onto phases of the structure as sampled and post holes

A space associated with the function of the domestic structure was identified (32050), and is interpreted archaeologically as an external space enclosed with or attached to the structure (Fleisher and Wynne-Jones 2013).

Figure 3 Wattle and Daub structure exposed within Trench 32 during excavation. McParland 2013

1.4 Plant use in the Swahili World: archaeological evidence and historical reference

The application of archaeobotanical analyses in East Africa is an emerging field, with growing evidence for the vegetal components of Swahili diet, craft or subsistence. Traditionally, archaeobotanical research has not been a focus of African Archaeology, of the 50 countries on the main African continent, only half have featured any archaeobotanical research (Fuller *et al.* 2014, 17). However, in East Africa, archaeobotanical sampling and recovery has been integrated into excavations of urban Swahili sites since the 1980's including excavations at Shanga, Pemba, Kilwa Kisiwani and Songo Mnara (Horton pers. comm.; Walshaw 2005; Walshaw 2010; Walshaw unpublished).

Excavations at Shanga employed an innovative systematic sieving approach to the recovery of finds and faunal material, using a 5mm mesh for recovery of artefacts and faunal remains (Horton 1996, 14) and flotation for the recovery of archaeobotanical remains (Horton pers. comm.).

Where there is a paucity of archaeobotanical evidence, this is often attributed to the greater effect of taphonomic processes in tropical environments, which impact on the preservation and recovery of charred plant remains (Hather 1994; Young 1999, 32). It is notable that major Swahili sites including Kilwa and Manda were excavated prior the adoption of large scale sieving and archaeobotanical flotation, though a concentration of charred sorghum (*Sorghum bicolor*), was visible in a household context at Kilwa (Chittick 1974, 52; Walshaw 2005, 55).

A comprehensive archaeobotanical sampling regime was employed during the excavation of urban and rural sites on Pemba Island, Zanzibar. Four sites were excavated over two seasons, 550 samples were processed and 100 were selected for further analysis, presenting the most comprehensive archaeobotanical study of Swahili plant use to date (Fleisher and LaViolette 2013; LaViolette and Fleisher 2009; Walshaw 2010; Walshaw 2005. Samples were taken from stone structures at Chwaka and wattle and daub or earthen dwellings at Tumbe, Kaliwa and Kimimba; facilitating an understanding of plant use within 'higher status' stone dwellings and wattle and daub structures, within an urban and rural hinterland setting dated between A.D. 8th-16th centuries (Walshaw 2005).

All archaeological contexts were sampled, where appropriate through the collection of composite samples, to provide a sample representative of the floor surfaces excavated (Walshaw 2005, 84; Pearsall 2000, 71). Discrete features were sampled through the collection of bulk samples (Walshaw 2005, 85).

The application of extensive archaeobotanical sampling in this context enabled distinctions to be made between urban environments which relied upon domesticated plant taxa, including pearl millet and rice, and rural environments, which exploited local food resources including fruits, starchy tubers and green leafy vegetables (Walshaw 2005). The evidence supports a family-centred food production model, rather than a centralised food production model designed to provide for urban consumption (Walshaw 2005). Rather, individual families undertook localised agriculture for subsistence, acting as a primary unit of trade (Walshaw 2005). Chwaka and Kaliwa, later settlements dated from 11^{th}-16^{th} Centuries AD, demonstrated a reliance on rice as a staple and increased use of imported crops (Walshaw 2005). The primary analysis of the assemblage focussed on food procurement strategies at urban and rural Swahili settlements, in order to assess the mode of Swahili food production and agriculture. The

research did not consider the spatial distribution of archaeobotanical remains within the structures, or differences in the use of space between rural and urban buildings. In terms of the wattle and daub structures, the ephemerality of the structures did not facilitate a systematic spatial approach (Fleisher pers. comm.).

Archaeobotanical remains are also being recovered from Songo Mnara from occupation surfaces within both wattle and daub and stone structures, providing an important comparative assemblage (Walshaw 2018). The spatially focused approach is, at present, unique to Songo Mnara on the East African coast. Although a broadly spatial approach was undertaken on Pemba characterising the open areas, the intensive and systematic approach at Songo Mnara is innovative. The arcaheobotanical results from excavations at Songo Mnara between 2009-2013 (Walshaw 2018) are discussed at length in Chapter 6, in the context of the phytolith results from Wattle and Daub structure 32.

1.4.1 Archaeobotanical Evidence: Trade of Organic Materials

Swahili trade is likely to have influenced the types of plant food consumed on Songo Mnara; there are clear trade links between East Africa and Aden on the Arabian Peninsula through the import of sgraffiato from the 11th to 16th centuries AD (Pollard 2008; Walshaw 2005, 230). In addition, trade links between East Africa and China are demonstrated through the import of celadon in the late 14th to 15th centuries and Blue and White porcelain from the 14th to 17th centuries AD (Pollard 2008; Fleisher and Wynne-Jones 2013; Walshaw 2005, 230). Given the nature of trade using the Monsoon system, it is possible that Songo Mnara was in trade contact with ports around the Indian Ocean rim. The majority of information related to trade of organic materials comes from archaeological evidence from the sites of Quseir al-Qadim and Berenike in North Africa which were directly trading with South East Asia, India and the Near East; and historical literary evidence from the Cairo Geniza and Quseir al-Qadim which support these trade links through shipping logs and trade accounts.

Most recently, the SeaLinks project incepted by the University of Oxford, has sought to establish early evidence of the transfer and transport of these crops by Indian Ocean sea routes, exploring ‘pre-Swahili maritime adaptations and early Indian Ocean trade connections’ through a series of re-excavations at key sites in East Africa to recover botanical remains, including Ukunju Cave on the Mafia Archipelago, Tanzania

(Crowther *et al.* 2014). Whilst the deposits at Ukunju contained imported pottery from the Middle East, China and South Asia, the resulting archaeobotanical assemblage contained only African crop species, demonstrating that although long distance trade connections were forged, in this instance, they did not initially appear to involve the movement of food items (Crowther *et al.* 2014, 41). This fits with the wider study which identified African crops as the dominant assemblage pre-11th century CE, with the exception of port sites which were engaged with Indian Ocean trade (Crowther *et al.* 2016).

The majority of African archaeobotanical research has focussed on Egypt (Fuller *et al.* 2014); the level of preservation of plant remains at Egyptian archaeological sites is often exceptional, revealing evidence of less visible archaeobotanical remains (Stevens and Clapham 2014, 151).

Archaeobotanical analysis at Berenike, Red Sea Coast Egypt, revealed evidence of local foodstuffs, as well as that of traded consumables, including the trade of Piper nigrum (Black Pepper) from India; providing the first support to historical literary sources. Berenike was well situated as an important Roman intermediary trade port for the transport of goods between the Indian Subcontinent and the near east as well as the interior African caravan routes (Cappers 1999). Excavations at another Red Sea port, Quseir al-Qadim, dated two distinct phases of activity, the first between AD 1-250, known as Myos Hormos, and the second during the Islamic period during the 11th-15th centuries AD (van der Veen 2011). Exceptional preservation at the site revealed evidence of the Indian Ocean spice trade through the identification of black pepper, ginger, cardamom and betelnut (van der Veen 2011; Cox and van der Veen 2008, 181).

1.4.2 Historical Evidence: Trade of Organic Materials

Few comparable port sites with preserved archaeobotanical assemblages enabling an understanding of plant based subsistence or craft, exist on the East African coast. Quseir al-Qadim is almost unique in featuring both an archaeobotanical assemblage and corresponding shipping logs, recording the trade of organic materials across the Indian Ocean from a contemporary Islamic site (van der Veen 2011). Further documentary evidence preserved within the stores of the Ben Ezra Synagogue in Fustat, Egypt, the Cairo Geniza, details the Jewish mercantile trade from Cairo, Egypt to Aden, Yemen

from the 10th to 13th centuries (Goitein and Friedman 2011). Both documents refer to the Indian Ocean trade with East Africa indirectly, the Cairo Geniza details Jewish mercantile trade with the Arabian Peninsula and India, several centuries before the occupation of Songo Mnara. Documents from Quseir al-Qadim are contemporary Islamic records, yet there is no reference to direct trade of plant resources with the Swahili (Goitein and Friedman 2011; van der Veen 2011). The value of these resources is as a demonstration of the types of organic or plant material which were involved in the wider Indian Ocean trade, and the way in which these goods were transported, though the limitations of these resources should be considered.

Analysis of the plant components of these historical records reveals a diversity of plant materials traded through the Indian Ocean trade network, unparalleled in the East African archaeobotanical record (see Appendix 11). Taphonomy has a role to play in this process; plant remains may not be visible in the archaeological record where they are not charred to enhance preservation. Therefore, where food preparation or production methods exist which preclude the opportunity for intentional or accidental charring, evidence of plant remains may not survive. On Pemba for example, the preservation of plant materials on house floors is attributed to an accidental event such as a fire, or the deposition of charred plant remains close to hearths (Walshaw 2005, 238). Hearths and areas of burning are often not visible archaeologically in East African contexts, and this can be attributed to food preparation methods that are unlikely to produce plant remains which are archaeologically visible, including the preparation of porridge or stew within pots (Young and Thompson 1999 as cited in Walshaw 2005, 71).

In addition, the use of *Mofa* (clay-pot) ovens is less likely to leave an archaeological signature, with ash or charred material emptied into a midden; in addition, house floors may have been swept, removing or reducing archaeobotanical remains from the archaeological record. *Mofa* (clay-pot ovens) were recorded archaeologically at Shanga (Horton 1996, 46).

Phytolith analysis has the potential to complement traditional archaeobotanical methodologies, providing evidence of plant materials which have degraded in-situ, preserved regardless of charring. Phytoliths have the potential to provide evidence of both plant based foods, food preparation practices and organic plant based craft objects.

1.4.3 Historical Evidence for Plant Use in East Africa

Evidence for plant use in East Africa is limited, largely due to the limited application of systematic archaeobotanical sampling on earlier archaeological sites (Boivin *et al.* 2013). The excavation of several large Swahili settlements including Shanga, Manda and Kilwa were undertaken prior to the systematic application of archaeobotanical sampling and flotation. As a result botanical evidence was only retrieved from one site, Kilwa, as a large concentration of charred Sorghum was visible during excavation within one of the structures (Chittick 1974). More recently, the successful application of archaeobotanical sampling (see above) has provided direct archaeological evidence of Swahili diet and crop processing.

Several historical documents which refer to travel along the East African coast, making reference to plant species in descriptions of destinations visited, suggest a wide range of plant resources growing both directly on Songo Mnara and Kilwa and along the entire East African coast. In addition, the documents refer to species which were being consumed.

Kilwa, for example, is described to varying degrees by Ibn Battuta, Prior, Dallons, Crassons de Medeuil and Bocarro (Freeman-Grenville 1962), suggesting that palms including Areca *(Areca catechu)* and Coconut Palm *(Cocos nucifera)* were growing on the island, though it *is* notable that references to *Cocos nucifera* occur at a later date (Freeman-Grenville 1962; see Table Appendix 10 for references). Rattan palm is described from elsewhere on the East African coast, and is still growing on Zanzibar today.

Several economic crops are referenced, including *Indigo (Indigofera tinctoria*), Cotton (*Gossypium* sp.) and Mangrove (Freeman-Grenville 1962). Consumable economic crops are discussed, including Millet and interestingly, Sugar Cane (*Saccharum officinarum*), though there is no archaeobotanical evidence for this at present (Freeman-Grenville 1962; see Appendix 10 for references). All of the authors agree that Rice was consumed on Kilwa, providing firm evidence alongside the archaeobotanical results from Songo Mnara, that *Rice Oryza* sp.) was consumed on these islands between the 14th-16th Centuries AD (Freeman-Grenville 1962; see Appendix 10 for references).

The historical documents make reference to the consumption and possible cultivation of spices though they are likely to be trade goods, on Kilwa, for which there is no comparable archaeobotanical evidence, including Tamarind (*Tamarindus indica*), ,

Cloves (*Syzygium aromaticum*), Black Pepper (*Piper nigrum*), Betel (*Piper betle*) (Freeman-Grenville 1962; see Appendix 10 for references). There is no comparable archaeobotanical evidence to suggest either the cultivation of spice herbs or their consumption.

The descriptions of Kilwa refer to it as a lush and green environment cultivating several fruits including Fig (*Ficus* sp.), Banana and Plantain (*Musa* sp.), and citrus including Lemon and Orange (*Citrus* sp.). Fig is represented in the archaeobotanical assemblage from Pemba (Walshaw 2005), but there is as yet, no archaeobotanical evidence for Banana and Plantain (*Musa* sp.), and citrus including Lemon and Orange (*Citrus* sp.) species are not at present represented in the archaeobotanical record. It is unlikely that they will be due to the method of preservation. There is no desiccated preservation on Kilwa or Songo Mnara, therefore these fruits would only be visible through carbonisation of their seeds. Given the lack of seeds within *Musa* sp. it is unlikely that these species would be archaeologically visible. There is some controversy surrounding the identification of Musa sp. phytoliths on the African continent, which is discussed in detail within section 2.5.

Further analysis of historical documents from the East African coast suggests the consumption of a variety of plan based foods, for example fruits including Mango *(Mangifera indica),* Date *(Phoenix dactylifera),* Lime (*Citrus sp.*) and Citron (*Citrus medica*) (see Appendix 11 for references). It is unlikely that Mango (*Mangifera indica*) was a trade item, though preservation for trade was described in the Cairo Geniza (Goitein and Friedman 2011, 317), it is probable that the species was imported to and cultivated in East Africa.

Spices, prominent trade goods as described in the Cairo Geniza (Goitein and Friedman 2011) are likely to have been traded with the East African ports, though there is no direct evidence of this. Spices and herbs described in reference to their occurrence in East Africa included Cumin *(Cuminum cyminum),* Frankincense *(Boswellia sp.),* Cinnamon *(Cinnamomum sp.),* Camphor *(Cinnamomum camphora)* and Nutmeg *(Myristica fragrans)* (see Appendix 11 for references). Again, there is no archaeological evidence for these species within the Swahili archaeobotanical record.

Evidently Swahili diet and cultivation practices were more varied than the archaeobotanical record reflects, the species noted in these historical accounts reflect a more diverse range of plant species as being present in close proximity to Swahili

settlements (see Appendices 10 and 11). The invisibility of many of these species may be due to preservational bias, and the application of phytolith analysis as part of a multi-proxy approach may help to broaden our understanding of the trade, consumption and use of plant species within Swahili settlements.

Historical documents including the Cairo Geniza (Goitein and Friedman 2011) make reference to an even wider diversity of plant resources involved in the Indian Ocean trade, which may have been connected to trade with East Africa through this. There is no documentary link between trade with East Africa and the Arabian Peninsula or Cairo, though artefactual envidence clearly links East Africa with this trading system.

It is clear that some plant resources discussed within the historical documents discussed above are invisible in the archaeobotanical record at present. The use of techniques such as phytolith analysis have the ability to expose uncharred plant assemblages and reveal evidence of materials not usually subject to preservation through charring. In order to understand the context in which these plants were used, intra-site spatial analysis of interior and exterior areas within a settlement may reveal evidence not only of the use of plant materials which were traded, consumed or formed craft based activities, but also of the context in which these plants were used

2. Literature Review

2.1 Introduction

This review introduces the environmental context of Songo Mnara, framing the site within both its local and regional environments. The local environment is considered in terms of climate and the influence of such factors on the local flora and the adoption of crop plants from other Tropical and Sub-Tropical environments. The local and regional environments, particularly the Monsoon systems, are key influences on the trade and transport of goods across the Indian Ocean, facilitating movement from the East African coast to the north of the continent, India and South East Asia.

The local environment of Songo Mnara is considered in terms of the influence of climate and geology on growing conditions on the island and the island ecology. There is limited evidence for plant based foods or organic materials within Swahili archaeology, though research on Pemba, Zanzibar and at Songo Mnara has sought to address this (Walshaw 2005; Walshaw 2018; Walshaw unpublished data).

Phytolith analysis is rarely applied to the understanding of spatial differentiation, particularly on the African continent which has rarely been the focus of phytolith research (see review in section 2.5). The analysis of trade documents, historical documents, and archaeological remains recovered from trade ports at Quesir al-Qadim and Berenike can help to provide information related to the trade of organic materials across the Indian Ocean (e.g. Cappers 1999; Goitein & Friedman 2011; Van der Veen *et al.* 2011). Information from these sources should be considered critically, as there are no direct references to trade with the Swahili, references to plant cultivation, flora, consumption and preparation are noted within historical documents and local histories refer directly to the East African coast, including Kilwa Kisiwani and Songo Mnara (e.g. Freeman-Grenville 1962). In essence, these documents provide evidence of trade of organic materials which had the potential to be traded with the Swahili in East Africa simply due to their inclusion within trade networks.

Archaeobotanical evidence for plant resources has traditionally been limited, though a renewed focus on archaeobotanical research has led to archaeobotanical research on Pemba and at Songo Mnara hasemployed a systematic approach to sampling , producing

contextually secure archaeobotanical evidence for Swahili plant use (Fleisher and Wynne-Jones 2011; 2013; Walshaw 2005; 2018). The application of phytolith analysis can provide evidence for plant materials which have not been charred, capturing the use of organic materials across an occupational surface, including those from non-food plants. The application of intensive systematic sampling for phytoliths across an occupation surface has the potential to reveal areas of activity within a structure. In particular, the potential of Phytolith analysis is considered within its regional and continental contexts.

There has been some success with the recent application of residue analysis to a copper-zinc alloy object thought to be the lid of an incense burner from Unguja Ukuu, Zanzibar (Crowther *et al.* 2015, 374). Analysis of residues adhering to the object by Gas chromatography mass spectrometry (GC-MS), identified traces of resin confirming the use of the object as an incense burner, and the use of fossil copal derived from from *Hymenaea verrucosa* (East African Copal) as an aromatic in the 7th- 8th Century CE (Crowther *et al.* 2015, 386). This is an important study, demonstrating the potential of residue analysis for the identification of plant uses which are not otherwise detectable by traditional archaeobotanical methods, or phytolith analysis.

Pottery residue analysis of an assemblage from Songo Mnara, which includes a selection of pottery types from across the site, is on-going (Wynne-Jones pers comm.) and the results have the potential to augment our understanding of plant use, trade and consumption at Songo Mnara.

A brief methodological review provides the background to a more detailed review in Chapter 6considering the potential of systematic sampling for spatial analysis within the context of Songo Mnara and within its wider continental and world contexts.

This review, undertaken in 2016, introduces the potential of phytolith research and presents the background information to support the interpretation and understanding of the importance of and the innovative aspects of this research within a local, regional and continental environment, drawing on wider Indian Ocean and world contexts where applicable. The review draws upon a range of historical and archaeological evidence to support this

2.2 Environmental Context

Songo Mnara lies within the Sub-Saharan, Afro-Tropical or wider Palaeotropical Biogeographical Zone (Linder *et al.* 2012, 1189). Traditionally, the African Sub-Continent has been considered within its confines in terms of phytolith research, though the flora of the continent is often considered part of the Palaeotropical Zone of 'Old World' flora covering the African and Asian Tropics, excluding the South American 'Neotropics'.

The continent of Africa is largely geologically stable, a continuous continent, divided into distinct vegetation zones influenced by climate - elevation and rainfall levels (Lovett and Friis 1996, 583; Reed *et al.* 2009, 770). Sub-Saharan Africa is diverse, with a huge diversity of flora and fauna, leading to debate and revision of intra-continental biogeographical zones over the past 100 years (Linder et al 2012, 1189). White (1983) produced a definitive vegetation map of Africa, detailing various vegetation zones. However, multivariate statistical analysis taking into account floral and faunal distributions has sought to clarify environmental zonation within the African continent (Linder *et al.* 2012).

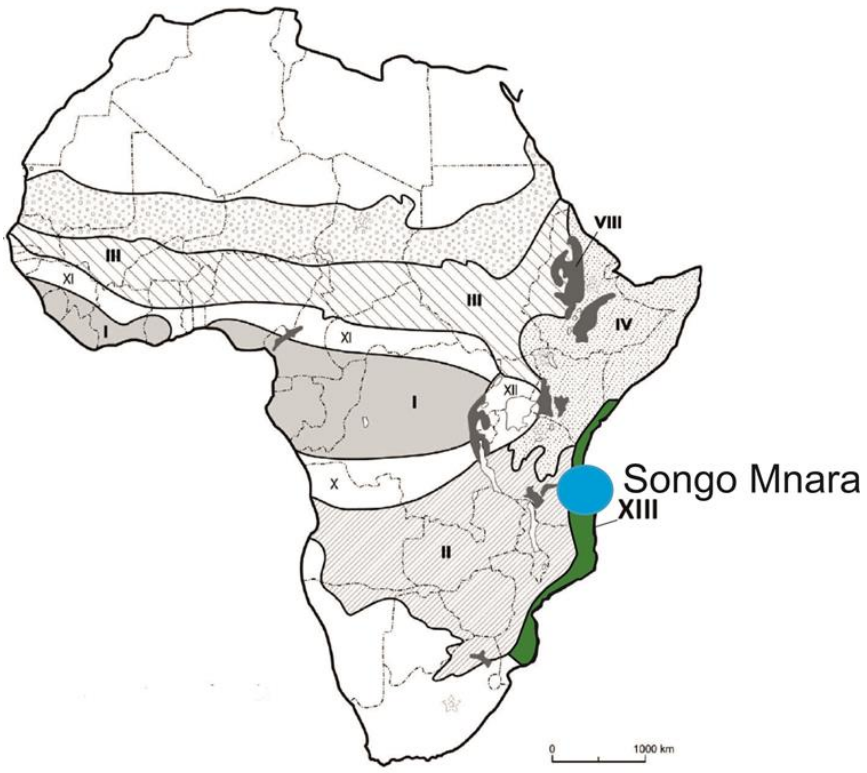


Figure 4 Songo Mnara shown within Zone XIII (after White 1983)

Songo Mnara is within Zone XIII 'The Zanzibar-Inhambane regional mosaic', detailed as its own unique vegetal composition of mosaic forest stretching along the coastal belt of tropical East Africa from Somalia to the mouth of the Limpopo river, largely below 200m elevation (with the exception of the East Usambara Mountains in Tanzania) and with rainfall levels on average between 800-1200mm per year (White 1983, 184). White (1982) is the primary reference for environmental background used in archaeological reports with an East African focus, relying upon the vegetation classifications as a broad background dataset. This thesis similarly refers to White (1983), though in reality Zone XIII vegetation along the coastal fringes includes units of Zanzibar-Inhambane undifferentiated forest, Zanzibar Inhambane scrub forest, 'separating the forests of the coastal region from the bushlands of the interior', Swamp forest, Zanzibar-Inhambane transition woodland and Zanzibar-Inhambane evergreen and semi-evergreen bushland and thicket (White 1983, 184-189).

The continent is rarely considered floristically with any other latitudinal biogeographical zones, it is noted that similar flora occur in both the Neotropics and the Old World Tropics, however, it is largely accepted that Sub-Saharan Africa forms a distinct Afro-Tropical Zone in terms of both Flora and Fauna (White 1983, 186).

Although botanically the flora of Africa has been considered within the confines of the continent, it is worth considering that a move away from palaeoenvironmental analyses introduces further anthropogenic influence. Fuller *et al.* (2011) explore the movement of plant and animal species across the Indian Ocean during prehistory, considering the movement of crops such as Pearl Millet (*Pennisetum glaucum*), Finger Millet (*Eleusine coracana*) and Sorghum (*Sorghum bicolor*) out of Africa, and the movement of Asian crops such as Broomcorn Millet and Banana (*Musa*) from Asia (547; 549); demonstrating a long tradition of movement of crops across the Indian Ocean from prehistory to the present day.

Recent research by the Sealinks project has sought to investigate the introduction of crops and the cultivation of plants within Madagascar, contextualised within wider Indian Ocean trade links (Crowther *et al.* 2016). This innovative approach to archaeobotanical analysis moved away from an intra-site approach, and assessed broad trends through a combination of new data from excavations in Madagascar, the Comoros and East Africa, contextualised within existing archaeobotanical datasets from East African sites (Crowther *et al*. 2016). The study revealed that all of the mainland

and coastal sites assessed, the archaeobotanical assemblage was dominated by African crops including sorghum(*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), cow pea (*Vigna unguiculata*) and baobab (*Adansonia digitata*), whilst Asian crops including Asian rice (*Oryza sativa*), mung bean (*Vigna radiata*) and cotton (*Gossypium* sp.), were concentrated within trading ports alongside evidence for Indian Ocean trade, representing only a small part of the overall archaeobotanical assemblage in these settings (Crowther *et al*. 2016, 6636-6637). Asian crops became more significant and reached a peak in the 11th century CE, and 'exotics' from the Near East began to occur alongside increasing trade with the wider Indian Ocean trade networks (Crowther *et al.* 2016, 6637). The project demonstrates the potential of archaeobotanical analysis and synthesis of intra-site studies, to contextualise Indian Ocean trade and crop introduction, along the East African coast; though the focu of the project was pre-11th century CE, further studies contextualising post-11th Century CE crop movement and trade, drawing on a larger dataset, may be valuable. In addition, this reseach highlights the movements of 'exotic crops' around the Indian Ocean and supports the discussion of visbility of plant remains in archaebotanical assemblages in section 2.3. Climate and rainfall levels are affected by the monsoon cycles that trade within East Africa relied upon. Two monsoon systems are active along the East African coast, the northeastern monsoon system is active between November and March, enabling trade between the near east, south and southwest Asia (Horton and Middleton 2000; McClanahan 1998, 192; Punwong et al. 2013b, 56; Walshaw 2005). The southeastern monsoon is active from April to October (Punwong et al. 2013b, 56). These monsoon cycles are directly affected by the Inter-Tropical Convergence Zone, the point at which these cycles meet (McClanahan 1998; Punwong et al. 2013a, 5; Punwong et al. 2013c, 383; Walshaw 2005). Further south down the East African coast, northeast monsoon activity in Rufiji, between Dar es Salaam and Songo Mnara, is active between December and April and the southeast monsoon between May and November (Punwong et al. 2013c, 383).

Climate and rainfall along the East African coast are influenced by a number of factors, including sea surface temperature (Marchant et al. 2006, 6; Punwong et al. 2013b, 56; Punwong et al. 2013c, 353); the shift between northeastern and southeastern monsoon patterns and wind strength and direction, increasing rates of precipitation between March and May and influencing shorter rainfall patterns between October and

December (Marchant et al. 2006, 6; Punwong et al, 2013b, 56). Research suggests that there is not one factor influencing climate and rainfall in East Africa, but a range of interacting factors (Marchant et al. 2006). For example, the Indian Ocean dipole (IOD), may have a regional impact on rainfall and climate anomalies in East Africa, and is a process of interactions between Sea Surface Temperature in the Western Indian Ocean (warm) and the Eastern Indian Ocean (cold), even small shifts in Sea Surface Temperature elicit an effect in terms of rainfall and wind, due to the increase in atmospheric moisture (Marchant et al. 2006).

The Arabian Peninsula is at the very limit of this monsoon system and directs Indian Ocean currents towards Africa (Parker *et al.* 2004). The southern monsoon cycle directs currents to the east between May-June, and towards the Arabian Peninsula in July, facilitating trade in the reverse direction (Horton and Middleton 2000; McClanahan 1998, 193; Walshaw 2005). Indeje *et al.* (2000, 22) divide the East African coast into two distinct zones based on an analysis of rainfall levels from 136 meteorological stations, including the Kilwa region. Whilst Zanzibar shares higher rainfall levels with Coastal areas of Kenya and Tanzania (zone I), Kilwa and Songo Mnara share rainfall levels of around 1000-1800mm per year average, with central and southern Tanzania (zone V) (Indeje *et al.* 2000; Davenport and Nicholson 1993). Rainfall and climate in East Africa affect the vegetal composition of the region and have a significant influence on anthropogenic activities within this environment, including farming, crop production and trade (Horton and Middleton 2000; Walshaw 2005; Lovett and Friis 1996, 583; Reed *et al.* 2009, 770). The environmental and climatic variability of Swahili settlements, traversing a 2500km transect of the East African coast, is evident in the effects of differing rainfall levels, geologies and vegetation (Walshaw 2005).

For example, the islands of Pemba and Zanzibar are located within an area of higher rainfall levels and higher vegetation diversity, facilitating greater resource exploitation and agricultural production (White 1983, 184). Songo Mnara is one of several trading communities situated on islands, including Pemba, Zanzibar, Kilwa, the Comoros Islands and Madagascar (Crowther *et al.* 2016; Walshaw 2005); the island ecology of Songo Mnara is directly influenced by its location in an area of lower rainfall levels and differing geology, which is likely to have a direct impact on agricultural output and diversity.

It is clear that the local climate is influenced to a great degree by the Monsoon cycles, not only facilitating trade with the Indian Ocean rim, but also affecting both regional and local climates, in turn influencing floral diversity and the range of crops adopted from similar tropical environments from South East Asia and later, the New World. In addition, regionally variable geology and climate along the East African coast influences island ecologies and the potential for agriculture, for example Zanzibar and Pemba have a more tropical climate and more diverse vegetation whereas Songo Mnara has a drier climate and comparatively poor soil. Whilst it is possible to grow rice (*Oryza* sp.) on Songo Mnara, growing conditions are not ideal, whereas on Pemba, conditions are more suited to riziculture. Islands often form their own unique ecology influenced by anthropogenic action.

Whilst there are both wider and local environmental impacts, Songo Mnara is subject to its own localised Island ecology which may have an influence upon the phytolith analysis. A further discussion of the local ecology on Songo Mnara is presented below.

2.2.1 Island Ecology and Environmental Exploitation

Songo Mnara is an island and supports a small island ecology, affected by anthropogenic activities including timber cutting and agricultural practices including the planting of crop plants and the clearance of existing vegetation for agriculture and plantation.

Songo Mnara is part of a group of islands off the Kilwa Peninsula situated within the Kilwa Estuary, of which the largest and most populous is Kilwa Kisiwani. Sangarungu harbour lies between Kilwa Kisiwani and Songo Mnara (Pollard *et al.* 2012). The geology of the island is comprised of areas of limestone 'coral rag' outcrop, natural quartz sand and sandy clay deposits, underlain by grey claystones (Nicholas *et al.* 2006, 442; Stoetzel 2011, 9). Part of the Kilwa geological group, the island is classified in the Kivinje subdivision observed across the Kilwa peninsula and on 'the low islands across the creek' (Nicholas *et al.* 2006). The northern, north eastern and southern boundaries of Songo Mnara are close to sea level on the edge of the inter-tidal zone, bounded by tidal Mangrove swamp (Pollard *et al.* 2012). To the west of the settlement, limestone cliffs rising several metres above sea level and eroded by tidal action have formed a natural inlet (Pollard *et al.* 2012, 48; Stoetzel 2011, 9).

Figure 5 The Location of Songo Mnara within the Indian Ocean

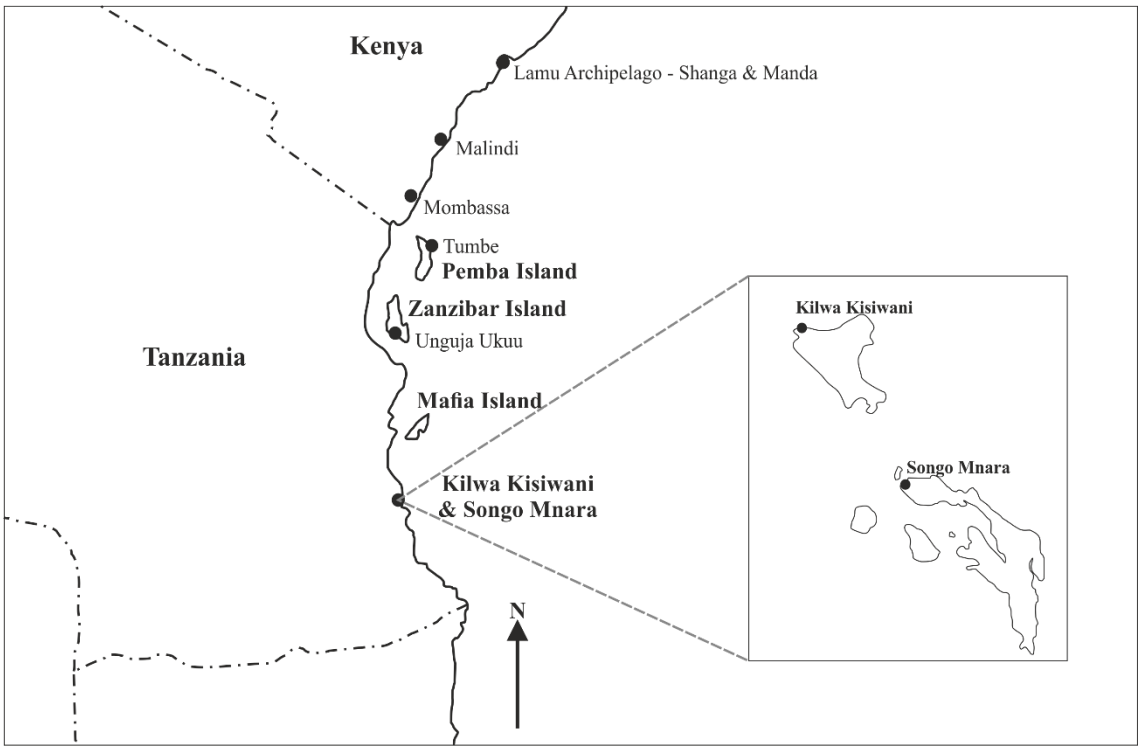


Figure 6 Modern Wattle and Daub structure at Kilwa. Image courtesy of S. Wynne-Jones

Nine species of mangrove are endemic along the coast of East Africa, six of these have been identified through survey on Songo Mnara (Muhando and Rumisha 2008, 18;

Nakamura 2011; Stoetzel 2009), whilst eight species were identified on Kilwa Kisiwani including Red mangrove (*Rhizophora mucronata*), Black mangrove (*Bruguiera gymnorrhiza)*, Red-Branched mangrove *(Lumnitzera racemosa*), Indian mangrove (*Ceriops tagal*), White mangrove (*Avicennia marina*), *Sonneratia alba*, Cedar mangrove (*Xylocarpus granatum*) and Looking-Glass mangrove (*Heritiera littoralis*) (Nakamura 2011). Red-Branched mangrove and Black mangrove were identified by the author on Songo Mnara during fieldwork in 2013. In East Africa, mangroves are traditionally used for firewood, charcoal making, boat building and fish smoking (Muhando and Rumisha 2008, 18). Mangrove wood was also used within the stone buildings of Songo Mnara as rafters for the ceilings, today it is used during conservation repair of the structures.

Contemporary wattle and daub structures, including those on Kilwa Kisiwani, are constructed using mangrove poles, infilled with mud and small limestone fragments and roofed with palm leaves (Nakamura 2011; see figure 6). Similar modern structures were observed on Songo Mnara and archaeologically, daub excavated from the wattle and daub structures at Songo Mnara features pole impressions, suggesting a similar method of construction. Mangrove wood was used on Songo Mnara, as elsewhere on the East African coast, for construction and for the manufacture of fish traps, Mangrove cropping is now prohibited by the Government to conserve the mangrove swamps, and other wood sources are now being exploited (Muhando and Rumisha 2008, 18).

Inland, Songo Mnara features outcrops of coral rag supporting dense thicket bushland and like Kilwa Kisiwani, areas of poor terra rossa soil overlying the limestone geology (Pollard 2008). In the immediate vicinity of Songo Mnara, a large coconut palm (*Cocos nucifera*) plantation has been established from the northern open area to the harbour of Sangarungu. Historical accounts and a DNA study of East African palms which included the plantation at Songo Mnara, suggest that coconut palms (*Cocos nucifera*) may have been grown on the island for centuries, perhaps since the occupation of Songo Mnara (Duran 1997; Schuiling and Harries 1994). It is likely that the plantation of *Cocos nucifera* has substantially influenced the vegetation in the area due to extensive nutrient requirements and large rooting systems (Baker pers. comm. 2013). It is also possible that the existing vegetation was cleared to create the plantation. Therefore, the environment within vicinity of the town of Songo Mnara may have changed substantially from the vegetation present on the site today.

Baobab (*Adansonia digitata*) trees grow near to the ruins of both Songo Mnara and Kilwa Kisiwani, producing an edible dehiscent dry fruit (see figure 7). These are not specifically cultivated, though the flesh of the fruit, dry at maturity, is consumed in its natural state, and can be prepared in a variety of ways. Similarly, baobab were noted growing in association with archaeology and relict structures at Shanga, and vegetation survey noted one baobab with a girth which indicated the tree may have coeoxisted with the active settlement (Horton 1996, 34). This association of baobab and archaeological remains is noted by Horton, who comments that 'baobabs frequently mark the location of ancient settlements along the East African coast' (Horton 1996, 34).

Figure 7 Stone structures at Songo Mnara, with coconut palm plantation in foreground and Baobab trees growing in association with the stone structures. Image © McParland, 2013.

Local farmers believed the terra rossa soil was good soil and they were happy with the growing conditions on the island, crops including sorghum (*Sorghum bicolor*), millet (*Pennisetum glaucum*), peas (Fabaceae) and papaya (*Carica papaya*) were observed growing in close proximity to Songo Mnara in the village of Mikadi (see Appendix 8). Banana (*Musa acuminate x balbisiana*), mango (*Mangifera indica*) and papaya (*Carica papaya*) were observed growing in the village of Mfuvu, whilst further afield, rice (*Oryza* sp.), okra (*Abelmoschus esculentus*), orange (*Citrus* × *sinensis*) and lime (*Citrus* sp.) were grown at Madaweni (see Appendix 8).

Cotton (*Gossypium* sp.) was grown in the Kilwa region until relatively recently (Sutton 1998 cited by Pollard 2008). Informal conversation with local farmers revealed that smallscale commercial growing was undertaken on Songo Mnara, and though this was not economically viable, cotton persists as an introduced species in some areas on the island. Cassava (*Manihot esculenta*), plantain (*Musa* sp.), sorghum (*Sorghum bicolor*), rice (*Oryza* sp.), okra (*Abelmoschus esculentus*), sesame (*Sesamum indicum*), cashew (*Anacardium occidentale*) and peanuts (*Arachis hypogaea*) are also cultivated in small fields of less than 1 hectare in Kilwa Kisiwani village (Nakamura 2011; Pollard 2008).

It is clear that present day Songo Mnara and Kilwa Kisiwani are able support the small scale agriculture undertaken by their respective local populations, through the cultivation of a variety of crops. It is likely that the present day island ecology of Songo Mnara has evolved due to anthropogenic influence, in particular the presence of baobab trees near to the settlement, and the modern coconut palm (*Cocos nucifera*) plantation. The presence of crops native to the New World introduced more recently, including papaya (*Carica papaya*), peanut (*Arachis hypogaea*), cashew (*Anacardium occidentale)* and cassava (*Manihot esculenta*) further support this assertion.

The environment of Songo Mnara and its local climate and geology have influenced to some extent the types of agriculture undertaken on the island in the present day. Both natural and anthropogenically introduced plant species were identified on the island during fieldwork (see Appendix 8), supporting the idea of Songo Mnara as an anthropogenically influenced island ecology. It is likely that some of the plant species present on the island in the present were first introduced to the local ecology during the occupation of Songo Mnara.

2.4. Intra-Site Spatial Sampling

Spatial sampling of horizontal surfaces facilitates an understanding of interactive social relationships and economic activities through the analysis of artefacts, faunal and archaeobotanical remains, geochemical data and plant microfossils preserved within an undisturbed archaeological matrix (Henry *et al.* 2008; Shahack-Gross *et al.* 2004). Integrity of the soil matrix is essential to enable the recording of meaningful spatial data; a multi-proxy approach provides a corresponding and complementary dataset to ensure that the patterning of data is non-random (Henry *et al.* 2008).

The interpretation of spatial data can provide an understanding of social relationships, including the interpretation and identification of public and private space within buildings, communal spaces and open spaces (Shahack-Gross *et al.* 2004). In addition, spatial sampling can identify areas of economic activity including livestock keeping and agriculture, and subsistence activities including food processing, preparation and storage, craft production and the use of organic artefacts (Shahack-Gross *et al.* 2004).

Household structures are often the focus of several activities within a small area, with distinct areas of activity, including cooking areas (hearths), sleeping areas, middens or pits and food processing areas (Tsartsidou *et al.* 2009).

Spatial sampling has traditionally focussed on the spatial distribution of artefacts, human or animal bones and plant macrofossils; the applications of microfossil analysis and soil geochemistry are more recent, enabling an understanding of the spatial distribution of activities within a settlement (Tsartsidou *et al.* 2008). The processes of deposition, combined with contemporary cultural processes such as floor cleaning or maintenance have led some researchers to refute the use of artefacts as a sole method for spatial analysis, instead referring to *in-situ* indicators such as geochemical analysis or phytolith analysis (King 2008).

The use of micromorphology and the application of geochemical analysis have been widely applied to address spatial questions. These methods enable the identification and interpretation of the use of space in contexts where preservation is limited and features are not immediately visible. This can facilitate the identification of areas indicative of activity areas such as hearths and areas of crop processing (Middleton and Price 1996; Rondelli *et al.* 2014) or food preparation and craft production (Milek and Roberts

2013). In addition, micromorphology and geochemical analysis can aid the identification and interpretation of midden deposits (Shillito 2011), agricultural and subsistence activities, commemorative activities and the use of open spaces (Sulas and Madella 2012).

Phytolith and geochemical signatures as in-situ indicators are considered more reliable than artefacts or charred plant materials due to lesser effects of post-depositional processes (King 2008). Phytoliths are still subject to both pre and post-depositional taphonomic effects, which must be fully considered. The application of ethnographic analogies can help to mitigate this by enabling the observation of depositional and post-depositional effects, providing an understanding of taphonomy and the role in which human action influences this.

