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Title: Geoarchaeology of urban space in tropical island environments: Songo Mnara, Tanzania

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Abstract

Past urban settlements in tropical island environments offer particularly challenging sites for mainstream archaeology. Often associated with shallow stratigraphic sequences, archaeological sediments and soils in these sites are strongly influenced by local geology and seawater. This study discusses the advantages and challenges of developing an integrated geoarchaeological program to examine the use of space at the Swahili stonetown of Songo Mnara Island, Tanzania. This exceptionally well preserved site, occupied for less than two centuries (C14th-16th AD), comprises a complex urban layout with stone-built houses, wattle-and-daub structures, funerary complexes, activity areas such as wells, and open areas. The program has combined geoarchaeological (soil macro- and micromorphology, ICP-AES, pH, EC), geophysical (magnetic susceptibility) and archaeological (large excavations, test trenches, artefact distribution mapping) techniques to investigate the use of space across different contexts. Initial geoarchaeological prospection and opportunistic soil sampling has allowed framing of the island's environmental settings and archaeological deposits as well as outlining open spaces in between buildings. Subsequent research applied a systematic sampling strategy to map geochemical and artefact distributions in conjunction with context-specific soil micromorphology. The results provide a means to map out the impact of occupation across the site as well as to differentiate between open, roofed and unroofed spaces. ICP-AES results, for example, demonstrate that measurements of Ca, Mg, P, S and Sr levels can help discriminate occupation/activity areas in tropical island environments. They also indicate that the depletion of certain elements (e.g. Na, K, and Ni) should be considered as a means of differentiating between roofed and unroofed spaces. The combination of different methodologies demonstrates the importance of addressing discrepancies as well as correlations between multiple datasets for deciphering features within urban spaces in tropical environments and interpreting ancient activities that occurred within them.

Keywords: **geoarchaeology, soil chemistry, soil micromorphology, space analysis, Swahili stonetowns**

1. Introduction

The archaeology of urban and domestic space in tropical regions poses challenges for a variety of reasons. Environmental conditions, created by local geology and climate, contribute to poor preservation in many areas. In addition, sites encountered in tropical environments are often not bounded, neatly-delineated, or densely-occupied urban configurations as might be found elsewhere in the world. In tropical Africa, urban centres frequently do not conform to those criteria, and can be diffuse and ephemeral, often constructed from impermanent materials. This raises issues that go beyond environmental constraints, created by the varied forms that past populations built to adapt to tropical regions. The range of site formation processes can complicate attempts at geoarchaeological reconstruction. In particular, archaeological stratigraphies tend to be very shallow in tropical African regions, created by a scattered occupation of a landscape with limited soil formation.

On the coast of eastern Africa, a series of Swahili towns have long been the focus of archaeological attention. These sites were often inhabited over long periods between the 7th and 16th centuries AD, resulting in dense occupation deposits relating to farming, fishing, craft production, and trade within the towns. In addition, they offer relatively-bounded urban settings for geoarchaeological reconstruction, with the remains of coral-built houses and mosques from the 11th century onwards, providing a guide as to the layout of settlement. These sites, then, offer the opportunity to explore the use of space through geoarchaeological techniques, yet they are not free of the complications of tropical environments. Indeed, their location on coral-reef and beach substrata means that they often have loose soils and sandy sediments, creating methodological challenges for sampling control.

In this paper, we explore the geoarchaeology of one of these Swahili stonetowns: Songo Mnara on the southern coast of Tanzania (Fig. 1). This site has unique features that make exploration of the use of space possible, including a relatively brief and spatially-bounded occupation between the late 14th and early 16th centuries AD. Since 2009, a large-scale research project has been exploring the use of space at Songo Mnara via a range of archaeological techniques (Wynne-Jones and Fleisher 2010, 2011), including systematic chemical analysis and context-specific soil micromorphology to investigate open spaces, house deposits, and activity areas (Sulas and Madella, 2012; Fleisher and Sulas, 2015). In this paper, we use our research at Songo Mnara to think about the potential and limitations of field strategies and laboratory techniques to investigate urban settlements in tropical island environments.

FIGURE 1 **(suggested position)**: Map of eastern Africa showing the location of Songo Mnara.