2.4.1 Ethnographic Applications

The development of an occupation surface is a complex process formed through a range of intentional or unintended cultural actions, spatially and temporally, creating palimpsests of activity indicators (Milek 2012). Ethnographic studies employing phytolith analysis as a method of spatial differentiation address the issue of floor formation and taphonomy through the provision of modern analogues to aid the interpretation of spatial patterning (Tsartsidou *et al.* 2008; Shahack-Gross *et al.* 2004; Rondelli *et al.* 2014)

For example, Milek (2012) demonstrated that the distribution of charred plant materials and burnt bone fragments were not always indicative of the loci of processing or consumption, representing the redistribution of materials from the hearth. Conversely, phytoliths can provide evidence of plant remains which were not subject to charring, although valuable in-situ indicators (Tsartsidou et al, 2008), the depositional environment, floor surface type and post-depositional factors can affect the integrity of the assemblage. Frequent cleaning of floor surfaces may displace or remove plant remains or phytoliths, though these may be preserved in high traffic areas or areas which are harder to reach, for example the corners of a room, entrances or exits (Milek 2012).

The floor surface onto which the remains are deposited can also affect the preservation of material - material may be preserved, moving through the soil profile due to trampling on compact sand floor surfaces, whereas ‘displacement’ is more likely to take place through cleaning on a compact plaster floor surface (MacPhail and Crowther

2007, 108; Milek 2012). Displacement is likely to be influenced by the availability of space, where space is restricted displacement is more likely to occur due to these processes; cleaning and flooring processes including plastering, or relaying flooring material, may also influence the phytolith assemblage to a greater extent than other cultural activities (Boivin 2000, 372; Milek 2012).

Ethnographic evidence suggests that phytolith concentrations can remain the same for all activity areas, with higher concentrations recorded in discrete features which have accumulated organic material, including refuse pits and hearths (Shahack-Gross 2004).

2.4.2 Post-abandonment Processes

Spatial sampling also has the potential to reveal post-abandonment processes; a structure may undergo a secondary use of space which may leave secondary deposits overlying the occupation surface. For example, structures may be used for storage, or for the keeping of livestock, obscuring the phytolith signature of the primary use of the context (Tsartsidou *et al.* 2008). Construction materials may also be identified through the phytolith assemblage, or the absence of phytoliths (Tsartsidou 2008).

2.4.3 Intra-site Spatial Analysis

Intra-site spatial analysis combines the analysis of activity loci on intensive and extensive scales, for example, the analysis of activities within a structure, or the analysis of activities within an environmental locus. In order to understand the relationship between an intensively sampled structure and its environment, the relationships and interactions between structures and the local environment must be considered (Shahack-Gross *et al.* 2004).

The analysis of adobe or wattle and daub structures with packed sand or adobe floor deposits may differ from that of stone buildings with plaster floor surfaces. Firstly, there may be variations in social practices or status between daub structures with packed sand floor surfaces and stone structures with plaster floor surfaces (Boivin 2000, 378). Secondly, post-depositional effects differ between packed sand and laminated clay or plaster floor surfaces, for example laminated clay or plaster floors may be re-surfaced seasonally or for cultural or religious events, whereas loose floor surfaces including packed sand facilitate the trampling and profile migration of artefacts and plant material leading to higher phytolith concentrations (Boivin 2000, 372; MacPhail and Crowther 2007; Milek 2012; Tsartsidou *et al.* 2009; Tsartsidou *et al.* 2008). The maintenance of floor surfaces can obscure cultural phytolith assemblages, an ethnographic example

from Thverá demonstrated that the spreading of ash and relaying of turf flooring designed to keep the food storage areas clean obscured the phytolith signature for food processing (Milek 2012).

Where intensive sampling is undertaken within structures for the identification of activity areas, the phytolith assemblage may not be easily distinguishable from that of the local environment due to post-depositional processes, though it is likely to differ from that of the regional environment (Tsartsidou *et al.* 2009; Shahack-Gross *et al.* 2004). The sampling of 'open areas' in the immediate vicinity of intensively sampled structures may not demonstrate spatial variability of the phytolith assemblage as these areas are also subject to intensive anthropogenic effects (Sullivan and Kealhofer 2004, 1663).

Where ephemeral deposits exist, the application of spatial sampling is essential; where diagnostic features including hearths and pits are not visible, the interpretation of activity areas is solely dependent on the spatial distribution of artefacts, microfossils and geochemical signatures (Middleton and Price 1996; Milek 2012; Sullivan and Kealhofer 2004). In addition, systematic sampling for spatial analysis has the potential to broadly contextualise the environment in which structures are situated; where structural boundaries are ephemeral, this approach may define the limits of these structures within their environments.

Phytolith concentrations have the potential to differ between rooms, ethnographic studies have demonstrated that areas within structures may differ substantially, for example less 'public' rooms such as store rooms may have more phytoliths due to a lack of floor covering, increased trampling of organic material or less 'cleaning' and resurfacing (Milek 2012; Shahack-Gross *et al.* 2004; Tsartsidou *et al.* 2008). Some structures, such as have clearly defined boundaries and internal divisions, immediately highlighting a difference in space within the structure. Conversely, more ephemeral daub structures do not have clearly defined boundaries or internal divisions; in both cases the application of high resolution systematic sampling has the potential to provide comparable and complementary data for spatial analysis. For example, systematic sampling for phytolith analysis within the rooms of the stone house (House 18) has the potential to identify plant-based activity areas within these delineated spaces; systematic sampling throughout Trench 32, including the daub structure, may identify similar phytolith signatures and similar activity areas to the stone house, enabling comparison

between the structures. This analysis is only possible with the application of intensive high-resolution spatial sampling.

Intra-site spatial analysis, particularly for the identification of activity areas in an urban environment, has not been attempted on the scale of investigations at Songo Mnara. Traditional applications of the technique on the African continent have instead focussed on the identification of areas of archaeological activity within a landscape, or the distribution of artefacts (Shahack-Gross *et al.* 2004).

2.4.4 Scale of sampling

Sampling for spatial analysis requires a systematic approach, particularly where the archaeological horizons are ephemeral. The scale of sampling within structures ranges from the targeted – high traffic areas, corners and centres of rooms (Sulas and Madella 2012) to the intensive 50cm or 1m for geochemical analyses (King 2008; Middleton and Price 1996; Sánchez *et al.* 1996). Wider scale local environment patterns are often systematically sampled on a scale from 2-5m to ensure that activity areas are identified and to provide a representative assemblage for analysis (King 2008; Sullivan and Kealhofer 2004, 1662). Sampling at Songo Mnara follows these methodologies, sampling at a scale of 50cm for geochemical analysis, and 1m for phytolith analysis across interior floor surfaces. Wider scale local areas at Songo Mnara are sampled on a 5m grid.

2.4.5 Micromorphology

An understanding of the formation processes of floor surfaces is essential for the interpretation and identification of the systematic sample surface, to ensure that the material studied truly represents the occupational surface or anthropogenic horizon, and that the depositional environment and post-depositional actions are fully understood (Matarazzo *et al.* 2010; Milek 2012). The development of an intensive sampling strategy should be supported by the use of soil micromorphology to contextualise the floor formation processes (Milek 2012). Micromorphology is particularly useful where deposits appear stratigraphically homogenous clearly identifying the floor surface, particularly where floor surfaces have undergone regular maintenance and re-surfacing or intensive activities leave a palimpsest of multiple super-imposed events (Milek 2012; Sulas and Madella 2012; Tsartsidou *et al.* 2009). Singular systematic sampling from a horizontal surface, as at Songo Mnara will homogenise palimpsests, producing a ‘time-

averaged' result whereas the combined application of micromorphology with systematic sampling enables an understanding of floor formation processes to aid the interpretation and selection of systematic samples (Milek 2012). The identification of in-situ deposits including phytoliths is also possible through micromorphology, verifying the integrity of the deposit and supporting systematic sampling of horizontal surfaces (Matarazzo *et al.* 2010; Shahack-Gross 2004). However, although micromorphology can provide information about the spatial integrity of the occupation surface, capturing phytoliths in situ, these may be partly obscured by the preserved organic material and the sole use of soil micromorphology will not provide the quantity of phytoliths required to assess the use of space.

The application of micromorphology may have enabled the post-depositional sequence of the daub structure to be established, enabling the compact sand floor surfaces to be clearly identified. It would also provide valuable information about the integrity of the samples in terms of bioturbation. However, the application of soil micromorphology relies on adequate field conditions and though possible within the stone structures, the sandy matrix within the daub structures at Songo Mnara was too loose to be safely sampled and transported intact. The integrated high resolution approach undertaken within the stone structures during the 2009 excavation season, which feature lime plaster floor surfaces with inset drains, enabled the identification of varying signatures indicating different activities taking place in different rooms (Sulas and Madella 2012, 156). In addition, the application of soil micromorphology enabled an understanding of post-depositional processes, and characterised building materials including daub and plaster (Sulas and Madella 2012, 153; 155; 156). It is possible that the application of soil micromorphological analysis might provide information about cleaning and re-plastering episodes when combined with the spatial resolution afforded by systematic sampling.

The use of soil micromorphology may have provided important contextual information about floor formation processes within the structures subjected to systematic sampling during the 2013 excavation season at Songo Mnara. Micromorphological analysis was successfully undertaken within stone house 44 at Songo Mnara during the 2009 excavation season (Sulas and Madella 2012, 148). The application of soil micromorphology can address some of the potential limitations of complementary techniques including phytolith analysis, enabling an understanding of taphonomy and

bioturbation affecting related proxies (Sulas and Madella 2012, 147). In addition, the application of soil micromorphology can enable an understanding of the formation processes and activities within ephemeral structures including daub structures (Sulas and Madella 2012, 147).

Though capable of providing information about taphonomy and bioturbation which may affect the phytolith assemblage, the analysis of soil micromorphology was not undertaken during the 2013 field season, particularly as the soil matrix within Trench 32, the daub structure, was too loose to enable sufficient sampling and transport from the field. To mitigate this, larger scale systematic sampling was employed for phytolith analysis.

2.5 Phytolith Analysis on the African Continent

In recent years, interest in the use of phytoliths as a tool of palaeoenvironmental analysis has developed, following the increasing integration of scientific techniques in African archaeology following a world trend (Killick 2006, 1).

Phytolith analysis on the African continent has focussed largely on the potential of the technique for palaeoenvironmental reconstruction and palaeoclimatology and the reconstruction of grassland dynamics, essential for both disciplines (Sulas and Madella 2012, 157); themes originally identified by Rovner (1983). With these aims in mind, several taxonomic studies have been carried out to identify the production of phytoliths within grasses, in East Africa, central Africa and West Africa (Fahmy 2007, 3; Palmer *et al.* 1985; Palmer and Gerbeth-Jones 1987; Palmer and Gerbeth-Jones 1986; Palmer and Tucker 1983; Palmer and Tucker 1981; Mercarder *et al.* 2010, 1953). East Africa has been the primary focus of research into grassland dynamics on the continent, and has remained so, despite the broadening of research into central and western Africa, likely due to interest in the environmental background to human evolution (Fahmy 2007, 3; Mercarder *et al.* 2010, 1953).

Grassland dynamics have been the key focus of research on the continent due to the abundant production of diagnostic phytoliths, which in many cases can be identified to genus or species level. In addition, the habitat specific requirements of grass species - including particular levels of precipitation, humidity and temperature – make them particularly suitable for palaeoenvironmental and palaeoclimatic reconstruction (Mercarder 2010, 1965). The suitability of grasses for palaeoenvironmental

reconstruction has seen the technique widely employed within Africa (Albert *et al.* 2006, 79); though more recent studies have begun to consider the assessment of tree cover through ratios of dicotyledon and grass phytoliths (Mercarder 2009).

It is widely acknowledged that phytolith analysis on the African continent is still within its infancy (Runge 1999, 24; Mbida 2009, 131; Sulas and Madella 2012). Research into the production of phytoliths within African taxa essentially began with Palmer's seminal study into the production of silicates within the epidermis of East African grasses, whereas research into African, Asian and European taxa has continued from the late 19th and 20th Centuries, comparatively much less is understood about phytolith production, taphonomy and potential on the African continent (Fahmy 2007, 3; Palmer *et al.* 1985; Palmer and Gerbeth-Jones 1987; Palmer and Gerbeth-Jones 1986; Palmer and Tucker 1983; Palmer and Tucker 1981; Mercarder *et al.* 2010, 1953). This review seeks to reassess the status of African phytolith research through a systematic review of research carried out across the continent to date.

In the case of Songo Mnara, the systematic sampling of an urban built environment introduces the potential impact and influence of trade and exchange, expanding the zone of potential floristic influence across the Indian Ocean. Though it is essential to understand phytolith research within these connected areas, for example the Near East, India, China and South East Asia, this review focuses on the state of the art of knowledge of phytolith production and research in East Africa, providing contextualisaton for the original research presented in this thesis.

Few in-depth studies into the phytolith production patterns of individual plant families have been carried out on the African continent, two notable examples are Eichorn's analysis of the production of diagnostic phytoliths within the seeds of West African Commelinaceae (Eichorn *et al.* 2010) and Palmer's comprehensive analysis of phytolith production within the epidermis of East African grasses (Palmer *et al.* 1985; Palmer and Gerbeth-Jones 1987; Palmer and Gerbeth-Jones 1986; Palmer and Tucker 1983; Palmer and Tucker 1981). Eichorn *et al.* (2010) investigate the production of phytoliths in Commelinaceae, a family with a limited number of species which inhabit very specific environments; the presence of diagnostic phytoliths within Commelinaceae may facilitate the establishment of a more accurate palaeoclimatic proxy. In addition, the study attributes several morphotypes previously ascribed to Cyperaceae and

Marantaceae taxa to Commelinaceae seeds, demonstrating the importance of in-depth family specific studies into phytolith production.

Palmer's studies into the anatomy of the epidermal layers and the production of diagnostic silicates within the epidermal layers of East African grasses are highly significant, not least because of the abundance of Poaceae within the phytolith record but also due to the environmental specificity of individual taxa (Palmer *et al.* 1985; Palmer and Gerbeth-Jones 1987; Palmer and Gerbeth-Jones 1986; Palmer and Tucker 1983; Palmer and Tucker 1981). This specificity, combined with the comprehensive analysis of modern reference material taken from herbaria specimens using scanning electron microscopy, demonstrates potential for the increased resolution of palaeoenvironmental proxies, including the potential to provide reconstructions of precipitation and palaeotemperature (Palmer and Tucker 1981, 1). The study encompassed 142 grass species, occurring within Uganda, Kenya and Tanzania, following and comparable with Flora of Tropical East Africa, providing a key to the identification of grasses to genus and species level (Palmer and Tucker 1981, 1).

The significance of Palmer's study is recognised by Barboni and Bremond (2009) in their assessment of the relationships between phytolith production, environment and taxonomy in the grasses of tropical East Africa (Barboni and Bremond 2009, 29). The study aimed to assess the viability of a broader assessment methodology against the traditional identification of individual taxa, arguing that a lower resolution analysis may be equally significant for palaeoenvironmental reconstruction (Barboni and Bremond 2009, 30; 40). The study expanded on Palmer's seminal research, assessing 20% of the species and 79% of the genera listed in Flora of Tropical East Africa, reassessing the production of diagnostic phytoliths within the grasses of a wide range of habitats from coastal to highland species, statistically validating the findings through Correspondence Analysis (CA) (Barboni and Bremond 2009, 30; 37). The study also assessed the potential to discriminate between taxa to provide an understanding of shade levels in order to predict canopy cover, demonstrating that it was impossible to do so with certainty as the phytolith 'signal' produced also occurred in damp environments (Barboni and Bremond 2009, 40).Though the study found that it was possible to improve the interpretation of palaeoenvironmental data through further assessment of the morphological differences in phytoliths within Poaceae, it ascertained that in terms of interpretation, abundance of diagnostic morphotypes rather than simply occurrence is the key factor (Barboni and Bremond 2009, 40).

In a seminal paper on the potential of phytolith analysis, Rovner (1983, 245), making reference to the work of Palmer (Palmer and Tucker 1983; Palmer and Tucker 1981), discussed the potential of Poaceae phytoliths as a palaeoclimatic proxy, based on the assertion that grasses respond to a change in temperature, sometimes as little as ± 1°C (Rovner 1983, 245). In addition the review suggested the potential of grassland dynamics as a palaeoenvironmental proxy through the analysis of C_3 and C_4 grass composition (Rovner 1983). Rovner clearly identified the key themes that would dominate the phytolith research agenda, ultimately influencing and directing research on the continent for the past 30 years. However, these assertions stemmed from Palmer's seminal studies into the production of diagnostic phytolith morphotypes within East African grasses and the production of Flora of Tropical East Africa (Palmer *et al.* 1985; Palmer and Gerbeth-Jones 1987; Palmer and Gerbeth-Jones 1986; Palmer and Tucker 1983; Palmer and Tucker 1981).

Grasses have long been the subject of phytolith research due the domestication of selected species as a cultivar, as well as their potential as palaeoecological indicators (Rovner 1983, 249); grasses are highly adaptive and will rapidly react to environmental changes, for example, changes in temperature or irrigation, providing an excellent climate proxy (Rossouw *et al.* 2009, 223; Rovner 1983). Analysis of grass phytoliths is particularly beneficial as they produce abundant diagnostic phytoliths, the most abundant in the archaeological and palaeoenvironmental record (Mercarder 2010, 1965). In addition, phytoliths are preserved in a wide range of environments with the exception of the strongly alkaline, affording visibility of plant remains where the preservation of more tradition palaeoenvironmental remains, including pollen and plant macrofossils, is unfavourable (Alexandre *et al.* 1997b; Bremond *et al.* 2008, 210; Rovner 1983, 245; Scott 2002, 51; Wooller *et al.* 2000).

Building on this substantial research, Mercarder *et al.* presented a comprehensive series of papers exploring the production of diagnostic phytoliths in the woody plants and grasses of Mozambique through a study of modern phytolith assemblages in soils; subsequently exploring archaeological contexts in Mozambique (Mercarder *et al.* 2013; 2010; 2011; 2009) Mercarder (*et al.* 2009) initially sought to investigate the production of phytoliths within the woody plants of the Miombo woodlands, Mozambique – including dicots, eudicots and monocots (Mercarder 2009). The study presents the first comprehensive reference collection for modern dicotyledonous plants from the Miombo Woodlands of Mozambique, discussing issues of taphonomy and redundancy, as many

of the species tested did not demonstrate diagnostic phytoliths (Mercarder 2009, 1111). Though few diagnostic phytoliths were identified in the modern reference material from the Miombo, several taxa demonstrated important diagnostic features (Mercarder 2009, 1111). Mercarder *et al.* subsequently discussed the modern grasses of the Niassa Rift, Mozambique (2010, 1953), creating 'an extensive modern reference collection and the largest quantative taxonomy of grass phytoliths within the '"Zambezian" Miombos' (Mercarder *et al.* 2010, 1966). These extensive resources are discussed in terms of their potential contribution to palaeoenvironmental and palaeoclimatic reconstruction in the region; the creation of the most comprehensive phytolith reference is highly significant, paving the way for future archaeological studies (Mercarder 2010, 1965). In order to test the efficiency of these reference collections, as well as explore potential taphonomic issues, Mercarder undertook a study of modern soil phytoliths from the Miombo Woodlands, Mozambique (Mercarder 2011). Samples were taken from the Niassa Rift, Mozambique along a 50km transect at various elevations – (Mercarder *et al.* 2011, 139-140). The study revealed changes within the local arboreal and grass taxa in comparison with the modern flora (Mercarder *et al.* 2011, 146). Despite the presence of a wide variety of diagnostic phytoliths within the modern soil assemblages, it was noted that fewer phytoliths were represented in the modern soils than were known to be produced by the flora, revealing that 'silicification itself does not warrant taphonomic fidelity' (Mercarder *et al.* 2011, 143-144).

Drawing on this substantial resource, Mercarder *et al.* (2013) subsequently undertook palaeoenvironmental analyses of phytolith assemblages in the Mozambican Rift, with an aim to contextualise the impact of climate change on human evolution (328). Sediments from both Ngalu cave and lake shores at Mikuyu and Mvumu were examined, the former providing evidence of anthropogenic impact on the environment in the form of exploitation of local woodlands, grasslands and bamboo; the second providing evidence of a largely forested environment (Mercarder *et al.* 2013, 335).

Runge and Runge (1997) created a modern plant phytolith reference collection, focussing on Eastern Zaire, Rwanda and Eastern Kenya, subsequently analysing modern soil assemblages from the bogs of Eastern Zaire and Eastern Kenya.

A similar study in Olduvai Gorge, Tanzania, also sought to build a strong modern comparative reference collection to interpret and support palaeoenvironmental evidence of Hominin land use (Bamford *et al.* 2006, 95). This reference collection relied on

evidence from both modern local plant species and local soil samples representing the local vegetation (Bamford *et al.* 2006, 97). The study successfully identified large quantities of fossil pollen in archaeological sediments; these were interpreted with the aid of the modern reference material, facilitating palaeoenvironmental reconstruction (Bamford *et al.* 2006, 110). In a related study, the same team of authors question the validity of the phytolith record in comparison with the plant macrofossil record suggesting that taphonomic factors have introduced bias to the assemblage (Albert *et al.* 2006). The study assessed modern phytolith assemblages from a range of sediment matrices, concluding that an assemblage is subject to pre-deposition taphonomy – or the way in which the phytolith enters the soil, the authors point out the fact that bark phytoliths will only enter the soil on the death of the tree, which occurs less frequently than the death of monocots for example - , as well as subject to the post-depositional processes of bioturbation and dissolution (Albert *et al.* 2006, 90).

Several studies within the African continent have also sought to broaden phytolith research beyond a study of individual families or taxa, creating larger scale modern reference collections encompassing a range of plant families, including grasses, as well as a range of monocots and dicots. A study by Albert *et al.* (2006, 78) analysed both modern reference material and modern soils, as well as archaeological samples, exploring the production and preservation of phytoliths within the soils from grasses, sedges, palms and dicots in a taphonomic review.

Barboni (*et al.* 1999) carried out a pilot study in the Middle Awash Valley, Ethiopia, drawing on previous reference collections and studies of biogenic silica within grasses for the identification of grass morphotypes. The study considers the usefulness of phytolith analysis, primarily of grass dynamics and tree cover density, as an environmental proxy where pollen is not preserved in anthropogenic sediments (Barboni *et al.* 1999, 87). Though the study did not contribute further modern reference collection material, it critically considered the potential impact of multiplicity and redundancy in the production of phytoliths within grass species, on the interpretation of a phytolith assemblage to genus and species level (Barboni *et al.* 1999, 91).

Bremond *et al.* (2008, 210) carried out an analysis of modern phytolith assemblages in areas of known vegetation cover, in order to assess the reliability and potential of phytolith indices to estimate the composition of C_3 and C_4 grasses within the grasslands of the tropical mountain regions of East Africa. Phytolith indices enable statistical

analyses of the abundance of grass morphotypes indicative of C_3 and C_4 environments. This approach relies on the combination of three different phytolith indices; Ic – which measures the abundance of short cell phytoliths from Pooideae (C_3) in comparison to those produced by Chloridoideae (C_4) and Panicoideae (C_4) grasses as a whole in any given environment; Iph – which measures the abundance of Chloridoideae phytoliths in comparison to an assemblage composed of Panicoideae and Chloridoideae grass morphotypes; and D/P° - which compares the proportion of dicotyledon phytoliths with those produced by grasses (Bremond *et al.* 2008, 214-215). This combined statistical approach ensured that the indices represent the study environment, as they are capable of calculating changes in the ratio of C_3 and C_4 grasses, as well as the ratio of dicotyledons to monocotyledons, demonstrating both forest cover and grassland biomes (Bremond 2008, 220).

In addition to research carried out in East Africa, evidence for the development of grasslands within inter-tropical Africa has also been determined through phytolith analysis. A study by Alexandre *et al.* (1997), one of the earliest to reconstruct the environment in Africa through phytolith analysis, established a new palaeoclimatic record through the analysis of phytoliths from lake sediments; interpretation of these assemblages was based on the analysis of samples of modern phytoliths taken within known vegetation zones (Alexandre *et al.* 1997b). Runge carried out a similar study, (1999, 24) focussing on the phytolith assemblage within modern soils of north eastern and eastern Democratic Republic of Congo and the Central African Republic. Comparisons between known vegetation and phytolith samples provided favourable results for the assessment of both dicots and grasses within the assemblages, suggesting that taphonomic factors governing the deposition of phytoliths into the archaeological record were minimal, as most assemblages accurately reflected their surrounding vegetation (Runge 1999, 50). A broader study of modern soil phytolith assemblages builds on the studies carried out by Alexandre *et al.* (1997) and Runge (1999) synthesizing data from studies in Congo, Senegal, Central Africa, Ethiopia, Cameroon, Mauritania and Tanzania (Barboni *et al.* 2007, 455). This study was necessitated by the fact that local studies presented varying levels of success in terms of palaeoenvironmental reconstruction, particularly in terms of tree cover density (Barboni *et al.* 2007, 455-456).

Few studies have focussed on the impact of fire on the palaeoenvironment - Mworia-Maitima (1997) undertook an interdisciplinary study using pollen, charcoal and

phytolith analysis of a lake sediment core from Lake Simbi, Kenya – to identify the potential cause of a vegetation change identified through pollen analysis, dated to 3300 BP. The study successfully links the change in vegetation identified through pollen analysis with grassland fires, tentatively suggesting an anthropogenic cause and demonstrating the effectiveness of phytolith analysis as part of an interdisciplinary analysis suite (Mworia-Maitima 1997, 415-416).

Building on this success, Wooller (*et al.* 2000) undertook a similar interdisciplinary palaeoenvironmental study, aiming to understand the impact of fire on the grassland dynamics at Sacred Lake, Mount Kenya, East Africa (208). The study involved the application of pollen and carbon isotope analysis, in addition to indirect phytolith analysis of grass in order to improve on the taxonomic resolution of pollen morphotypes (Wooller *et al.* 2000, 207). Although phytoliths are in situ proxies representing vegetation, Wooller *et al.* undertake a novel approach, analysing phytolith morphotypes from within charred grass cuticles, providing taphonomic security (2000, 214). This approach has provided a valuable in situ comparison with the pollen assemblage and has successfully demonstrated the importance of fire in shaping the ecology of Mount Kenya (Wooller *et al.* 2000, 227). Wooller (2002) subsequently explored the methodological and taphonomical aspects of phytolith recovery from lake cores in tropical Africa for the purpose of palaeoecological and palaeoclimatological reconstruction in a methodological review.

Traditionally there has been a clear focus on phytolith production within grasses from East and Central Africa and the potential of the technique as a tool of palaeoenvironmental reconstruction (Fahmy 2007, 3). Fahmy has attempted to redress this imbalance, carrying out a preliminary study into the production and diversity of phytoliths within West African grasses based on modern herbaria specimens from the Sahel region, including Benin, Burkina Faso, Mali, Niger, Nigeria and Senegal (Fahmy 2007, 4). Morphometric analysis of grass bilobates from a range of species has increased the resolution of phytolith analysis and afforded identification, in some cases, to species level; in this case Fahmy demonstrates the value of the modern reference material, successfully identifying grass phytoliths from within an archaeological context in Nigeria (Fahmy 2007, 20).

Palaeoclimatic and Paleoenvironmental phytolith studies from West Africa are also somewhat lacking, Bremond *et al.* address this through the application of pollen

analysis and phytolith indices to assess the palaeoclimatic record in four bioclimatic zones defined by White (1982): the Guinean, Sahelian, Sudanian and Saharan zones (2005, 313). Modern soil samples were taken from areas within each of these zones, including from Mauritania, Senegal, Guinea Bissau and Guinea, with the vast majority coming from Senegal (Bremond *et al.* 2005, 313). The predeliniated vegetation zones were clearly defined in the phytolith assemblage, with representation of local fauna and regional faunal suites within these zones (Bremond *et al.* 2005, 322). In addition, differentiation between C^3 and C^4 grasslands was achieved, providing a valuable palaeoclimatic indicator (Bremond *et al.* 2005, 323). A further result of the study, supports the existing palaeoclimatic data, suggesting that a phytolith index developed to identify grass water stress can identify increased irrigation of grasses due to the increased production of bulliform cell phytoliths (Bremond *et al.* 2005, 323).

Neumann *et al.* (2009) use micromorphology, phytolith, pollen and charcoal analysis in the palaeoenvironmental reconstruction of the environment surrounding the site complex of Ounjougou, Mali. The palaeoenvironmental research agenda fits with the archaeological research agenda, hoping to gain an understanding of how local environmental factors may have influenced activities on site (Neumann *et al.* 2009). Grassland and vegetation dynamics are determined and demonstrate largely open grassland, unaffected by fire, framed by gallery forest (Neumann *et al.* 2009, 104). The study reinforces the importance of understanding taphonomy through micromorphology and an understanding of phytolith taphonomy, identifying a clear need for extensive modern reference material (Neumann *et al.* 2009, 104).

Lake Chad has been the focus of two phytolith studies to date. A study at Zilum, North East Nigeria, in the basin of Lake Chad focussed on the analysis of phytolith remains from a pit dated to 600-400 cal. BC, in addition to plant macrofossil analysis (Fahmy & Magnavita 2006). The presence of Panicoideae phytoliths within the pit, making up 8% of the phytolith assemblage is optimistically attributed to the possible inclusion of crop plants, such as *Sorghum bicolor*, *Pannicum* sp. and potentially Pearl Millet (*Pennisetum glaucum*), the function of the pit interpreted as a grain storage pit (Fahmy & Magnavita 2006, 831).

Phytolith analysis was also carried out in the Sahel of Burkina Faso and the Lake Chad area in Borno Sttate, north eastern Nigeria, in West Africa as part of a lager programme of palaeoenvironmental research (Polcyn *et al.* 1997, 181). A suite of

palaeoenvironmental techniques were used, including pollen and archaeobotanical analyses, with phytolith analysis supported by a large modern reference collection of 58 non-grass plant species selected based on environmental criteria (Polcyn *et al.* 1997, 182). Samples were taken from lake sediment cores and from archaeological sediments, with the latter yielding large assemblages of phytoliths (Polcyn *et al.* 1997, 183). The study proved the presence of potentially diagnostic phytoliths, though the results highlight the fact that a systematic study of phytolith morphotypes from modern reference material needed to be carried out to improve taxonomic identification (Polcyn *et al.* 1997, 183).

The most famous and contentious debate in Old World phytolith research surrounds the domestication of the Banana and its introduction to the African continent (Mbida 2009, 128). As Neumann & Hildebrand (2009, 354) succinctly put it, 'understanding *Musa*'s entry and spread across the African continent is…crucial to several major questions in African archaeology'. Bananas present a peculiar problem to archaeobotanists and archaeologists; where plant remains are visible in archaeological sediments their inclusion is usually due to charring or waterlogging of the seeds, vegetal structure or roots, in some cases, plant remains are visible through a proxy, such as pollen; leaving the vegetally propagated, often seedless, cultivated Banana almost invisible in the archaeological record (Vrydaghs & De Langhe 2003, 14; Perrier *et al.* 2011, 11312). This lack of visibility made the domestication and spread of the cultivated Banana from south east Asia to Africa difficult to trace prior to the discovery of diagnostic phytoliths within *Musa* species (Vrydaghs & De Langhe 2003, 14). The native range of the genus *Musa* spreads from Nepal and southern China to Indonesia and New Guinea; a single species is endemic to north eastern Australia (De Langhe *et al.* 2009, 166). Despite a possibly anthropogenic eastern outlier, discovered on Pemba Island, *Musa* species are not native to the African continent (De Langhe *et al.* 2009 166; De Langhe 2009).

Historically there were three theories of introduction - the first suggests that Bananas were introduced by the Portugese during the 16th Century (Mbida *et al.* 2009, 128); the second posits the theory that Bananas were introduced by Arab or Persian Traders before the 8th Century (Mbida *et al.* 2009, 128); whilst the third supports the idea that Bananas were introduced by Austronesian settlers in Madagascar during the first century AD (Lejju *et al.* 2006, 108; Mbida *et al.* 2009, 128). Blench (2009) examines both botanical and linguistic evidence, concluding that cultivated Bananas (*Musa*) may have arrived in West Africa through an as yet, unknown route, as part of an agricultural

package with Taro (*Colocasia esculenta*) and Water Yam (*Dioscorea alta*) (Fuller *et al.* 2011, 549; Neumann & Hildebrand 2009). Blench discounts entry into Africa through East Africa due to the lack of evidence of agriculture of the three crops (Blench 2009, 375).

Despite the commonly held belief that Bananas did not reach Africa prior to 2000 BP, recent research at Nkang, central Cameroon and Kivu, in the Democratic Republic of Congo provides evidence of the presence of cultivated *Musa* morphotypes in archaeological sediments dating to around 2500 BP, challenging these widely held beliefs and hinting at a potentially different type of agricultural subsistence than previously assumed (Lejju *et al.* 2005; Mbida *et al.* 2009, 128; 131; Runge 2001). Lejju (*et al.* 2006, 105) identifies the presence of *Musa* phytoliths in a sediment cores from Munsa, Uganda, dating conventionally to the past 1000 years, and more controversially to 4000 BC, presence far earlier than anything posited to date. Lejju *et al.* (2006, 108) self-critique the unusual result discussing the unusually early presence of *Musa* phytoliths in terms of taphonomy and the lack of integration with existing evidence, this is supported by agreement from Blench (2009). These findings have inspired substantial critical debate, questioning the route of entry to Africa and the route of dispersal and the time frame during which this may have happened (Mbida *et al.* 2009, 128).

Vansina questions the validity of the claim that phytoliths were present at Nkang, Cameroon as early as 2500 BP, focussing on possible issues with the secure dating of sediments from which the phytoliths were extracted and the potential for confusion between cultivated Banana (*Musa*) and native African false Banana (*Ensete*) (Vansina 2003, 174). The argument focuses on the limitations and validity of the modern reference material used to confirm the identifications of fossil phytoliths (Vansina 2003, 174). Though Mbida (*et al.* 2009) later rebut this, criticising Vansina's (2003) insistence on African Banana's having entered Africa through India.

Critically reviewing the evidence for the presence of *Musa* phytoliths in sediments dated to more than 2000 BP, presented by Mbida (*et al.* 2001) and Lejju (*et al.* 2006), Neumann and Hildebrand (2009, 357) question the validity of the claims based on Harlan and De Wet's (1973) criterion. Their adaptation of Harlan and De Wet's criterion suggests that order to confirm validity, the findings must be authentic - clearly identified and securely dated; abundant – high volumes of identified phytoliths; and crucially, must be able to be integrated with comparable contemporary research

(Neumann & Hildebrand 2009, 356). Neumann and Hildebrand critique the evidence presented by Mbida (*et al.* 2001) and Lejju (*et al.* 2006) for 'unreliable identification' of *Musa* species within their respective phytolith assemblages (based on photographic evidence) (Neumann & Hildebrand 2009, 359); for a lack of abundance, evidenced by low phytolith counts of 14 identified morphotypes (Lejju *et al.* 2006) and a lack of clarity due to a lack of quantification (Mbida *et al.* 2001; Neumann & Hildebrand 2009, 357; 359); and a lack of integration – questioning both the validity of dating calibrations, as well as a comparability issue with the local palaeoenvironmental record (Neumann & Hildebrand 2009, 359) .

However, Neumann and Hildebrand (2009) and Vansina (2003) fail to consider that the Nkang project in Cameroon (Mbida et al, 2000) was not solely a phytolith research project - that the evidence was opportunistic in nature and part of a multidisciplinary project - or discuss the retrieval of the phytolith assemblage, from pottery residue which provides some element of taphonomic security, or consider the comparative botanical evidence presented alongside the phytolith evidence, focussing solely on the evidence for Banana (*Musa*). Recent revisions of the identification criteria used for the Nkang, Cameroon assemblage confirm the presence of cultivated Banana (*Musa*) phytoliths rather than the native African false Banana (*Ensete*) (Perrier *et al.* 2011, 11313).

For secure identification, it is imperative that the cultivated variety of *Musa* is separated from the numerous endemic local varieties through extensive comparative phytolith reference material, the difficulty of which formed a large part of the debate surrounding the introduction and dispersal of the species in Africa (Mbida *et al.* 2009, 129; Neumann & Hildebrand 2009, 355). In particular the potential for confusion between the native African false Banana (*Ensete*) and the cultivated Banana (*Musa*) dominated the discussion (Mbida et al 2009, 131; Vansina 2003). However, Mbida (*et al.* 2001; 2009, 131) proved that both *Musa* and *Ensete* demonstrated distinctive characteristics that the other genus did not share, negating the need for statistical analyses between morphotypes as a method of identification to genus level.

There are few studies of phytoliths in their archaeological context on the African continent; this may be due to the general lack of employment of archaeobotanical techniques in African archaeology (Fuller *et al.* 2014, 17) or the fact that further local reference collections, analysis of phytolith production and taphonomic factors are all required to enable the interpretation of archaeological assemblages.

Shahack-Gross *et al.* (2003; 2004) undertook phytolith analysis within modern abandoned Maasai settlements in East Africa initially with an aim to identify livestock enclosures, broadening to examine the potential of phytolith analysis to identify spatial organisation within the settlements, an experimental study designed to consider a similar application to pastoral Neolithic sites in Eastern Africa. The study – presented in two papers – explores the potential of phytolith analysis, mineralogy, micromorphology and ethnography for the identification of activity areas within a temporary modern pastoral settlement environment of Maasai culture (Shahack-Gross 2003, 440; 457). The Maasai were selected as modern proxies as their current non-sedentary pastoral lifestyle presents similarities with the interpretation of prehistoric East African pastoralists (Shahack-Gross *et al.* 2003, 453). Samples were taken from four abandoned and one occupied Boma (house/settlement area) through 1x1m test pits, dug to a depth of 20cm. Both phytolith analysis and micromorphology were used successfully to identify livestock enclosures, though taphonomic issues were noted due to evidence of phytolith dissolution, potentially due to high levels of ammonia in an enclosed space (Shahack-Gross *et al.* 2003, 456). In addition the study was unable to differentiate between cattle and sheep/goat enclosures (Shahack-Gross *et al.* 2003, 457). Similarly, when analysing human habitation sites, refuse pits, hearths and livestock gates were readily identifiable through various combinations of phytolith analysis, micromorphology and mineralogical analysis (Shahack-Gross *et al.* 2003, 1406). However, surprisingly, perhaps due to the way in which the samples were taken, it was not possible to differentiate or identify those features which may be deemed most visible in the archaeological record, living surfaces, houses or fence lines (Shahack-Gross *et al.* 2003, 1406). The importance of phytolith analysis, micromorphology and mineralogy providing visibility to the most ephemeral of Africa's prehistoric cultures cannot be overestimated and the study provides a useful caution when selecting appropriate sampling strategies.

Specialists from other sub-disciplines within environmental archaeology are becoming more involved with Phytolith analysis. Badenhorst (2009), a Zooarchaeologist, explored the potential identification of livestock (cattle vs. sheep) within the enclosures of early Iron Age sites in Southern Africa, considering the taphonomic issues of introduction to the sediment and phytolith representation (Badenhorst 2009, 48). Badenhorst had more success differentiating between sheep and cattle dung than Shahack-Gross *et al.* (2003), however, the taphonomic issues raised, include the penning of various types of animals

within the same enclosure, and the increased defecation volume of cattle leading to over representation, are well considered (Badenhorst 2009, 48-49)

Recent research at Songo Mnara has developed a novel spatial approach as a tool of understanding the use of space within a Swahili stonetown (Sulas and Madella 2012). The study assessed samples from the interior occupation surfaces of a house structure, from within three room divisions, through micromorphology, phytolith and geochemical analyses (Sulas and Madella 2012, 149). The same analytical techniques were applied to the open areas within the immediate vicinity of the site in order to characterise use of space, the open area samples were taken on a 5m staggered grid - each sample was taken from the subsoil at a depth of 10cm rather than from defined archaeological horizons (Sulas and Madella 2012, 148). Spatial analysis on a micro-scale is a developing technique within worldwide archaeology, with few studies having employed the technique to identify activity areas within buildings (Tsartsidou *et al.* 2009; Rosen 2005; Shahack-Gross 2004). Even rarer is the application of combined systematic sampling within buildings and their associated open areas. The pilot study demonstrated the potential of a systematic sampling strategy for phytoliths and geochemistry to define activities within buildings, in particular, to differentiate between activities carried out within individual rooms (Sulas and Madella 2012, 156). Bulk samples were taken for phytolith and geochemical analyses, from the corners and centre of the rooms within House 44, as well as the door thresholds (Sulas and Madella 2012). The results suggested a difference in activity between the rooms, with the results for the southwestern room suggestive of food storage (Sulas and Madella 2012, 156). The results for the remaining rooms were less convincing, yet they demonstrated differences in chemical composition and in the phytolith assemblage (Sulas and Madella 2012, 157). A systematic sampling strategy using a grid system within the rooms may provide further evidence of activity within the rooms, with the potential to provide higher resolution results. In addition, the results of phytolith and geochemical analyses from the subsoil samples revealed areas of potential animal browsing and occupation (Sulas and Madella 2012, 155). Further systematic sampling from the archaeological horizon rolled out across all open areas may provide further evidence of the use of the open spaces within the settlement.

In Southern Africa, Scott presents a comprehensive review of the palaeoenvironmental evidence for grassland dynamics during the Last Glacial Maximum, considering published pollen, isotopic and phytolith evidence in terms of environmental

reconstruction (2002, 47). This review considers the dynamics of both C_3 and C_4 grasses through phytolith evidence, concluding that the contrasting pollen evidence from tropical Africa suggests that during the Last Glacial Maximum, those areas of woodland at present were in fact areas of sub-tropical grassland (Scott 2002, 55).

Though phytolith studies in tropical Africa are advancing beyond grassland dynamics and palaeoenvironmental studies to consider anthropogenic sediments, little research has been carried out to date in South Africa and southern Africa. A recent study by Cordova (2012) has built on this further, assessing the potential of phytolith analysis of C_3 grasses and Restionaceae phytoliths to form palaeoenvironmental and precipitation proxies (Cordova 2012, 1). Both C_3 Poaceae and Restionaceae species are strongly environment specific, favouring particular levels of precipitation; both species produce diagnostic phytoliths to species level (Cordova 2012, REF). Initial palaeoenvironmental studies were also carried out by Rossouw (*et al.* 2009) and Finnè (2010), with a focus on palaeoenvironmental analysis, grassland dynamics and palaeoclimates. A single study has been carried out in Lesotho, exploring the late Holocene environmental history of the Lesotho Highlands in southern Africa through phytolith and carbon isotope proxies for vegetation and grassland dynamics (Parker *et al.* 2011). The study indicates a clear shift from C_4 dominated grasslands, to a brief period of C_3 domination around 2960 cal. BP, suggestive of a period of climate change to cooler, wetter weather, before a return to drier weather and C_4 dominated taxa from 2100 cal. BP (Parker *et al.* 2011, 209).

Two studies to date have examined usewear traces of phytoliths on stone tools from Peninj, Tanzania (Dominguez-Rodrigo et al., 2001) and at Sibidu Cave, KwaZulu-Natal, South Africa (Lombard 2005). Both studies identify phytolith inclusions as use wear, demonstrating that the tool was used for plant processing, in the case of Peninj, the tool is identified as a woodworking tool based on the phytolith evidence (Dominguez-Rodrigo *et al.* 2001, 298); whereas the phytolith assemblage at Sibidu Cave is largely unidentified (Lombard 2005).

Whilst it is clear that palaeoenvironmental and palaeoclimatic studies have dominated the phytolith research agenda in Africa to date, these have largely been enabled by the body of evidence for diagnostic grass species presented by Palmer (*et al*.) (Palmer and Gerbeth-Jones 1987; Palmer and Gerbeth-Jones 1986; Palmer *et al.* 1985; Palmer and Tucker 1983; Palmer and Tucker 1981). Recent studies in East, Central and West Africa

have sought to assess the potential of phytolith production within local flora and importantly, within dicotyledons, building local, modern reference collections in the process. It is the creation of these reference collections which has enabled taphonomic studies of topsoils to be undertaken, to further understand the potential of the phytolith record on an archaeological level. In addition, these studies have led to the tentative application of phytolith analysis to archaeological sediments and contexts, including usewear analysis. However, at present, the majority of these applications are focussed on prehistoric archaeology. The application of both phytolith analysis and geochemistry at Songo Mnara attempts to create a new research agenda, demonstrating the value of such techniques for our understanding of the use of space on all archaeological sites, including those post-dating the prehistoric period.

Phytolith research to date has focussed on the tropical and sub-tropical regions of the African continent, rather than in the temperate zones, although several palaeoenvironmental studies have been undertaken in South Africa in recent years. This is not a phenomenon unique to Africa, European phytolith analysis is burgeoning, when compared to research within tropical and sub-tropical zones, though interestingly, this trend does not apply to North America. It is certainly possible that the lack of preservation of traditional archaeobotanical remains in tropical regions has led to a reliance on more progressive scientific techniques as a way of addressing those issues of preservation and archaeological visibility.

2.6 Potential for Intra-Site Spatial Analysis through Phytolith Analysis and Distribution

Phytolith analysis on the African is a developing field, research at Songo Mnara forms one of the most comprehensive studies to date. Previous research at Songo Mnara (Sulas and Madella 2012) demonstrated the potential of the technique within the stone houses and open areas of the site. The use of phytolith analysis will enable the identification of non-charred plant remains, within the structures and open areas of Songo Mnara, facilitating the identification of areas of food storage, preparation and consumption, or areas of craft production or use.

Intra-site spatial analysis using phytolith analysis has the potential to enable the identification of a range of locally exploited and traded plant resources used for subsistence or craft within the structures at Songo Mnara. The use of an intensive systematic sampling regime on a grid system within the structures and open areas,

combined with the application of spatial statistics including ANOVA and PCA will enable the identification of activity areas throughout the structures, through the analysis of the phytolith assemblage. Clearly differentiating between interior spaces and exterior spaces, with the potential to identify areas of craft production, food production and crop processing as well as areas marked by the presence of organic craft items for example areas of matting. Systematic sampling across structures enables the comparison of spatial use within contemporary structures including high status stone houses and wattle and daub structures.

Considering the phytolith evidence alongside the archaeobotanical and geochemical evidence will enable a more complete understanding of the use of space within interior and exterior spaces within a planned Swahili stonetown, Songo Mnara.

This project is an innovative project, making several unique contributions to our understanding of the use of space and life within a Swahili stonetown, presenting the first large scale, systematic analysis of phytoliths on the African continent, providing an understanding of the use of plants and the trade of organic materials within a Swahili settlement.

The use of phytolith analysis enables the identification of plant material which is not reliant on charring for preservation, enabling an understanding of the use of craft materials, crop processing or consumption areas across the occupation surface and the exterior spaces. When assessed with the complimentary archaeobotanical data presented above, it provides and more complete understanding of the use of space.

The project considers the interpretation of the phytolith assemblage with the results of geochemical, archaeobotanical and artefactual data, providing a comprehensive intensive integrated interpretation of the use of space within both stone built and wattle and daub structures within a planned Swahili stonetown. This analysis will identify the liminal spaces, differentiating between interior and exterior spaces, including transient spaces which house activities associated with interior spaces, such as food preparation, which are in fact taking place in an exterior location.

3. **A Review of the Potential Production of Opaline Silica Phytoliths in Plant Species of Economic and Environmental Importance on Songo Mnara**

3.1. Introduction

It is essential to consider, prior to phytolith assessment and analysis, which plant species may be visible within the phytolith record, particularly those which are indicative of specific environmental parameters, those which may provide evidence for agricultural management regimes (e.g. crops or crop weeds), and those which provide direct evidence for plant use. This consideration of the visibility of particular plant species within the phytolith record, in both environmental contexts and anthropogenic contexts, will contextualise the results of phytolith analysis and facilitate interpretation of the assemblages. In order to achieve this, the present day environment of Songo Mnara is considered through a review of recent botanical and archaeobotanical research on the island, observations within the field, and interviews undertaken with local farmers. In addition, a review of historical documents which reference plants growing locally on Kilwa and in some cases, perhaps on Songo Mnara was undertaken in combination with a review of East African coast shipping logs, which illustrate the diversity of consumable plants and plant-derived crafts being traded. Further context is provided through an initial review of local floras including Flora of Tropical East Africa and the 'Useful and Ornamental Plants of Zanzibar and Pemba'. Whilst these floras do not directly reference plant species which may have grown on Songo Mnara, the environmental characteristics of the genus and species are outlined, illustrating those species which have the potential to grow within the environmental parameters on the island. In addition, these documents provide useful information about the use of plant materials for medicinal purposes, craft activities and consumption.

The curation of a local phytolith reference collection is essential; whilst some phytolith production is genetically determined, forming within specialist cells, other phytoliths form in intra or extra-cellular spaces as a response to environmental conditions (Hodson 2016, 63; Stromberg *et al.* 2016). The creation of a local reference collection can aid an understanding of the potential contribution of phytoliths from plant species which have not previously been assessed for phytolith production, provide valuable information about the nature of silicification within the local environment, and aid an understanding

of the potential contribution of likely non-diagnostic environmentally induced phytolith forms.

3.2 Phytolith Production

3.2.1 Production of Phytoliths

At present, there are limits to our full understanding of the way in which phytoliths form, and the mechanisms governing and promoting silicification. However, recent research and review has sought to address this, moving beyond simpler descriptions of silicification occurring during transpiration, identifying some of the key drivers within the process (e.g. Hodson 2016; Stromberg *et al.* 2016).

Phytoliths are intra or extracellular deposits of opaline silica within the plant cell structure, effectively forming a negative of the cell structure within which they are deposited (Piperno 2006; Stromberg *et al.* 2016). The process of phytolith formation, also referred to as polymerisation, starts with the absorption of monosilicic acid (H_4O_4Si) during groundwater uptake. The concentration of monosilicic acid (H_4O_4Si) within the soil, is variable within a concentration range of 0.01-0.6 (-2.0) mM, influenced by a range of geological factors including soil pH and soil composition (e.g. clay; organics; metallic elements) (Epstein 1994; Hodson 2016; Tubaña and Heckman 2015, 7; Stronmberg *et al.* 2016). Root membranes facilitate the uptake of soluable silica into the transpiration stream, through the Xylem – long tracheal vessel elements facilitating transport of water from the roots to the shoots and leaves (Alexandre *et al.* 2015, 863; Carnelli *et al.* 2001, 425; Hodson 2016, 63; Ma and Yumaji 2006; Tubaña and Heckman 2015, 18).

Recent research has identified the active uptake of silicon within species with a genetic determination to silicification, which feature specialised cell structures to support the process, including sugar cane, horsetail, wheat and rice (Carnelli *et al.* 2001, 425). The recently established presence of silica transporting transmembrane NIP III proteins and Lsi2, an anion transporter, promote the active uptake of silica from the groundwater (Hodson 2016, 63; Ma and Yamaji 2015; Stromberg *et al.* 2016; Trembath-Reichert *et al.* 2015; Tubaña and Heckman 2015, 13). Ma and Yumaju (2006) established that in some species with a genetic propensity to silicification (e.g. wheat, rice), intensive concentration of monosilicic acid within the xylem (> 2mM), precipitated the process of polymerisation within the vessel, leading to a high concentration of silicic acid within the sap, without full silicification.

Phytolith production concentrates within cells with a genetic propensity to silicification (e.g. specialised cells) and within the intra or extracellular spaces of those which exhibit an environmental response, precipitating during transpiration, to solid opaline silica; silicification focuses on three locations: within cell walls, within cell lumen, and within intra or extracellular spaces (Carnelli *et al.* 2001; Hodson 2016, 63; Stromberg *et al.* 2016). Production within plant tissues varies on a family, genus or species level, and phytoliths can be produced within the cell structure of roots, stems, leaves and inflorescences (Hodson 2016, 63). Diagnostic and morphological variation is common where phytoliths form within intracellular or extracellular spaces, and formation outside of specialised cells may mean that these phytoliths are more likely to be non-diagnostic (Carnelli *et al.* 2001). In some cases, phytoliths form a negative of the intra or extracellular cell structure outside of specialised cells during transpiration; though these may be diagnostic to family, genus or species level, these phytoliths are more commonly mulitiplicitous or redundant (occurring in multiple unrelated species), the most commonly occurring of which are epidermal cells (particularly polyhedral phytoliths), vessel or tracheal elements and stomata (Piperno 2006; Trembath-Reichert *et al.* 2015; Stromberg *et al.* 2016).

Once deposited, following transpiration – phytoliths remain in situ in the plant tissue and are not subject to secondary transport within the plant structure (Carnelli *et al.* 2001, 425; Tubaña and Heckman 2015, 18). Deposition of opaline silica can increase with the age of the plant, with increased or in the case of grasses, complete silicification achieved towards the end of the life cycle (Farmer *et al.* 2005, 74; Hodson et al., 1996; Hodson and Sangster, 1998; Wyttenbach et al., 1991). Upon degradation of the organic matter, through whatever means, phytoliths are released from the cell structure and enter the archaeological or palaeoecological record.

3.3 The Environmental Characteristics of Songo Mnara

The environment and flora of Songo Mnara has been relatively understudied, as a result, little is understood of the impact of anthropogenic activities on the flora of the island, and there is little palaeoenvironmental evidence upon which to assess these potential impacts. In part, the lack of suitable palaeoenvironmental information may be due to a lack of suitable deposits for sampling; Stoezel (2014) attempted to identify evidence of Swahili land use strategies through assessment of a 150m transect of intact geoarchaeological cores from the seaward edge of Mangrove Forest, adjacent to the site

at Songo Mnara, with a particular focus on phytoliths analysis. Unfortunately, no diagnostic phytoliths were present within the samples, which might provide evidence of anthropogenic influence, or palaeoenvironmental change (Stoetzel 2009; 2010).

Rainfall levels on Songo Mnara and Kilwa are similar to those experienced in mainland central and southern Tanzania (zone V), of 1000-1800mm per year (Indeje *et al.* 2000; Davenport & Nicholson 1993). This is not as precipitous as Zanzibar and Pemba, due to variance in environmental and climate variability along the East African Coast (Walshaw 2005), and a lack of available fresh water has a significant impact upon farming on the island. The island ecology supported on Songo Mnara, strongly influenced by local geology and climate, has been heavily impacted by anthropogenic activities, including crop introductions, agricultural practices, land clearance, plantation and timber cutting. In some instances, it is likely that this has significantly impacted upon the surrounding vegetation (e.g. *Cocos nucifera* plantation). This may mean that the representative vegetation on the island, at least in the areas most impacted by anthropogenic activities, is not representative of past vegetation dynamics.

In reviewing Flora of Tropical East Africa, Songo Mnara, Kilwa Kisiwani and associated islands do not appear to have been the focus of routine botanical collections, with limited records deriving from the area (e.g. Greenway). An initial vegetation survey undertaken by Stoetzel (2011) identified several key vegetation zones including areas dominated by Mangrove, Land Thicket, Coral Rag, Sand and Mud and Land Scrub. A more detailed botanical survey undertaken by Kayombo and Stoetzel (Stoetzel 2014), surveyed areas of Miombo Woodland, Bushland, Mangrove Forest, an area of Cocos nucifera plantatation, and Sangarungu island. In contrast to expectations, botanical survey of Songo Mnara revealed a dominance of woody plants within Miombo Woodland, Bushland and Mangrove forest (Stoetzel 2014, 45). The concentration of grasses within the island is greatest in cleared areas, around the built heritage, within the Cocos nucifera plantation and surrounding habitation areas and in villages.

The lack of botanical or palaeoenvironmental survey of the island is compounded by limited historical reference resources; whilst Freeman-Grenville (1962) has compiled many known historical accounts of the Swahili world, including those by Ibn Battuta, Prior, Dallons, Crassons de Medeuil and Bocarro. These sources suggest that palms including Areca (*Areca catechu*) and Coconut Palm (*Cocos nucifera*) were growing

within a lush environment on Kilwa Kisiwani, which also supported the growth of fruits including Fig (*Ficus* sp.), Banana and Plantain (*Musa* sp.), and citrus including Lemon and Orange (Citrus sp.). At present there is a lack of archaeobotanical evidence from Songo Mnara which might indicate that these edible species were grown on the island. In part this is likely a preservation issue, as in these species are, with the exception of *Cocos nucifera*, rarely represented in charred plant assemblages. *Cocos nucifera*, *Ficus* sp. and *Musa* sp. all produce family specific diagnostic phytoliths and therefore may be visible within archaeological contexts; the citrus family, Rutaceae, on the other hand, does not produce diagnostic phytoliths.

It is essential to understand, prior to assessment of phytolith samples from soils or sediments, exactly what the contribution of phytoliths to the soil profile might be (e.g Carnelli *et al.* 2001). Undertaking this type of assessment provides an indicator of the potential value of phytolith analysis for the interpretation of environmental or anthropogenic contexts, especially within an area for which existing reference resources are limited, enabling the development of key research questions. For example, in a forested environment of which the some of the key species produce diagnostic phytoliths, this may lead to the development of a research question considering environmental change from grassland to forest cover, since it has been established that there will be sufficient representation of arboreal taxa through diagnostic phytoliths (Carnelli *et al.* 2001).

In addition, not all of the species with the potential to grow on the island will be represented by the current flora, which may have adapted due to modern farming practices, plantations and land use.

The following ethnographic interviews with local farmers and a review of flora from Zanzibar and Pemba, and a review of botanical survey undertaken on Songo Mnara (Stoetzel 2014) has identified plant species likely to have been present on the island, has resulted in an understanding of:

- the plant species growing locally or on Zanzibar and Pemba, which have the potential to contribute diagnostic phytoliths to the archaeobotanical and anthropological records.

- the visibility of natural resources on Songo Mnara, Zanzibar and Pemba, and the potential visibility of subsistence and craft activities through phytolith analysis.

- the types of plants potentially exploited for subsistence, medicinal purposes, craft or construction on Songo Mnara, Zanzibar and Pemba.

- the particular crop husbandry practices employed on the island today, in order to mitigate the inherent problems of farming on Songo Mnara (e.g. lack of available water for irrigation; coral inclusions in the soil).

3.3.1 Accounts of Farming on Songo Mnara

A series of interviews were undertaken with local Farmers during July 2013, to gain information about the way in which crops are planted and managed and processed on the island, including crop rotation and harvesting, and the management of crop weeds. The interviews were facilitated by Ms. Mariam Mgusi, who acted as a translator. Dr Federica Sulas assisted with one of the interviews, whilst Dr Sarah Walshaw undertook one of the interviews in my absence. Full transcripts are appended in Appendix 8.

Names, and in some cases, identifying features have been redacted from these transcrips, in order to protect the identities of the farmers and their families, following publication of this thesis.

Discussion of Mangrove use and *Cocos nucifera* plantation are based upon observations in the field, and limited discussion with locals.

3.3.2 Farming Conditions

The farmers interviewed had variably lived in their present location for between three and 50 years. They were largely positive about the farming conditions on Songo Mnara, despite the lack of available fresh water for drinking or irrigation, declaring the conditions to be good. Some salinated water is collected from natural wells for drinking.

The main villages and associated shambas on Songo Mnara are situated outside the Heritage Site, and agricultural activity is not focussed within the area of archaeological and heritage sensitivity (Mturi 1987, 981). The northern part of the Island skirting the northern edge of the Songo Mnara ruins, is dominated by a *Cocos nucifera* plantation. The palms are approximately the same height and are arranged in rows, suggesting that they were planted contemporaneously. The plantation extends to the fishing village port on the northern edge of the island; only the northern tip of the island is subject to *Cocos nucifera* plantation, it is posited that this is due to the location of favourable growing conditions within the sediment surrounding the Songo Mnara ruins and local sands, and the availability of space, as the area is sparsely populated. Recent geophysical survey

and excavations, undertaken in 2013 (discussed further in chapter 6), revealed the presence of previously unknown archaeological remains of wattle and daub structures and associated external spaces (Fleisher & Sulas 2015; Sulas *et al.* 2016; Welham *et al.* 2014). These structures were in some cases, directly impacted by the placement of the *Cocos nucifera* (Coconut) plantation, demonstrating a need to consider a 'buffer zone' around built heritage remains, to protect any associated and non-visible archaeology.

There is evidence for large scale *Cocos nucifera* (Coconut) processing at the fishing port (Sangarungu); yet, though produced in other locations along the East African coast, coir is not produced on Songo Mnara. Instead the outer fibrous husk of the Coconut is discarded after removal of the fruit.

It is likely that the plantation of *Cocos nucifera* has substantially influenced the vegetation in the area due to extensive nutrient requirements and large rooting systems (B. Baker pers. comm.). It is also possible that the existing vegetation was cleared to create the plantation. Therefore, the environment within vicinity of the town of Songo Mnara may have changed substantially from the vegetation present on the site today. The vegetation within the palm plantation is within partial shade, and dominated by several species of grasses, Fabaceae including *Indigofera* sp. and *Crotalaria* sp. (Shack Shack) and herbs including Justicia sp. (Stoetzel 2014).

3.3.3 Mangrove Swamp

There are six species of Mangrove on Songo Mnara, identified during extensive survey (Stoetzel 2014). Red-branched Mangrove (*Lumnitzera racemosa*; Mkandaa-dume) and Black Mangrove (*Bruguiera gymnorrhiza*; Mkifu) have been collected as reference material collection on Songo Mnara (see below).

Mangrove species were used archaeologically within the buildings of Songo Mnara as props for the ceilings. There are impressions within the daub of the wattle and daub structures excavated during 2013, which demonstrate the use of wooden poles to support the structures. It is feasible that these poles would also have been Mangrove poles, as in the stone structures. They are used today during conservation to reconstruct ceilings within the stone structures, following collapse. There are six species of Mangrove on Songo Mnara, identified during extensive survey (Stoetzel 2014). Red-branched Mangrove (*Lumnitzera racemosa*; Mkandaa-dume) and Black Mangrove (*Bruguiera gymnorrhiza*; Mkifu) have been collected as part of the reference material collection on Songo Mnara.

Mangrove cropping is prohibited by the government and crafts, such as the manufacture of fish traps which would have previously have used Mangrove now make use of other wood sources on the island.

3.3.4 Economic Crops

The following discussions of the growth of economic crops on Songo Mnara are based upon interviews undertaken with local farmers (Appendix 8).

Local farmers grow a range of crops on Songo Mnara, some for personal subsistence, others, including *Musa acuminata x balbisiana* (Banana; Ndizi) for distribution at market. Planting of *Musa* sp. begins in December each year during the rainy season, with plants propagated from cuttings taken from the previous crop. A single *Musa* sp. plant is planted in a hole dug with a shovel within the local sediment and is ready for harvest by the following May-July. No additional water is used to water the crop during the dry season, as all water required is provided during the rainy season. At harvest time, the men cut down the crop, storing it within the Banda, whilst the leaves and stalks are left in the field to dry and rot, fertilising the soil for the following crop. Burning of the leaves and stalks does not take place in the *Musa* sp. shamba, and *Musa* sp. grow in an area devoid of other crops. No animals are grazed within the enclosure at any time and no additional fertiliser is added to the crop. sp. is stored and consumed by the family, with excess crops being sold at market. On Kilwa Kisiwani, individual *Musa* sp. plants are grown within individual shambas on a smaller scale.

On Songo Mnara, a single annual crop of Sorghum (*Sorghum* sp.) is sown into a prepared shamba, in which the thicket and palm have been cut and burned, following the first rainfall in December. The burned material is left in situ, adding valuable nutrients to the soil and a significant store of biogenic silica. Up to five days prior to the first rainfall, grains are planted by hand within compact holes made by jembe (hoe), if rainfall does not take place within 5 days, germination will be impaired. Regular weeding is undertaken during growth by the farmer himself. Harvesting is undertaken after 5 months, during which the men remove the inflorescence, for the grain to be processed in the banda (house/structure). The stalk remains in the field until the field until the following year, when it is burned. The yield of Sorghum is significantly impacted by the availability of water, when rainfall levels are low, Sorghum does not reach its full height and much cannot be harvested.

In addition to Sorghum, Ufuta (peas) are grown and harvested contiguously. The impacts of this are discussed further below. Following harvest and drying, the peas are processed in the banda by shaking the dehisced pods to extract the peas. As with sorghum, the un-harvested parts of the plant remain in the field and are burned the following year prior to planting.

3.3.5 Shamba

In addition to cultivation of a single crop on a large scale for the production of surplus, family cultivation in garden plots, or shambas close to houses, is common on Songo Mnara. This includes the cultivation of *Musa* sp. (Banana/Plantain), Fabaceae (beans/peas), *Carica papaya* (Papaya), *Zea mays* (Maize), *Cucurbita* sp. (Pumpkin), *Solanum lycopersicum* (Tomato), *Abelmoschus esculentus* (Okra) and *Ipomoea batatas* (Sweet Potato). Many New World crops have been introduced to East Africa, and Songo Mnara is no exception, it is unlikely, the majority of the taxa commonly cultivated today are not reflective of the types of crop likely to have been cultivated prior to contact with the New World (e.g Sweet Potato, Pumpkin, Tomato, Maize, Papaya).

In some cases, individual crops are grown adjacent to the houses, for example *Carica papai* (Papaya) is grown by one family in the choo at the rear of the house (toilet). This may be for personal use, clearly separated from the shamba, the produce of which is also sold at market; alternatively, it may make use of the additional nutrients and water provided by the choo (toilet).

3.3.6 Gathered Resources

Some resources are gathered, for example, palm fronds for matting, banda construction or crafting e.g. rope making. Women often undertake crafting outside the banda, or wherever they stop to rest. Wood is gathered for a variety of uses, including lime production and construction.

Other resources, such as green leafy vegetables known as ‘Mchicha’, used in the same way as Spinach – are gathered or fortuitously grow with crops, but are not deliberately planted. It appears that there are some trees, including for example, Lime and palms (excluding *Cocos nucifera* plantation) which are not within a shamba and are treated as communal.

3.3.7 Crop Management

Following the harvest, the area to be planted is prepared for the following season by burning the remaining stems or stalks within the field. This is to ensure that vital nutrients are added to the soil, which is worked with a jembe. Other than this, crops do not receive additional fertilisation. In one case, however, Sorghum and Peas were grown in tandem, the combination of which likely promoted maximum productivity of the Sorghum, through the addition of nitrates to the soil (Ghaley *et al.* 2005).

Crops on Songo Mnara are not watered or irrigated; the sole source of irrigation comes from seasonal rainfall. There is a lack of fresh water on the island, and that which is suitable is used for drinking.

From the interviews undertaken, there is no suggestion that coral is added to fields for improvement, rather it is undesirable. These inclusions are also not removed to improve the soil, even where problematic. Coral inclusions are not removed from the soil.

Soils and sediments on Songo Mnara are predominantly terra rossa-type, derived from coal limestone and quartz, featuring pockets of dark brown silty loam (Sulas *et al.* 2017, 54). Local farmers use natural features to their advantage for the cultivation of Ndizi (*Musa* sp.; Banana). Bush pigs are a concern for all farmers on Songo Mnara, since they cause destruction of crops by gouging the stem of Musa sp., or by chewing the leaves of Sorghum.

3.4 Field Collection Methods

In addition to archaeological samples, samples of modern vegetation were taken from various locations on Songo Mnara see figure 8), within the vicinity of the archaeological site and from local shambas, in order to build a modern comparative phytolith reference collection. Sampling at Songo Mnara was opportunistic and was undertaken during the dry season only, between June 29th and July 31st 2013, purely because sampling coincided with the excavation season. It is worth considering that the full range of flora would not have been accessible at this point, with many species, including grasses, at the limit of their seasonal growth. This in fact, is beneficial for collection, as Poaceae may not fully silicify until the limit of their growth is reached due to the increase in opaline silica throughout the ageing process (with up to five times more silica deposited at the end of the growth cycle, than in earlier stages) (Wyttenbach et al., 1991; Hodson et al., 1996; Hodson and Sangster, 1998).

Phytolith Reference Collection Sampling Locations (July 2013).

A. Samples were taken from the vicinity of the stonetown.

B. Samples of Rice grown on the island were collected from Madaweni. Raised berms are observed separating the fields. Other crops grown in the local village included Okra, Orange and Lime.

C. Samples were also collected from settlement areas on the island, where farming is undertaken in shambas in association with the banda. Locally grown crops included Banana, Mango and Papaya grown at Mfuvu; Sorghum, Millet, Peas and Papaya at Mikadi, near to Songo Mnara stonetown.

D. Coconut palm plantations were established within the town walls at Songo Mnara, and at Sangarungu.

Figure 8 Phytolith Reference Collection Sampling Locations (July 2013)

However, almost all phytolith reference collections are created with a seasonal bias, as it is almost impossible to obtain all parts of the plant described above during a single collection.

Where possible, all parts of the plant were sampled, including the stem, leaf, inflorescence, fruit and seed, as different phytolith morphotypes may be formed within different parts of the plant structure (Piperno 2006). Samples of wild flora were taken, including grasses (Poaceae), Asteraceae (Daisy family), Fabaceae (legume family) and Lamiaceae (Mint family) from the open areas, mangroves from the mangrove swamps bordering the site, Adansonia digitata (Baobab) growing within close proximity of the site and *Cocos nucifera* (Coconut Palm) subject to plantation across the open areas.

In addition, samples of locally cultivated crops, including Sorghum bicolor (Sorghum), *Pennisetum glaucum* (Pearl Millet), *Oryza* sp. (Rice), *Gossypium* sp. (Cotton) and cultivated Fabaceae (legume) species were taken from local Shambas (Household Farms), accompanied by information about planting, husbandry and growth from interviews with local farmers who provided the samples. Local farmers provided information about local crop weeds, which were also opportunistically sampled.

Fruit bearing crop samples were also obtained from local shambas, including Banana (*Musa* sp.), Mango (*Magnifera indica*), Papaya (*Carica papaya*), Orange (*Citrus* sp.) and Lime (*Citrus* sp.).

Due to the production of diagnostic Palm phytoliths, and the many economic uses of various parts of the plant, several species of palm currently growing on Songo Manara were sampled, including *Cocos nucifera* (Coconut Palm), *Hyphaene* sp. (Doum Palm) and *Phoenix* sp. (Date Palm).

3.5 Processing Methodology

This section details a specific phytoliths processing methodology for the reference collection material. This is different to the discussion in the following chapter, which considers approaches to the extraction of phytolith material from a sediment matrix, drawing on this discussion to outline a methodology for phytolith extraction at Songo Mnara.

Samples were collected within the field, photographed, and immediately pressed and dried, using locally produced and specialised press. Successfully drying plant tissues

within a tropical environment within a restricted period of time is somewhat difficult to achieve.

On return from the field, the samples were catalogued and frozen to control insect infestation. Following a period of freezing, each sample was extracted, weighed and sonicated in distilled water to remove adhering contaminant phytoliths from the plant tissue. This process is much easier to achieve with fresh plant tissues, rather than rehydrated tissues.

Following sonication, samples were placed in ceramic crucibles within a muffle furnace and heated to 500°C for five hours, ensuring that organics are sufficiently removed, yet does not promote physical changes to the silica structure which occur at higher temperatures. Samples were then weighed and transferred to glass vials. An additional wash with HCl (Hydrochloric acid) would ensure removal of carbonates from the reference collection material, it is sometimes desirable to concentrate the phytoliths assemblage and ensure separation of phytoliths from mineral matter through floatation in heavy liquid (Sodium Polytugstate). However, based on previous significant experience preparing reference material, in this instance, removal of carbonates and concentration of phytoliths was not undertaken, as the aim was simply to undertake initial assessment of presence/absence and abundance of diagnostic phytolith morphotypes, rather than to provide a quantitative assessment of phytolith production within each species. The resulting samples, which are stored as ash, can be subject to removal of carbonates and phytolith concentration, should quantification from this environment prove useful in the future.

A known quantity of ashed plant tissue was measured onto each reference collection slide, which will facilitate quantification of phytoliths per gram of plant tissue, if that is desired during further phases of work. At this stage the aim was simply to characterise the assemblage to better understand the production of phytoliths within plants growing within the study area and full quanitification of phyoltih production was not undertaken. Each slide created was scanned by transect at x400 magnification using an Olympus iX71 inverted binocular microscope. Identified morphotypes were photographed, providing a visual reference. The results of this are discussed further below.

The purpose of this reference collection was to aid identification of the phytolith assemblage, understanding the range of morphotypes procuced locally and the levels of silicification of various elements. The production of a comprehensive reference

collection for the Island would constitute a project in its own right and as the material has been collected, this is an aspiration. What is presented in this thesis is an example of the types of material recovered and used to guide identifications of the archaeological assemblage. Every effort was sought during fieldwork to discuss plant use with local communities and to use this ethnography to inform interpretations of the archaeological phytolith assemblage. Combined with the review of phytoith production and botanical review presented below, this provides a comprehensive understading of the potential local production of diagnostic phytoliths which might reasonably be condributed to the archaeological horizon and ground truths this through collection and use of local reference material.

3.6 A Botanical Review of Zanzibar, Pemba and Songo Mnara

With limited botanical information for Songo Mnara, two sources: 'Useful and Ornamental Plants of Zanzibar and Pemba' (Williams 1949) and a recent botanical survey of the island undertaken by Stoetzel (2014), were reviewed to assess potential contribution of phytoliths to the anthropogenic and palaeoenvironmental records within Swahili contexts. The review collated information including family, genus and species names, vernacular names and Swahili names from these documents, and combined them with an assessment of phytolith production based predominantly on Piperno (2006) and other phytolith references, developing an understanding of the potential phytolith contribution to the archaeological and palaeoenvironmental records.

For the purpose of this assessment, Piperno's (2006, 7) phytolith classification system was adopted as follows 'I, I*, II, II*' - Families where production is usually abundant, producing diagnostic morphotypes to sub-family, genus or species level or where production may not be abundant, but morphotypes are diagnostic to subfamily, genus or species level, or specific to environmental conditions. 'III' - Families which commonly produce phytoliths, though these may not be diagnostic to species or genus level. 'IV' and 'V' - Families where production of diagnostic morphotypes is limited, where production of phytoliths is variable depending on the genus, species or environment or where phytolith production has not been observed. Not all species are listed in Piperno's (2006) work, and therefore additional references from the phytolith literature were used to supplement the table, following the same guidelines, these entries are denoted by the addition of a[1] following classification. Where phytolith production had been identified by a study, but redundancy and multiplicity had not been considered, the classification

used is +, phytolith production has been observed, but it is unclear whether this is diagnostic. For the purposes of the assessment below, those entries with a +, have been added to category III.

3.6.1 Results

Overall, considering the entire dataset, there are few plant species (largely those in the Poaceae and Arecaceae families) with the potential to contribute highly diagnostic species specific forms in abundance, with 28.82% classified as category I or II. The majority of these forms (20.47%) produce diagnostic phytoliths in all parts of the plant, including the inflorescence, denoted by the addition of a * in Piperno's classification system (2006). This category includes domesticated crops from the Poaceae family, and other subsistence plants including Cucurbitaceae (Squash; Melon), Arecaceae (Palms), and Zingiberaceae (Ginger). In addition, environmental indicators including Asteraceae (Daisy family), Cyperaceae and Orchidaceae (Orchid family) all produce highly diagnostic phytoliths.

A small minority of plant species were classified in the III (+) category, families which commonly produce phytoliths, but where these may not be diagnostic to genus or species level (e.g. Anacardiaceae). These forms are still useful for the identification of a range of plant families during phytolith assessment.

However, 50.72% of species assessed were classified within categories IV or V, families which are not known to produce phytoliths, and where phytolith production is observed, diagnostic morphotypes indicative of species or family are limited. These categories include some of the major subsistence, craft and construction species, including Gossypium sp. (Cotton; IV); the Fabaceae family (Legumes; IV), which includes edible crops, a large proportion of arboreal cover, with wood often used for construction or fuel; and the Rutaceae (Citrus family; V) which does not produce phytoliths at all. Only 7.21% of the species listed have not been tested for phytolith production. It is recommended that those species which have not yet been subject to assessment, and which have an economic use or are indicative of specific environmental parameters are subject to assessment for phytolith potential.

Further assessment of those species with an economic, industrial, craft or medicinal value was also undertaken. This identified 31 plants of medicinal value, of which 64.52% were unlikely to produce diagnostic phytoliths (IV/V), and 12.90% which would produce morphotypes indicative of family, genus or species (I/II). A further

12.90% were classified as producing abundant phytoliths, which may be of limited taxonomic significance. This suggests that the majority of medicinal uses would not be visible within the phytolith record, not least because of the probable infrequency with which these treatments are employed. This perceived lack of visibility of the majority of medicinal plants is likely influenced due to abundant use of plants from the Fabaceae family.

Of the 79 plant species identified as edible or subsistence plants, 25.32% produce diagnostic family, genus or species specific phytoliths (I*/I, II*/II), 6.32% produce phytoliths that, whilst abundant, may not be indicative of a specific plant family, genus or species (III) and 63.29% were unlikely to produce phytoliths, or where produced these were unlikely to be abundant or diagnostic. Only 5.06% had not been subject to assessment. Those species unlikely to contribute phytoliths to the archaeological or palaeoenvironmental record include: *Citrus* sp. (Lime, Lemon etc.); *Piper nigrum* (Black Pepper); *Piper betle* (Betle); and *Dioscorea* sp. (Yam). Aside from the standard crop plants including Sorghum, Pearl Millet and Finger Millet, which are not included within the botanical review, those plants which produced diagnostic phytoliths included *Zingiber officinalis* (Ginger); *Ficus* sp. (Fig); Arecaceae (Palms); Cucurbitaceae (Squash/Melon); *Musa* sp. (Banana/Plantain); *Vanila* sp. (Vanilla); and *Saccharum officinarum* (Sugar Cane).

Craft plants, including those used for basket weaving, matting, string or rope making, tanning, dyeing or fish trap construction likely have a more visible phytolith presence due to the use of Arecaceae (Palms) for many of these activities (e.g. basketry, weaving, matting, string or rope making). Evidence for cotton working is likely to be limited (IV), though the local reference collection demonstrates the production of vessel tracheid phytoliths in the woody parts of Gossypium sp. These are non-diagnostic and likely environmentally induced forms, which may not survive or may not be diagnostic outside the context of the reference collection (Stromberg *et al.* 2016; Piperno 2006, 42). Evidence for dyeing using Indigofera sp. would also be lacking, due to the variable and non-standard production of phytoliths within the Fabaceae (IV). Of the plants with defined craft uses, the majority, 41.67%, produced diagnostic phytoliths to family, genus or species level (I*/II*/I/II), whilst 13.89% may produce abundant non-diagnostic forms (III), 30.56% are unlikely to produce phytoliths, or are unlikely to produce forms which are standard and representative of a single plant family, genus or species. A total of 13.89% had not been assessed for production of phytoliths.

Of those plants defined as being used for fuel (a total of 7), the majority do not produce diagnostic phytoliths (57.14%; IV/V). This is due to the use of Fabaceae and Mangrove species for fuel, with the only species identified to produce diagnostic phytoliths being Cocos nucifera. Similarly, a reliance on Arecaceae (Palms) and Ficus sp. for construction, potentially enhances the visibility of this activity within the phytolith record, with 46.67% of records (a total of 15) identified as family, genus or species specific phytolith producers (I*/II*/I/II). The use of Arecaceae, which produce phytoliths in all parts of the plant, would enhance visibility even where those parts which would usually produce diagnostic phytoliths (leaves/stems) were stripped off for construction; Fabaceae for building, however, would not afford visibility.

The most diagnostic activity within this study, is the use of fodder crops (71.43%; I*/II*/I/II). As the focus of this activity is primarily on grasses, producing abundant and highly diagnostic phytoliths, there is a good chance of being able to identify foddering or grazing, especially as grasses produce differing diagnostic phytoliths in the leaf, stem and inflorescence. Sulas and Madella (2012) identified grazing within the open areas at Songo Mnara, through the general absence of inflorescence phytoliths, due to the grass never reaching maturity.

Of those plants specifically identified during botanical survey of Songo Mnara (Stoetzel 2014), the majority are unlikely to contribute diagnostic phytoliths to the archaeological or palaeoenvironmental record (52.78%; IV/V). As discussed previously, Stoetzel noted that grasses were not as abundant on Songo Mnara as previously expected, and tree cover on the island is dominated by the Fabaceae and Mangrove populations. Of the flora identified on the island, 22.22%, has the potential to produce highly diagnostic and abundant phytoliths.

The basis of the botanical survey (Stoetzel 2014) was not exhaustive, nor are the results of Williams (1949) likely to be entirely representative of the flora of Songo Mnara. However, the survey undertaken by Stoetzel (2014) identified some common species which occurred within Williams' flora (1949). Despite the obvious limitations of these sources, they provide a baseline understanding of the potential contribution of phytoliths to the natural environment on East African coastal islands, presenting a sample of species with known economic, medicinal, craft and construction uses. This facilitates an understanding of the visibility of different activities, with the most visible

being construction, and grazing, whilst a number of edible cultivated and wild plant resources produce highly diagnostic phytoliths, aside from those primarily cultivated.

4. Methodology: Preparation of Soil Samples from Songo Mnara

4.1 Introduction

This chapter details the methodology for the preparation of soil samples from Songo Mnara, Tanzania.

The selection of this methodology is considered and justified through a comprehensive review of 40 randomly selected phytolith methodologies from a range of geographical locations, resulting in the largest overview of methodological practices to date. This review identifies and outlines the lack of a standardised methodology for phytolith sample preparation, wide variation in practices and the application of different methodologies for specific soils and sediments including Oxisols, Sands, Clays and those rich in organic material.

Such a comprehensive review has not been published to date, and the following discussion is a unique contribution of this thesis, to the wider phytolith analytical field.

4.2. Phytolith Extraction Protocol

The phytolith extraction protocol used for the extraction of phytoliths from sediments at Songo Mnara was adapted from the protocol employed by Madella *et al.* (1998) and Sulas and Madella (2012); adaptations included an increased sample size, from 2-4g of sediment to 10g of sediment to facilitate greater recovery of phytoliths from relatively poor preservation conditions (See Chapter 6 – Taphonomy), and the use of gravity sedimentation rather than centrifugal sedimentation (see discussion).

4.2.1 Sample Preparation, Deflocculation and Clay Removal

For each sample, 10g of material was weighed into a 400ml beaker using an analytical balance; 250ml (approx. 8cm column) of ultrapure deionised water sieved through a 0.22µm resin filter, was added to the beaker with 15ml of Sodium Hexametaphosphate ($Na_6P_6O_{18}$) solution to aid disaggregation, and removal of clays through deflocculation and gravity sedimentation. The sample was stirred vigorously by hand using a ceramic stirring rod to aid suspension of clays within the solution; after one hour the sediment had settled whilst the clays were suspended in solution, around 2/3 of the suspense was poured off at a steady rate taking care not to disturb the sediment. The process was repeated 7-8 times until the suspense was clear. The sample was then transferred to a clean 50ml centrifuge tube and centrifuged at 2000rpm for 5 minutes at a temperature of

16°C. The supernatant was decanted with the resulting sample subjected to the process of carbonate removal.