2. Geoarchaeology and eastern Africa

Chemical analyses, including measurements of pH, Electrical Conductivity (EC), and multiple elements have long been used in archaeology; mainly, but not exclusively, to investigate preservation conditions and traces of past activities (e.g. Middleton and Price, 1996; Milek and Roberts, 2013; Oonk et al., 2009; Ottaway and Matthews, 1988; Shahack-Gross et al., 2003; Wells, 2004). Phosphorus analysis has been popular as this element can concentrate in food wastes, hearth debris, stabling and latrine deposits, and can provide a useful index of the spread and intensity of past occupation (Leonardi et al., 1999; Holliday and Gartner, 2006). Yet, the number of routes by which phosphorus might be enriched also means that this element alone cannot distinguish between different activities (cf. Wells, 2010). Multi-element analysis – particularly Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) – is now increasingly applied to a wide range of archaeological contexts. The ability to compare datasets from different elements makes this technique highly sensitive to subtle differences in the chemical composition of archaeological sediments, making it possible to distinguish between a wide range of human activities and geochemical processes (Middleton, 2004; Middleton et al., 2010; Wilson et al., 2008). Concentrations of plant nutrients (e.g. Ca, Fe, P, S, Zn) and trace elements (Ba, Sr) can be used as proxies for human activities (Middleton and Price, 1996; Oonk et al., 2009; Ottaway and Matthews, 1988; Wilson et al., 2008). Calcium, potassium, and magnesium, for example, can concentrate where wood ash is deposited but, together with sodium and sulphur, they are also present in seawater and, thus, can be released into the ground through the presence of sea-related products and/or processes. Metallic elements (e.g. Al, Cr, Co, Ni, Pb) can also be found concentrated in archaeological contexts associated with burning, food processing, and the presence of metal-bearing resources (Bu and Cizdziel, 2013; Wells, 2004). In tropical environments, linking chemical concentrations with human activities is complicated further as high temperature and high humidity speed up soil formation processes such as mineral alteration and biological activity (Limbrey, 1975: 214-215). In alkaline environments with high pH, for example, some salts and nutrients (e.g. Ca, K, Mg, Na) may concentrate due to natural processes (e.g. hydrolysis, clay-humus complex, cation exchange capacity; see French, 2003: 10-19; Limbrey, 1975: 50-71; Schaetzl and Anderson, 2005: 181-182, 186-187). In *terra rossa* soils, the dissolution of calcareous rock surfaces during the humid period results in the freeing up of silica (clays and iron oxides), leading to base saturation (Duchaufour, 1977: 379-382). In addition, concentrations of some metallic elements (e.g. Sc, Ti) are also found in *terra rossa* soils on reef environments (e.g. Muhs and Budahn, 2009; Muhs et al., 2012). Although not normally considered, vanadium is a trace metal common in minerals (Aubert and Pinta, 1977: 79-84) and found also in *terra rossa* soils (e.g. Muhs et al., 2012). As a plant nutrient, vanadium is used by sea algae and, thus, may enter archaeological deposits together with sea-related resources.

It is, therefore, clear that careful interpolation between datasets is important, and there is no easy match between particular chemical signatures and past activities. This may be the reason that soil chemistry has been applied only infrequently in eastern Africa, where familiarity with these techniques and their interpretation is only now developing (e.g. French et al., 2009; Juma, 2004; Shahack-Gross et al., 2003).

Soil micromorphology offers the potential to reconstruct activities that have left only microscopic traces in the archaeological record and is now routinely applied in archaeology across a wide range of contexts and environments (Courty et al., 1989; French, 2003; Goldberg and Macphail, 2006). The technique has so far seen only limited but important applications in African archaeology (e.g. Goldberg, 2000; Mallol et al., 2007; Shahack-Gross et al., 2003; Zerboni, 2011; Stewart et al., 2012).

3. Environmental and cultural background

3.1 Swahili coast and island environments

The coral-limestone geology of the eastern African coast and the effects of sea-water have a profound effect on local soils and sediments, and influence the formation, preservation and modification of organic and inorganic archaeological records. Limestone/coral is composed largely of soluble calcium carbonate, which is dissolved during weathering so that only small amounts of impurities in the rock provide the residue to form soils, hence they are never very deep (Fitzpatrick, 1986: 198-199). This has implications for archaeological deposits which are often poorly consolidated and thin and, thus, difficult to sample for context-specific laboratory analyses.