4.2.2 Carbonate Removal

Following the removal of clays, the sample was transferred to a 50ml centrifuge tube for removal of carbonates, 25ml of 10% (conc.) Hydrochloric acid (HCl) was added to each sample. Due to high carbonate levels within the samples, the effervescent reaction of the Hydrochloric acid could be violent; care was taken to add Hydrochloric acid in increments to avoid the loss of sample through effervescence and this stage of the process was undertaken under the fume hood. When the effervescent reaction had reduced, the sample was gently agitated on a vortex mixer to ensure that all carbonates were exposed to the Hydrochloric acid. The solution was heated in a sand bath to 40°C for 2 hours to increase the reaction; the reaction was complete once effervescence ceased. Milli-Q or distilled water was added to the top of the 50ml centrifuge tube, the sample was agitated on a vortex mixer and centrifuged at 2000rpm for 5 minutes, reducing the sample to a pellet at the bottom of the centrifuge tube. The supernatant was poured off and the process was repeated twice more to ensure that the Hydrochloric acid was rinsed from sample.

4.2.3 Removal of Organics

The removal of Organics stage of the process was undertaken under the fume hood, 20ml 33% volume of Hydrogen peroxide (H_2O_2) was added to the sample, which was then shaken gently. Centrifuge tubes have a venting cap and this was left open to ensure that Carbon dioxide (CO_2) resulting from the oxidation of organics, could escape. The sample was placed in a heated sand bath for no less than 8 hours at a temperature of 30 ^oC. Care was taken to ensure that a violent reaction did not lead to the loss of sample in the effervescence. The reaction ceased when all organics had been oxidised by the H_2O_2. Milli-Q or distilled water was added to the top of the tube, which was then agitated on a vortex mixer and centrifuged at 2000rpm for 5 minutes. This step was repeated twice more.

4.2.4 Removal of Non-Phytolith Mineral Material

Phytoliths were separated from the remaining sand, silt and mineral matrix through heavy liquid flotation. A 10ml solution of Sodium polytungstate (SPT) ($Na_6(H_2W_{12}O_{40})\cdot H_2O$) with a specific gravity of 2.3g/cm^3, was added to the sample using an automatic pipette fitted with a 15ml tip. The solution was gently agitated using a vortex mixer, and centrifuged for 5 minutes at 1000rpm. Non-Phytolith mineral

material, silt and sand were concentrated at the base of the centrifuge tube, whilst phytoliths, which have a density of 2.1-2.2g/cm³, were mobilised and suspended below the surface of the heavy liquid. Phytoliths were recovered from the surface or subsurface of the suspension using a Pasteur pipette, and transferred to a labelled 15ml centrifuge tube. The suspension was then agitated using a vortex mixer and centrifuged for 5 minutes at 1000rpm, before a second round of phytolith recovery was undertaken to ensure maximum possible retrieval of phytoliths.

Distilled or Milli-Q water was added to the top of the tube containing the recovered phytolith suspension, which was agitated on a vortex mixer before being centrifuged at 2000rpm for 5 minutes to ensure that the phytolith fraction was concentrated in a pellet at the bottom of the tube. The supernatant was then poured off. All SPT was retained for filtration, recycling and reuse.

4.2.5 Dehydration of the Phytolith Fraction

To ensure that the phytolith fraction was completely dry before weighing and mounting, the sample was treated with 1ml Methanol. The sample was agitated on a vortex mixer to ensure saturation, and centrifuged at 2000rpm for 10 minutes; the phytolith fraction concentrated at the bottom of the tube allowing the supernatant to be poured off. This process was undertaken three times and the sample was left to dehydrate for a further 2-3 days. Methanol was selected rather than Acetone, as Acetone may react with plastic centrifuge tubes.

4.2.6 Mounting of Slides

Each phytolith sample was weighed to three decimal places using an analytical balance, allowing the concentration of phytoliths per gram of sediment to be calculated. The entire sample was mounted with no reserve held due to the low concentration of phytoliths. Soil sample vouchers were held in reserve to enable the process to be repeated resulting in the preparation of an extra sample if necessary.

Approximately 2ml of Entellan® new mounting fluid was added to each tube, the sample was then gently mixed using a glass pasteur pipette which was used to draw up the solution and deposit it onto the slide. Entellan® new has a refractive index of 1.49 - 1.50, providing good visibility of phytoliths (see discussion). In addition, Entellan® new is a rapid setting mounting medium, resulting in the preparation of samples suitable for long term storage.

4.2.7 Microscopy

Each slide was examined by transect at x400 magnification using an Olympus iX71 inverted binocular microscope. A maximum of 300 phytolith morphotypes were counted on each slide for statistical analysis, with the remainder of the slide examined for significant diagnostic morphotypes (Piperno 2006). Phytolith ratios were recorded on a proforma sheet (see Appendix 4), each identified morphotype was photographed, measured and catalogued providing a visual reference for each identification.

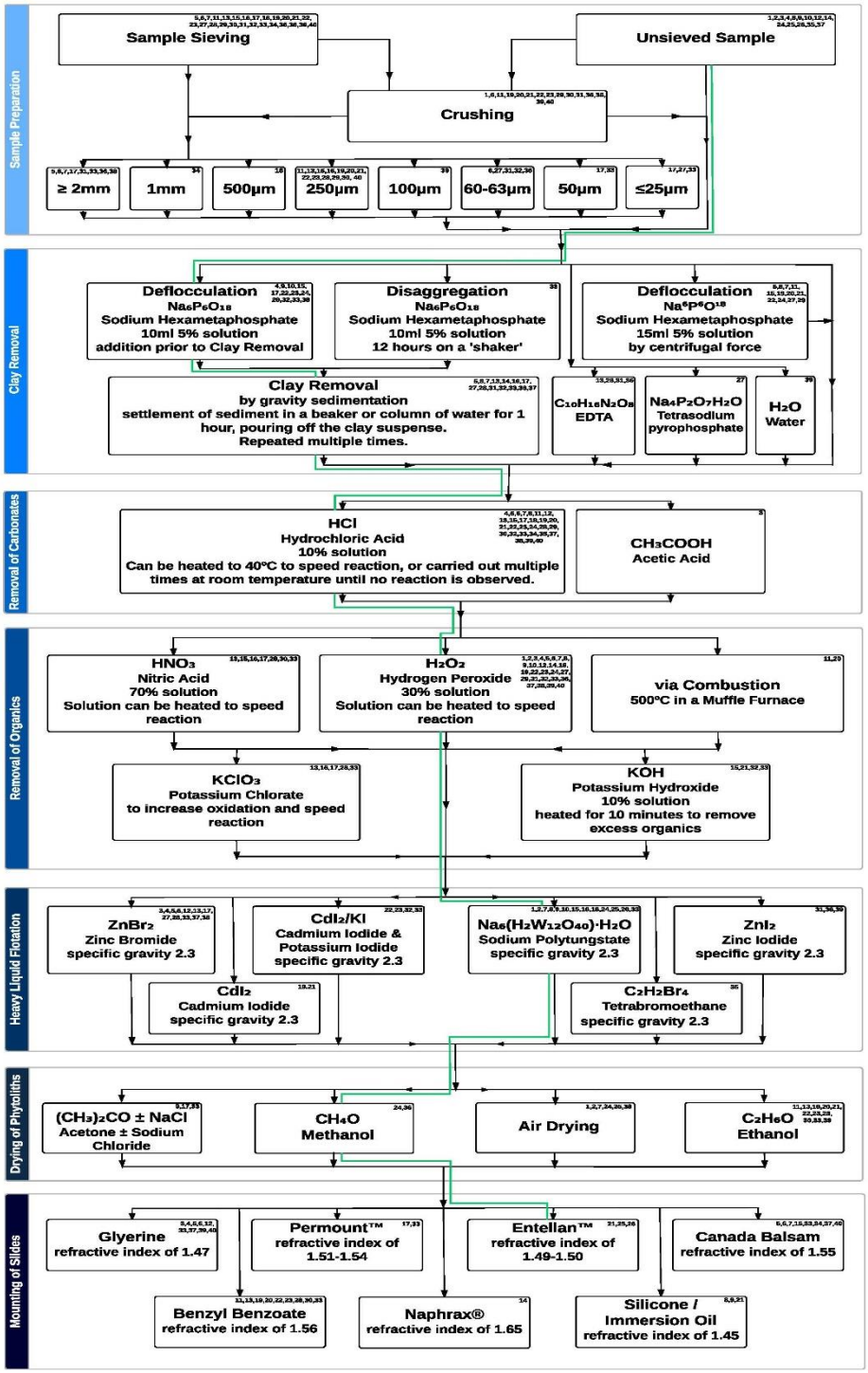
4.2.8 Additional Considerations

The import and storage of soil samples from outside the UK is controlled by FERA (Food and Environment Research Agency), who issue institutional licences for the handling of such materials (Appendix 5 details the FERA licence obtained). In order to comply with these guidelines, all soil samples were stored in a locked cabinet designated for the storage of FERA licenced material. Additional precautions were undertaken in the laboratory, including the treatment of all waste water products with Avisafe disinfectant prior to disposal, the autoclaving of all materials which had come into contact with imported soil samples and the cleaning and of any spilled or excess soil using designated cleaning equipment for FERA licenced material.

4.3. A Review of Phytolith Processing Procedures

The selection of the above methodology was carefully considered, as there is no standard phytolith processing methodology (Fig. 8; Appendix 2). The discussion below details the rationale behind the selection of the phytolith processing methodology detailed above, and more generally, provides a critical review of phytolith processing methodologies.

Figure 9: Phytolith Methodology Matrix. Representing the most common methodologies; stages of the process are interchangeable, see table below for details and references. The Songo Mnara sample processing methodology is indicated by the secondary (green) line.



4.3.1 Sieving

Sieving soil samples through a 2mm, 1mm, 500µm or 250µm mesh is commonly undertaken at the beginning of the phytolith extraction process, removing small macrofossils and potentially modern intrusive roots from the sample, avoiding

contamination of the phytolith assemblage (Alam *et al.* 2009; Alexandre *et al.* 2012; Bremond *et al.* 2008; Bremond *et al.* 2005; Burrough *et al.* 2012; Calegari *et al.* 2013; Cordova 2013; Fahmy *et al.* 2006; Garnier *et al.* 2013; Holmgren *et al.* 2012; Horrocks 2005; Horrocks 2002; Iriarte and Paz 2009; Katz *et al.* 2010; Lentfer and Boyd 1999; Lentfer and Boyd 1998; Madella *et al.* 1998; Mercarder *et al.* 2013; Mercarder *et al.* 2011; Mercarder *et al.* 2000; Misra and Bhattacharyya 2014; Neumann *et al.* 2009; Novello *et al.* 2012; Parr 2002; Pearsall 2001; Pearsall 1989; Piperno 2006; Powers and Gilbertson 1987; Rovner1971; Zhao and Pearsall1998). In addition, finer sieving may be undertaken at 63-50μm for the removal of sands, 50-25μm for the removal of coarse silt, and <20μm for the separation of fine silt, effectively dividing each sample into two or three fractions (Bremond *et al.* 2008; Iriarte and Paz 2009; Mercarder *et al.* 2000; Pearsall 2001; Pearsall 1989; Piperno 2006, 91; Zhao and Pearsall 1998).

Though organic materials are removed during the 'Removal of Organics' stage of the process (see below), this will release any phytoliths contained within the modern organic matter into the phytolith assemblage, introducing modern contaminants. This step is in some cases, seen as crucial for the removal of modern organic contaminants, yet the process has the potential to exclude some phytoliths from the assemblage (Piperno 2006, 91). Where articulated phytoliths or silica skeletons are present, as within Trench 32 at Songo Mnara, these may be larger than 250μm and subsequently damaged or removed during the sieving process (Piperno 2006, 91). Piperno (2006, 91) mitigates this in contexts where larger domesticated crop phytoliths may occur through the use of a 500μm sieve.

The sieving stage has the potential to effectively concentrate phytoliths by size, with the potential to concentrate larger quantities of diagnostic crop phytoliths (Piperno 2006, 92). Though this can be beneficial, particularly in tropical environments, the sieving stage of the process is time consuming and increases the number of samples subject to these processing procedures.

In order to preserve larger articulated phytoliths and to allow time for the processing of a greater quantity of samples, this protocol omits sieving for the removal of organic materials. This is not detrimental to the overall assemblage, as modern organic materials are removed via flotation through deflocculation by gravity sedimentation. Although this may not remove all of the organic materials present, the repetition of the process

increases the removal of modern organic materials, limiting the potential for contamination whilst preserving larger phytolith morphotypes.

A larger sample size, the maximisation of phytolith retrieval through heavy liquid flotation and the mounting of entire assemblages mitigate the concentration of phytoliths which may be achieved through fine sieving for the concentration of phytolith morphotypes by size.

4.3.2 Homogenisation

Grinding or crushing samples at various stages of the phytolith extraction protocol is seen as an essential homogenisation process by some phytolith analysts, yet is of disputed relevance (Madella pers. comm.; Bestel pers. comm; Rosen pers. Comm.;). This step has the potential to break up some of the larger fragments of shell or small fragments of coarse rock, enabling the removal of carbonates and removal of organics to be more effective. Though this could easily be achieved through sieving, both sieving and grinding or crushing and grinding are potentially detrimental to the preservation and recovery of larger silica skeletons. Incidentally, the application of crushing or grinding at any stage of the process has the potential to damage or break larger silica skeletons (Madella pers. comm.; Bestel pers. comm; Rosen pers. comm.; Alam *et al.* 2009; Albert *et al.* 1999; Alexandre *et al.* 2012; Bremond *et al.* 2008; Cordova 2013; Lentfer and Boyd 1999; Lentfer and Boyd 1998; Misra and Bhattacharyya 2014; Parr 2002; Pearsall 2001; Zhao and Pearsall 1998).

The homogenisation of samples at this stage is unnecessary, particularly where the sample is weighed out before homogenisation or the entire sample is processed; defloculation by gravity sedimentation would easily homogenise the sample, as would the removal of carbonates and removal of organics processes. Therefore, this protocol does not homogenise samples through grinding or crushing, instead relying on homogenisation through deflocculation by gravity sedimentation. Though particles of shell or coarse sediment may be retained within the sample, these may be removed during removal of carbonates. Where persistent, the use of heavy liquid flotation separates phytoliths from these denser particles.

4.3.3 Removal of Iron Oxides

Iron and aluminium oxides are a common constituent of clays in tropical and sub-tropical regions, the presence of these metallic elements may impact upon the deflocculation process, as positively charged clays are more successfully aggregated

due to the presence of positively charged anions (Pearsall 2001, 417). Sodium based deflocculants such as Sodium hexametaphosphate may not be as effective when applied to Iron and Aluminium oxide rich soils as positively charged anions are incapable of exchanging 'with sodium ions (Na+)' (Pearsall 2001, 417). The removal of Iron and Aluminium oxides from tropical sediments is essential to enable successful deflocculation and clay removal (see discussion below). This can be achieved via a variety of methods including soaking in 36% Hydrochloric acid for several days, the application of a combined Hydrochloric acid and Nitric acid (HNO_3) solution, (Pearsall 2001, 418; Zhao and Pearsall 1998). The application of strong acids does not cause etching or dissolution of phytoliths in the short term, as phytoliths are stable within solutions with a low pH (Pearsall 2001, 418; Yost pers. comm.).

Alternatively, Sodium citrate ($C_6H_5Na_3O_7$), with or without the inclusion of either Sodium Bicarbonate or Dithionite ($Na_2O_4S_2 \cdot H_2O_2$) or Sodium acetate (NaOAc), can be used for the removal of Iron oxides (Bremond *et al.* 2005; Calegari *et al.* 2013; Novello *et al.* 2012). In Oxisols it is suggested that a specific step for the deflocculation of sediments and the removal of clays in unnecessary, instead employing two stages of Iron oxide removal (Calegari *et al.* 2013).

In all cases, the removal of Iron oxides stage of the protocol must either take place prior to the deflocculation and removal of clays process (Bremond *et al.* 2005; Pearsall 2001, 418; Novello 2013) or replace the deflocculation and removal of clays process (Calegari *et al.* 2013).

The removal of Iron oxides was not thought necessary for this protocol, phytoliths were sufficiently recovered for analysis from sediments and soils at Songo Mnara by Sulas and Madella (2012) using a similar methodology and the recovery of phytoliths from both domestic contexts (SM32 and House 18) and open area contexts (SOA and NOA) is sufficient.

4.3.4 Deflocculation by Gravity Sedimentation

Clay particles naturally form a loose aggregate with silts and sands within sediments, these particles act as a single mass and, when suspended in water, will sink at the same rate as one another. Clay particles are not effectively removed from the sample through the removal of organics or removal of carbonates steps, though if removal of organics is carried out using Hydrogen Peroxide (H_2O_2) this may consequently act as a clay disperant (Gray *et al.* 2010; Pearsall 2001, 370). Deflocculation is essential as it enables

the separation of clays from the sediment matrix; the addition of a deflocculating agent creates a colloid, suspending the clays within the solution, whilst allowing denser particles, including silts, sands and phytoliths, to settle. Sodium hexametaphosphate ($Na_6P_6O_{18}$), a commonly used deflocculant for the dispersal of clays, enables a clay colloid to form through the replacement of Ca2+ and Mg2+ ions on the surface of the clay mineral with Na+. This increases the overall negative surface charge due to absorption as an anion (Andreola et al., 2004; Castellini *et al.* 2013, 163). Clays are then removed through the decantation of the colloid suspension, when combined with the use of Stoke's Law for gravity sedimentation (see below). Less commonly used alternative deflocculating agents include Ethylenediaminetetraacetic acid (EDTA) ($C^{10}H^{16}N^2O^8$) and Tetrasodium pyrophosphate ($Na_4P_2O_7H_2O$)(Fahmy *et al.* 2006; Garnier *et al.* 2013; Mercarder *et al.* 2000; Neumann *et al.* 2009; Pearsall 2001).

Piperno's (2006) protocol calls for a disaggregation stage carried out immediately prior to deflocculation, in which a solution of Sodium hexametaphosphate and deionised water ($Na_6P_6O_{18}$ + H_2O) is added to the sample, and placed on an automatic shaker for 24 hours (Piperno 2006, 91). This stage agitates the sample, increasing clay dispersal and, as a result, deflocculation (Piperno 2006, 91).

The stage at which deflocculation is carried out varies, with arguments put forward for deflocculation prior to the removal of organics and carbonates (Madella pers. comm.; Rosen pers. comm.; Scott-Cummings pers. comm.) and after the removal of organics (Pearsall 2001, 370). Deflocculation prior to the removal of organics and carbonates may enable the selected reagents for these processes to be more effective, since there are no adhering clay particles the organic and carbonate materials will have more exposed surface areas. However, there is an argument for the removal of organics prior to deflocculation, as organic material adheres to and binds clay particles and in particularly heavy organic rich clays Sodium Hexametaphosphate may not be as effective (Pearsall 2001, 370). Undertaking removal of organics prior to deflocculation would improve the efficiency of deflocculation (Pearsall 2001, 370). It is suggested that undertaking both removal of organics and removal of carbonates prior to deflocculation may lead to enhanced clay removal prior to heavy liquid flotation (Pearsall 2001, 370).

In addition, if clay colloids are still intact when Hydrochloric acid treatment for removal of organics is carried out they may form a buffer, preventing adequate carbonate removal. Although Sodium hexametaphosphate has a neutral pH (7) and may neutralise

the Hydrochloric acid if residue is still present – this is mitigated through the use of 10% Hydrochloric acid rather than 5-7% Hydrochloric acid used by Madella (*et al.* 1998). Undertaking gravity sedimentation prior to the removal of organics allows allows the bulk of modern organic material, for example uncarbonised intrusive rootlets, to be poured off in the supernatant creating a more relevant phytolith assemblage.

There are three types of gravity sedimentation process detailed within the archaeological literature, gravity sedimentation: by beaker (Stoke's Law) (Pearsall 2001, 419; Piperno 2006 91-92), by fractionator (Pearsall 2001, 425; Zhao and Pearsall 1998), and by centrifuge (Madella *et al.* 1998; Sulas and Madella 2012). The most commonly used methods of clay removal are deflocculation by gravity sedimentation using a beaker and deflocculation and sedimentation by centrifugal force. Fractionation combines both sieving to 250µm and clay removal, it also facilitates easy fractionation of the sample (Pearsall 2001. 420; Zhao and Pearsall 1998). However, this process requires specialist equipment and takes 24 hours to complete the process, when compared with gravity sedimentation (8 hours) and centrifugal sedimentation (2 hours) this is a lengthy process, though after the initial set up it does not require regular maintenance to complete the process, as with gravity sedimentation and centrifugal sedimentation (Pearsall 2001. 420; Zhao and Pearsall 1998). As fractionation is rarely used for clay removal in phytolith extraction protocols, this process is not considered in detail in this instance.

Gravity sedimentation by beaker employs the principles of Stokes' law, which predicts settlement velocity based on friction upon and the diameter of a particle within a viscous fluid, assuming that the particle is spherical (Pearsall 2001, 419; Piperno 2006, 92). The sample is placed within a beaker in a known volume of deionised water, with or without a deflocculating agent, the sample is stirred and settlement velocity calculated using Stokes' Law. Following settlement, the clay colloid or the supernatant is poured away; the process is repeated until the supernatant is clear, or for at least 8 cycles (Pearsall 2001, 420; Piperno 2006, 91).

Gravity sedimentation by centrifugal force employs similar principles, setting the retention parameters to recover the smallest and, consequently, the lightest phytoliths (5µm) (Pearsall 2001, 420). The sample is placed within a centrifuge tube of deionised water, with or without the addition of a deflocculating agent, mixed using a vortex mixer and centrifuged. Silts and sands settle whilst the clay remains suspended in a

colloid, which is then poured away; this process is repeated between 3-5 times. The use of centrifugal sedimentation is much quicker than gravity sedimentation by beaker (Stokes' Law), providing comparable results. A single equation calculates the settling velocity of denser particles through centrifugal force:

Equation 1: Calculating Settlement Rates of Particles >5µm through Centrifugal Force (After Pearsall 2001, 420)

$$\text{Time (in seconds)} \qquad \frac{90{,}000 \text{ X (depth in centimetres of solution)}}{\text{(gravitational force of centrifugation)}}$$

All three processes follow the same principle, to enable the settling of denser particles >5µm, including silt and sand. Simply put, as particles of different densities settle at different rates, sands will settle faster than silts, whilst clays will remain suspended in the colloid solution for longer (Pearsall 2001, 419). Phytoliths are contained within the silt and sand fractions, ranging between 5-200µm in size, therefore the dispensation of the supernatant, whichever method is used, will not impact upon phytolith recovery, simply removing the clays (particles <2µm) (Lentfer and Boyd 1999; Pearsall 2001, 419).

There is a risk that particularly small phytoliths smaller than 5µm (e.g. Bromeliaceae) may remain in suspension with the clays during gravity sedimentation (Piperno 2006, 91). In order to test this, a sample supernatants were retained from the first four stages of deflocculation and processed in order to assess the level of phytolith loss during the process of gravity sedimentation. Samples were examined for presence of microcharcoal and phytoliths. The results demonstrated no significant loss of phytoliths, and no significant loss of phytoliths smaller than 5µm (see Table 1), with a maximum loss of 5 phytoliths from any stage of the process, and only a single diagnostic phytolith (Arecaceae echinate sphere) identified. The results strongly suggest that loss of phytoliths is more likely to occur during the first decantation of deflocculant, when clays are suspended in Sodium hexametaphosphate. It is not clear whether some phytoliths are also mobilised by this process, further testing would be needed to establish this.

Table 1 Counts of phytoliths and microcharcoal from the supernatant extracted during deflocculation by gravity sedimentation, demonstrating no significant loss of phytoliths with clay removal.

Sample		Context	Test Number				Notes
			Phytolith Presence +/- (Microcharcoal Count)				
			1	2	3	4	
SM39	GT29	39007	- (45)	- (2)	- (2)	- (5)	-
SM55	GT29	55002	1 (12)	N/A	- (0)	N/A	-
SM39	GT30	39007	5 (16)	-	- (4)	-	-
SM55	GT5	55002	2 (8)	-	- (0)	-	-
SM33	GT65	33041	-	-	- (0)	2 (38)	-
SM39	GT1	39007	- (9)	-	- (0)	-	-
SM33	GT62	33040	1 (7)	-	- (3)	-	-
SM55	GT28	55002	3 (22)*	-	- (1)	-	*1 Arecaceae echinate sphere

This protocol omits disaggregation in favour of combined disaggregation with gravity sedimentation by beaker was employed based upon the calculation of settlement velocity using Stokes' Law, for an 8cm column of water within a 400ml beaker. The settlement velocity for silts and sands is calculated as 1hr and 10 minutes with the inclusion of a deflocculating agent, which suspends clays in a colloid for longer, and 1hr for subsequent water rinses. Though there is a case for centrifugal sedimentation, the outcome of both processes would be comparable.

4.3.5 Removal of Carbonates

This protocol employed a 10% (conc.) solution of Hydrochloric acid for the removal of carbonates. This is an almost universal approach for the removal of carbonates from

samples, which can be expedited through heating of the sample to 40°C (Alam *et al.* 2009; Alexandre *et al.* 2012; Barboni *et al.* 2010; Bremond *et al.* 2008; Bremond *et al.* 2008; Burrough *et al.* 2012; Calegari *et al.* 2013; Cordova 2013; Fahmy *et al.* 2006; Garnier *et al.* 2013; Holmgren *et al.* 2012; Horrocks 2005; Iriarte and Paz 2009; Katz *et al.* 2010; Lentfer and Boyd 1998; Lentfer and Boyd 1999; Madella *et al.* 1998; Misra and Bhattacharyya 2014; Parr 2002; Pearsall 1989; Piperno 2006; Powers and Gilbertson 1987; Rovner 1971; Novello *et al.* 2012).

In the past, the removal of carbonates has also been undertaken using Acetic acid (CH_3COOH), though more recent approaches have favoured the use of Hydrochloric acid (Barboni *et al.* 1999; Barboni *et al.* 2010).

The removal of carbonates can be undertaken following the removal of organics, though this may necessitate the implementation of a further stage for removal of organics, for example Pearsall (1989) uses Potassium hydroxide (KOH) as an extra removal of organics stage to ensure that all organics are removed (Alam *et al.* 2009; Lentfer and Boyd 1998; Lentfer and Boyd 1999; Mercarder *et al.* 2000; Parr 2002). Evidently some protocols omit the removal of carbonates from the process altogether, whilst others omit the removal of carbonates in favour of the removal of Iron oxides (see below for discussion) (Calegari *et al.* 2013; Holmgren *et al.* 2012; Horrocks 2002).

In some instances, the removal of carbonates and the removal of organics have been combined into a single stage, using a solution of Hydrochloric acid and Nitric acid ($HCl+HNO_3$) (Albert *et al.* 2006; Albert *et al.* 1999; Mercarder *et al.* 2013; Pearsall 2001; Zhao and Pearsall 1998). Phytolith processing is a lengthy procedure, and the combination of processes has the potential to produce a more expedient processing methodology. However, this is not the case, as typically the combination of removal of carbonates and removal of organics processes require a further removal of organics stage, often undertaken using Hydrogen peroxide (H_2O_2) (Mercarder *et al.* 2013; Pearsall 2001; Albert *et al.* 2006; Albert *et al.* 1999; Zhao and Pearsall 1998). Though, the application of a combined removal of organics and removal of carbonates methodology, followed by a further removal of organics step may enhance the removal of organics, particularly from organic rich soils and sediments.

This protocol favoured removal of carbonates as an essential stage of the process, using Hydrochloric acid (HCl) prior to removal of organics using Hydrogen peroxide (H_2O_2) for two reasons: 1) It is possible that organics may be occluded within the carbonates, if

the removal of organics stage was undertaken prior to the removal of carbonates, these occluded organics may not be released; 2) If carbonates were present within the sample during removal of organics through Hydrogen peroxide (H_2O_2) oxidation, the Hydrogen peroxide (H_2O_2) may also act upon the carbonates, reducing the effectiveness of removal of organics. This assertion is supported by Pearsall, who suggests that the presence of carbonates has the potential to inhibit the effectiveness of Hydrogen Peroxide (H_2O_2) for the removal of organics (2001, 417). As Fig. X demonstrates, the removal of carbonates using Hydrochloric acid (HCl) prior to removal of organics using Hydrogen peroxide (H_2O_2) is the most common approach (Barboni *et al.* 1999; Barboni *et al.* 2010; Bremond *et al.* 2005; Bremond *et al.* 2008; Burrough *et al.* 2012; Calegari *et al.* 2013; Garnier *et al.* 2013; Iriarte and Paz 2009; Katz *et al.* 2010; Madella *et al.* 1998; Neumann *et al.* 2009; Piperno 2006; Zhao and Pearsall 1998; Novello *et al.* 2012; Misra and Bhattacharyya 2014).

4.3.6 Removal of Organics

Removal of organics may be carried out prior to or after deflocculation and the placement of this stage within the process may vary. There are arguments for the removal of organics prior to deflocculation, which may improve deflocculation as organic particles binding clay particles will have been removed (Alam *et al.* 2009; Albert *et al.* 2006; Alexandre *et al.* 2012; Barboni *et al.* 2010; Fahmy *et al.* 2006; Holmgren *et al.* 2012; Katz *et al.* 2010; Lentfer and Boyd 1998; Novello *et al.* 2012; Pearsall 2001, 370; Pearsall 1989; Zhao and Pearsall 1998); and for the process to be carried out following deflocculation in order to enhance the effectiveness of the oxidising agent in removing the organic material (Madella pers. comm.; Rosen pers. comm.; Scott-Cummings pers. comm.; Bremond *et al.* 2008; Bremond *et al.* 2005; Calegari *et al.* 2013; Garnier *et al.* 2013; Horrocks 2005; Iriarte and Paz 2009; Lentfer and Boyd 1999; Madella and Powers Jones 1998; Mercarder *et al.* 2000; Neumann *et al.* 2009; Parr 2002; Piperno 2006). Though there is some variability in the placement of this stage within the process, the removal of organics should always follow the removal of carbonates, particularly where Hydrogen Peroxide (H_2O_2) is used as the primary oxidant, as the presence of carbonates will inhibit the effectiveness of Hydrogen Peroxide (H_2O_2) for the removal of organics (Pearsall 2001, 417).

Organic material may be removed through two processes, wet oxidation and combustion. Wet oxidation can be undertaken using concentrated Nitric Acid (HNO_3), with or without the addition of Potassium chlorate ($KClO_3$) an oxidising agent which

increases the reaction (Garnier *et al.* 2013; Horrocks 2005; Horrocks 2002; Iriarte and Paz 2009; Neumann *et al.* 2009; Parr 2002; Piperno 2006). In some cases, a 10% solution of Potassium hydroxide (KOH) can be added in place of Potassium chlorate, in order to remove excess organics and humic colloids, especially relevant to organic rich waterlogged deposits (e.g. Horrocks 2005; Lentfer and Boyd 1998; Pearsall 1989; Piperno 2006). The use of strong base (alkali) solutions is often discouraged due to the potential solubility of phytoliths in high pH solutions (see Taphonomy chapter for discussion). However, experiments with the application of Sodium hydroxide solution (NaOH) for the removal of excess lipids within reference collection samples did not reveal dissolution, etching or pitting of phytolith morphotypes (McParland 2009). Therefore, it is likely that short term exposure to strong base solutions does not have a substantial impact on phytolith preservation, in some cases the risk of phytolith dissolution is countered by the benefits of the removal of excess organics. The use of Nitric acid (HNO_3) results in a more expedient process, than the use of Hydrogen Peroxide (Piperno 2006, 92).

More commonly, Hydrogen peroxide (H_2O_2) is the principal oxidising agent, as it is as effective as Nitric Acid (HNO_3), potentially less harmful and more affordable (Alam *et al.* 2009; Albert *et al.* 2006; Albert *et al.* 1999; Alexandre *et al.* 2012; Barboni *et al.* 1999; Barboni *et al.* 2010; Bremond *et al.* 2008; Bremond *et al.* 2005; Burrough *et al.* 2012; Calegari *et al.* 2013; Fahmy *et al.* 2006; Holmgren *et al.* 2012; Katz *et al.* 2010; Lentfer and Boyd 1999; Lentfer and Boyd 1998; Madella *et al.* 1998; Mercarder *et al.* 2000; Misra and Bhattacharyya 2014; Novello *et al.* 2012; Parr 2002; Pearsall 2001; Pearsall 1989; Piperno 2006; Zhao and Pearsall 1998).

In some instances, Nitric Acid (HNO_3) is combined with Hydrochloric Acid (HCl) for combined removal of organics and removal of carbonates, followed by Hydrogen Peroxide treatment for the removal of the remaining organics (Albert *et al.* 1999). This process is perhaps useful where deposits are particularly organic rich, though concentrated Nitric Acid (HNO_3) treatment combined with Potassium chlorate ($KClO_3$) is effective even in organic rich waterlogged deposits (McParland 2009).

The use of combustion at 500°C for the removal of organics is less common than the wet oxidation approach (Cordova 2013; Lentfer and Boyd 1998). The method for removal of organic material should be selected carefully, based upon the type of analysis to be undertaken and the type of soil or sediment to be processed. For example,

comparative studies of both wet oxidation and dry ashing have demonstrated that in some cases dry ashing has the potential to preserve the bonds between multi-celled phytoliths or silica skeletons, which may be broken during traditional wet oxidation techniques (Jenkins 2009). This has implications for the identification of cultivated crop phytoliths and the analysis of water availability (Jenkins 2009). However, other studies have found little difference between wet oxidation and dry ashing for the preservation of multi-celled phytoliths (Parr *et al.* 2001). Comparative experiments have also shown that dry ashing has the potential to produce 'cleaner' slides through the complete oxidation of organic material, than those produced using wet-oxidation methodologies (Parr *et al.* 2001; Wang *et al.* 2014). This can be mitigated through the application of a double wet-oxidation stage or the additional use of oxidising agents including Potassium chlorate ($KClO_3$) or Potassium hydroxide (KOH) as described above. The effectiveness of any method of organic removal varies depending on the sediment type, sample size and the amount of organic material present, though it appears that dry ashing requires less 'adjustment' for varying sediment types that wet oxidation (Parr *et al.* 2001; Wang *et al.* 2014).

4.3.7 Heavy Liquid Flotation

Heavy liquid flotation is undertaken in order to separate the phytoliths from their surrounding matrix. When suspended in a heavy liquid calibrated to 2.3g/cm³, phytoliths, which have a density of 2.1-2.2g/cm³ can be separated from the surrounding mineral matrix through centrifugal force and will remain suspended in the solution. This enables the phytolith fraction, or the Acid Insoluble Fraction (AIF) to be recovered from the surface or just below the surface of the heavy liquid. A range of heavy liquids which can be calibrated to 2.3g/cm³ can be used for heavy liquid flotation, including Tetrabromoethane ($C_2H_2Br_4$), Cadmium Iodide (CdI_2), a combined Cadmium Iodide (CdI_2) and Potassium Iodide (KI) preparation, Zinc Iodide (ZnI_2), Sodium Polytungstate (SPT) ($Na_6(H_2W_{12}O_{40})\cdot H_2O$) or Zinc Bromide ($ZnBr_2$). The most commonly used heavy liquids are Sodium Polytungstate (SPT) ($Na_6(H_2W_{12}O_{40})\cdot H_2O$) or Zinc Bromide ($ZnBr_2$) (Albert *et al.* 2006; Albert *et al.* 1999; Barboni *et al.* 2010; Barboni *et al.* 1999; Bremond *et al.* 2008; Bremond *et al.* 2005; Burrough *et al.* 2012; Calegari *et al.* 2013; Fahmy *et al.* 2006; Garnier *et al.* 2013; Horrocks 2005; Horrocks 2002; Iriarte and Paz 2009; Katz *et al.* 2010; Madella *et al.* 1998; Mercarder *et al.* 2013; Mercarder *et al.* 2011; Mercarder *et al.* 2000; Neumann *et al.* 2009; Novello *et al.* 2012; Piperno 2006). The use of Tetrabromoethane ($C_2H_2Br_4$) appears to have been discontinued due to the

carcinogenic nature of the preparation (Piperno 2006); comparatively Zinc Bromide ($ZnBr_2$) appears to be decreasing due to similar concerns. Though a combined Cadmium Iodide (CdI_2) and Potassium Iodide (KI) preparation is thought to give the 'cleanest' results with increased phytolith recovery, it is expensive and toxic, and as a result rarely used (Fig. X) (Piperno 2006). Pearsall and Zhao (1998) equally favour the use of a combined Zinc Bromide and Hydrochloric acid ($ZnBr_2$+HCl) preparation or a Zinc iodide preparation (ZnI_2) producing the 'cleanest' results in tropical soils (Piperno 2006). However, the preparation of Zinc Bromide ($ZnBr_2$) aside from its toxicity is expensive as it cannot be recycled. Though the use of SPT ($Na_6(H_2W_{12}O_{40})\cdot H_2O$) can lead to samples with occluding organic matter, the impact of this is minimal, particularly in soils and sediments with poor organic preservation, as at Songo Mnara. SPT ($Na_6(H_2W_{12}O_{40})\cdot H_2O$) benefits from the fact that it can be recycled through double filtration and reduction; although filtration is a lengthy process, the use of SPT ($Na_6(H_2W_{12}O_{40})\cdot H_2O$) is much cheaper than the alternatives as it can be reused multiple times (Madella *et al.* 1998; Zhao and Pearsall 2001).

This protocol selected to use SPT ($Na_6(H_2W_{12}O_{40})\cdot H_2O$) for heavy liquid separation of the AIF. Used SPT was recycled and double filtered before being reduced and reused; each batch of recycled SPT was tested for phytolith contamination before use.

4.3.8 Drying of Acid Insoluble Fraction (AIF)

The AIF needs to be completely dehydrated before weighing (to calculate phytoliths per gram of sediment) and mounting; mounting fluids including Entellan®, are formulated for the mounting of dehydrated specimens. There are two main methods used for the dehydration of the AIF – air drying and alcohol dehydration.

The AIF can be air dried, a method preferred by some phytolith analysts (e.g. Albert *et al.* 2006; Albert *et al.* 1999; Alexandre et al.2011; Burrough *et al.* 2012; Madella *et al.* 1998;Mercarder et al.2011). However, air drying of samples can take a significant amount of time and complete dehydration is not certain, whereas the use of alcohol dehydration accelerates the drying process and ensures complete dehydration. Traditionally, Acetone (C3H6O) and Ethanol (C2H6O) have been used for the dehydration of the AIF (Alam *et al.* 2009; Calegari *et al.* 2013; Cordova 2013; Garnier *et al.* 2013; Iriarte and Paz 2009; Lentfer and Boyd 1999; Lentfer and Boyd 1998; Neumann *et al.* 2009; Parr 2002; Piperno 2006); however, Methanol (CH4O) may also be used (Madella *et al.* 1998; Zhao and Pearsall 1998). It is clear that though there may

be a preference for a particular alcohol for the dehydration of the AIF, there is no difference in performance, with the exception of Acetone (C3H6O) which has the potential to react with plastic centrifuge tubes. Based upon this, this protocol selected to use Methanol (CH4O) rather than Acetone (C3H6O), due to the use of plastic centrifuge tubes.

4.3.9 Mounting of Slides

Phytoliths have a refractive index of 1.42, to maximise visibility mounting mediums with a refractive index ranging between 1.51-1.54 should be used (Piperno 2006, 93). As Fig. X demonstrates – in practice, a range of mounting mediums with a variety of refractive indices are used including Permount™, Entellan®, Canada Balsam, Naphrax®, Glycerine, Benzyl Benzoate and Silicone Oil. The selection of mounting medium may instead depend on the use of the slide, for example, glycerine and silicone oil are not suitable for long term storage, whereas resinous mounting media including Permount™ and Entellan® can be archived in the long term. However, as phytoliths are three dimensional objects, a liquid mounting media which allows the morphotype to rotate such as Glycerine and Silicone Oil can be beneficial (Piperno 2006, 93). As Permount™ and Entellan® can 'set' within 20 minutes, slides must be examined immediately after mounting in order to ensure that the media remains liquid throughout analysis, revisiting the slide may mean that it has to be remounted as it will become impossible to rotate the phytoliths (Piperno 2006, 93).

This protocol has selected to use Entellan®, allowing longer term archive storage of the slides; in order to mitigate the rigidity of the medium, samples are floated, dried and mounted immediately before analysis.

4.4 Rationale

Whilst it is impossible to compare the results of all of these methodological variants, the phytolith processing protocol used for the Songo Mnara samples is a rational selection based upon an understanding of the methodological variations presented in this review. This protocol eschews sieving and disaggregation in favour of disaggregation and the removal of organics through flotation during gravity sedimentation; larger particles which are not removed prior to sample preparation separated from the AIF during heavy liquid flotation and are of minimal impact on phytolith concentration. This significantly reduced the processing time required, enabling a larger volume of samples to be processed, and essential for the spatial approach taken. Low overall concentrations of

phytoliths were mitigated through the use of a larger sample size, and the mounting of 100% of the AIF. Though this does not provide extra material for double mounting in Entellan®, if necessary, a soil voucher sample has been retained, enabling a further sample to be processed.

Deflocculation by gravity sedimentation was favoured over centrifugal sedimentation based on experience and preference, as both methodologies are comparable to one another. A small risk of loss of small phytoliths in the supernatant was acknowledged and a small sample of supernatants were tested to assess the level of potential loss through this process.

In order to maximise the removal of organics using Hydrogen peroxide, the removal of carbonates stage undertaken with Hydrochloric acid was carried out first. It is acknowledged that the use of SPT for densimetric separation of phytoliths using heavy liquid does not produce the 'clean' results free of organic material, possible with the use of Zinc Bromide; the identification of phytoliths is minimally impacted by this selection. The benefits of SPT, including the ability to recycle the preparation for multiple uses and the relative low toxicity outweigh the benefits of the use of Zinc Bromide in this instance.