The town of Songo Mnara is located on the north-western tip of the island in an open plain of approximately 7 ha; thick vegetation covers the areas to the south and mangrove swamps are found at the coast to the north and west (Fig. 2). On the island, coral-limestone and quartz give rise to *terra rossa*-type soils and sediments with alkaline pH (>8), low contents of plant macronutrients (e.g. Ca 15%, P 1690ppm, Zn 10ppm), and varied concentrations of metal and trace elements (Ba, Cr, Cu, Ni). In addition to the regional sediments, pockets of dark brown silty loam tend to be associated with cultural deposits both visible on the surface and buried at the site (Table 1). The general stratigraphic sequence of the site ranges between 40 and 50 cm in thickness and consists of about 15-20 cm of *terra rossa*-type topsoil overlying a cultural layer of variable thickness (c. 20-40 cm), which rests on a sterile deposit of very fine beach sands. A relatively shallow stratigraphy is most likely the result of urban occupation followed by almost complete abandonment, which allowed vegetation regrowth and surface stabilization.

FIGURE 2 **(suggested position)**: Site plan with the locations of sampling areas (houses, trenches and open areas).

FIGURE 3 **(suggested position)**: Views from the site: a. standing architecture and environmental settings; b. Excavation trench (SM006) at the well.

TABLE 1 **(suggested position)**: Local soils and sediments.

3.2 Archaeology

The archaeology of the eastern African Swahili coast has long been focused on port towns that developed from 7th to 8th century-roots to become important participants in the second millennium Indian Ocean trade system (Fleisher et al., 2015; Horton and Middleton, 2000). In these later towns, houses and mosques built of coral rag and lime mortar stood alongside wattle-and-daub houses. The site of Songo Mnara was built and occupied over a relatively short period of about 150 years, from the late 14th to early 16th centuries; this coincides with the peak of commerce and expansion in Swahili towns more generally. Songo Mnara was built on a grand scale, with dozens of coral-built houses, six mosques, and extensive cemeteries with coral tombs (Garlake, 1966). It is an exceptionally well-preserved site with significant standing architecture and stratigraphic sequences that have not suffered from much disturbance by subsequent settlement or activities (Figs. 2 and 3). The site has been the focus of a large-scale campaign of excavation designed to explore uses of space across a Swahili town (Wynne-Jones and Fleisher, 2010, 2011). The comparatively limited period of occupation makes the site ideal for exploring horizontal differentiation in archaeological deposits, as opposed to vertical complexity from long-term occupation. Geoarchaeology at Songo Mnara is, therefore, part of a much broader methodology encompassing more traditional archaeological techniques of excavation and test pit survey.

3.3 Descriptions of the contexts investigated

Archaeology at Songo Mnara has been structured around two types of space: 1) open spaces, including activity areas around a well and marked elsewhere by geophysical anomalies; 2) stone-built houses and a wattle-and-daub structure (Fig. 2 and Table 2). These investigations were designed to recover evidence of past activity across the site, and geoarchaeological techniques were combined with archaeology throughout.

The core urban plan of Songo Mnara features several large open areas. These have been investigated via a programme of shovel test pits (STPs, ca. 30cm in diameter) on a staggered 5m grid, as well as open area excavations. Chemical and sediment mapping was focused on the cultural layer recovered in each STP (Fleisher and Sulas, 2015). Trenches have been excavated in possible functional areas, including the area adjacent to a well (SM006) and areas marked by geophysical anomalies (e.g. SM007).

The coral-built stonehouses of Songo Mnara have been explored through large-scale excavation of complete houses that provide a sample of the buildings at the site (Wynne-

Jones, 2013). Some buildings (e.g. House 44) have been excavated in their entirety, while elsewhere particular types of space (courts, entryways, back rooms) have been targeted (e.g. House 23). Wattle-and-daub structures have also been excavated, first identified through geophysical anomalies (Welham et al., 2014) and by the presence of daub in STPs. Some of the wattle-and-daub structures have been investigated with test trenches (e.g. SM007) and one was fully excavated in 2013; the single trench (SM032), over 96.5 sq. m, revealed a dense area of daub representing a collapsed earthen structure with a full range of domestic debris.