4.4.1 Summary

This review presents the most comprehensive assessment of phytolith processing methodologies to date, framing and justifying the selection of the protocol used for the processing of samples from Songo Mnara. Importantly, this review identifies the lack of a single standardised phytolith processing methodology. Though small scale methodological comparisons have been carried, a wider review of all methodologies is required in order to understand the impact of methodological differences on the comparability of samples. Figure 8 and Appendix 2 represent the variability of phytolith methodologies, identifying differences between researchers and between individual studies. Whilst the selection of methodologies may be chosen to produce the best possible results relating to a specific to the soil or sediment type, in other instances the methodological selection may be due to researcher preference or the availability of chemicals. Methodologies are often modelled on those of Piperno (2006), Pearsall (2001) and Lentfer and Boyd (1999).

There appears to be a shift towards the use of less toxic or carcinogenic chemicals for phytolith processing, for example moving away from the use of Nitric Acid, Cadmium

Iodide and Potassium Iodide preparations and Zinc Bromide towards the use of Hydrogen peroxide and SPT.

In addition to variability of chemicals used in each process, there is demonstrable variability in the order in which these processes are undertaken (see Fig. X). At present, this suggests that the processing stages can be 'mixed and matched', producing comparable results. A single standardised methodology, adjusted and accounting for soil and sediment characteristics, may ensure that results are comparable across studies, at present this is not necessarily the case and an understanding of the variability, benefits and potential problems with each method, relies upon the understanding and judgment of the reviewer.

5. Phytolith Taphonomy within the Wattle and Daub Structure

5.1. Introduction

Plant remains, particularly phytoliths, are subject to complex taphonomic processes which can influence the inclusion and preservation of phytoliths within the archaeological record (Madella and Lancelotti 2012, 76). For example, anthropogenic influences can increase the concentration of phytoliths within archaeological sites, due to the use of plant materials for subsistence or craft (Cabanes 2011, 2480). This chapter considers the range of factors that can affect the production and preservation of phytoliths, as a means of understanding the record from Songo Mnara.

5.2. In Situ Indicators?

Phytoliths are released into the soils following the necrolysis of plant tissues, the process of decay or destruction through burning for example, and are incorporated into soils through the complex processes of disaggregation and biostratinomy (Madella and Lancelotti 2012, 79; Piperno 1985, 265).

As phytoliths are produced within the cells of the vegetative structures of the plant and are not an active part of the reproductive system of the plant, they are released into the soil and are not designed to become immediately airborne (Bartoli and Guillet 1977; Piperno 1985, 265). Therefore, phytoliths usually enter the archaeological record in the area in which necrolysis and biostratinomy took place, providing an in situ indicator of plant material (Bartoli and Guillet 1977; Piperno 1985, 265; Runge 1999, 50).

The in situ preservation of phytoliths facilitates spatial analysis, as plant remains have the potential to be concentrated within activity areas on house floors, within working areas, or within discrete features including cess pits, pits or middens (Piperno 1985, 265).

However, as with all aspects of taphonomy, the issue is more complex. Though phytoliths are not a functioning part of the reproductive system of plants, they are capable of travelling long distances through wind transport (Piperno 1985, 265); the first discovery of phytoliths was made by Christian Ehrenberg in 1841, in a sample of dust taken from the deck of the HMS Beagle by Charles Darwin. Phytoliths are particularly susceptible to wind transport prior to their incorporation into the archaeological record, during biostratinomic processes; in particular, phytoliths

originating from burned plant material can be released into the air and incorporated into the wind transport systems (Piperno 1985, 265). The analyses of modern phytolith assemblages and their comparison with local vegetation signatures have revealed evidence of wind transported phytoliths, confirming the possibility of long range wind transport (Barboni *et al.* 1999, 87; Madella and Lancelotti 2012, 79; Osterrieth *et al.* 2009, 78). The taphonomic action of wind transport raises concerns that the phytoliths transported and redeposited extra situ may appear to be local when viewed within an archaeological assemblage (Osterreith *et al.* 2009m 78). However, the impact of contamination by wind transport is largely considered negligible, with the majority of the assemblage considered as an in situ indicator (Piperno 1985, 265; Runge 1999, 50).

Phytoliths may also be subjected to other taphonomic processes, including translocation, here defined as the movement of phytoliths within soil, for example through colluvial or alluvial processes, or anthropogenic effects, such as moving clay deposits for construction purposes. Phytoliths may be redeposited due to colluvial slippage with larger phytolith deposits at the base of hills, though this process is often more visible in the soil profile and can be easily identifiable in the field (Osterreith *et al.* 2009, 78). Similarly, they may also be translocated during alluvial processes.

Phytoliths may also be translocated within soils and sediments through anthropogenic action, for example, it is possible that daub and clay transported to the site of Songo Mnara contained a phytolith assemblage local to the area the deposit originated from. The phytolith signature of a daub structure may therefore add a non-local phytolith signature to the anthropogenic layers, as is the case with the 'use of older anthropic sediments for the construction of new structures' (Madella and Lancelotti 2012, 79).

The location and sediment type of Songo Mnara may facilitate phytolith dispersal or redeposition through wind transport, though the effect of these processes is thought to be negligible, particularly within the structures at Songo Mnara which will have been protected from these natural taphonomic effects to some degree. The interior of the structures at Songo Mnara are more likely to have been the subject of anthropogenic effects of taphonomy, including pre-depositional and post-depositional effects (discussed below). Pre-depositional taphonomic effects are pertinent due to the widely accepted hypothesis that phytoliths are an in situ indicator, representing the local plant signature or in the case of anthropogenic action, the intra-locus inclusion of plant materials within the archaeological record.

Phytolith Inclusion in the Archaeological Record

Phytoliths are included within the archaeological record through a series of complex taphonomic process:

1) Necrolysis: The decomposition and disaggregation of plant materials, releasing phytoliths from the plant tissue (Madella and Lancelotti 2012, 79; Osterreith *et al.* 2009, 71).

2) Biostratinomy: The processes which take place after Necrolysis (plant death) but prior to incorporation within the deeper sediments (Alexandre *et al.* 679-681; Madella and Lancelotti 2012, 79; Osterreith *et al.* 2009, 71).

3) Pedogenesis: Phytoliths become incorporated into the soil formation processes including the cumulative 'effect of physical, chemical, biological and anthropogenic processes on soil parent material' (Alexandre *et al.* 679-681; Madella and Lancelotti 2012, 78).

4) Fossil Diagenesis: The combined effects of physical, chemical and biological processes upon the phytolith assemblage within the soil or sediment, including dissolution, weathering and other taphonomic effects which may change the nature or visibility of the assemblage (Madella and Lancelotti 2012, 79; Osterreith *et al.* 2009, 71).

Each stage of this process encompasses further taphonomic processes affecting the visibility and preservation of the phytolith assemblage. Although phytoliths are relatively stable, abundant and almost 'universally' preserved within sediments – phytolith preservation is not dependent on preservation within anoxic environments or particular sediments for example due to the nature of silicate preservation – preservation is 'selective' and most likely to be affected during necrolysis and biostratinomy (Piperno 1985, 248-249).

Prior to necrolysis whilst the phytoliths are housed within the plant tissues, the effects of dissolution, mechanical breakage and weathering are limited (Madella and Lancelotti 2012, 77-78); however, upon release, the morphotypes are subject to the effects of biostratinomy - the transport and movement of phytoliths through wind or water action which may abrade the diagnostic components of the phytolith - in the case of more fragile morphotypes this abrasion may break them and leave them subject to rapid

dissolution and chemical weathering within the soils (Farmer *et al.* 2005, 72; Madella and Lancelotti 2012, 78). Phytoliths may also be incorporated within soils through the effects of bioturbation within the O horizon, particularly the effects of earthworm and insect activity (Farmer *et al.* 2005, 72; Hart and Humphreys 1997, 98). The abrasive effects of this process clarify a phenomenon observed within phytolith reference collections, the lack of evidence for phytolith morphotypes within archaeological contexts from plant species known to produce diagnostic phytoliths and endemic within the local environment (Piperno 1985, 248-249).

Following the inclusion of the plant material within the soils diagenetic changes take place, which have the potential to considerably alter or affect the preservation of the phytolith assemblage, through the impact of weathering and dissolution (Madella and Lancelotti 2012, 79; Osterreith *et al.* 2009, 71).

5.2.1 Phytolith Preservation: Weathering and Dissolution

Phytoliths are often considered to be universally preserved and abundant within soils and sediments (Piperno 1985, 262); as research has expanded across the globe and into a wide range of environments it has become clear that a range of taphonomic effects can affect the preservation and survival of individual morphotypes and assemblages. These processes are complex and influenced by a range of factors including soil properties, local climate and weather (Madella 1997, 49).

The silica composition of phytoliths facilitates their preservation in a wide range of environments, phytoliths are preserved within sediments dating from prehistoric to modern periods and within modern reference samples. Phytoliths are preserved within all environment types from anoxic wetland deposits, to sandy deposits on coral (McParland 2009; Sulas and Madella 2012). However, the quality of phytolith preservation may be affected by the processes of weathering and dissolution. These taphonomic issues are pertinent as the interpretation of the phytolith assemblage relies on an assessment of the morphotypes present, their relative abundance and often their state of preservation (Cabanes *et al.* 2011, 2481). As morphotypes may be subject to differing levels of dissolution it is essential to understand the taphonomic factors which may have affected the assemblage, to enable a valid interpretation of the assemblage (Cabanes *et al.* 2011; Madella 1997, 49). The dissolution and weathering of phytoliths are influenced by a variety of factors, and are not dependent on any one factor.

5.2.2 Weathering

The term ‘weathering’ refers to the observation of deterioration of the phytolith surface, suggesting that the phytolith has begun the process of dissolution. Though the level of dissolution is fundamentally linked to the pH of the environment, it is also influenced by other factors, including the surface area of the phytolith, the level of silicification and the ‘purity’ of the phytolith (Osterrieth *et al.* 2009, 78).

Although primarily composed of silica, other minerals can be co-deposited during phytolith formation, for example aluminium (Al) in the form of aluminosilicate or hydroxyalumino silicate can in some cases be deposited within the cells of arboreal dicotyledons and gymnosperms (Carnelli *et al.* 2002, 346). Conversely, although the co-deposition of aluminium (Al) within monocotyledons is possible, it is not as common as within vascular plants, gymnosperms and arboreal dicotyledons (Carnelli *et al.* 2002, 349). Aluminium can be toxic, and it suggested that silica mitigates this toxicity; it is therefore beneficial for plants absorbing high rates of aluminium (Al) to co-deposit aluminium (Al) and silica (Si) (Carnelli *et al.* 2002 349). In addition, phytoliths can also co-deposit calcium (Ca), sodium (Na) and iron (Fe) alongside silica (Si) (Osterrieth *et al.* 2009, 74-75). The ‘purity’ of the phytolith in terms of its silica content can influence the level of weathering and dissolution the phytolith undergoes, the higher the silica (Si) content the more resistant to chemical attack, weathering and dissolution the phytolith. This is due to the fact that the occluded elements within the silica matrix produce structural irregularities within the phytolith, leaving it more susceptible to the effects of chemical dissolution and weathering (Osterrieth *et al.* 2009, 74-75).

However, the level of silicification of the phytolith may also influence the weathering, dissolution and preservation of the morphotype. Osterrieth *et al.* (2009, 74) suggest that the level of weathering observed on the surface of a phytolith may be influenced by the level of silicification of the phytolith within the cell structure of the plant. It is suggested that incomplete silicification may produce phytoliths with a ‘weathered’ appearance, which may be more susceptible to dissolution and abrasion (Madella and Lancelotti 2012, 77; Osterrieth *et al.* 2009, 74). In addition, phytoliths with a ‘weathered’ appearance within sediments are often interpreted as representative of fossil assemblages, yet due to the fact that less-silicified phytoliths can be released from modern plant material with a ‘weathered’ appearance, this may not be an accurate assumption (Osterrieth *et al.* 2009, 74).

It is thought that the weathering process primarily takes place during Necrolysis and Biostratinom, prior to the inclusion of the phytolith within the archaeological record (Fraysse *et al.* 2006; Osterrieth *et al.* 2009, 74). This suggests that the weathering and abrasion of phytoliths during these taphonomic processes stabilises on inclusion within the soil environment and is potentially overtaken by the process of dissolution. The evidence above suggests that phytoliths with a 'weathered' appearance may also be indicative of poor silicification within the plant tissues, therefore entering the archaeological record with a 'weathered' appearance, and as with the case of 'impure' phytoliths, leaving the morphotype more open to the effects of dissolution.

5.2.3 Phytolith Preservation and the Impact of Soil pH

Soil pH is not thought to be a limiting factor for phytolith preservation; only extremely alkaline contexts are thought to affect phytolith preservation, contexts including hearths or ashy deposits with a pH above 9 (Cabanes *et al.* 2011, 2486; Fraysse *et al.* 2009; Karkanas *et al.* 2002; Piperno 1985 262). However, evidence suggests that whilst phytoliths are best preserved within an acidic environment (pH 3), a base pH of 8-8.5 can significantly influence or accelerate the dissolution and weathering within soils (Bartoli and Guillet 1977; Farmer *et al.* 2005, 75; Fraysse *et al.* 2009, 205; Cabanes *et al.* 2011, 2481; Osterreith *et al.* 2009, 72; 78). It is suggested that pH is the primary catalyst for chemical degradation of phytoliths within basic soils, in soils with a pH above 8-8.5 phytoliths may be subject to full or partial rapid dissolution within 'years' rather than 'hundreds of years' (Cabanes *et al.* 2011, 2486; Fraysse *et al.* 2009, 205). Further factors influence the rate of chemical dissolution and may present a preservational bias in the phytolith record including the composition of the phytoliths themselves (Osterreith *et al.* 2009, 78). Soils with high pH values contain a higher quantity of phytoliths displaying the characteristic signs of 'weathering', due to the hostility of the preservational environment (Osterrieth *et al.* 2009, 74).

5.2.4 Dissolution

Dissolution refers to the chemical destruction of phytoliths composed of solid opaline silica and co-deposited minerals and their reversion to Monosilicic acid within the soil profile, the process of dissolution is part of a silica cycle, influenced primarily by local vegetation, climate and hydrology. This process has the potential to affect the preservation of phytoliths within the archaeological record and the resulting interpretation of archaeological and palaeoenvironmental assemblages. Therefore, a full

understanding of the potential taphonomic impacts of both weathering and dissolution processes are imperative.

Modern vegetation, particularly in forest environments has a key impact on the dissolution of phytoliths from within sediments (Madella and Lancelotti 2012, 79). If the phytolith mineral is heavily affected by the process of weathering, or was inadequately silicified within the plant tissues, it is more susceptible to the chemical processes of dissolution (Osterrieth *et al.* 2009, 74-75). Dissolution is influenced by several key factors, the local vegetation, climate, hydrology, bioturbation and soil chemistry (Cabnes *et al.* 2011, 2486; Madella 1997).

Local hydrology, climate and vegetation are key considerations; phytoliths are incorporated into the archaeological record as 'hydrated' particles which once dehydrated may be dissolved as part of the silica (Si) cycle; in an environment with stable Monosilicic acid content within the ground water phytoliths are likely to remain stable within the soils or sediment (Alexandre *et al.* 1997a, 677; Cabanes *et al.* 2011, 2489; Madella and Lancelotti 2012, 78).

However, root action contributes to the dissolution of phytoliths, silica reverted to Monosilicic acid through the process of weathering and chemical dissolution is absorbed through the roots of local vegetation, to become redeposited as opaline silica within the plant cell structure (Alexandre *et al.* 1997a; Madella and Lancelotti 2012, 79). In tropical soils, phytoliths are a significant source of silica as a result of poor mineral content of the soils, phytoliths reverted to Monosilicic acid through the processes of weathering and dissolution are subsequently absorbed by existing vegetation which takes up any available Monosilicic acid in the soils (Alexandre *et al.* 1997a; Farmer *et al.* 2005, 71). This process is aided by climatic and hydrological factors which mobilise Monosilicic acid, enabling the leaching of silica from the soil during periods of increased rainfall or hydrological action (Cabanes *et al.* 2011, 2486; Farmer *et al.* 2005, 71).

These processes form a silica (Si) cycle, through which Monosilicic acid is absorbed by vegetation and deposited as solid opaline silica within the plant tissues before being released from the plant tissue during necrolysis. The majority of weathering and dissolution processes appear to happen during biostratinomy, although these processes continue through dissolution during pedogenesis, the impact of these taphonomic processes decreases with soil depth, though the phytoliths which stabilise within these

soils may be visibly weathered or ‘corroded’ (Fraysse *et al.* 2009, 205; Madella and Lancelotti 2012, 79; Madella 1997, 55; Runge 1999, 25). Vegetation increases the rate of weathering and dissolution, absorbing the silica for redeposition as opaline silica within plant tissues (Alexandre *et al.* 1997a, 681; Farmer *et al.* 2005, 71). This process is particularly effective within tropical equatorial forests due to the efficiency of the silica cycle in local vegetation (Alexandre *et al.* 1997a, 677).

The process of dissolution is more effective where phytoliths have been affected by mechanical abrasion, the physical breakage and abrasion of phytolith morphotypes during biostratinomy and the early stages of pedogenesis (Cabanes *et al.* 2011, 2480). In addition, mechanical abrasion may render phytoliths unidentifiable due to breakage and the abrasion of identifiable diagnostic decorative appendages (Cabanes *et al.* 2011, 2481).

5.2.5 Impact of Weathering and Dissolution on the representation of individual families or species

One of the main factors contributing to differential preservation through differential dissolution and weathering of phytolith morphotypes is the variation in silicification of phytoliths; the low level of silicification, or the co-deposition of silica with other minerals leading to a compromised silica structure more susceptible to dissolution and weathering.

Although diagnostic phytoliths may be observed within reference collections, they do not always enter the archaeological record (Piperno 1985, 248-249), this discrepancy is explained by the theory that dissolution and weathering affect phytoliths which are less silicified or formed of impure silica. It is known that phytoliths from different plant species suffer from differential preservation (Cabanes *et al.* 2011, 2481; Fraysse *et al.* 2009). In the same way, various morphotypes are also affected by differential preservation, and these may originate from the same or different species (Cabanes *et al.* 2011, 2486). For example, epidermal cells, ‘hairs, papillae, bulliform, parallelepedal psilate, irregular psilate’, and decorated long cells including ‘sinuous long cells and verrucate long cells’ are all identified as relatively unstable in the archaeological record (Cabanes *et al.* 2011, 2486; Osterrieth *et al.* 2009, 78; Piperno 1985, 264). On the other hand, the size of the phytolith may be the factor influencing preservation, it is suggested that the larger surface area exposed on morphotypes over 50μm in size may exacerbate and facilitate the effects of mechanical abrasion and dissolution (Osterrieth *et al.* 2009, 74; 78). It is suggested that smaller forms from grasses including rondels and trapezoid

phytoliths, with surface areas smaller than 38μm may not suffer from dissolution and mechanical abrasion as forms with larger surface areas may (Osterrieth *et al.* 2009, 74), though their small size may increase the taphonomic impact of profile migration (see below). In addition, burned phytoliths are more susceptible to dissolution than unburned phytoliths (Cabanes *et al.* 2011, 2486).

The hypothesis that phytoliths over 50μm with highly decorated surfaces are more susceptible to dissolution, has wider implications for the interpretation of phytolith assemblages, as it is precisely these phytoliths which are often diagnostic of plants of economic importance, crop plants; for example, Oryza sp. bulliform cells or Triticum sp. dendriform cells (Cabanes *et al.* 2011, 2486).

Perhaps, instead of classifying the preservation of the assemblage based on the degree of weathering the assemblage has undergone, as is current standard practice, the degree of preservation could be assessed by the preservation of those morphotypes vulnerable to mechanical abrasion and dissolution (Cabanes *et al.* 2011, 2488). The presence or absence of weathered phytoliths is often used to assess the level of profile migration within an assemblage; this discussion demonstrates that these criteria are not necessarily indicative of profile migration as some morphotypes, particularly those which have a smaller surface area, are less likely to demonstrate features of weathering and more likely to migrate through the profile. Weathered phytoliths can also be representative of poor silicification of cells within the plant tissues, entering the archaeological record in a weathered state. All of these taphonomic processes should be taken into account when assessing the phytolith assemblage in order to inform the interpretation of the assemblage.

5.2.6 Profile Migration

Profile migration, here defined primarily as the horizontal movement of phytoliths between contexts within the soil profile, may also refer to the horizontal movement microfossils through contextual boundaries. Profile migration is also referred to as translocation, phytolith illuviation or mixing within the literature (Hart and Humphreys 1997, 93). However, translocation can also refer to the physical movement of soils containing phytoliths.

The issue of profile migration is a major taphonomic consideration and a contentious subject within the phytolith literature; there is a division between the belief that phytoliths are not subject to migration and relatively stable within the soil profile

(Fisher *et al.* 1995; Piperno 1985; Rovner 1986) and the opposing belief that phytoliths move between the profiles (Alexandre *et al.* 1997a; Farmer *et al.* 2005; Fishkis *et al.* 2010a; Gol'yeva 1997; Hart and Humphreys 1997). The issue is incredibly complex and both theories have obvious and serious implications for the interpretation of phytolith assemblages.

5.2.7 Soil Profile Migration

Profile migration may occur as a result of bioturbation or the mechanical movement of fine soil particles through soil porosity as a result of macropore channels between 30-300μm in size, this movement may be influenced by local climate and hydrological regimes (Hart and Humphreys 1997, 97; White 1985 PAGE). Evidence for phytolith profile migration is observed within soil profiles, demonstrating that vertical movement is facilitated through sediment voids and macropore channels (Osterrieth et al., 2009, 75; White 1985, PAGE). The size of phytoliths (>10μm) prohibits their progression through the natural soil matrix in the absence of macropore channels, which are formed through the impacts of bioturbation (Fisher *et al.* 1995; Fishkis *et al.* 2010a; Runge 1999, 25). Clay sized particles may freely move throughout the soil matrix, however, phytoliths as silt sized particles are restricted to movement within macropore channels within the soil (Fishkis *et al.* 2010a, 27; Fishkis *et al.* 2010b, 453; Runge 1999, 25). Macropore channels primarily facilitate the movement of water through the soil profile; consequently phytoliths may be impacted upon, with movement facilitated by hydrological and climatic regimes (Van den Berg and Ullersma 1991).

Small sized phytoliths may be more susceptible to the processes which influence profile migration, primarily due to the fact that smaller sized phytoliths are more likely to pass through macropore channels which facilitate their vertical migration through the soil profile (Fishkis *et al.* 2010b, 452). This has the potential to influence the interpretation of assemblages due to the potential for over-representation of smaller sized phytoliths at greater depths within the soil profile (Fishkis *et al.* 2010b, 452).

It is important to note however, that macropore channels are not perpetually stable (Van den Berg and Ullersma 1991), they are unlikely to continuously support the movement of phytoliths throughout the profile therefore, it is possible that the causes of profile migration are not as detrimental or as simplistic as suggested above.

5.2.8 Hydrology and Climate

Local hydrology and climate directly influence the movement of phytoliths through soil macropore channels; light or heavy levels of rainfall (1-10mm) may be enough to mobilise phytoliths through voids within the soil profile (Hart and Humphreys 1997, 98; Fishkis *et al.* 2010b, 445; White 1985). Experimental data suggests that the impacts of hydrology or bioturbation have the potential to move phytoliths up to 4cm per year down through the soil profile (Fishkis *et al.* 2010a, 34; Madella and Lancelotti 2012). Soil type variation has been shown to have a significant impact on the velocity of movement through the profile (Fishkis *et al.* 2010a, 34; Madella and Lancelotti 2012, 78). These processes may produce size or shape biased phytolith assemblages due to the preferential transport of smaller phytoliths (Fishkis *et al.* 2010a, 34).

5.2.9 Profile Depth

One of the key arguments for phytolith stability within the profile is the relative abundance of phytoliths within the A horizon (topsoil) compared to decreasing concentrations within deeper horizons. Though this is in part due to the effects of weathering and dissolution (see above for discussion), it is expected that should profile migration be a major influence on the archaeological phytolith assemblage, it would increase in concentration throughout the profile (Fishkis *et al.* 2010a, 31; Hart and Humphreys 1997, 93; Piperno 2006; Piperno 1985; Runge 1999, 25). However, the main indicator to support this hypothesis is the presence of phytoliths with surface characteristics of the effects of weathering or dissolution within the lower soil horizons. The presence of 'modern' phytoliths, lacking the surface characteristics of weathering and dissolution within the lower soil horizons, are indicative of profile migration (Barboni *et al.* 1999, 98).

However, this issue is more complex than previously understood, as modern plants have been shown to produce phytoliths with a weathered appearance, particularly where these have not fully silicified within plant tissues (see above) (Osterrieth *et al.* 2009, 74). Conversely, increasing concentrations of phytoliths with depth, the concentration of phytoliths on an impermeable surface (see below), or the concentration of phytoliths within natural sediments are often considered to occur as a result of profile migration (Alexandre *et al.* 1997a, 679; Fishkis *et al.* 2010a; Fishkis *et al.* 2010b, 445; Hart and Humphreys 1997, 93; Piperno and Becker 1996).

This method makes the interpretation of phytolith stability within the sediments problematic as 'modern' intrusive phytoliths moving though macropore channels may

be indistinguishable from those within archaeological layers. It is often assumed that the 'age of phytoliths increases with soil depth', this has significant implications for the interpretation of phytolith assemblages as differences within the assemblage throughout the soil profile are interpreted as evidence of changes in vegetation profile or plant use through time (Fishkis *et al.* 2010b, 445; Hart 2003; Hart and Humphreys 1997). The use of soil micromorphology by thin section may facilitate a greater understanding of the soil matrix, and provide evidence for the movement of phytoliths along macropore channels (Fisher *et al.* 2010a, 28; Gol'yeva 1997, 16).

However, it has been argued that the distinctive patterns within the soil profile are not random, as they would be if they were subject to profile migration, but 'distinctive' and representative of anthropogenic activities, supporting the hypothesis of phytolith stability (Piperno 1985, 266). Rovner (1984) believed that though profile migration was possible and was worthy of consideration, it was unlikely to have a large impact on the interpretation of the phytolith assemblage. It is a complex and contentious issue, but it is suggested that there are significant indicators of phytolith movement through the soils including:

1. The presence of phytoliths lacking the surface characteristics of weathering and dissolution.

2. The presence of large quantities of phytoliths which represent the modern flora.

3. A homogenous spread of phytoliths throughout the profile; the concentration of phytoliths traditionally decreases with soil depth.

These are not absolute criteria and their application is dependent on context; as discussed above, there are complex issues with the employment of such criteria and as a result, their application when acknowledging the potential for profile migration may perhaps represent a more pragmatic, holistic approach to phytolith analysis, as opposed to a wholly scientific approach. These criteria have been used to assess the extent of phytolith profile migration within sediments, and in many cases this has not had a detrimental impact on the analysis of the phytolith assemblage (Gonzales and Osterieth 1997, 88; Madella 1997, 55; Piperno 1985, 266; Rovner 1984).

5.2.10 Soil Type

Profile migration is evidently influenced by a range of factors, including soil type; it is well known that phytoliths are least common in sandy soils, their size (5-50μm) means

that they are most often contained within the silt fraction (Bobrova and Bobrov 1997, 7; Fishkis *et al.* 2010a, 27; Hart and Humphreys 1997, 97). There is little difference in hydrologically influenced migration rates between silty loam and loamy sand, even when subjected to a hydrologically exaggerated experiment which simulated rainfall levels of (Fishkis *et al.* 2010a, 34; Fishkis *et al.* 2010b, 451). However, it is possible that phytolith profile migration may be more significant within sandy sediments (Gol'yeva 1997, 15; Hart and Humphreys 1997, 98; Piperno 1985, 265).

Concentrations of phytoliths also occur where profile migration is prevented by a more resistant soil horizon (Bartoli and Guillet 1977; Hart and Humphreys 1997, 93; 98). For example, clay horizons may present an impermeable layer, mitigating the impact of the processes of profile migration; leading to a concentration of phytoliths which have migrated through the profile to settle above the clay deposit (Alexandre 1997, 679-681; Bartoli 198; Fishkis *et al.* 2010a; Fishkis *et al.* 2010b, 445; Gol'yeva 1997, 19; Hart and Humphreys 1997, 99).

Though clay sediments are likely to be resistant to profile migration, limited migration of phytoliths through resistant layers within the profile may occur where the profile is subject to bioturbation and the creation of macropore channels to facilitate the flow of water.

5.2.11 Bioturbation and Mixing

Macropore channels facilitate profile migration through the soil profile allowing water ingress which mobilises phytoliths; these channels may be created through the act of bioturbation, in which soil fauna or plant roots impact upon the soil or sediment (Piperno 1985; Hart and Humphreys 1997, 93). Natural environmental processes including shrink swell, may stimulate mixing of the soil profiles, however, these effects should be confined to the later deposits in a soil profile.

Whilst it is understood that bioturbation may effect profile migration and mixing, the potential impacts of the process are little understood (Alexandre et al., 1997; Bobrova and Bobrov 1997, 9; Hart and Humphreys 1997; Humphreys *et al.* 2003; Farmer *et al.* 2005; Fishkis *et al.* 2010a, 27; Madella and Lancelotti 2012, 78; Runge 1999). In addition, the movement of soil fauna may also physically move phytoliths within the profile. An understanding of the potential impact of bioturbation is essential despite the complexities of the process, due to the potentially detrimental effects of the process to the interpretation of the phytolith assemblage.

The impacts of bioturbation may depend on the characteristics of the local environment and the soil type, for example termite channels may facilitate extreme down-profile progression of phytoliths from the surface to a depth of 2 metres (Madella and Lancelotti 2012, 78; Runge 1999, 25). These impacts may be highly localised or confined to macropore channels, leading to variation within individual soil horizons (Madella and Lancelotti 2012, 78). Conversely, earthworm activity has the potential to physically move phytoliths through the profile and to facilitate the movement of phytoliths through the flow of water through open macropore channels. In experimental conditions, earthworm activity did not have a significant impact on the rate of phytolith migration within the sediment, above that of hydrology and climate (Fishkis *et al.* 2010a, 34; Fishkis *et al.* 2010b, 453). There is clear evidence that 'faunal channels' facilitate the movement of phytoliths within the profile, identified through assemblage differences between faunal channels and the archaeological deposit (Hart 2003).

Where bioturbation and mixing have occurred it is unclear whether this may be represented by homogeneity or diversity of the assemblage (Fishkis *et al.* 2010b, 445; Piperno 1985, 265). Whilst the effects of bioturbation have been identified through the presence of phytoliths within macropore channels, the effects may be negligible, as although phytoliths may be subject to some movement within the profile, this may be localised to macropore channels with minimal effect on the overall assemblage (Grave and Kealhofer 1999).

It is clear that bioturbation is not an isolated process and that the impacts of the process may vary depending on soil type, hydrological regime, climate, and mixing processes, in addition to the intensity of bioturbation (Alexandre *et al.* 1997a; Boettinger 1994; Fishkis *et al.* 2010b, 445; Hart and Humphreys, 2003; Hart and Humphreys 1997). Bioturbation is a complex process contributing to the complexity of phytolith taphonomy, it is impossible to assess the impact of bioturbation as an isolated process, due to its interaction with a suite of taphonomic processes described above. The effects of bioturbation must be considered on a case by case basis.

5.3 Phytolith Taphonomy at Songo Mnara

5.3.1 Introduction

Although floor surfaces have the potential to facilitate spatial analysis at Songo Mnara as the concentration of plant-based activities within confined spaces leads to the deposition of a concentration of phytoliths in situ, the interpretation of the phytolith

assemblage as ‘in situ’ depends upon a range of taphonomic processes (Piperno 1985, 265). Although phytoliths normally enter the archaeological record following the processes of disaggregation and biostratinomy, anthropogenic and natural processes can disrupt the phytolith assemblage (Bartoli and Guillet 1977; Madella and Lancelotti 2012, 79; Piperno 1985, 265; Runge 1999, 50). Following pedogenesis, processes including dissolution and weathering, mixing or bioturbation have the potential to affect the in-situ preservation of the phytolith record.

5.3.2 Soil Type

The soil type at Songo Mnara in the ‘open area’ – an area devoid of stone structures, yet in part populated by wattle and daub structures - is a ‘brown silty sandy loam’, which due to anthropogenic effect, differs from the regional sediment derived from coral limestone bedrock, a ‘reddish brown, medium to fine textured sandy loam’ (Sulas and Madella 2012, 149).

The sandy soils at Songo Mnara may be more likely to facilitate profile migration and the effects of weathering and dissolution may be more pronounced. Phytoliths are more often contained within the silt fraction and low numbers of phytoliths have been observed within sandy sediments (Bobrova and Bobrov 1997, 7; Fishkis *et al.* 2010a, 27; Hart and Humphreys 1997, 97). However, although phytoliths are often contained within the silt fraction due to size (5-50μm), the majority of diagnostic cultivars are towards the upper end of the size spectrum and are often contained within the sand fraction. This may lead to a disparate assemblage favouring the preservation in situ of cultivars over smaller sized phytoliths including grasses.

The potential influence of soil type on the processes of weathering and dissolution is a complex process. Processes which affect the rates of weathering and dissolution including the rate of silicification and the ‘purity’ of the phytolith, as discussed above, are impossible to predict, particularly as they may be environmentally influenced, subject to spatio-temporal variation or variable by species.

Though soil pH is not thought to limit preservation, it is also considered the primary driver of weathering and dissolution processes, demonstrably, dissolution rates dramatically increase at a pH of 8-8.5, whilst an extremely alkaline soil pH above 9 further increases the rates of dissolution and weathering, primarily affecting the preservation of phytoliths within ashy deposits, including hearths (Cabanes *et al.* 2011,

2486; Fraysse *et al.* 2009, 205; Karkanas *et al.* 2002; Osterrieth *et al.* 2009, 78; Piperno 1985 262).

Soils and sediments at Songo Mnara are basic (pH >8), with high coral limestone and quartz mineral content due to the underlying coral limestone geology (Sulas and Madella 2012, 149). Extensive soil pH analysis undertaken prior to the commencement of phytolith analysis, demonstrated that the basic pH persists across all soil profiles within the open area, with pH ranging between 8.4-8.3. Samples processed for phytolith analysis were not assessed as the prior studies demonstrated preservation of phytolith morphotypes and little value in such an approach, given the lack of variability in pH across the soil profiles (Sulas 2010, 18; Sulas and Madella 2012). This understanding of the local geoarchaeology, an understanding of the effects of basic pH on phytolith preservation, and observations of phytolith morphotypes during assessment and analysis, inform this discussion of phytolith taphonomy and preservation.

Soil conditions within the rooms of stone structures at Songo Mnara are also basic - potentially influenced through the creation of a microenvironment due to degradation of coral limestone architecture and lime plaster floor surfaces – ranging between a pH of 8.3-9.3 (Sulas 2010; Sulas and Madella 2012). The presence of a phytolith assemblage at Songo Mnara supports the hypothesis that phytoliths are preserved in all soil conditions, however, the basic pH (>8) has the potential to facilitate 'full or partial rapid dissolution within 'years' rather than 'hundreds of years', perhaps leading to the preservation and recovery of a reduced phytolith assemblage (Cabanes *et al.* 2011, 2486; Fraysse *et al.* 2009, 205; Sulas and Madella 2012).

The elevated pH within the stone houses may have had a significant impact on the preservation of an entire phytolith assemblage in situ; however, if the limitations of the preservational environment are taken into account, the remaining assemblage retains its value.

Floor surfaces within the wattle and daub structures are subject to a differing range of taphonomic influences. Though the pH of the anthropogenic sediment is basic (<8), it is lower than that within the stone structures which range from pH 8.5 within rubble collapse overlying the archaeological deposits, to pH 9.3 on the lime plaster floor surface, and 8.8 within the primary archaeological sequence, beneath the floor surfaces (which comprises a light brownish grey fine sand matrix with charcoal and shell inclusions) (Sulas 2010, 10).

Floor surfaces within the wattle and daub structures are subject to a differing range of taphonomic influences. Though the pH of the anthropogenic sediment is basic (< 8), it is lower than that within the stone structures which range from pH 8.5 within rubble collapse overlying the archaeological deposits, to pH 9.3 on the lime plaster floor surface, and pH 8.8 within the primary archaeological sequence, beneath the floor surface (which comprises a light brownish grey fine sand matrix with charcoal and shell inclusions (Sulas 2010, 10). The use of daub as a building material and the use of packed earth floors more closely resemble the pH of the local environment.

Local vegetation also drives the process of dissolution through silica cycling; it is notable that phytoliths occur in lower concentrations within samples from the 'open area' suggesting that silica cycling may have increased the rate of dissolution. However, the open areas may be subject to other taphonomic processes including profile migration and bioturbation. It is clear, however, that occupation horizons within the structures have been protected from this process through overlying deposits of coral rag within the stone houses and daub collapse within the wattle and daub structures.

Preservation of the assemblage in the open areas is drastically reduced when compared with that of the occupation surfaces, though it is arguable that occupation surfaces lead to concentrations of phytoliths in a reduced space. The presence of clay horizons within a sandy soil have the potential to form an impermeable barrier to profile migration and bioturbation, leading to a concentration of phytoliths above the more resistant soil horizon (Alexandre 1997, 679-681; Bartoli and Guillet 1977; Bartoli 198; Fishkis *et al.* 2010a; Fishkis *et al.* 2010b, 445; Gol'yeva 1997, 19; Hart and Humphreys 1997, 93). The preservation of phytoliths in situ in these contexts, supports the hypothesis that overlying 'barriers' of building material have protected the occupation surface from the impacts of dissolution. Though profile migration as a result of bioturbation and water ingress is possible, it is likely that where a clay horizon forms the impacts of these processes is minimised and mitigated.

The entire size spectrum of phytolith morphotypes has been recovered from a range of contexts at Songo Mnara; however, the assemblage is demonstrably biased towards larger morphotypes, particularly in the 'open areas'.

5.3.3 Profile Migration

Though the sediments and soils at Songo Mnara are more likely to facilitate profile migration (see above for discussion) there is little evidence for profile migration within

the samples taken from anthropogenic contexts. There is some evidence that the effects of bioturbation are limited to the upper profiles of soils, which may in turn limit the effects of hydrology, reducing the potential for profile migration (Hart and Humphreys 1997, 93). However, archaeological deposits at Songo Mnara are shallow, c. 30cm below the soil surface and demonstrate little evidence of the effects of profile migration.

5.4. Trench 32: Wattle and Daub Structure

5.4.1. Profile Migration

Though the sediments and soils at Songo Mnara are more likely to facilitate profile migration (see above for discussion) there is little evidence for profile migration within the samples taken from anthropogenic contexts in Trench 32. It is suggested within the literature that the effects of bioturbation are limited to the upper profiles of soils, which may in turn limit the effects of hydrology, reducing the potential for profile migration (Hart and Humphreys 1997, 93). However, archaeological deposits at Songo Mnara are shallow, c. 30cm below the soil surface and demonstrate little evidence of the effects of profile migration; this may be attributed to the unique preservation conditions within Trench 32.

The floor surface within Trench 32 was overlain by a thick layer of collapsed daub which, as with natural clay deposits within soils, may have formed a barrier, inhibiting the impacts of bioturbation and water ingress and protecting the surface and the phytoliths from the effects of profile migration. The presence of modern phytoliths within the assemblage would provide evidence of profile migration through contamination of modern phytoliths, though this is not the case; there is no evidence suggesting profile migration in floor surface samples. The modern vegetation is dominated by a large Cocos nucifera plantation, yet there is little evidence for the presence of palm within the archaeological assemblage, supporting the hypothesis that the overlying daub collapse has reduced the effects of bioturbation and hydrology, the key influences of profile migration.

5.4.2 Bioturbation

Soil fauna activity was intense across the open area, including within Trench 32; in particular, Ants were frequently observed. This does not appear to have induced large scale profile migration within the assemblage. Deposits impacted by soil fauna bioturbation may produce an incoherent phytolith assemblage, due to the transport of phytoliths from their original location (Piperno 1985, 265).

Sampling the natural sediment may determine the effects of bioturbation due to soil fauna, through the presence of elements of an anthropogenic phytolith record. However, natural sediments below the anthropogenic contexts of Trench 32 were not sampled. Where soil fauna bioturbation has impacted on the phytolith assemblage, you would expect to see vast differences in the phytolith assemblage within a context, particularly over a horizontal spatial context (Piperno 1985, 265). If the assemblage had been subject to a major impact by soil fauna, the observed homogeneity of the floor surface within Trench 32 would not be possible. It is also likely that the singular or combined impacts of both soil fauna bioturbation and hydrology would influence not only profile migration, but also dissolution and weathering.

There is an observed discrepancy between preservation of the phytolith assemblage within interior contexts and exterior contexts within Trench 32. Interior contexts within Trench 32 feature enhanced phytolith preservation, which may be attributed to a combination of the following factors:

- Interior 'domestic' contexts form foci for intensive activities which make use of plant materials e.g. food preparation, food storage, craft working, organic craft objects.

- Interior spaces are enclosed and therefore plant-based activities undertaken within these spaces may lead to an accumulation of phytoliths even where sweeping or floor maintenance is undertaken, removing the majority of the material.

- Interior spaces are protected from the effects of biostratinomy, pedogenesis and theoretically, climate induced hydrology, lessening the effects of weathering and dissolution. Though interior deposits will be affected by a range of other taphonomic processes.