TABLE 2 **(suggested position)**: Summary data on the number of samples examined by context.

4. Methods

4.1 Field methods

Geoarchaeological field investigations included collection of bulk soil samples for laboratory analysis, and micromorphological sampling of consolidated stratigraphy in targeted areas. Different sampling schemes were employed across the site, as part of an evolving methodology through multiple field seasons. Open spaces were first investigated in 2009 with four transects that ran across the Western and Central Areas (Fig. 2); along these transects, 74 bulk samples were collected from approximately 10cm below the ground surface (Sulas and Madella, 2012). In 2011, testing expanded to a larger area, including the Central and Western areas, where STPs (c. 30cm in diameter) were dug down to the depth of the sterile substratum (beach sands) in order to record the full stratigraphy and to sample the cultural layer. A total of 266 STPs were dug at staggered 5m intervals over 19 E-W transects, and 240 bulk samples were taken from the cultural layer (Fleisher and Sulas, 2015). In combination, the 2009 and 2011 sampling covers an area of about 6450m^2 in between buildings (Figs. 2 and 4).

The first two seasons of excavation (2009 and 2011) also allowed for sampling particular house contexts within excavation trenches; these were aimed at characterising features such as room fills, middens, and hearths. In 2013, a programme of systematic sampling at 50cm intervals was carried out across the packed earth floor of a wattle-and-daub structure (SM032, 275 bulk samples) among other locations. This sampling programme sought to explore internal variation in the use of space.

In addition, a series of soil samples were taken from off-site locations, including agricultural fields and a lime-processing area. These provide control data for comparison with anthropogenic sediments in the town (Tables 1 and 2).

For all these samples, the same recording strategy for sediments was applied, described as follows: depth; Munsell colour on wet samples; texture by eye evaluation and finger-texturing on dry and wet samples; mineral and organic fractions were described and contents were estimated on pre-set categories (common, rare, none).

Oriented blocks were taken using a sharp knife from cohesive deposits for soil micromorphology (Table 2): one sample from a packed earth floor excavated inside a room in House 23 (SM015; Fig. 2); one sample from an ash-rich deposit identified inside a room of House 44 (SM004, Fig. 2) and provisionally interpreted as a hearth; two samples from stratified deposits rich in cultural material which were excavated through a trench placed against the wall of a well (SM006; Figs. 2 and 3b); and, one sample of a buried *terra rossa*-type soil deposit from a likely wattle-and-daub house floor (SM007) (Fig. 2).

4.2 Laboratory methods

Soil samples were processed for pH and Electrical Conductivity (EC), multi-element and micromorphological analyses (Tables 2 and 3).

pH and EC values were measured using a Hanna electronic meter and three replicas per sample were run. Sub-samples (particles of <250μm; 10-11.5g) were analysed by ALS Global Minerals for Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) to determine 33 elements using four acid digestion (ASL Minerals, 2009, 2010).

Micromorphological thin sections were manufactured at the McBurney Laboratory for Geoarchaeology, Cambridge. Undisturbed blocks were oven dried and thin sectioned, and slides were first scanned then analysed using petrographic microscopes at different magnifications under plane-polarized light (PPL), cross-polarized light (XPL), and oblique incident light (OIL). The description of the thin sections was performed following Bullock *et al*. (1985) and Stoops (2003).

4.3 Successes and challenges

The key challenge faced in implementing this methodology was the nature of the archaeological sediments. Although Songo Mnara deposits represent only a single cultural layer, it can be difficult to define the boundaries of that layer in the loose sandy sediments. This represents a challenge for the physical act of taking a sample, as well as for the interpretation of the cultural matrix in which it sits. In general, bulk soil samples were easier to isolate to a particular type of sediment, which could be considered a broad indicator of cultural activity in these spaces, even if the precise boundary between contemporaneous contexts and features was more difficult to define. Micromorphological sampling was, however, more profoundly influenced by these concerns, as it often proved impossible to cut a block and maintain its internal structure in the sandy silts at the site. Successful micromorphology blocks were cut from the more cohesive sediments: the plaster floors of stonehouses, and baked daub walls worked very well, as did a sample from a packed-earth floor in House 23. Micromorphological sampling was difficult in the looser sediments associated with impermanent architecture and activity areas, with only a single successful block taken from a buried soil deposit interpreted as the floor of a wattle-and-daub house in the western open area (SM007).

5. Results

5.1 Characterisation of activity zones in open areas

Geoarchaeological techniques have proven particularly useful in characterising broad activity zones across the site and distinguishing between areas that would be difficult to discern with traditional archaeological techniques alone. They have also been valuable in characterising the sediments more effectively, with a feedback effect into interpretation of other datasets. For example, pH readings revealed moderately to strongly alkaline conditions (8-8.5) across the entire sample set, which are consistent with background values (pH 8-8.6). Similarly, EC values reflected generally poor nutrient contents (>160ms/cm) throughout the site. These allowed little distinction between activity areas, but do inform understandings of preservation conditions for other remains such as macrobotanical remains and phytoliths (McParland and Walshaw, 2015). The sediments from the houses showed slightly lower alkaline pH (8.2-8.5) and conductivity (EC 81-169 mc/cm) with off-set readings found in specific contexts; these are comparable with activity areas elsewhere on the site (well and SM007, pH 8.2-8.4; EC 96-131 ms/cm) suggesting a general indicator of activity.

Geochemical testing using ICP-AES was, however, much more successful at isolating particular activity zones in both the subsurface deposits and cultural layer across the open areas as well as archaeological sediments from excavated deposits. Results across the site show increased contents of calcium, magnesium, phosphorus, zinc and strontium, and lower amounts of barium, cobalt, and potassium in samples from activity areas than those found in the background samples. In contrast, other elements showed very little or no difference in concentration (e.g. Ag, Sb, Ti, and U). Enhanced concentrations of calcium and magnesium could also be associated with local environmental conditions (high pH >7.5; coral reef-limestone geology; tropical and coastal settings; see e.g. Duchaufour, 1977: 380). Under active calcium carbonate conditions, (pedogenic) carbonate features (e.g. coatings, crusts, etc.; see e.g. Duchaufour, 1977: 42; Goldberg and Macphail 2006: 68-71) may be seen in the soil profiles or in thin section; none were observed in the field or in thin section at Songo Mnara (see thin section analytical data in Table 4). Furthermore, a cluster of elements (Ca, Ba, Co, Mg, P, K, Zn, Sr) yielded different values in seemingly similar contexts across the open areas and inside buildings.

At the intra-site level, different chemical signatures were detected in the subsurface samples from the open areas which showed generally enhanced levels of calcium, copper, magnesium, sodium, phosphorus, strontium and zinc; however, other elements which usually follow a similar path (e.g. Ba, Fe, Mn) were found in generally depleted concentrations. These chemical trends were also detected in samples that targeted the buried cultural deposit associated with the occupation of the site (2011; Fleisher and Sulas, 2015). However, ICP-AES results from the cultural layer also revealed clusters of chemical concentrations suggestive of particular activities (Fig. 4). In the Western Area, for example, enhanced levels of calcium, magnesium, sodium, sulphur, and strontium marked a rectangular space with no structural remains. To the N and S of this rectangular space, higher levels of both nutrients (Ca, Co, Cu, Fe, Mg, Mn, P, S, Zn) and metallic elements (Al, Cr, Na, Ni, Sr) demarcated features on the borders of the space, including craftworking areas and wattle-and-daub houses (Fleisher and Sulas, 2015).

FIGURE 4 **(suggested position)**: Composite map of open areas showing key clusters of chemical concentrations (Ca, Mg, Na, and Sr) detected in the buried cultural layer via shovel test pits (STPs) dug on a staggered 5m grid; the background shows magnetic susceptibility anomalies.