5.4.3. Palimpsests and Activity Areas

The presence of a packed sand floor surface within the wattle and daub structure likely facilitated the 'capture' of organic remains due to the porous nature of the floor surface. Human action, for example trampling, may hasten the inclusion of both organic remains and archaeological artefacts within the packed sand floor surface (Nielsen 1991, 488). A packed earth floor surface will be somewhat compacted and this compaction forms an impenetrable barrier to the inclusion of artefacts or organic remains (Nielsen 1991, 488). However, overlying this compacted layer, the upper surface of a packed sand floor surface is actually looser and more penetrable due to the erosive action of trampling and abrasion of artefacts upon the surface (Nielsen 1991, 488). This loose surface has the

potential to incorporate artefacts and organic remains within it, particularly those <2m which can be assumed to include the majority of plant remains. Therefore, even if the upper layer of the floor surface was swept, we can assume a level of retention for both artefacts and organic remains within packed earth floors (Nielsen 1991, 492).

Floor or 'living' surfaces rarely present evidence of a single activity, instead forming a spatio-temporal palimpsest of activity (Malinsky-Buller *et al.* 2011, 89). Both sweeping and trampling of floor surfaces can lead to homogenisation of the artefact assemblage, and it is suggested consequently, the phytolith assemblage. The act of cleaning or sweeping may limit the accumulation of a palimpsest of activity markers, transporting larger objects, which may not be immediately incorporated into the floor deposit as smaller remains may be, to the periphery of the surface (Malinsky-Buller *et al.* 2011, 89; Nielsen 1991, 501). As a result, there will be a contrast between high traffic, trampled areas and areas on the periphery of activity (Nielsen 1991, 501). Therefore, the act of cleaning or sweeping is likely to preserve activity markers within the floor deposit, as smaller activity markers will have been effectively captured and retained within the floor deposit leaving them unaffected by the act of sweeping (Nielsen 1991, 501). However, this assumes that activity areas remain the same over time; assuming that activities undertaken within a restricted space can also vary, the continued accumulation of smaller objects within the floor surface may lead to the creation of 'rapid-accumulation' palimpsests within what appears to be a 'single occupation horizon' (Malinsky-Buller *et al.* 2011, 89). In this instance activities may be represented by a palimpsest or a homogenous spread of material, with the variation in spatial organisation caused by seasonal habitation or repeated occupation episodes (Malinsky-Buller *et al.* 2011, 89). Conversely, long term occupation can lead to a 'slow accumulation palimpsest' of activity markers through the exposure of the living surface to the taphonomic effects of occupation, resulting in the homogenisation of the assemblage without the representation of spatially distinct activity areas (Malinsky-Buller *et al.* 2011, 89).

Trampling may distribute objects arbitrarily across the horizontal profile, potentially obscuring activity patterns (Nielsen 1991, 501). In roofed or interior contexts, trampling may have a greater effect due to the intensity of human activity within a restricted space; in addition, dry deposits exaggerate the effects of trampling, leading to increased inclusion of artefacts and potentially organic remains including phytoliths (Nielsen 1991, 501).

Homogenisation of phytoliths across the packed sand floor surface within Trench 32 may represent palimpsests or trampling or a combination of both. However, as the majority of studies of household activity areas have drawn on ethnographic parallels, very few have considered the potential impact of post-depositional processes (Hutson *et al.* 2007, 453).

6. Phytolith Sampling Strategy

6.1 Archaeological Deposits

Samples from archaeological floor deposits were obtained by removing all material down to the layer immediately overlying the deposit, laying out a 0.5m grid and digging through the overlying deposit onto the floor surface, which was then sampled. This approach was designed in order to minimise modern contamination of the samples taken primarily for geochemical analyses; the floor surfaces are composed of plastered layers as well as compacted silty sand and are often thin layers. With such ephemeral deposits, modern contamination may be caused by treading or trampling during excavation and overzealous cleaning of the surface can lead to little or no material remaining for sampling in places. However, it is clear that sampling in this way may lead to contamination of the cultural phytolith assemblage with the post-abandonment material, in addition, sampling in this way is, in effect, sampling blind, as it is not clear upon which context you are descending; likewise the thickness of the deposit you are attempting to sample through the keyhole excavation is unknown. In some cases, where the floor surface was broken up, thin or ephemeral, the sample was unwittingly taken from a different deposit than that intended.

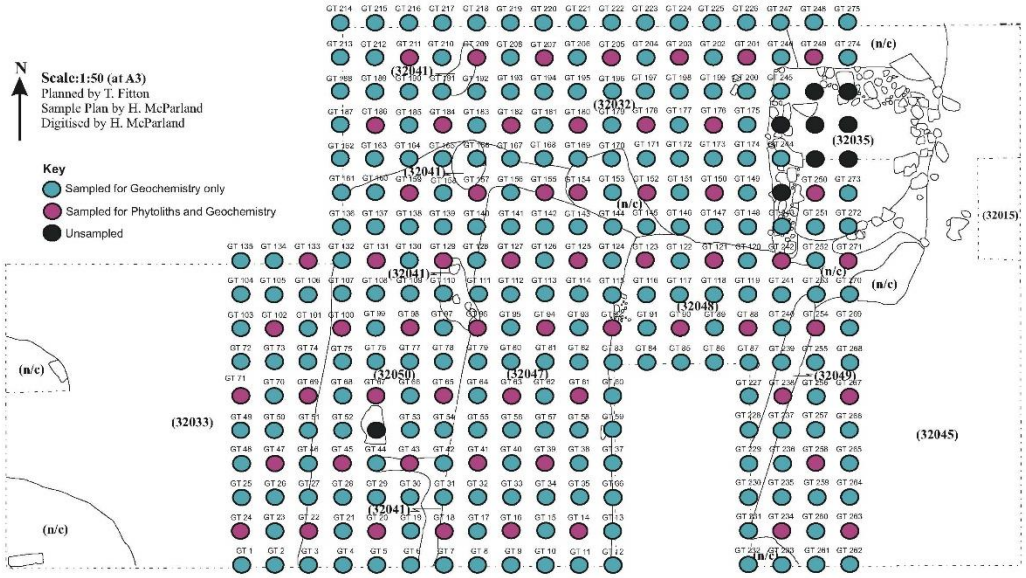
Systematic Sampling of Occupation Surfaces

Soil samples were taken from stratified floor deposits within structures, as well as from discrete features, such as drains or cess deposits within structures.

Systematic sampling was carried out during the 2013 excavations, with a focus on both stone built structures and daub structures of possible domestic function; in addition, systematic sampling was carried out within a Mosque.

Sampling for phytoliths was carried out using a 1m staggered grid system, originating from the northern corner of the deposit, whilst geochemical samples were taken on a 0.5m grid. As the phytoliths samples were subsampled from the geochemical sample assemblage, comparability with the geochemical results is facilitated. Although preferable to attempt the same resolution as the geochemical samples, given the originality of this approach, sampling at a 1m scale afforded a high resolution and allowed comparability with the geochemical data whilst enabling the investigation of a wider range of contexts due to a manageable quantity of samples.

Figure 10 Plan of Trench 32 with sample locations



6.1.2 Sampling of Related Features

In addition to the sampling of floor surfaces, features contemporary with the floor surface, for example, pits dug into the floor surface, drains, or toilets were sampled opportunistically. Evidence from sites such as Catalhoyuk suggests that plaster floors would have been routinely swept and in some cases, regularly replaced; where features are contemporary with and cut into the floor surface, it is possible that these may contain debris such as food remains, remains of craft processes, organic remains or ash (Boivin 2000; Matthews *et al.* 1996; Piperno 2006, 83). It is likely that the phytolith floor assemblage may contain evidence of several activities, both contemporary and post-depositional; for example contemporary remains may include evidence of food or craft processing or organic material culture, such as matting or basketry; conversely, floor surfaces may also contain post-depositional markers, such as evidence of roofing materials (Pearsall 2008, 401; Piperno 2006, 83). Discrete, secure features such as pits, postholes or drains may contain evidence of contemporary activities whilst excluding the majority of the post-depositional phytolith signal.

In contrast, the structure within Trench 32 shows clear evidence of domestic occupation, in both structure and the associated cultural assemblage. Trench 32 revealed a collapsed daub layer, overlying a compact trampled sand floor surface, possible ephemeral daub

walls were also present. The floor surface itself revealed a rich assemblage of beads, shell beads, coins, pottery and domestic artefacts. The entire structure was not excavated due to the proximity of two Palm trees.

Trench 32 covered the outer limits of the building, including a possible outside space attributed to the structure; in addition an ‘alleyway’ between buildings may be marked by a regular ‘cleared’ area between two areas of daub rubble to the northern corner of the trench.

6.2 Sampling Regime

6.2.1 Open Areas

Extensive test pitting survey was undertaken in the open areas surrounding and within the settlement at Songo Mnara in 2009 (Sulas and Madella 2012), 2011 and 2013 (Fleisher and Wynne-Jones 2013). The test pits were designed to cover the majority of the open areas associated with the settlement on a 5m staggered grid, in order to assess and characterise the use of the open spaces associated with the town. The test pits were excavated down to the natural sand deposits, with the location and depth of cultural deposits recorded as well as the presence of any artefacts. The results from the test pits are characterised in GIS, representing clusters or densities of artefacts, daub and geochemical data. Phytolith and geochemical samples were taken from all test pits excavated, yielding a large dataset of over 600 samples.

Ideally, all samples from the open areas would be assessed for phytolith content; however, in terms of the scope of this project, this is impractical and a system was required to enable characterisation on a broader scale.

Samples from both the 2011 and 2013 open area test pits were selected as a subsample of the original datasets, focussing on samples surrounding Trench 32 in order to contextualise activtity within the wattle and daub structure, two samples SOA GT 149 and NOA GT 314, were selected as ‘outliers’, as they were not known to be situated near to a wattle and daub structure and therefore were considered to represent open space..

Following initial assessment of the open area samples, a sequence of 14 samples surrounding Trench 32 were selected to assess whether there was variation between the domestic structure and the surrounding area. A single sample – SOA GT 149 was selected as a control, as this was not known to be near to a wattle and daub structure.

Sample SOA GT 149 suffered from low preservation, as was evident in the majority of the open area samples assessed, yet the small assemblage of 13 phytolith morphotypes, contained 10 Poaceae morphotypes including one bilobate phytolith, one bulliform phytolith and seven smooth elongate forms, all diagnostic of grass leaves. There were no vascular or tracheid type morphotypes identified in this sample, and this supports the interpretation that these forms are associated in some way with the settlement (see Appendix 9 for full counts).

Sample GT NOA 314 was also an outlier, not associated with any structure in particular. However, this sample contained low overall concentrations of phytoliths, containing only 7 vascular or tracheid forms which are interpreted as representative of Dicotyledons (see Appendix 9 for full counts).

Overall, the phytolith concentrations within these samples were too low to be considered meaningful (11 of 14 samples contained 20 or fewer phytoliths), and though diagnostic morphotypes were identified within these assemblages, the concentrations of diagnostic forms did not facilitate any meaningful statistical assessment (see Appendix 9 for full counts).

On this basis, no further assessment of these samples was proposed and the focus of the research was on the structure itself.

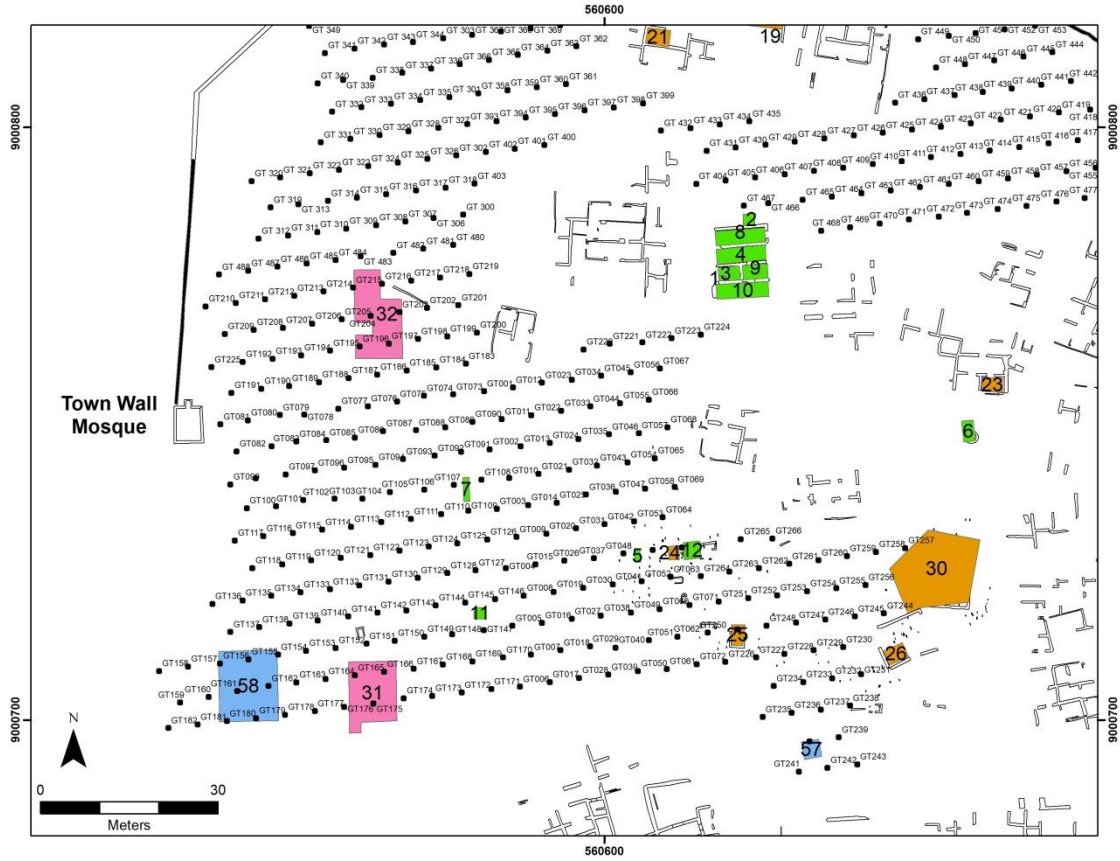


Figure 11 GIS image of GT test pits across the open areas and their association with Trench 32. Courtesy of J. Fleisher and S. Wynne-Jones.

7. Results of Phytolith Analysis of a Single Wattle and Daub Structure (Trench 32)

7.1. Introduction

High resolution systematic sampling was undertaken on a grid across the footprint of the structure (Trench 32) as defined by a concentration of daub and geophysical data (Welham *et al.* 2014). The use of grid sampling is the most efficient method with which to capture and analyse spatial patterning across a horizontal surface (Cole *et al.* 2001). However, the use of grid sampling introduces the assumption that the spatial patterning of anthropogenic activity is homogenous (Wells 2010). In order to avoid the exclusion of spatial data and avoid assumed homogeneity, high resolution sampling was undertaken on a 1m grid for phytolith samples.

The wattle and daub structure was more ephemeral with little 'internal' differentiation, representing a series of contextually different packed sand floor surfaces, identified through the presence of artefacts as an occupational surface. In addition the outer limits of the structure were not clearly archaeologically well-defined, except where bounded by natural sand, making it difficult to differentiate between 'interior' surfaces and 'exterior' surfaces.

Overall, the preservation of phytoliths was poor, with the majority displaying signs of significant weathering and in some cases large proportions of the assemblage were unidentifiable. This is likely due to unfavourable preservation conditions within the local sediments, which feature pH values >8 (Sulas and Madella 2012; Sulas *et al.* 2017). Despite the lack of exceptional preservation, affording consistent counts of 200-300 phytoliths, there is still value in the interpretation of the assemblage for the identification of activity areas. For full raw phytolith counts, see Appendix 6.

Overall phytolith concentrations within Trench 32 were low, with only six of 53 samples producing an assemblage over 200 phytoliths, and only one sample producing over 250 phytoliths. Further to recent work by Sulas and Madella (2012), sample size was increased from 2-4g of sediment, to 10g to mitigate relatively poor preservation conditions (see Chapter 4 for further discussion). However, the results demonstrate that this sample size was not sufficient to produce a statistically robust sample size for analysis. Morphotypes were counted either in their entirety per slide, or until a count of 250 identifiable phytoliths was reached. An average number of 91.46 phytoliths were recovered, per 10g soil sample, with a maximum of 259 and a minimum of 0. The entirety of each sample was mounted in Permount for assessment and analysis, yielding concentration ratios of phytoliths per 10g.

The highest concentrations of diagnostic phytoliths were observed in open area samples: 234 (32045); 176 and 184 (32032); 47 and 135 (32033). Within interior space (32047), within the daub structure, the highest concentrations of phytoliths were observed in samples 14, 16, 18, 61 and 96. Within exterior spaces associated with domestic activity (32050), the highest concentrations of phytoliths per 10g sample were observed in samples 129 and 157. The lowest concentrations of phytoliths per 10g sample were observed solely in the open areas in the vicinity of the structure, including samples: 238, 254, 263 and 271 (32045) and 151, 178, 201, 203, 205, 207, 209 (32032). This strongly suggests that there is a trend toward lower phytolith concentrations outside the limits of

the structure. This may be a taphonomic trend, since the samples within the open spaces have not been afforded the protection of the daub layer sealing them above a compact surface. Instead, samples in the open areas exist within a high pH sandy matrix. This has the potential to increase the impact of the effects of pedogenesis and increase weathering (see Chapter 7 for a full discussion of Taphonomy).

Therefore, for the purposes of this project, assessment of general distribution of morphotypes is more revealing than a detailed statistical analysis, which is not feasible due to the vast disparity between phytolith concentrations within individual samples. Importantly, a basic analysis and assessment of phytolith morphotypes, focussed on raw counts and normalised quantification (percentage) is sufficient to address three of the project aims:

1. Presence and use of plant material, for subsistence or craft purposes within a single wattle and daub structure at Songo Mnara.
2. Whether there is a noteable difference between interior and exterior spaces, detectable through the phytolith signature.
3. Differentiation of plant-based activity areas within the structures.

It is recommended that if further work is undertaken, trials should be undertaken to assess the sample size required to produce a diagnostic assemblage. Assessment of the number of morphotypes required to produce a statistically viable assemblage should also be undertaken prior to further work in the region.

Identification of phytoliths in this study focussed on morphotype type, description of which followed the International Code for Phytolith Nomenclature 1.0 (Madella *et al.* 2005). Morphotypes were then grouped into broad classes, to aid interpretation of variance across the floor surface of the structure, including: Poaceae; other Monocotyledons e.g. Cyperaceae and Arecaceae; Dicotyledons including globular phytoliths; vascular or tracheal elements); Eudicots and Basal Angiosperms. This approach was selected following initial assessment of the samples, in order to obtain the most significant results regarding use of space within the structure, and the associated external spaces, from the dataset. Two examples, discussed below, outline some of the constraints which limited genus or species specific identifications of the assemblage.

Identification of phytoliths to family level was possible for some species, for example, Arecaceae, which produce echinate spheres from all parts of the plant. A study

attempting to differentiate between the Arecaceae echinate spheres at species level, suggests that whilst this is theoretically possible, it is not yet feasible (Fenwick *et al.* 2011). In any case, such an approach would rely on sufficient quantities of morphotypes within each sample to undertake morphometric analysis, and sufficient levels of preservation to facilitate measurement. In this case, preservation is poor, to the extent that a number of morphotypes can only be classified as cf. to denote those morphotypes that are difficult to identify with certainty due to, predominantly, preservation of diagnostic attributes, completeness or visibility.

Vascular or tracheal elements comprised a significant proportion of each assemblage in both single cell and extensive silica skeleton forms, but are broadly undiagnostic in that they may derive from a range of taxa irrespective of family, genus or species (Piperno 2006, 42). Therefore, for the purposes of this study, no differentiation has been attempted between vascular or tracheal elements, instead they are considered a broad marker for Dicotyledons, in particular, the vascular and tracheal elements identified may be representative of soft woods. Similarly, epidermal cells, forming a substantive assemblage within several samples, and occurring throughout the structure and within the open area, are not diagnostic to family, genus or species level (Piperno 2006, 42). Epidermal cells often cannot be differentiate between Monocotyledons, Dicotyledons, Eudicots or Basal Angiosperms, and are frequently produced by many species (Piperno 2006, 42). With this in mind, no attempt has been made, in the course of this study, to ascribe epidermal cells to any particular class, instead assessing relative concentration as a marker of human-plant activity areas.

The identification of Poaceae phytoliths beyond a family or sub-family level, even with the presence of a local reference collection, relies of sufficient quantities of well-preserved and articulated silica skeletons (Ball, T., pers. comm.). Insufficient quantities of diagnostic, well preserved and articulated morphotypes were identified within these samples to facilitate a morphometric approach.

There is no currently accepted standard quantity of phytoliths which must be counted per sample to produce a statistically viable sample, and it is likely that this quantity varies, for example, based upon the research questions the sample is intended to address and the environment from which the samples are recovered (Stromberg 2007). However, there is a risk that counting too few diagnostic phytoliths per sample may negatively influence interpretation; where counts are too low, statistical difference

between samples may be impossible to establish (Stromberg 2007). A minimum count of 200 phytoliths is appropriate in many circumstances (Stromberg 2007, 138), whilst Piperno (2006, 115) suggests a minimum analytical count of 300 phytoliths. For the purposes of this study, a minimum count of 250 diagnostic phytoliths was intended. Such an approach proved impossible in this case, and a large proportion of the phytoliths identified within the samples comprised vascular or tracheal elements or epidermal cells, which are non-diagnostic (due to their occurrence in a variety of taxa) (Piperno 2006). In mitigation, all identifiable phytoliths were quantified from each sample, although in many cases, concentrations were negligible.

In summary, preservation of phytoliths within the study area is poor, with few samples yielding the counts necessary for a statistical study of phytolith concentration for the identification of human-plant activity areas, within internal or external spaces. However, broad concentrations of individual morphotypes are capable of identifying activity areas within internal and external activity areas, addressing the aims of this study.

For full raw phytolith counts, see Appendix 6.

7.2 Results

The results of analysis demonstrate distinct differences between archaeologically ephemeral interior and exterior spaces, demonstrating clear differences in concentration between interior activity areas and external activity areas.

Unidentified phytoliths are classified as those which are identifiable as phytoliths, but are too degraded to identify the morphotypes type; those which are truly unidentified and unable to be placed within one of the broader categories are rare due to the limited variance of the assemblages. The percentage of unidentifiable phytoliths has been assessed, revealing similar concentrations of unidentified morphotypes by proportion, within each sample. With the exception of samples 201, 203, 205 and 209, which also featured relatively low phytolith counts, where increased quantities of unidentified phytoliths is interpreted as a taphonomic effect of the preservational environment. These samples were external to the daub spread, and were within a high pH sand matrix. There is a marked preservational difference within these samples.

The results of both raw counts of phytolith concentration and normalised counts – those which are counted as a percentage of total phytoliths within the sample, are discussed

below. The normalised counts offer a more representative view of phytolith concentration, as this mitigates the effect of different quantities of phytoliths preserved in each sample. The discussion below first discusses trends by phytolith morphotype, and then as a whole.

7.2.1 Silicified Vascular and Tracheal Elements

Silicified vascular and tracheal elements are non-diagnostic and are formed in a range of species; at present, it is not possible to undertake identification to family, genus or species level. However, the presence of silicified vascular or tracheal elements may indicate the presence of soft wood. Some of the forms identified were biorefringent, though phytoliths are not ordinarily biorefringent, the inclusion of cellulose within the silica matrix, results in a phenomenon called 'form biorefringence' (Hodson 2016).

Differences between morphotypes were not taken into account during quantification, since it is not possible to identify the forms to a high taxonomic level; the purpose of analysis being to identify a broad concentration of the morphotypes for the identification of possible plant-based activity areas. Vascular and tracheal elements presented in a range of single morphotypes, in large concentrations of silica skeletons and those morphotypes deemed to have some of the characteristics of a vascular or tracheal element, despite poor preservation or visibility.

Raw counts of vessel and tracheal elements, including those for which identification was not certain, suggested that these elements were distributed fairly even distribution across the structure, with a single spike of multi-cells in open area sample 180 (32032). Single cell vessel and tracheal elements are broadly concentrated within the structure, with the largest concentrations occurring towards the centre of the structure within samples 14, 18, 39, 61 and 96 in association with the internal floor surface (32047) and sample 88, in association with internal floor surface (32048). Another clear concentration was identified within sample 234, at the limits of (32048), which may derive from a possible Daub wall. A concentration of possible vascular or tracheal elements was identified within context (32050), sample 65, an exterior area interpreted as possible liminal domestic space.

However, when normalised distributions are assessed (by percentage of sample), particularly where all vascular and tracheal elements, including single cell presentations, silica skeletons and those which are identified tentatively, it is evident that considered together, the distribution and concentration of this type of morphotypes simply reflects

the structure. This correlation has been observed in the assessment of samples within the wider open area surrounding the structure, concentrations of these elements are generally low, and have been observed to increase with proximity to daub concentrations and geophysical anomalies interpreted as possible structures.

It is possible that the presence of these morphotypes in significant concentrations within the open areas, may be used to identify the presence of wattle and daub structures.

7.2.2 Epidermal Cells

Epidermal cells are produced by a range of vegetation within almost any part of some vegetative structures, including within dicotyledons and herbaceous plants. Epidermal cells are not diagnostic to species but indicate the presence of dicotyledonous or herbaceous plants.

Raw counts of epidermal cells, epidermal silica skeletons and possible epidermal cells (cf.) suggest several concentrations of epidermal phytoliths within the vicinity of the structure. For example, samples 47 and 69 show a significant concentration of epidermal single cells within open area (32033), whilst samples 22, 69, 133 occur at the limit of contexts (32050) and (32033) concentrated along the limits of the domestic structure. A concentration of epidermal silica skeletons was identified within context (32050), within samples 67 and 129. A further concentration of epidermal single cells within samples 22 and 157, located on the limits of possible external domestic space (32050). Epidermal single cells were also concentrated in sample 65 also located within the external domestic space (32050), but interpreted through phytolith concentration as a possible entryway into the structure.

In association with interior activity areas, epidermal cells are concentrated within the centre of the structure, in association with context (32047) within samples 16, 18, 61, 92 and 125.

Epidermal silica skeletons appear to demonstrate a concentration, in raw count within samples 16, 18, 61, 92 and 125, all in association with internal domestic floor surfaces (32047) and (32048) with the majority concentrated within context (32047); the highest concentration of which were in the centre of the structure within samples 61, 92 and 125.

When raw counts are assessed, it is clear that there is a concentration of epidermal silica skeletons between the structure and the open areas, within samples 176, 180 and 184,

perhaps forming a correlation between sample 18 and 129. Considered as a whole, with epidermal single cell concentrations, this association is further supported, demonstrating a possible correlation between samples 18, 43, 65, 129, 184, 176 and 180 – bordering the outer limits of the daub structure.

Further concentrations of epidermal silica skeletons were identified in open area (32045) within samples 234 and 263, in close association with the structure. A linear progression identified between samples 61, 65, 67 and 69 is particularly interesting, moving from the external domestic spaces to the internal domestic spaces.

However, assessment of a normalised sample (through percentage of whole) suggests rather an overarching background signature of epidermal cells, both single cell and silica skeleton, throughout the structure and the associated open spaces. Normalised sample concentrations identify concentrations of epidermal single cell phytoliths within samples, 22, 47 and 69 – associated with the limit between external domestic space (32050) and the open area (32033). A strong concentration of single epidermal cells, above the background signature, was highlighted in sample 65, at the limit of the internal and external domestic spaces, and interpreted as a possible entrance way.

Strong concentrations of epidermal silica skeletons were identified within the structure, in association with floor surface (32047; sample 16) and in open area (32045; sample 263).

It is clear from the distribution of normalised quantities, that there is a potential taphonomic effect, preferentially preserving silica skeletons beneath the daub layers. This is considered more likely to be a taphonimic effect than an ecofact. It is difficult to determine whether the epidermal cells are directly associated with the daub itself, or simply a taphonomic artefact.

7.2.3 Poaceae

Overall, concentrations of grass phytoliths were low in comparison to the abundance vascular or tracheal elements. Grasses were largely represented by the presence of larger, more robust elements, elongate cells derived from the leaf or stem of the grass. Inflorescence elements were limited to two examples of husk dendritic elements, discussed below, and a single rondel morphotype, derived from the inflorescence. Whilst this may suggest that grasses were being grazed, limiting the opportunities for grasses to reach maturity, it may also represent a taphonomic effect. Particularly since the preservation of smooth and sinuate elongates is variable, with many morphotypes

displaying significant effects of weathering and dissolution. The absence of inflorescence phytoliths accords with the observation of Sulas and Madella (2012), who undertook analysis of phytoliths from within the open areas at Songo Mnara.

The results of the raw count identified significant variation in preservation between morphotypes, even within single samples. Many of those morphotypes classified as cf. smooth elongate were extremely degraded, either weathered morphotypes or 'shadows' of morphotypes, others were mechanically degraded or partial.

The majority of smooth elongate morphotypes, both single cell and silica skeleton appear to be located within samples in the external open areas. Although it appears that the morphotypes form a concentration within samples 67 and 69, moving from the exterior domestic space to the interior domestic space. The concentration of grass smooth elongates within context 67 is supported by both raw counts and normalised counts (by percentage). Both counts identify a trend towards increasing grass concentration within the open areas.

On examining the normalised concentration (by percentage) of phytoliths, and plotting the distribution of all Poaceae elements, a clear pattern emerges, demonstrating a background spread of grasses within the structure and associated external domestic space (with the exception of sample 100 within (32050)), with high concentrations of grass phytoliths identified in the open area to the East of the structure.

A single morphotype was identified as a dendriform phytolith, produced in the inflorescence bract of some grass species (Ball 1999). The dendriform is tentatively identified as a possible cultivated dendritic husk morphotype, as the phytolith is incomplete. Multiple phytoliths encapsulated within their silica skeleton are required for morphometric analysis, and it is not possible to differentiate the species of a single, partial morphotypes. The morphotype was identified within context (32047), a context interpreted as a floor surface within the structure, in association with imported ceramics and a possible quern stone.

Similarly three tentatively identified and poorly preserved *Oryza* type Bulliform cells were noted, which may suggest the presence of domesticated Rice within sample 94, associated with interior floor surface (32047). However, the nature of the preservation makes it difficult to undertake full assessment of these morphotypes to be able to determine whether these represent cultivated domesticated *Oryza* sp.

Overall, it is clear from the distribution of grasses represented here, that the open area surrounding the structure was likely grassland. The lack of inflorescence morphotypes may suggest that this area was perhaps grazed or cut prior to flowering of the grasses. If this is the case, it may have some important implications for the preservation of Poaceae phytoliths within this environment. There are minor distributions of grasses associated with the structure, but these form a general background signature.

The presence of two possible crops is insinuated by few morphotypes of a possibly domesticated grass husk and the presence of possible *Oryza* sp. morphotypes. The presence of these morphotypes in association with interior floor surface (32047) and within proximity of a concentration of imported ceramics and a possible quern stone, may lend further credence to the inference that these may represent processing or consumption of domesticated crops within these structures, despite the lack of convincing concentrations of diagnostic morphotypes.

7.2.4 Cyperaceae

A single Cyperaceae achene phytolith was identified within sample 61 (32047) and another was identified within sample 88 (32048), both samples are interpreted as interior floor surfaces within the daub structure. Their presence may indicate the processing of reeds and the removal of the flowering parts or the presence of organic crafts. However, the concentrations presented within the context of this study are negligible and do not enable such inferences about potential plant use for craft purposes to be drawn. Cyperaceae were identified growing within the intertidal zone in the vicinity of the structure during fieldwork.

7.2.5 Arecaceae

Arecaceae echinate spheres are produced in all parts of the Palm and therefore may represent leaf elements, stem elements of fruit elements. Overall, concentrations of Palm phytoliths were identified, though the highest concentrations of these morphotypes were in direct association with the presence of a *Cocos nucifera* palm in samples 14, 16, 41, 88, 92 and 234. It is likely that these samples are modern and intrusive, despite the presence of the daub layer. Markedly, there are no high concentrations of Palm phytoliths which might be indicative of roofing material.

Arecaceae echinate spheres were noted in samples 65, 67,125 and 129, on the limits of the structure. It is possible that samples 125 and 129 demonstrate a more ‘external’ signature, despite being within an internal context. Sample 96 features possible echinate

spheres, and is interpreted as at the limit of interior context (32047) and the interface with exterior domestic space (32050). This suggests that the sample may be external in nature. Echinate spheres are also present within the exterior domestic area (32050) within samples 65, 67 and 157. Normalised concentrations (by percentage of sample) note the presence of Palm echinate phytoliths within the external domestic area (32050) within samples 96 and 157.

Assessment of normalised concentrations (by percentage of sample) supports the interpretation of possible intrusive echinate spheres in association with the existing modern Palm. A moderate to high concentration of echinate sphere is identified within samples 88 and 92 (interior contexts 32048; 32047), which are also in association with the existing modern Palm. Again, this likely represents intrusive Palm phytoliths.

The most convincing concentrations of Arecaceae echinate are located within the exterior domestic area (32050) within samples 67, 96 and 157 and within the open area directly to the east of the structure (samples 149, 184).

Although low concentrations of Arecaceae echinate spheres are present within the samples, there is variation in preservation throughout, from excellent preservation to poor preservation with significant effects of degradation e.g. etching, or partial loss of decorative diagnostic spikes. The extent of intrusive echinate spheres in unclear, though the presence of higher concentrations in direct association with the existing modern Palm suggests that there has been a degree of profile migration in this location. It is possible that the signature from the eastern open space and the external domestic space are representative of activity in association with the structure, although this is somewhat difficult to determine, given the situation of the structure within a modern Palm plantation.

7.2.6 Globular Smooth and Granulate Morphotypes

Globular phytoliths are representative of the leaves of dicotyledons. Overall, the presence of smooth and granulate globular morphotypes presents a background signature across the structure, with significant concentrations identified within samples 43 (32047) which is at the interface between an internal floor deposit and the external domestic space (32050), in association with a possible daub wall. Sample 127 also featured a concentration of globular morphotypes at the eastern extent of (32047) and interpreted as perhaps forming the outer boundary of the structure in this location.

Sample 61 also featured a concentration of globular morphotypes, and is on the boundary between contexts (32047) and (32048).

The location of these significant concentrations perhaps suggests a correlation between boundaries and presence of globular phytoliths indicative of woody dicotyledons. It is perhaps possible that these examples are representative of building or structural materials preserved within the daub matrix, or external to the daub matrix.

7.3 Summary

Context (32050) is interpreted as an enclosed external space, with a phytolith signature that is neither representative of internal or external spaces, with high concentrations of microcharcoal and an increase in Poaceae morphotypes. This is interpreted as an external activity area.

The concentration of 'external' indicators to the east of the structure, including grass morphotypes and globular morphotypes which might represent the presence of within samples 121, 125 and 127, strongly suggests that the floor platform of the structure extended beyond the limits of the walls, perhaps forming an exterior covered space or veranda. Such spaces are common in local houses, visitors are greeted in these spaces, and families sit and rest or undertake craft activities within these areas.

The results of the analysis demonstrate clear differences between interior and exterior spaces, identifying concentrations of individual morphotypes within select contexts. For example samples 61 and 92 within (32047) perhaps feature morphotypes indicative of use of the structure for crop processing or consumption, and though the concentrations of these morphotypes are too low to be truly diagnostic, consideration of the presence of a quern stone and imported ceramics within the interior context, further supports this inference.

It is feasible that the presence of concentrations of globular morphotypes derived from Dicotyledons, are indicative of building materials used to construct the wattle and daub structure. This is evident in the concentration of the morphotypes at the limits of internal contexts, where concentrations of daub suggest internal and external divisions lay. There is also a clear association between the presence of Vascular and Tracheal elements deriving from dicotyledons, and the structure itself, a correlation observed in the assessment of samples within the wider open area surrounding the structure, in which concentrations of these elements increase with proximity to possible structures.

This clear correlation between vascular and tracheal elements and structures may derive from materials used in the construction of the wattle and daub structures. When considered with the concentration of globular morphotypes, this seems more feasible.

Whilst epidermal cells demonstrated an overall spread across the structure, they also indicated a potential a potential taphonomic effect, preferentially in the preferential preservation of silica skeletons beneath the daub layers. Similarly the presence of Arecaceae phytoliths suggests an issue with profile migration, as these are demonstrably concentrated in association with the existing modern Palm tree. Poaceae phytoliths are concentrated within the open areas surrounding the site, suggesting an open grassed area was maintained, in fitting with previous research (Sulas and Madella 2012).

Figure 12 Distribution of Vascular and Tracheal phytoliths by percentage of each sample including silica skeletons and single cells, shown with boundary of daub structure and context 32050

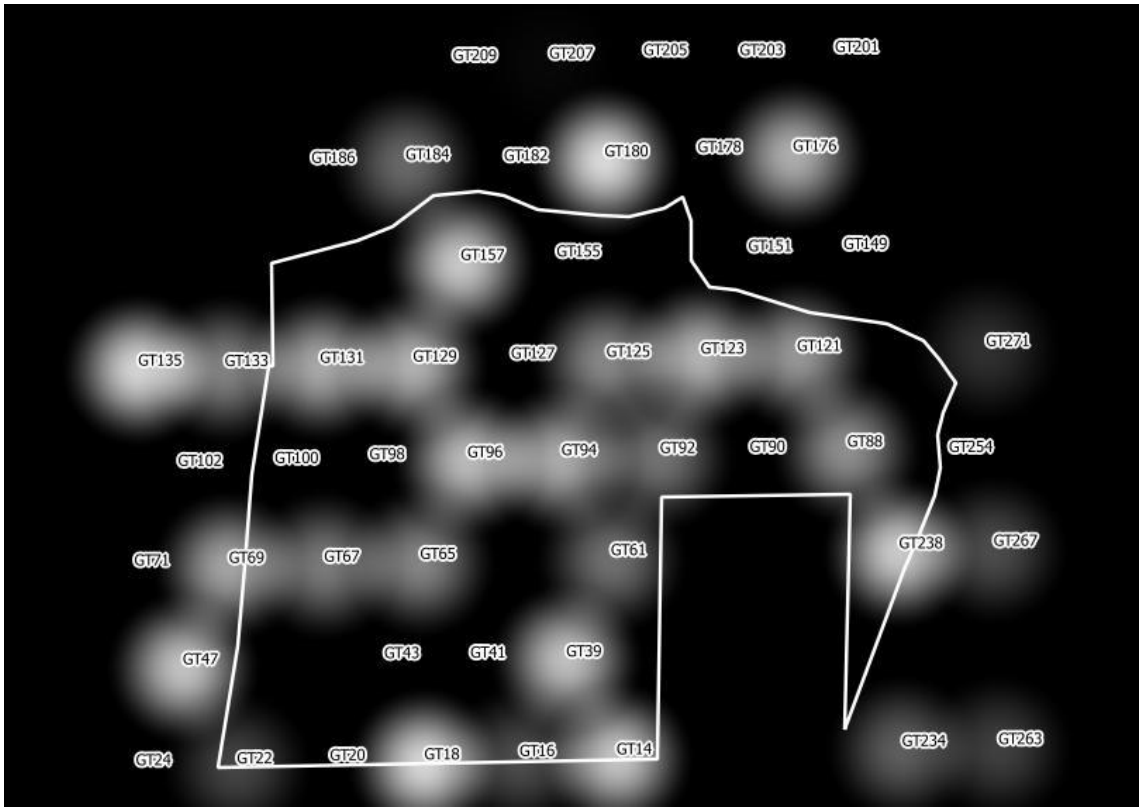


Figure 13 Distribution of Poaceae phytoliths by percentage of each sample, shown with boundary of daub structure and context 32050.

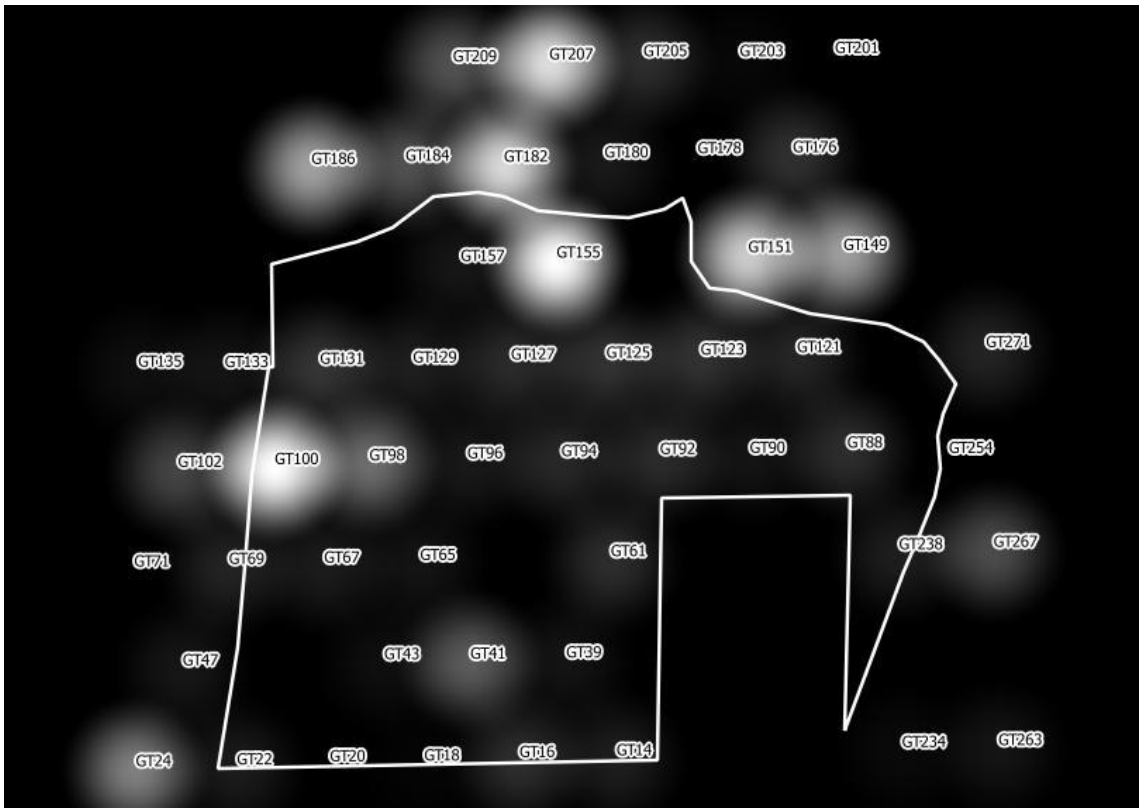


Figure 14 Distribution of Globular Smooth and Globular Granulate phytoliths by percentage of each sample, shown with boundary of daub structure and context 32050.

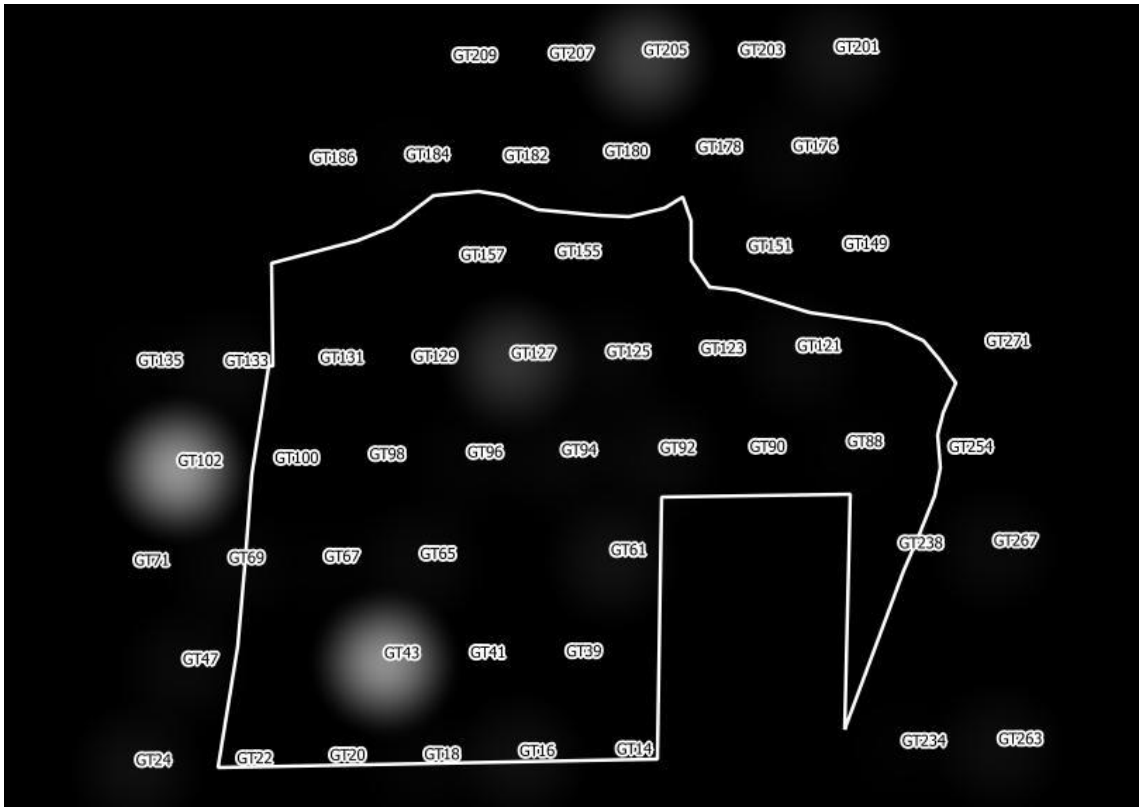


Figure 15 Distribution of Dicotyledon phytoliths by percentage of each sample, shown with boundary of daub structure and context 32050.

Figure 16 Distribution of Unidentified phytolith morphotypes by percentage of each sample, shown with boundary of daub structure and context 32050.

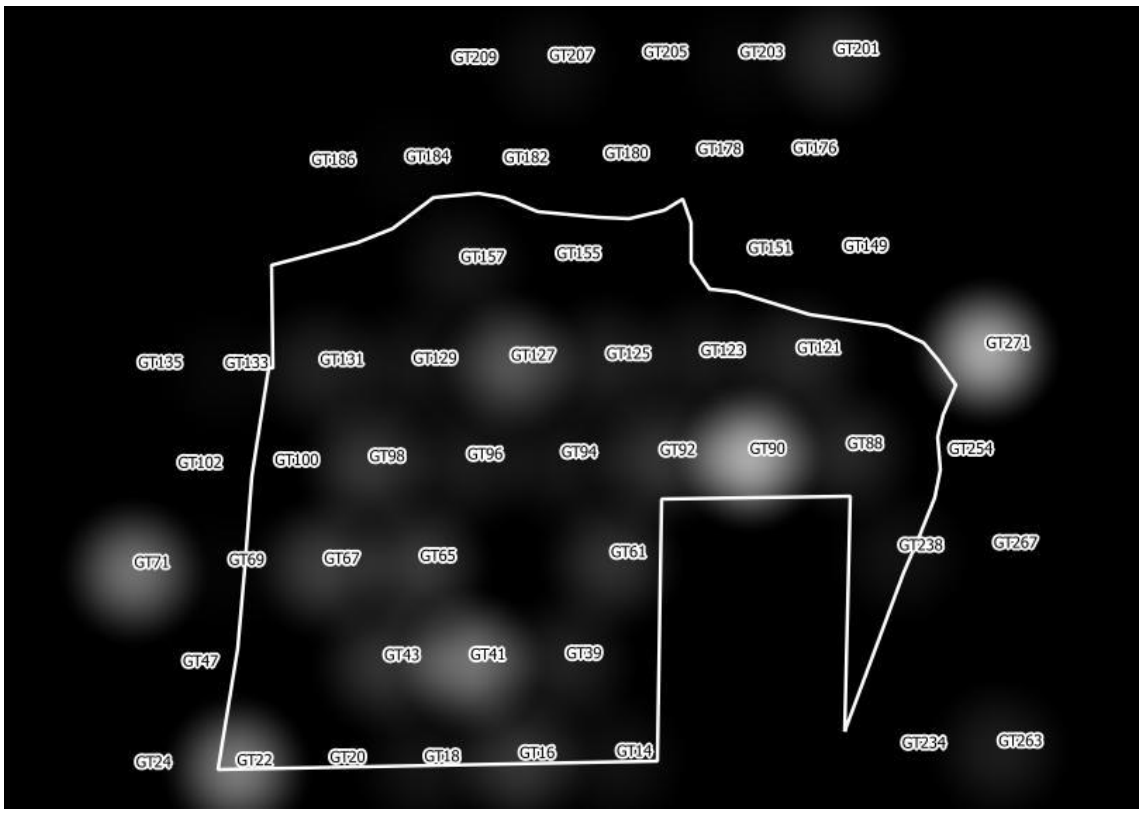


Figure 17 Concentration of Phytoliths per Sample by Raw Count, demonstrating variability in phytolith preservation. , shown with boundary of daub structure and context 32050.

Figure 18 Concentration of Vascular and Tracheal phytoliths, shown with boundary of daub structure and context 32050.

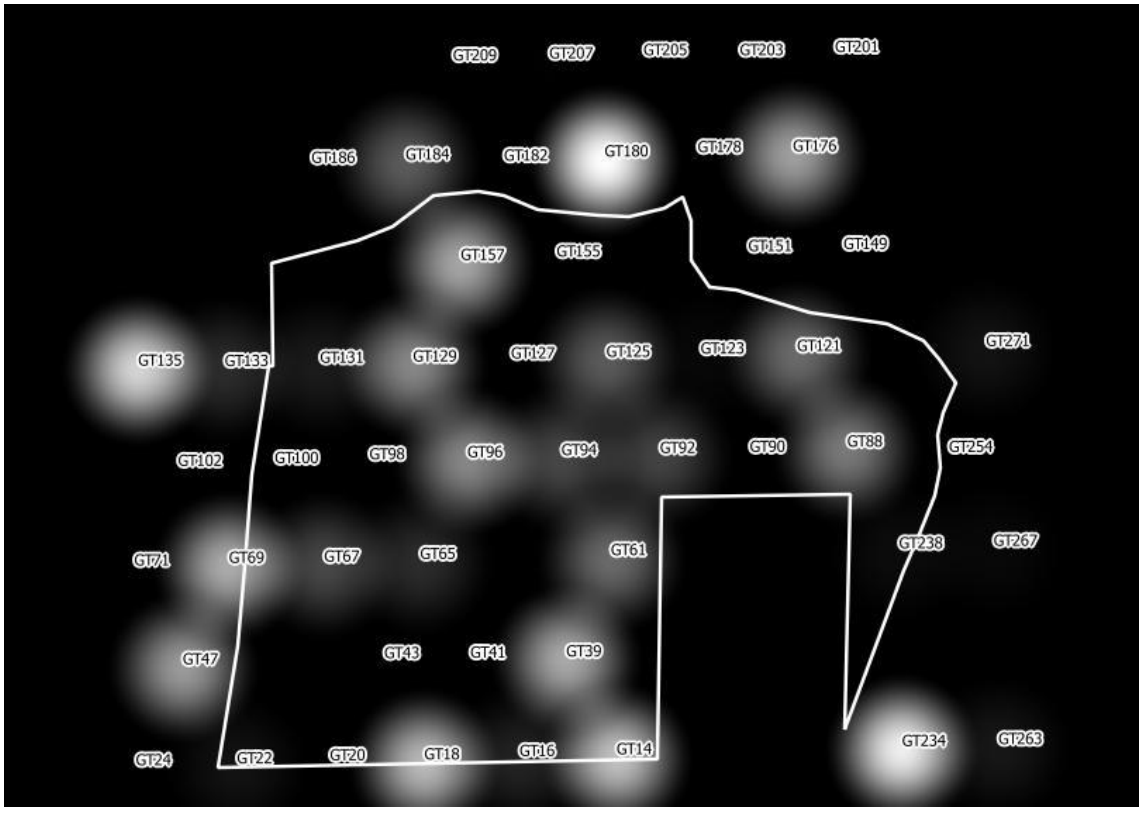


Figure 19 Concentration of Poaceae phytoliths, shown with boundary of daub structure and context 32050.

Figure 20 Concentration of Globular Smooth and Globular Granulate phytoliths, shown with boundary of daub structure and context 32050.

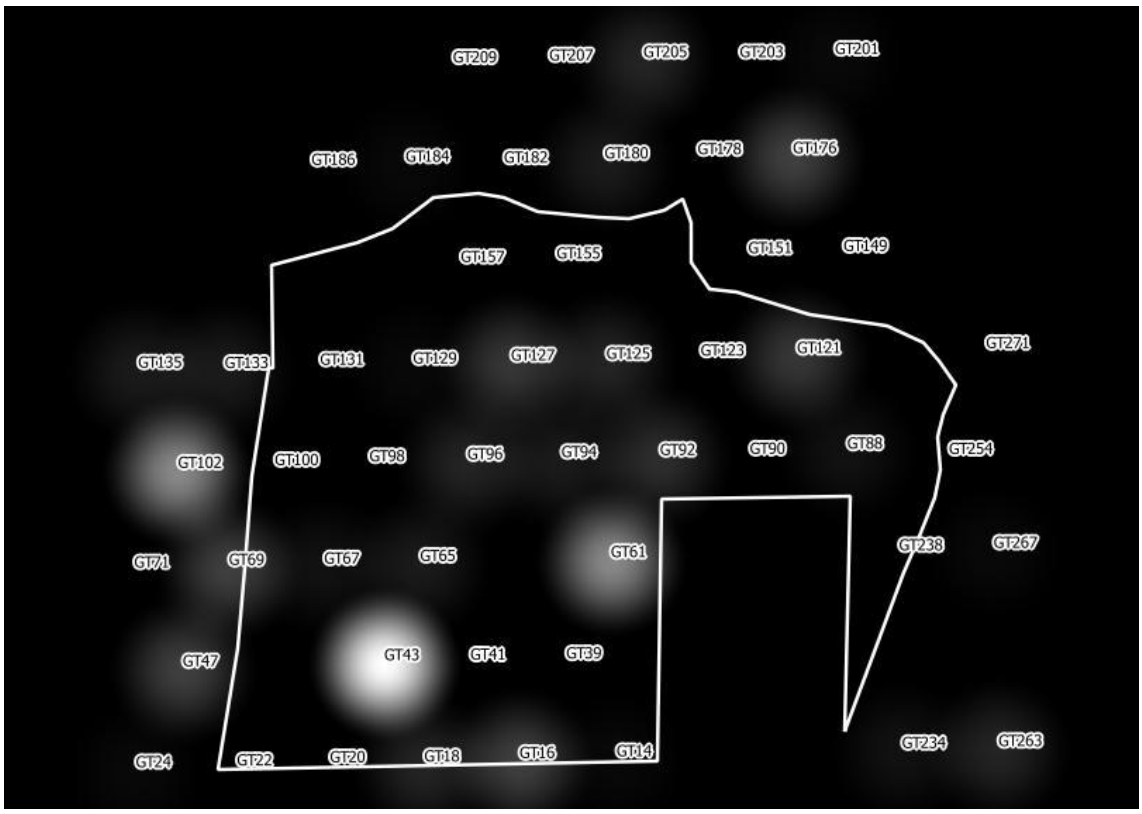


Figure 21 Concentration of Dicotyledon phytoliths, shown with boundary of daub structure and context 32050.

8. Discussion of Results from Trench 32

The analysis of phytoliths from the wattle and daub structure within trench 32, highlights the potential of a spatial approach for the understanding of plant-based activity areas within ephemeral structures, even those within marginal preservational environments and a high pH not normally conducive to phytolith preservation.

Although the low concentration of phytoliths within the samples has not facilitated full statistical analysis and spatial interpolation, an approach considering normalised concentrations of individual morphotypes, through an assessment of concentration per sample, has led to the identification of several distinct activity areas, highlighting the potential of the approach for the elucidation of activity areas within ephemeral of poorly defined domestic structures.

The sampling intervals facilitated the approach, increasing interpretation across the structure and enabling differentiation between interior and exterior activity areas and open spaces surrounding the structure. For example, it is clear that the analysis of open areas, as dominated by grasses, matches the interpretation of Sulas and Madella (2012). In addition, the lack of inflorescence phytoliths, again, supporting the interpretation made by Sulas and Madella (2012), suggests that this grassland was managed.

One of the challenges of this analysis was the general lack of diagnostic morphotypes, which did not enable identification of phytoliths to species level. To mitigate this, a broad approach, categorising phytolith by family, where feasible, or broader descriptive group, e.g. dicotyledons, was used to differentiate between phytolith concentrations. As previously discussed (Chapter 3), the island environment itself is unlikely to contribute significant assemblages of diagnostic phytoliths to the archaeological record. Stoetzel's (2014) botanical survey of the island, for example, though not exhaustive, suggests that the majority of species fall into classifications IV/V (52.75%), producing phytoliths which are non-diagnostic to family, species or genus level or not producing phytoliths at all. This is slightly higher than the wider literature review (Chapter 3), which considers that 50.72% of plant species discussed, are unlikely to produce diagnostic phytoliths. This includes species of economic importance, including the Fabaceae, Rutaceae and Malvaceae families, the latter of which includes Cotton. Tree cover on the island is presently dominated by Fabaceae and Mangrove populations, species of both are used

for construction, and it is assumed at these species, particularly the latter which share a similar cell structure to many of the morphotypes, are contributing vascular and tracheal elements to the assemblage.

Grasses and Palms are likely the main contributor of diagnostic phytoliths on the island, and although Stoetzel (2014) noted that grasses were not as abundant on the island as may be assumed, it is clear from the results of this study and previous research (Sulas and Madella 2012), that the open spaces between structures featured a maintained grassland area, which, given the lack of inflorescence phytoliths, may have been used for grazing, fodder or perhaps physically maintained.

Overall, assessment of of Stoetzel's (2014) botanical survey of the island, suggests that a marginal 22.22% of species noted have the potential to contribute diagnostic phytoliths to the environment and considering the wider East African coast, there are few species with the potential to contribute highly diagnostic forms to the environment. The assessment of 22.22% of species on Songo Mnara which have the potential to contribute diagnostic phytoliths fits with the wider assessment of 28.82% of species considered in the literature survey (chapter 3). This may account for the large concentrations of non-diagnostic phytoliths observed within the assemblage and the relative abundance of Poaceae phytoliths.

8.1. Interior and Exterior Plant-Based Activity Areas

Phytolith analysis highlighted clear differences in phytolith concentration between the two interior activity areas, (32047) and (32048), and this is suggestive of different functions for these two areas, with plant based activities carried out in the former (32047), adjacent to the open space (32050) rather than the latter (32048). The archaeobotanical evidence suggests that processing of African Millets, represented by the presence of both grains and chaff, and Asian rice, represented by small concentrations of chaff were processed in the external space (32050), alongside beans or peas and cotton or baobab (Walshaw, S. pers. comm. Unpublished data). This interpretation lends further credence to the presence of phytoliths deriving from a domesticated Poaceae, and *Oryza* sp. husk phytoliths within context (32047). This context is interpreted as a transitional space between the interior of the structure and the exterior domestic area, in which the majority of crop processing was undertaken, supported by the presence of limited archaeobotanical remains including probable mung beans, two fragments of cotton or baobab and one Polygonaceae seed were identified,

alongside six Coconut endocarp fragments (Walshaw, S. pers. comm. Unpublished data). This suggests that some plant based processing activities were carried out in both the domestic external space (32050) and in the first room of the internal space (32047). Incidentally, beans and peas (Fabaceae), Cotton (Malvaceae) and Polygonaceae do not produce phytoliths, or produce non-diagnostic forms invariably, highlighting the importance of the combined archaeobotanical and phytolith approach for our understanding of human-plant interactions within domestic settings.

The interpretation of context (32050) as a space in which crop processing and food preparation was undertaken is supported by high quantities of microcharcoal observed within the contexts.

A concentration of Poaceae smooth elongate and globular morphotypes indicative of dicotyledon leaves were also identified within this sample; though it is unclear what this signature represents, it lends further credence to the interpretation of this locus as an activity focus. The entrance to the structure is interpreted as located to the north of the structure, represented archaeologically through the positioning of post-holes. This would suggest that this sample is within close proximity of the entrance, which may explain elevated levels of exterior indicators.

The presence of increased 'external' phytolith indicators, including globular morphotypes, and elongate morphotypes derived from grasses, concentrated within samples 67, 65 and 61, in a linear progressing from the external domestic space (32050) through to the focus of plant-based activity within the internal domestic space (32047), presents an interesting pattern. It is not entirely clear what this represents, however, as the entrance to the structure is represented through the presence of post holes to the north of the structure, these samples are likely located within the vicinity of this entrance, accounting for the increased ratio of external indicators in this area. A similar pattern is observed in the entryway of the stone house, where drains have accumulated significant assemblages of grass phytoliths, suggesting that these were indeed traversing in from external spaces.

Although treated as one interior space, divided into two contexts (32047) and (32048), context (32048) features a markedly different phytolith signature. Whilst the background signature is similar, this context lacks the concentration of diagnostic crop plant phytoliths which suggest that plant based activities were being undertaken. There are some concentrations of morphotypes at the limits of the context, along the daub

defined walls, which might suggest accumulation of morphotypes through cleaning or sweeping. The clear interpretation, however, is that this space is markedly different to the adjacent internal context (32047). Geochemically there was little difference between the two contexts with high concentrations of Aluminum, Arsenic, Barium, Cobalt, Chromium, Potassium, Magnesium, Phosphorus, and Zinc, interpreted as with organic enrichment of the floor sediments through domestic occupation of the internal spaces (Sulas and Wynne-Jones Pers. comm. Unpublished Data). Organic enrichment of the floor surfaces might account for the background signature of epidermal phytoliths for example.

The geochemical signatures also suggest possible human-plant interaction within the interior spaces of the structure, consumption of plant based food, rather than preparation of plant materials, may account for the increased Phosphate values within the structure (Sulas and Wynne-Jones Pers. comm. Unpublished Data). Although the presence of Magnesium, Chromium and Zinc are suggestive of processing of plant resources within the interior spaces, the lack of microcharcoal within the structure, evidence for hearths or areas of burning or concentrations of animal bone, suggest that these values may also derive from consumption rather than processing (Sulas and Wynne-Jones Pers. comm. Unpublished Data). This does not, however, take into account the potential use of the space for plant processing prior to cooking and consumption, for example final stage crop processing.

Overall, the geochemical data supports the inference of a generally homogenous background spread of organic materials through the structure, and when considered alongside the archaeobotanical and phytolith data, there is significant evidence to support the use of interior areas (32047, 32048) for the processing or consumption of plant materials.

One interesting feature, defined through a change in character between samples 125, 127 and 129, demonstrates a marked ‘exterior’ signature, featuring increased grass morphotypes and dicotyledons. This suggests that perhaps the eastern extent of the archaeologically defined floor platform was constructed prior to the walls, and that this platform may have extended outside the defined limits of the structure. The geochemical data demonstrates a marked change in concentration of Zinc, associated with organic enrichment of soils in the same area, and this may support such an inference (Sulas and Wynne-Jones Unpublished Data).

8.2 Evidence for Structural Materials

In considering the abundance of vascular and tracheal elements, which as discussed above, are found in close association with wattle and daub structures within the open areas; analysis of samples from the open area further from the structure feature markedly lower concentrations of vascular or tracheal elements, possibly derived from soft woods including Mangrove or Fabaceae, this is further supported by the geochemical data which demonstrates increased iron concentrations in these locations (Fleisher 2014; Sulas and Wynne-Jones Unpublished Data). These concentrations increase as daub concentrations representing potential structures are approached. The presence of vascular and tracheal elements, though not diagnostic, may represent building materials used in the construction of the wattle and daub structures. This interpretation is further supported by the geochemical data, which identified high values of Iron in association with the daub structures, interpreted as deriving from the daub itself (Sulas and Wynne-Jones Unpublished Data). Micromorphological assessment of daub, identified an iron and clay rich fabric used for the construction of the daub buildings (Sulas and Madella 2012). Both high correlations of iron rich sediment, and increased vascular and tracheal element phytoliths in association with the daub material, strongly suggest that the vascular and tracheal elements derive from dicotyledons, most likely soft wood, used in the construction of the wattle and daub structures. The presence of a linear concentration of external phytoliths traversing samples The presence of increased 'external' phytolith indicators, including globular morphotypes, and elongate morphotypes derived from grasses, concentrated within samples 67, 65 and 61, progressing from the external domestic space (32050) through to the focus of plant-based activity within the internal domestic space (32047), is suggestive of an entrance way, with transport of external phytolith materials into the interior space through movement between the two areas. This is further supported by analysis of samples from drainage structures within a Stone House, which also demonstrates high concentrations of, particularly Poaceae phytoliths, interpreted as being transported into the entrance through movement from the open area into the building.

8.3 Evidence for External Environments

The concentration of Poaceae morphotypes within the open area to the east of the structure (32032) strongly suggests an area of open grassland. The lack of identifiable inflorescence phytoliths within this area, may be a taphonomic artefact, however, low

concentrations are observed suggesting that preservation is possible. Methodological tests (see Chapter 4 for discussion) demonstrate no meaningful loss of smaller morphotypes including Poaceae inflorescence morphotypes including Rondels. It is more likely, that as discovered by Sulas and Madella (2012), the lack of Poaceae inflorescence phytoliths and the abundance of grass leaf morphotypes indicates that this area of grassland was managed, either physically, or through grazing of animals.

8.4 Summary

It is suggested that the exceptional preservation of wattle and daub structures at Songo Mnara were facilitated by large concentrations of daub overlying occupation surfaces. These are likely to have preserved the floor surfaces and associated phytolith signatures in situ, limiting pedogenic processes, bioturbation and water incursion to some degree, preventing the movement of phytoliths through the profile. This interpretation is supported by the enhanced preservation of epidermal silica skeletons beneath the spread of daub, and the clear weathering and fragmentation of Poaceae morphotypes outside the spread of the daub structure. However, the presence of Arecaceae phytoliths, is suggests that some profile migration is taking place to transfer modern Palm morphotypes beneath the daub spread.

The simple stratigraphic sequence at the site, and the exceptional preservation conditions for phytoliths beneath the daub spread combined with a single phase of occupation, facilitated the application of spatial sampling for phytolith analysis, enabling the methodology to be tested to assess its efficacy for the identification of plant-based activity areas within domestic structures, and the viability of the methodology for exploring interior and exterior spaces.

This application of this methodology has enabled an understanding of the construction of this wattle and daub structure, with Iron rich sediment imported to act as daub for a structure likely constructed of soft wood, as evidenced by the presence of vascular or tracheal elements (Fleisher 2014; Sulas and Madella 2012). The phytolith signature suggests that the floor platform was laid first, with the daub walls constructed on top of this, creating an external area of floor platform to the east of the structure. This is evidenced through high concentrations of epidermal cells and a general background signature of phytoliths within the structure, with a clear linear pattern of samples to the eastern limits of the floor platform, which display a clear ‘external’ signature comprising Poaceae phytoliths and globular phytoliths deriving from Dicotyledons.

However, the presence of high concentrations of globular phytoliths has been observed within association with possible daub walls, and these may be indicative of structural materials, rather than an external environment.

This approach has facilitated contextualisation of an understanding of the setting of the structure, within an open area, identifying marked oncentrations of Poaceae morphotypes within the open area to the east of the structure (32032). This sets the structure within an open area of maintained grassland, which may have been used for the grazing of livestock (Sulas and Madella 2012).

Most importantly, there are marked interior phytoliths signatures, clearly identifying external context (32050) as an external activity area, with external phytolith signatures, in which the archaeobotanical record suggests that domestic activities, including crop processing and cooking, were undertaken. This is further supported by a marked increase in microcharcoal observed within the phytolith slides in this location. Internal space (32047) was identified as the foci of plant-based activity within the structure, with a geochemical signature high in plant based elements (Sulas and Wynne-Jones Pers. comm. Unpublished data), artefacts including imported ceramics and a possible quern, which support the suggestion of plant processing in this location, and the presence of an archaeobotanical assemblage indicative of cultivated crops including the macrobotanical presence of mung beans, two fragments of cotton or baobab and one Polygonaceae seed (Walshaw Pers. comm. Unpublished Data) and a microbotanical phytolith signature including possible cultivated Poaceae, perhaps Sorghum or Millet, and the presence of a small concentration of cultivated Rice morphotypes within a single sample. Conversely, internal context (32048) features little evidence for plant-based activities in this area, despite being considered, geochemically, as one context. This may be due to the presentation of a homogenised background signature across the floor platform, with activities indicated by increased concentrations within individual samples.

This approach is most valuable in ephemeral contexts where discrete features or the limits of space are ill defined and activity indicators, such as hearths or artefacts, are not indicative of activity areas. In this particular context, the lack of discrete features including hearths, post-holes or pits, or spreads including midden deposits, made it difficult to target sampling to its best effect. However, despite the intensity of sampling, a 10g subsample of a complex floor deposit may not prove wholly representative.

Despite the challenges of relatively poor phytolith preservation conditions, these results demonstrate that this approach is capable of revealing clear definition of interior and exterior activity areas. As this approach is successful within an environment with poor preservation of phytoliths, it is likely that it would be successful in an environment with more favourable preservation.

8.5 Conclusion

It is evident from the results presented above, that consideration of the phytolith data with other proxies, including archaeobotanical and geochemical data is key to interpretation and in many ways mitigates potential taphonomic artefacts which may arise as a result of differential preservation.

The high intensity spatial sampling methodology employed here has facilitated an enhanced understanding of the construction, use and setting of an ephemeral structure, highlighting pathways through the structure and activity areas within the internal space. It has also elucidated the relationship between an external space associated with the structure and the internal spaces themselves, presenting a liminal area in which domestic activities are carried out externally, including crop processing and likely food preparation. Whilst the geochemical signature suggests food consumption is likely to have taken place inside the structure, there is little archaeobotanical or phytolith evidence to support this interpretation.

There were few archaeological markers delimiting the extent of the structure, and the structure itself was ephemeral in nature, with a complete absence of discrete features upon which to target a sampling strategy. Due to the ephemerality of the deposits, the application of systematic spatial sampling for phytoliths was an essential tool for the identification of plant-based activity areas. At present, we have relatively little physical evidence for plant use within Swahili stonetowns, particularly the use of plant materials spatially within domestic structures of both stone and wattle and daub construction and ethnographic evidence is reasonably limited in the vicinity of Songo Mnara itself. This approach, however, has provided a valuable and rare insight into the use of domestic space within a wattle and daub structure and associated open space. Such an innovative and integrated approach perhaps highlights the potential of an intensive spatial sampling methodology for the elucidation of activity areas within ephemeral context, even in environments with relatively poor preservation of phytoliths. Ideally, where the preservational environment is more conducive to preservation of phytoliths, full

geospatial kriging and statistical analyses should be undertaken, to further support interpretations of activity areas within these structures. However, given the relative limitations of the dataset, the analytical approach taken proved sufficient for the confident identification of activity areas, corroborated through consideration of complementary geochemical and archaeobotanical data.

9. Conclusion

It was identified through the reference collection review (chapter 3), that the island ecology itself was unlikely to contribute a large proportion of diagnostic phytolith morphotypes to the archaeobotanical record, with unfavourable preservation conditions (see Taphonomy chapter for further discussion) further inhibiting the ability to undertake detailed statistical analysis of the assemblage due to low or extremely variable phytolith counts. Often phytolith concentration is low within sandy sediments, and despite an increase in sample size to mitigate this effect, sufficient quantities for statistical analysis were not obtained (Bobrova and Bobrov 1997, 7; Fishkis *et al.* 2010a, 27; Hart and Humphreys 1997, 97). It is possible that a greater increase in sample size, for example a sample of greater than 20g, would return higher phytolith concentrations within similar environmental and geological conditions, although such an approach would substantially increase processing time and costs and assessment time. This would be a valuable next step, though it is not clear whether this would mitigate the clear size bias observed withi the assemblage and this would be a major consideration. Research into the effect of increasing sample size is currently under discussion with academic colleagues, as initial assessment of samples from an alkaline dryland environment in the UK has identified potential difficulties with increasing sample size, though initial results suggest that there may be the potential to mitigate some of the effects of low deposition environments and poor preservaton (McParland, Forthcoming).

There is a clear size bias within the phytolith assemblage derived from the Wattle and Daub structure, towards those larger and more robust phytoliths, particularly in the open areas. This is interpreted as an ecofact, rather than a taphonomic artefact, since the entire size spectrum of phytolith morphotypes has been recovered from a range of contexts at Songo Mnara. It is also evident that there is little loss of phytoliths through the processing process, including those of smaller size, between 10-20μm. The sandy soils at Songo Mnara may be more likely to facilitate profile migration, and this was

observed through the concentration of Arecaceae echinate spheres in direct association with a modern Coconut Palm; these morphotypes are thought to be intrusive. However, in more generally it was not possible to differentiate between those phytoliths which were were potentially intrusive and those which were archaeological, despite significant variation between the preservation of phytoliths within the sample. Taphonomic processes are comples, and it is possible, as observed during the analysis of reference material, that some morphotypes are more susceptible to the effects of weathering and dissolution, and that some morphotypes may enter the archaeological record incompletely silicified, or occluding other elements or carbonates which may be more rapidly weathered, compromising the structure of the phytolith itself.

It is clear though, that preservation of the phytolith assemblage is markedly different within the open areas, compared to those areas covered by the spread of daub. This is evidenced by increased preservation of epidermal silica skeletons within these contexts, which are particularly susceptible to weathering and dissolution. Despite these clear taphonomic effects and the nature of the island environment and ecology itself, a spatial approach to sampling mitigated not only the ephemerality of the structure and lack of discrete features on which to target sampling, but also the taphonomic effects. The results demonstrate that further mitigation of these factors is achieved through integrated consideration of the phytolith data with other proxies, including archaeobotanical and geochemical data.

The high intensity spatial sampling methodology employed here was an innovative approach, testing such a methodology for the identification of interior and exterior domestic activity areas through phytolith analysis, which does not rely on carbonisation of plant remains for preservation, and therefore presents a more varied picture of human-plant interaction that archaeobotanical analysis alone.

The approach, particularly where integrated with geochemical data and archaeobotanical data, elucidated an understanding of human-plant interactions within the domestic settings of the structure, clearly delineating interior spaces from exterior spaces and setting this within an understanding of movement through the structure itself and identifying foci of activity in both interior and exterior areas, framed within an understanding of how the structure was constructed. In particular, the methodology shows significant promise for the identification and understanding of the complex

relationships between plant use in external spaces associated with the structure and internal domestic spaces, despite the liminal associations between such spaces.

Despite lacking a statistical basis, the methodology selected proved suitable for the interpretation of the data extracted from the sampling process, presenting a novel and innovative methodology for the interpretation of the use of space within ephemeral interior and exterior domestic contexts, and associated open spaces.

Review of the existing archaeobotanical data along the East African coast and review of local and regional botanical surveys identified those species which were most likely to produce diagnostic phytoliths, highlighting the paucity of production of highly diagnostic forms, particularly within the island ecology.

Intensive spatial sampling and analysis of the resulting phytolith assemblages identified the use of plant materials for construction of the structures themselves, successfully differentiating between activity areas and affording visibility to evidence for plant processing or subsistence within the interior space (32047).

The greatest output of this project is the ability to effectively identify marked differences between interior and exterior spaces through phytolith analysis, revealing not only activities within the structure itself, but also activities within the wider open area, highlighting an area of open grassland which may have been managed with grazing. This is relevant not only to the coastal East Africa, but also to any continent where there are short-lived and well preserved ephemeral structures which could be defined through this approach.

In addition, the thesis presents the most comprehensive methodological review of phytolith processing methodologies to date; a study of this type has not previously been published and it will prove a useful starting point for discussions regarding comparability of datasets where different processing methodologies are used, and further discussion and research may start to establish a set of common protocols for processing of samples from various environments. 9.1 Future Directions

1. It is clear that there is significant potential for the identification of plant-based activity areas within domestic structures, and this is particularly the case and given the ephemerality of the structures examined here. There is clear potential for this methodology to be employed for the identification of similarly ephemeral sites, in any location, especially where the extent of the domestic area is not clear.

2. As previously discussed, an amendment to sample size should be explored in order to assess whether this has the potential to mitigate the poor preservation conditions.

3. However, it may also be useful to explore in future seasons of work, the potential of midden deposits. These deposits are likely to feature concentrations of plant remains within them, potentially preserving evidence of crop processing and consumption, which may have been cleaned from domestic areas. The comparison between a midden deposit and the results from the wattle and daub structure and stone house may be of intrest. Whilst the spatial approach has proved useful for the idientification of activity areas in an ephemeral context, clearly delineating the boundaries of the structure, where discrete features exist, they may be more likely to preserve evidence from the structure. Certainly this is an avenue which should be explored.

Bibliography

Alam. M A K M, Xie, S and Wallis, L (2009) Reconstructing late Holocene palaeoenvironments in Bangladesh: phytolith analysis of archaeological soils from Somapura Mahavihara site in the Paharpur area, Badalgacchi Upazila, Naogaon District, Bangladesh in *Journal of Archaeological Science*, vol. 36, issue 2. pp. 504-512.

Albert, RM, Tsatskin, A, Ronen, A, Lavi, O, Estroff, L, Lev-Yadum, S and Weiner, S, (1999) Mode of occupation of Tabun cave, Mt Carmel, Israel during the Mousterian period: a study of the sediments and phytoliths in *Journal of Archaeological Science*, vol. 26, issue 10. pp. 1249–1260.

Albert, R M, Bamford, M K and Cabanes, D (2006) Taphonomy of phytoliths and macroplants in different soils from Olduvai Gorge (Tanzania) and the application to Plio-Pleistocene palaeoanthropological samples in *Quaternary International*, vol. 148. pp. 78–94.

Alexandre, A, Meunier, J-D, Colin, F and Koud, J-M (1997a) Plant impact on the biogeochemical cycle of silicon and related weathering processes in *Geochimica et Cosmochimica Acta*, vol. 61, issue 3. pp. 677-682.

Alexandre, A, Meunier, J D, Lézine, A M, Vincens, A and Schwartz, D (1997b) Phytoliths: indicators of grassland dynamics during the late Holocene in intertropical Africa in *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 136. pp. 213-229.

Alexandre, A, Crespin, J, Sylvestre, F, Sonzogni, C and Hilbert, D W (2012) The oxygen isotopic composition of phytolith assemblages from tropical rainforest soil tops (Queensland, Australia): validation of a new paleoenvironmental tool in *Climate of the Past*, vol. 8 pp. 307–324.

Alexandre, A, Basile-Doelsch, I, Delhaye, T, Borshneck, D, Mazur, J C, Reyerson, P and Santos, G M (2015) New highlights of phytolith structure and occluded carbon location: 3-D X-ray microscopy and NanoSIMS results in *Biogeosciences*, vol. 12. pp. 863–873.

Andreola, F, Castellini, E, Manfredini, T and Romagnoli, M (2004) The role of sodium hexametaphosphate in the dissolution process of kaolinite and kaolin in *Journal of the European Ceramic Society*, vol. 24, issue 7. pp. 2113–2124.

Badenhorst, S (2009) Phytoliths and Livestock Dung at Early Iron Age Sites in Southern Africa in *The South African Archaeological Bulletin*, vol. 64, no. 189. pp. 45-50.

Bamford, M K, Albert, R M and Cabanes, D (2006) Plio-Pleistocene macroplant fossil remains and phytoliths from Lowermost Bed II in the eastern palaeolake margin of Olduvai Gorge, Tanzania in *Quaternary International*, vol. 148. pp. 95-112.

Barboni, D, Bonnefille, R, Alexandre, A and Meunier, J D (1999) Phytoliths as paleoenvironmental indicators, West Side Middle Awash Valley, Ethiopia in *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 152, issues 1-2. pp. 87-100.

Barboni, D, Bremond, L, Bonnefille, R (2007) Comparative study of modern phytolith assemblages from inter-tropical Africa in *Palaeogeography, Palaeoclimatology, Palaeoecology* vol. 246. pp. 454–470.

Barboni, D and Bremond, L (2009) Phytoliths of East African Grasses: an assessment of their environmental and taxonomic significance based on floristic data in *Review of Palaeobotany and Palynology*, vol. 158. pp. 29-41.

Barboni, D, Ashley, G M, Dominguez-Rodrigo, M, Bunn, H T, Mabulla, A Z P and Baquedano, E (2010) Phytoliths infer locally dense and heterogeneous paleovegetation at FLK North and surrounding localities during upper Bed I time, Olduvai Gorge, Tanzania in *Quaternary Research*, vol. 74, issue 3. pp. 344–354

Bartoli, F (1983) The biogeochemical cycle of silicon in two temperate forest ecosystems in *Environmental Biogeochemistry Ecology Bulletin*, vol. 35. pp. 469–476.

Blench, R (2009) Bananas and Plantains in Africa: re-interpreting the linguistic evidence in *Ethnobotany Research and Applications*, vol. 7. pp. 363-380.

Bobrova, E and Bobrov, A (1997) Phytoliths in Soils: Species composition, distribution along a soil profile, and value as environmental indicators in Pinilla, A, Juan-Tresserras, J and Machado, M J (eds.) (1997) *The State-of-the-art of Phytoliths in Soils and Plants (Estado Actual de los Estudios de Fitolitos en Suelos y Plantas)*, Centro de Ciencias Medioambientales (CSIC), Madrid. pp. 5-13.

Boivin, N (2000) Life Rhythms and Floor Sequences: Excavating Time in Rural Rajasthan and Neolithic Catalhoyuk in *World Archaeology*, vol. 31, no. 3 'Human Lifecycles' (2000). pp. 367-388.

Bremond, L, Alexandre, A, Peyron, O and Guiot, J (2005) Grass water stress estimated from phytoliths in West Africa in *Journal of Biogeography*, vol. 32, Issue 2. pp. 311–327.

Bremond, L, Alexandre, A, Wooller, M J, Hélya, C, Williamson, D, Schäfer, P A, Majule, A and Guiota, J (2008) Phytolith indices as proxies of grass subfamilies on East African tropical mountains in *Global and Planetary Change*, vol. 61, issues 3-4. pp. 209-224.

Burrough, S L, Breman, E and Dodd, C (2012) Can phytoliths provide an insight into past vegetation of the Middle Kalahari palaeolakes during the late Quaternary? in *Journal of Arid Environments*, vol. 82. pp. 156–164.

Cabanes, D, Weiner, S and Shahack-Gross, R (2011) Stability of Phytoliths in the Archaeological Record: a dissolution study of modern and fossil phytoliths in *Journal of Archaeological Science,* vol. 38. pp. 2480-2490.

Calegari, M R, Madella, M, Vidal-Torrado, P, Oterod, X L, Macias, F and Osterrieth, M (2013) Opal Phytolith Extraction in Oxisols in *Quaternary International*, vol. 287. pp. 56–62.

Cappers, R (1999) Trade and Subsistence at the Roman Port of Berenike, Red Sea Coast, Egypt in van der Veen, M (1999) *The Exploitation of Plant Resources in Ancient Africa.* Springer. pp. 185-197.

Carnelli, A L, Madella, M, Theurillat, J-P (2001) Biogenic Silica Production in Selected Alpine Plant Species and Plant Communities in *Annals of Botany*, vol. 87. pp. 425-434.

Carnelli, A L, Madella, M, Theurillat, J P and Ammann, B (2002) Aluminum in the opal silica reticule of phytoliths: a new tool in palaeoecological studies. *Am. J. Bot.* 89, 346-351.

Castellini, E C, Malferrari, D and Bernini, F (2013) Sodium hexametaphosphate interaction with 2:1 clay minerals illite and montmorillonite in *Applied Clay Science* vols. 83–84. pp. 162–170.

Chittick, H N (1974) *Kilwa: An Islamic trading city on the East African Coast*. British Institute in East Africa, Nairobi.

Cordova, C E (2013) C_3 Poaceae and Restionaceae phytoliths as potential proxies for reconstructing winter rainfall in South Africa in *Quaternary International*, vol. 287. pp. 1-20.

Cox, A and van der Veen, M (2008) Changing foodways: Watermelon (Citrullus lanatus) consumption in Roman and Islamic Quseir al-Qadim, Egypt in *Vegetation History and Archaeobotany* vol. 17, supplement 1. pp. S181-S189.

Crowther, A, Horton, M, Kotarba-Morley, A, Prendergast, M, Morales, E Q, Wood, M, Shipton, C, Fuller, D Q, Tibesasa, R, Mills, W and Boivin, N (2014) Iron Age agriculture, fishing and trade in the Mafia Archipelago, Tanzania: new evidence from Ukunju Cave in *Azania: Archaeological Research in Africa*, Vol. 49, No. 1. pp. 21-44.

Das, S, Ghosh, R and Bera, S (2013) Application of non-grass phytoliths in reconstructing deltaic environments: A study from the Indian Sunderbans in *Palaeogeography Palaeoclimatology Palaeoecology*, vol. 376. pp. 48–65.

Davenport, M L and Nicholson, S E (1993) On the relation between rainfall and the Normalized Difference Vegetation Index for diverse vegetation types in East Africa in *International Journal of Remote Sensing*, vol. 14 issue 12 (1993). pp. 2369-2389.

De Langhe, E (2009) Relevance of Banana Seeds in Archaeology in *Ethnobotany Research and Applications*, vol. 7. pp. 271-281.

De Langhe, E, Vrydaghs, L, de Maret, P, Perrier, X and Denham, T (2009) Why Bananas Matter: An introduction to the history of banana domestication in *Ethnobotany Research and Applications*, vol. 7. pp. 165-177.

Dominguez-Rodrigo, M, Serrallonga, J, Juan-Tresserras, J, Alcala, L and Luque, L (2001) Woodworking activities by early humans: a plant residue analysis on Acheulian stone tools from Peninj (Tanzania) in *Journal of Human Evolution*, vol. 40. pp. 289-299.

dos Santos, C P, Gomes Coe, H H, Borrelli, N, Carvalho da Silva, A L, Furtardo de Sousa, L O, Ramos, Y B M, Silvestre, C P and Seixas, A P (2015) Opal phytolith and isotopic studies of "Restinga" communities of Maricá, Brazil, as a modern reference for

paleobiogeoclimatic reconstruction in *Brazillian Journal of Oceonagraphy*, vol. 63, issue 3. pp. 255-270.

Duran, Y, Rohde, W, Kullaya, A, Goikoetxea, P and Ritter, E (1997) Molecular analysis of East African tall coconut genotypes by DNA marker technology in *Journal of Genetics and Breeding*, vol. 51 (1997). pp. 279-288.

Eichorn, B, Neumann, K and Garnier, A (2010) Seed Phytoliths of West African Commelinaceae in *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 298, Issues 3–4. pp. 300-310.

Epstein, E (1994) The anomaly of silicon in plant biology in *Proceedings of the National Academy of Sciences USA (PNAS).* Vol. 91, issue (1). pp. 11–17.

Fahmy, A and Magnavita, C (2006) Phytoliths in a Silo: Micro-botanical Evidence from Zilum (Lake Chad Basin) NE Nigeria (C. 500 Cal BC) in *Journal of Biological Sciences*, vol. 6, issue 5. pp. 824-832.

Fahmy, A G (2007) Diversity of lobate phytoliths in grass leaves from the Sahel region, West Tropical Africa: Tribe Paniceae in *Plant Systematics and Evolution*, vol. 270. pp. 1-23.

Fahmy, A G E and Kahlheber, S (2011) Phytolith Analysis of Charred Leaf Remains of Plaited Basketry in Petit, L P, von Czerniewiczm, M and Pelzer, C (eds.) (2011) *Oursi hu-beero: A Medieval House Complex in Burkina Faso, West Africa*. Sidestone Press, Leiden. pp. 163-167.

Farmer, V C (2005) Forest vegetation does recycle substantial amounts of silicon from and back to the soil solution with phytoliths as an intermediate phase, contrary to recent reports in *European Journal of Soil Science*, vol. 56, issue 2 (2005). pp. 271–272

Farmer, V C, Delbos, E and Miller, J D (2005) The role of phytolith formation and dissolution in controlling concentrations of silica in soil solutions and streams in *Geoderma*, vol. 127 (2005). pp. 71–79.

Fishkis, O, Ingwersen, J, Lamers, M, Denysenko, D and Streck, T (2010) Phytolith transport in soil: a field study using fluorescent labelling in *Geoderma*, vol. 157. pp. 27–36.

Finnè, M, Norström, E, Risberg, J and Scott, L (2010) Siliceous microfossils as late-Quaternary palaeo-environmental indicators at Braamhoek wetland, South Africa in *The Holocene*, vol. 20. pp. 747-760.

Fleisher, J and LaViolette, A (2013) The early Swahili trade village of Tumbe, Pemba Island, Tanzania AD 600–950 in *Antiquity* vol. 87 (2013). pp. 1151–1168.

Fleisher, J and Wynne-Jones, S (2010) *Archaeological Investigations at Songo Mnara, Tanzania: 2009 Field Season Preliminary Report*. Unpublished Report. Submitted to the Department of Antiquities, Republic of Tanzania.Fleisher, J and Wynne-Jones, S (2011) *Archaeological Investigations at Songo Mnara, Tanzania: 2011 Field Season Preliminary Report*. Unpublished Report. Submitted to the Department of Antiquities, Republic of Tanzania.

Fleisher, J and Wynne-Jones, S (2013a) *Archaeological Investigations at Songo Mnara, Tanzania: 2011 Field Season Preliminary Report*. Unpublished Report. Submitted to the Department of Antiquities, Republic of Tanzania.

Fleisher, J and Wynne-Jones, S (2013b) *Archaeological Investigations at Songo Mnara, Tanzania: 2013 Field Season Preliminary Report*. Unpublished Report. Submitted to the Department of Antiquities, Republic of Tanzania.

Fleisher, J and Sulas, F (2015) Deciphering public spaces in urban contexts: Geophysical survey, multi-element soil analysis, and artifact distributions at the 15th-16th -century AD Swahili settlement of Songo Mnara, Tanzania in *Journal of Archaeological Science*, vol. 55. pp. 55-70.

Fraysse, F, Cantaisa, F, Pokrovsky, O S, Schotta, J and Meunier, J-D (2006) Aqueous reactivity of phytoliths and plant litter: Physico-chemical constraints on terrestrial biogeochemical cycle of silicon in Journal of *Geochemical Exploration*, vol. 88, issues 1–3, (Jan–March 2006). pp. 202–205.

Fraysse, F, Pokrovsky, O S, Schotta, J and Meunier, J-D (2009) Surface chemistry and reactivity of plant phytoliths in aqueous solutions in *Chemical Geology*, vol. 258 (2009). pp. 197–206.

Freeman-Grenville, G S P (ed.) 1962. *The East African coast: select documents from the first to the earlier nineteenth century*, Oxford, Clarendon Press.

Fuller, D Q, Nixon, S, Stevens, C J and Murray, M A (2014) African Archaeobotany Expanding in Stevens, C J, Nixon, S, Murray, M A and Fuller, D Q (eds.) (2014) *Archaeology of African Plant Use*, Institute of Archaeology Publications 61, University College London. pp. 17-24.

Fuller, D Q, Boivin, N, Hoogervorst, T and Allaby, R (2011) Across the Indian Ocean: the prehistoric movement of plants and animals in *Antiquity*, vol. 85. pp. 544-548.

Garnier, A, Neumann, K, Eichorn, B and Lespez, L (2013) Phytolith taphonomy in the middle- to late-Holocene fluvial sediments of Ounjougou (Mali, West Africa) in *The Holocene*, vol. 23, no. 3. pp. 416-431.

Ghaley, B B, Hauggaard-Nielsen, H, Høgh-Jensen, H and Jensen, E S (2005) Intercropping of Wheat and Pea as Influenced by Nitrogen Fertilization in *Nutrient Cycling in Agroecosystems*, Vol. 73, Issue 2. pp 201–212.

Goitein, S D and Friedman, M A (2011) *India Traders of the Middle Ages: Documents from the Cairo Geniza 'India Book'.*

Gol'yeva, A A (1997) Content and distribution of phytoliths in the main types of soils in eastern Europe in Pinilla, A, Juan-Tresserras, J and Machado, M J (eds.) (1997) *The State-of-the-art of Phytoliths in Soils and Plants (Estado Actual de los Estudios de Fitolitos en Suelos y Plantas)*, Centro de Ciencias Medioambientales (CSIC), Madrid. pp. 15-22.

Gonzales, G and Osterrieth, M (1997) Estudio de sílicobiolitos en suelos , paleosuelos y sus materiales parentales, Buenos Aires, Argentina in Pinilla, A, Juan-Tresserras, J and Machado, M J (eds.) (1997) *The State-of-the-art of Phytoliths in Soils and Plants, Centro de Ciencias Medioambientales (CSIC)*, Madrid. pp. 83-92.

Goodman-Elgar, M (2008) The devolution of mudbrick: ethnoarcaheology of abandoned earthen dwellings in the Bolivian Andes in *Journal of Archaeological Science*, vol. 35. pp. 3057-3071.

Gray, A B, Pasternack, G B and Watson, E B (2010) Hydrogen peroxide treatment effects on the particle size distribution of alluvial and marsh sediments in *The Holocene*, vol. 20, no. 2. pp. 293-301.

Hart, D M and Humphreys, G S (1997) The mobility of phytoliths in soils: pedological considerations in Pinilla, A., Juan-Tresserras, J. and Machado, M.J. (eds.) (1997) *The State-of-the-art of Phytoliths in Soils and Plants*, Centro de Ciencias Medioambientales (CSIC), Madrid. pp. 93–100

Hather, J G (1994) *Tropical Archaeobotany: applications and new developments*. One world archaeology 22. Routledge, London, New York.

Henry, A G, Brooks, A S and Piperno, D R (2011) Microfossils in calculus demonstrate consumption of plants and cooked foods in Neanderthal diets (Shanidar III, Iraq; Spy I and II, Belgium) in *Proceedings of the National Academy of Sciences*, vol. 108, no. 2. pp. 486-491.

Hodson, M J (2016) The development of phytoliths in plants and its influence on their chemistry and isotopic composition. Implications for palaeoecology and archaeology in *Journal of Archaeological Science*, vol. 68. pp. 62–69.

Holmgren, K, Risberg, J, Freudendahl, J, Achimo, M, Ekblom, A, Mugabe, J, Norström, E and Sitoe, S (2012) Water-level variations in Lake Nhauhache, Mozambique, during the last 2,300 years in *Journal of Paleolimnology*, vol. 48, issue 2. pp. 311-322.

Horrocks, M, Jones, M D, Beever, R E and Sutton, D G (2002) Analysis of plant microfossils in prehistoric coprolites from Harataonga Bay, Great Barrier Island, New Zealand in *Journal of the Royal Society of New Zealand*, vol. 32, issue. 4. pp. 617-628.

Horrocks, M (2005) A combined procedure for recovering phytoliths and starch residues from soils, sedimentary deposits and similar materials in *Journal of Archaeological Science*, vol. 32, issue 8. pp. 1169–1175.

Horton, M C and Middleton, J (2000) *The Swahili: The social landscape of a mercantile society*. Oxford, Blackwells.

Humphreys, G S, Hart, D M, Simons, N and Field, R J (2003) Phytoliths as indicators of process in soils in Hart, D M and Wallis, L A (eds.) (2003) *Phytoliths and Starch*

Research in the Australian-Pacific-Asian Regions: The State of the Art. Terra Australis, vol. 19. pp. 93–104.

Hutson, S R, Stanton, T W, Magnoni, A, Terry, R and Craner, J (2007) Beyond the buildings: Formation processes of ancient Maya houselots and methods for the study of non-architectural space in *Journal of Anthropological Archaeology,* vol. 26. pp. 442-473.

Indeje, M, Semazzi, F H M, and Ogallo, L J (2000) Enso Signals in East African Rainfall Seasons in *International Journal of Climatology,* vol. 20 (2000). Pp. 19-46.

Iriarte, J and Paz, E A (2009) Phytolith analysis of selected native plants and modern soils from southeastern Uruguay and its implications for paleoenvironmental and archeological reconstruction in *Quaternary International*, vol. 193, issues 1-2. pp. 99-123.

Jenkins, E L, (2009) Phytolith taphonomy: a comparison of dry ashing and acid extraction on the breakdown of conjoined phytoliths formed in Triticum durum in *Journal of Archaeological Science,* vol. 36. pp. 2402-2407.

Katz, O, Cabanes, D, Weiner, S, Maeir, A M, Boaretto, E and Shahack-Gross, R (2010) Rapid phytolith extraction for analysis of phytolith concentrations and assemblages during an excavation: an application at Tell es-Safi/Gath, Israel in *Journal of Archaeological Science,* vol. 37, issue 7. pp. 1557–1563.

Katz, O (2015) Silica phytoliths in angiosperms phylogeny and early evolutionary history in *New Phytoligist*, vol. 208, issue 3. pp.642-646.

Killick, D (2006) Editorial in *Journal of African Archaeology,* vol. 4, issue 1. pp. 1-2.

King, S M (2008) The spatial organization of food sharing in Early Postclassic households: an application of soil chemistry in Ancient Oaxaca, Mexico in *Journal of Archaeological Science*, vol. 35, Issue 5 (2008). pp. 1224–1239.

LaViolette, A and Fleisher, J (2009) The Urban History of a Rural Place: Swahili Archaeology on Pemba Island, Tanzania, 700-1500 AD in *The International Journal of African Historical Studies,* vol. 42 no. 3 (2009). pp. 433-455.

Lentfer, C J and Boyd, W E (1998) A Comparison of Three Methods for the Extraction of Phytoliths from Sediments in *Journal of Archaeological Science*, vol. 25. pp. 1159–1183.

Lentfer, C J and Boyd, W E (1999) An assessment of techniques for the deflocculation and removal of clays from sediments used in phytolith analysis in *Journal of Archaeological Science*, vol. 26, issue 1. pp. 31-44.

Lejju, B J, Robertshaw, P and Taylor, D (2006). Africa's Earliest Bananas? in *Journal of Archaeological Science*, vol. 33. pp.102-113.

Linder, H P, de Klerk, H M, Born, J, Burgess, N D, Fjeldsa, J and Rahbek, C (2012) Notes on the partitioning of Africa: statistically defined biogeographical regions in sub-Saharan Africa in *Journal of Biogeography*, vol. 39 (2012). pp. 1189–1205.

Lombard, M (2005) Evidence of Hunting and Hafting during the Middle Stone Age at Sibidu Cave, KwaZulu-Natal, South Africa: a multianalytical approach in *Journal of Human Evolution*, vol. 48. pp. 279-300.

Lovett, J C and Friis, I (1996) Patterns of endemism in the woody flora of north-east and east Africa in van der Maesen, L J G, van der Burgt, X M and van Medenbach de Rooy, J M (eds.) (1996) *The Biodiversity of African Plants: Proceedings XIVth AETFAT Congress 22–27 August 1994, Wageningen, The Netherlands*. Springer, Netherlands. pp. 582-601.

Ma, J F and Yamaji, N (2006) Silicon uptake and accumulation in higher plants in *Trends in Plant Science*, vol. 11, no. 8.

Ma, J F and Yamaji, N (2015) A cooperative system of silicon transport in plants in Trends in *Plant Science*, vol. 20, no. 7. pp. 435-442.

MacPhail, R, and Crowther, J (2007) Soil Micromorphology. Chemistry and Magnetic Susceptibility studies at Huzui (Yilao region, Henan Province, N. China) with special focus on a typically Yangshao floor sequence in *Indo-Pacific Prehistory Association Bulletin*, no. 27(2007). pp. 103-113.

Madella, M (1997) Phytoliths from a Central Asian loess-paleosol sequence and modern soils: their taphonomical and palaeoecological implications in Pinilla, A, Juan-Tresserras, J and Machado, M J (eds.) (1997) *The State-of-the-art of Phytoliths in Soils*

and Plants (Estado Actual de los Estudios de Fitolitos en Suelos y Plantas), Centro de Ciencias Medioambientales (CSIC), Madrid. pp. 49-58.

Madella, M, Alexandre, A, and Ball, T (2005) International Code for Phytolith Nomenclature 1.0. *Annals of Botany*, volume 96. pp. 253–260.

Madella, M, Powers-Jones, A H and Jones, M K (1998) A Simple Method of Extraction of Opal Phytoliths from Sediments Using a Non-Toxic Heavy Liquid in *Journal of Archaeological Science*, vol. 25. pp. 801–803.

Madella, M and Lancelotti, C (2012) Taphonomy and Phytoliths: a user manual in *Quaternary International*, vol. 275 (2012). pp. 76-83.

Malinsky-Buller, A, Hovers, E and Marder, O (2011) Making Time: 'Living floors', 'palimpsests' and site formation processes – A perspective from the open-air Lower Palaeolithic site of Revadim Quarry, Israel in *Journal of Anthropological Archaeology*, vol. 30. pp. 89-101.

Marchant, R, Mumbi, C, Behera, S and Yamagata, T (2006) The Indian Ocean dipole – the unsung driver of climatic variability in East Africa in *African Journal of Ecology*, vol. 45. pp. 4–16.

Matarazzo, T, Berna, F and Goldberg, P (2010) Occupation Surfaces Sealed by the Avellino Eruption of Vesuvius at the Early Bronze Age Village of Afragola in Southern Italy: A Micromorphological Analysis in *Geoarchaeology: an International journal*, vol. 25, Issue 4 (2010). pp. 437–466.

Matthews, W, French, C, Lawrence, T and Cutler, D (1996) Multiple surfaces: the micromorphology in Hodder, I (ed.) (1996) *On the Surface: Catalhoyuk 1993-95,* The MacDonald Institute for Archaeological Research and British Institute of Archaeology at Ankara, Cambridge. pp. 301-342.

Mazumdar, J (2011) Phytoliths of Pteridophytes in *South African Journal of Botany*, vol. 77, Issue 1. pp. 10–19.

Mbida, C M, Van Neer, W and Vrydaghs, L (2000) Evidence for Banana Cultivation and Animal Husbandry During the First Millennium BC in the Forest of Southern Cameroon in *Journal of Archaeological Science*, vol. 27. pp. 151-162.

Mbida, C, Doutrelepont, H, Vrydaghs, L, Swennen, R L, Swennen, R J, Beeckman, H, de Langhe, E and de Maret, P (2001) First archaeological evidence of banana cultivation in central Africa during the third millennium before present in *Vegetation History and Archaeobotany*, vol. 10. pp. 1-6.

Mbida, C, Doutrelepont, H, Vrydaghs, L, Swennen, Ro, Swennen, Ru, Beeckman, H, De Langhe, E, de Maret, P (2005) The Initial History of Bananas in Africa. A Reply to Jan Vansina, Azania, 2003 in *Azania: Archaeological Research in Africa*, Vol 40, Issue 1. pp. 128-135.

McClanahan, T R (1988) *Seasonality in East Africa's coastal waters in Marine Ecology Progress Series 1*, vol. 44 (1988). pp. 191-199.

Mcintosh, R J (1974) Archaeology and mud wall decay in a West-African village in *World Archaeology*, vol. 6. pp. 154–171.

Mcintosh, R J (1977) Excavation of mud structures—experiment from West-Africa in *World Archaeology*, vol. 9. pp. 185–199.

McParland, H J (2009) *An Assessment of Phytolith Production in Selected Plants from the Somerset Levels, England, and the Potential for use of the Technique in Archaeological and Palaeoenvironmental Research*. Unpublished MSc. Dissertation, University of Exeter.

McParland, H J (forthcoming) *Assessment of Phytoliths from Selected Pits and Stone Artefacts within the Stonehenge World Heritage Site south of the A303*
, Historic England Research Report Series.

Mercarder, J, Runge, F, Vrydaghs, L, Doutrelepont, H and Ewango, C E N (2000) Phytoliths from archaeological sites in the tropical forest of Ituri, Democratic Republic of Congo in *Quaternary Research*, vol. 54, issue 1. pp. 102-112.

Mercarder, J, Bennett, T, Esselmont, C, Simpson, S, Walde, D (2009) Phytoliths in woody plants from the Miombo woodlands of Mozambique in *Annals of Botany*, vol. 104, issue 1. pp. 91-113.

Mercarder, J, Astudillo, F, Barkworth, M, Bennett, T, Esselmont, C, Kinyanjui, R, Laskin Grossman, D, Simpson, S and Wade, D (2010) Poaceae phytoliths from the Niassa Rift, Mozambique in *Journal of Archaeological Science*, vol. 37. pp. 1953-1967.

Mercarder, J, Bennett, T, Esselmont, C, Simpson, S and Walde, (2011) Soil phytoliths from miombo woodlands in Mozambique in *Quaternary Research,* vol. 75, issue 1. pp. 138-150.

Mercarder, J, Bennett, T, Esselmont, C, Simpson, S and Walde, D (2013) Phytoliths from Middle Stone Age habitats in the Mozambican Rift (105–29 ka) in *Journal of Human Evolution,* vol. 64, issue 5. pp. 328–336.

Meunier, J D, Colin, F and Alarcon, C (1999) Biogenic silica storage in soils in *Geology,* vol. 27. pp. 835–838.

Middleton, W D and Price, T D (1996) Identification of Activity Areas by Multi-element Characterization of Sediments from Modern and Archaeological House Floors Using Inductively Coupled Plasma-atomic Emission Spectroscopy in *Journal of Archaeological Science,* vol. 23. pp. 673-687.

Milek, K (2012) Floor formation processes and the interpretation of site activity areas: An ethnoarchaeological study of turf buildings at Thverá, northeast Iceland in *Journal of Anthropological Archaeology,* vol. 31, issue 2 (2012). pp. 119–137.

Milek, K and Roberts, H M (2013) Integrated geoarchaeological methods for the determination of site activity areas: a study of a Viking Age house in Reykjavik, Iceland in *Journal of Archaeological Science,* vol. 40. pp. 1845-1865.

Misra, S and Bhattacharyya, A (2014) Analysis of the late Holocene climate vis-a-vis vegetation dynamics along the southwest coast of India: Thrissur (Kerala) in *Quaternary International,* vol. 325. pp. 150–161.

Muhando, C A and Rumisha, C K (2008) *Mangroves in East Africa (from distribution and status of coastal habitats and resources in Tanzania),* draft report submitted to WWF, Dar es Salaam, July 2008.

Mworia-Maitima, J (1997) Prehistoric fires and land-cover change in western Kenya: evidences from pollen, charcoal, grass cuticles and grass phytoliths in *The Holocene,* vol. 7. pp. 409-417.

Nakamura, R (2011) Multi-Ethnic Co-Existence in Kilwa Island, Tanzania: The basic ecology and fishing cultures of a Swahili maritime society in *Shima: The International Journal of Research into Island Cultures*, vol. 5, no. 1 (2011). pp. 44-68.

Neumann, K, Fahmy, A, Lespez, L, Ballouche, A and Huysecom, E (2009) The Early Holocene palaeoenvironment of Ounjougou (Mali): Phytoliths in a multiproxy context in *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 276, issues 1-4. pp. 87-106.

Neumann, K and Hildebrand, E (2009) Early Bananas in Africa: The State of the Art in Ethnobotany Research and Applications, vol. 7. pp. 353-362.

Nicholas, C J, Pearson, P N, Bown, P R, Jones, T D, Huber, B T, Karega, A, Lees, J A, McMillan, I K, O'Halloran, A, Singano, J M and Wade, B S (2006) Stratigraphy and sedimentology of the Upper Cretaceous to Paleogene Kilwa Group, southern coastal Tanzania in *Journal of African Earth Sciences*, Vol. 45, Issues 4–5 (2006). Pp. 431–466.

Nielsen, A E (1991) Trampling the Archaeological Record: An Experimental Study in *American Antiquity*, vol. 56, no. 3. pp. 483-503.

Novello, A, Barboni, D, Berti-Equille, L, Mazur, J, Poilecot, P and Vignaud, P, (2012) Phytolith signal of aquatic plants and soils in Chad, Central Africa in *Review of Palaeobotany and Palynology*, vol. 178, pp. 43–58.

Osterrieth, M, Madella, M, Zurro, D and Alvarez, M F (2009) Taphonomical aspects of silica phytoliths in the loess sediments of the Argentinian Pampas in *Quaternary International*, vol. 193 (2009). pp. 70-79.

Palmer, P G and Tucker, A E (1981) A Scanning Electron Microscope Survey of the Epidermis of East African Grasses, vol. I, Number 49, *Smithsonian Contributions to Botany*, Smithsonian Institution Press, Washington.

Palmer, P G and Tucker, A E (1983) A Scanning Electron Microscope Survey of the Epidermis of East African Grasses, vol. II, Number 53, *Smithsonian Contributions to Botany*, Smithsonian Institution Press, Washington.

Palmer, P G, Gerbeth-Jones, S and Hutchison S (1985) A Scanning Electron Microscope Survey of the Epidermis of East African Grasses, vol. III, Number 55, *Smithsonian Contributions to Botany*, Smithsonian Institution Press, Washington.

Palmer, P G and Gerbeth-Jones, S (1986) A Scanning Electron Microscope Survey of the Epidermis of East African Grasses, vol. IV, Number 62, *Smithsonian Contributions to Botany*, Smithsonian Institution Press, Washington.

Palmer, P G and Gerbeth-Jones, S (1988) A Scanning Electron Microscope Survey of the Epidermis of East African Grasses, vol. V, Number 67, *Smithsonian Contributions to Botany*, Smithsonian Institution Press, Washington.

Parker, A G, Eckersley, L, Smith, M M, Goudie, A S, Stokes, S, Ward, S, White, K, Hodson, M J (2004). Holocene vegetation dynamics in the northeastern Rub' al-Khali desert, Arabian Peninsula: a phytolith, pollen and carbon isotope study in *Journal of Quaternary Science*, vol. 19, issue 7. pp. 665–676.

Parker, A, Lee-Thorp, J and Mitchell, P J (2011) Late Holocene Neoglacial conditions from the Lesotho Highlands, southern Africa: phytolith and stable carbon isotope evidence from the archaeological site of Likoaeng in *Proceedings of the Geologists Association*, vol. 122. pp. 201-211.

Parr, J F (2002) A comparison of heavy liquid floatation and microwave digestion techniques for the extraction of fossil phytoliths from sediments in *Review of Palaeobotany and Palynology*, vol. 120, issues 3-4. pp. 315-336.

Pearsall, D (1989) *Paleoethnobotany: A Handbook of Procedures*, Academic Press, San Diego.

Pearsall, D M (2001) *Paleoethnobotany: a handbook of procedures.* Academic Press, San Diego, London.

Pearsall, D M (2015) *Paleoethnobotany, Third Edition: A Handbook of Procedures.* Routledge. p. 513.

Perrier, X, De Langhe, E, Donohue, M, Lentfer, C, Vrydaghs, L, Bakry, F, Carreel, F, Hippolyte, I, Horry, J, Jenny, C, Lebot, V, Risterucci, A, Tomekpe, K, Doutrelepont, H, Ball, T, Manwaring, J, de Maret, P and Denham, T (2011) Multidisciplinary Perspectives on Banana (Musa spp.) domestication in *PNAS* vol. 108, No. 28. pp. 11311-11318.

Piperno, D R (1985) Phytolith Taphonomy and Distributions in Archeological Sediments from Panama in *Journal of Archaeological Science*, vol. 12. pp. 247-267.

Piperno, D (1988) *Phytolith Analysis: An Archaeological and Geological Perspective.* London: Academic Press Inc.

Piperno, D R (2006) *Phytoliths: a comprehensive guide for archaeologists and palaeoecologists*, San Diego, Altamira Press.

Polcyn, M, Polcyn, I, Rovner, I and Neumann, K (1997) Phytolith Contribution to Palaeoenvironmental Investigations in the Sahel of Burkina Faso, West Africa in Pinilla, A, Juan-Tresseras, J and Machado, M J (eds.) (1997) *Estado actual de los estudios de fitolitos en suelos y plantas (The State of the Art of Phytoliths in Soils and Plants)*, Consejo Superior de Investigaciones Cientificas, Monografia 4, Centro de Ciencias Medioambientales, Madrid. pp. 181-183.

Pollard, E J (2008) The maritime landscape of Kilwa Kisiwani and its region, Tanzania, 11th to 15th century AD in *Journal of Anthropological Archaeology*, vol. 27, Issue 3 (2008). pp. 265–280.

Pollard, E J D, Fleisher, J and Wynne-Jones, S (2012) Beyond the stone town: maritime architecture at fourteenth – fifteenth century Songo Mnara, Tanzania in *Journal of Maritime Archaeology*, vol. 7. pp. 43–62.

Powers, A H and Gilbertson, D D (1987) A simple preparation technique for the study of opal phytoliths from archaeological and quaternary sediments in *Journal of Archaeological Science*, vol. 14, issue 5. pp. 529-535.

Punwong, P, Marchant, R and Selby, K. 2013a. Holocene mangrove dynamics from Unguja Ukuu, Zanzibar in *Quaternary International*, vol. 298. pp.4-19.

Punwong, P, Marchant, R. and Selby, K. 2013b. Holocene mangrove dynamics in Makoba Bay, Zanzibar in *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 379–380, Pages 54-67.

Punwong, P, Marchant, R and Selby, K 2013c. Holocene Mangrove Dynamics and Environmental Change in the Rufigi Delta, Tanzania in *Vegetation History and Archaeobotany*, vol. 22. pp. 381-396.

Rapp, G Jr and Mulholland, S C (1992) Phytolith Systematics: An Introduction in Rapp, G Jr and Mulholland, S C (eds.) (1992) *Phytolith Systematics, Emerging Issues. Advances in Archaeological and Museum Science*, vol. 1. Springer US. pp. 1-13.

Reed, D N, Anderson, T M, Dempewolf, J, Metzger, K and Serneels, S (2009) The spatial distribution of vegetation types in the Serengeti ecosystem: the influence of rainfall and topographic relief on vegetation patch characteristics in *Journal of Biogeography*, vol. 36. pp. 770–782.

Rohan, SH, Fenwick, RSH, Lentfer, CJ, and Weiser, MI (2011) Palm reading: a pilot study to discriminate phytoliths of four Arecaceae (Palmae) taxa. *Journal of Archaeological Science*, volume 38, Issue 9. pp. 2190–2199.

Rondelli, B, Lancelotti, C, Madella, M, Pecci, A, Balbo, A, Ruiz Pérez, J, Inserra, F, Gadekar, C, Cau Ontiveros, M A and Ajithprasad, P (2014) Anthropic activity markers and spatial variability: an ethnoarchaeological experiment in a domestic unit of Northern Gujarat (India) in *Journal of Archaeological Science*, vol. 41 (2014). pp. 482-492.

Rosen, A M (2005) Phytolith Indicators of Plant and Land Use at Catalhoyuk in Hodder, I (ed.) (2005) *Inhabiting Catalhoyuk reports from 1995-99 seasons by members of the Catalhoyuk teams*, McDonald Institute for Archaeological Research and British Institute of Archaeology at Ankara.

Rossouw, L, Stydner, D D, Haarhof, P (2009) Evidence for Opal Phytolith Preservation in the Langebaanweg 'E' Quarry Varswater Formation and its Potential for Palaeohabitat Reconstruction in *South African Journal of Science*, vol. 105. pp. 223-227.

Rovner, I (1971) Potential of opal phytoliths for use in paleoecological reconstruction in *Quaternary Research*, vol. 1. pp. 343-359.

Rovner, I (1983) Plant Opal Phytolith Analysis: Major Advances in *Archaeobotanical Research in Advances in Archaeological Method and Theory*, vol. 6. pp. 225-266.

Rovner, I (1986) Downward Percolation of Phytoliths in Stable Soils – a non-issue in Rovner, I (ed.) (1986) Plant Opal Phytolith Analysis in Archaeology and Palaeoecology, proceedings of the 1984 phytolith research workshop, North Carolina State University, Raleigh, North Carolina. Occasional Papers No. 1 of *The Phytolitherien.*

Runge, F and Runge, J (1997) Opal Phytoliths in East African Plants and Soils in Pinilla, A, Tresserras, J, Machado, M J (eds.) (1997) *Estado Actual de los Estudios de*

Fitolitos en Suelos y Plantas (The State-of-the-Art of Phytoliths in Soils and Plants). Centro de Ciencias Medioambientales, Monografias 4. Madrid. pp. 71-82.

Runge, F (1999) The opal phytolith inventory of soils in Central Africa – quantities, shapes, classification, and spectra in *Review of Palaeobotany and Palynology*, vol. 107. pp. 23-53.

Runge, F (2001) Evidence for land use history by opal phytolith analysis: examples from the central African tropics (eastern Kivu, D.R. Congo). In: Meunier, J D, Colin, F (2001) *Phytoliths: Applications in Earth Sciences and Human History*, Balkema, Lisse. pp. 73-85.

Schuiling, M and Harries, H C (1994) The Coconut Palm in East Africa. 1. East African Tall in *Principes*, vol. 38, issue 1 (1994). Pp. 4-11.

Scott-Cummings, L (1992) Illustrated Phytoliths from Assorted Food Plants in Rapp, G Jr and Mulholland, S C (eds.) (1992) *Phytolith Systematics, Emerging Issues. Advances in Archaeological and Museum Science*, vol. 1. Springer US. pp. 175-192.

Scott, L (2002) Grassland development under glacial and interglacial conditions in Southern Africa: review of pollen, phytolith and isotope evidence in *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 177. pp. 47-57.

Shahack-Gross, R, Marshall, F and Weiner, S (2003) Geo-Ethnoarchaeology of Pastoral Sites: The Identification of Livestock Enclosures in Abandoned Maasai Settlements in *Journal of Archaeological Science*, vol. 30. pp. 439-459.

Shahack-Gross, R, Marshall, F, Ryan, K and Weiner, S (2004) Reconstruction of spatial organisation in abandoned Maasai settlements: implications for site structure in the Pastoral Neolithic of East Africa in *Journal of Archaeological Science*, vol. 31. pp. 1395-1411.

Shillito, L M (2011) *Daily Activities, Diet and Resource Use at Neolithic Çatalhöyük Microstratigraphic and biomolecular evidence from middens*. BAR International Series Report S2232. Oxford. BAR.

Stevens, C J and Clapham, A J (2014) Botanical Insights into the Life of an Ancient Egyptian Village: Excavation Results from El-Amarna in Stevens, C J, Nixon, S,

Murray, M A and Fuller, D Q (eds.) (2014) *Archaeology of African Plant Use*, Institute of Archaeology Publications 61, University College London. pp. 151-164.

Stoetzel, J (2010) *Songo Mnara: a case study in Swahili induced intertidal aggradation*, presented within the session: 'Urban Space and Social Memory at Songo Mnara, Tanzania', PAA/SAfA meeting in Dakar, Senegal, Nov 2010.

Stoetzel, J (2010) Songo Mnara Intertidal Survey in Fleisher, J and Wynne-Jones, S (2010) *Archaeological Investigations at Songo Mnara, Tanzania: Urban Space, Social Memory and Materiality on the 15th and 16th century Southern Swahili Coast*. Preliminary Report Submitted to the Department of Antiquities, Republic of Tanzania.

Stoetzel, J (2011) Archaeological Survey of Songo Mnara Island in *Nyame Akuma*, vol. 76. Pp. 9-14.

Stoetzel, J M (2014) *Towards a Swahili Historical Ecology: Phytolith-based Analysis in Coastal Eastern Africa since AD 600*, unpublished PhD Thesis, University of Virginia.

Stromberg, C A E (2004) Using phytolith assemblages to reconstruct the origin and spread of grass-dominated habitats in the great plains of North America during the late Eocene to early Miocene in *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 207. pp. 239–275.

Strömberg, C A E (2009) Methodological concerns for analysis of phytolith assemblages: Does count size matter? *Quaternary International*, Volume 193. pp. 124–140.

Stromberg, C A E, Di Stilio, V S and Song, Z (2016) Functions of phytoliths in vascular plants: an evolutionary perspective in *Functional Ecology*, Vol. 30 'The Functional Role of Silicon in Plant Biology'. pp. 1286-1297.

Sulas, F (2010) *Intra-site Geoarchaeology at Songo Mnara, Tanzania. Preliminary Report - January 2010*. Unpublished project report.

Sulas, F and Madella, M (2012) Archaeology at the micro-scale: micromorphology and phytoliths at a Swahili stonetown in *Archaeological and Anthropological Science*, vol. 4. pp. 145-159.

Sulas, F, Fleisher, J and Wynne-Jones, S (2017) Geoarchaeology of urban space in tropical island environments: Songo Mnara, Tanzania in *Journal of Archaeological Science*, vol. 77. pp. 52-63.

Sullivan, K A and Kealhofer, L (2004) Identifying activity areas in archaeological soils from a colonial Virginia house lot using phytolith analysis and soil chemistry in *Journal of Archaeological Science*, vol. 31 (2004). pp. 1659-1673.

Trembath-Reichert, E, Wilson, J P, McGlynna, S E and Fischer, W W (2015) Four hundred million years of silica biomineralization in land plants in *PNAS*, vol. 112, no. 17. pp. 5449–5454.

Tsartsidou G, Lev-Yadun S, Efstratiou N, and Weiner S (2008) Ethnoarchaeological study of Phytolith assemblages from an agro-pastoral village in northern Greece (Sarakini): development and application of a Phytolith difference index in *Journal of Archaeological Science*, vol. 35. pp. 600-613.

Tsartsidou, G, Lev-Yadun, S, Efstratiou, N and Weiner, S (2009) Use of space in a Neolithic village in Greece (Makri): phytolith analysis and comparison of phytolith assemblages from an ethnographic setting in the same area in *Journal of Archaeological Science*, vol. 36. pp. 2342-2352.

Tubaña B S and Heckman J R (2015) Chapter 2: Silicon in Soils and Plants in Rodrigues, F A and Datnoff L E (eds.) (2015) *Silicon and Plant Diseases*, Springer International Publishing. pp. 7-51.

Vansina, J (2003) Bananas in Cameroun c. 500 BCE? Not proven in *Azania: Archaeological Research in Africa*, vol. 38, issue 1. pp. 174-176.

Van den Berg, J A and Ullersma, P (1991) Hvdroloncal Basis of Ecologically Sound Management of Soil and Groundwater in *Proceedings of the Vienna Symposium, August 1991*, International Association of Hydrological Sciences Publication no. 202. pp. 163-172.

van der Veen, M (2011) *Consumption, Trade and Innovation: Exploring the Botanical Remains from the Roman and Islamic Ports at Quseir al-Qadim, Egypt.* Africa Magna Verlag, Frankfurt.

Vrydaghs, L and De Langhe, E (2003) Phytoliths: an opportunity to rewrite history in *INIBAP annual report 2002*. INIBAP: Montpellier. pp. 14-17.

Walshaw, S C (2005) *Swahili Urbanization, Trade, and Food Production: Botanical Perspectives from Pemba Island, Tanzania, AD 700-1500*. Unpublished PhD Thesis (2005), Washington University in St Louis.

Walshaw, S C (2010) Converting to rice: Urbanization, Islamization and crops on Pemba Island, Tanzania, AD 700–1500 in *World Archaeology*, vol. 42. pp. 137–154.

Wang, X, Jiang, H, Shang, X, Wang, T, Wu, Y, Zhang, P, Wang, W and Wang, C (2014) Comparison of dry ashing and wet oxidation methods for recovering articulated husk phytoliths of foxtail millet and common millet from archaeological soil in *Journal of Archaeological Science*, vol. 45. pp. 234-239.

Watling, J and Iriarte, J (2013) Phytoliths from the coastal savannas of French Guiana in *Quaternary International*, vol. 287. pp. 162–180.

Welham, K, Fleisher, J, Cheetham, P, Manley, H, Steele, C and Wynne-Jones, S (2014) Geophysical Survey in Sub-Saharan Africa: magnetic and Electromagnetic Investigation of the UNESCO World Heritage Site of Songo Mnara, Tanzania in *Archaeological Prospection*, vol. 21. pp. 255-262.

White, F (1982) *Vegetation Map of Africa – a descriptive memoir to accompany the UNESCO/AETFAT/UNSO vegetation map of Africa*, Natural Resources Research Report.

White, R E (1985) The influence of macropores on the transport of dissolved and suspended matter through soils in *Advances in Soil Science*, vol. 3. pp. 95-120.

Williams, R O (1949) *The useful and ornamental plants in Zanzibar and Pemba. Zanzibar Protectorate*.

Wooller, M J, Street-Perrott, F A and Agnew, A D Q (2000) Late Quaternary Fires and Grassland Palaeoecology of Mount Kenya, East Africa: evidence from charred grass cuticles in lake sediments in *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 164. pp. 207-230.

Wooller, M J (2002) Fossil grass cuticles from lacustrine sediments: a review of methods applicable to the analysis of tropical African lake cores in *The Holocene* vol. 12. pp. 97-105.

Wynne-Jones, S (2016) *A Material Culture: Consumption and Trade in Precolonial East Africa*. Oxford. Oxford University Press.

Wynne-Jones, S and Fleisher, J (2016) The multiple territories of Swahili urban landscapes in *World Archaeology*, vol. 48. pp. 349-362.

Young, R (1999) Finger Millet Processing in East Africa in *Vegetation History and Archaeobotany*, vol. 8, Issue 1-2. pp. 31-34.

Zhao, Z and Pearsall, D M (1998) Experiments for Improving Phytolith Extraction from Soils in *Journal of Archaeological Science*, vol. 25, issue 6. pp. 587–598.

Appendices