5.2 Characterisation of space inside structures

Chemical results from structures at Songo Mnara have also demonstrated the potential for differentiating activities and picking up on variation between similar structures. Results from two coral-built houses, House 44 and House 23, showed very different signatures in rooms that appeared quite similar. In general, samples from House 44 showed increased contents of calcium, copper, lanthanum, and sulphur with very high levels of magnesium, phosphorus, and strontium; and very low amounts of iron, potassium, and manganese (Table 3). Concentrations of metallic elements were found in areas of possible burning, and a midden deposit in the back room; the latter also contained enhanced levels of nutrients (Mg, S). These point to differences between areas of burning within the structure, as the hearth in the central room had depleted amounts of elements linked to food processing (e.g. P, Zn). Further insights into the nature of this 'hearth' deposit were provided by the soil micromorphology study which showed primarily plaster fragments embedded within an ash-rich matrix. It was then suggested that the hearth may have been associated with processing of non-organic materials involving burning, perhaps on occasional basis (Sulas and Madella, 2012; Wynne-Jones, 2013).

House 23 contained enhanced levels of metallic elements (Al, As, Cr, Cu, Fe, Mn, and Zn) and low amounts of nutrients (Ca, Na, S, and Sr) across the packed earth floor (Table 3). In the central room (SM015), the packed-earth floor yielded very high concentrations of metallic elements (Al, As, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sc, Zn) and the lowest recorded levels of calcium, sulphur, sodium, and strontium. The inner courtyard (SM014) and the external staircase (SM013) both yielded enhanced levels of metallic elements, calcium, phosphorus, and strontium—much higher than those recorded in the central room floor—which may be related to the presence and/or processing of metal-bearing material such as metals, pigments, or tanning salts.

Micromorphological analysis was performed on samples from the floors in House 44 and House 23(Table 4, Fig. 5). Thin sections from the houses were useful in defining the nature of building materials, with fragments of lime plaster cemented by a medium to fine-textured matrix in House 44 (Sulas and Madella, 2012) and an unconsolidated iron- and organic-rich sediment making up the packed earth floor in House 23 (Table 4, Fig. 5a-b).

The values recorded in the systematic sampling of the wattle-and-daub structure (SM032; Table 3) illustrate yet another chemical signature marked by the highest concentration of silver across the entire sample set, and generally enhanced levels of calcium, cobalt, copper, magnesium, sodium and strontium. Depleted levels of common nutrients (Fe, K, Mn, P, Zn) may suggest an environment relatively clear of waste from use or processing of plant/animal resources. However, enhanced concentrations of salts (Mg, Na), metallic elements (Ag, Cu, Sr) and calcium may be linked with the presence/use of sea-resources in this space such as shells, fish (Ca, Cu, Mg), and fishing nets (Mg, Na). Higher levels of metallic elements (Ag, Cu, Sr) and salts could also be associated with tanning or the use of pigments. In addition, ICP-AES analysis also detected different chemical signatures across the house. For example, the house floor under the daub yielded high amounts of metallic elements (e.g. As, Co, Cu, Pb) and lower contents of calcium, magnesium and sodium. The spaces outside the original structure, instead, yielded high contents of calcium, magnesium, sodium, and sulphur.

Trench SM007 was excavated across a geophysical anomaly which proved to represent some kind of wattle-and-daub structure; a floor surface was revealed during excavation with plentiful artefact remains. This earth floor was bulk sampled, and it was also possible to take a micromorphological sample. The soil material is consistent with the *terra rossa*-type sediments present elsewhere on the island (Sulas and Madella, 2012). However, here the buried deposit yielded enhanced levels of calcium, magnesium, sodium, sulphur, and strontium, and depleted levels of other plant nutrients (P, K, Mn). In thin section, this deposit consisted of poorly sorted, fine sandy material with a bio-microstructure (Table 4 and Fig. 5e). The organic and biogenic components included charcoal and micro-charcoal, plant tissue remains, bone fragments, and (gastropod/bivalve) shell fragments (Fig. 5f). The chemical signature and micromorphological records suggest input of organic and inorganic material into the system such as, for example, domestic waste. Animal herding would contribute organic input into the ground, but this is usually associated with enhanced manganese and phosphorus, which are here found in depleted amounts. It is worth noting that the chemical signature from the floor at SM007 shows some similarities with the one recorded in the floor of the wattle-and-daub structure SM032. They both yielded a high content of sodium and generally enhanced concentrations of calcium, magnesium, and strontium. Both contexts also contained depleted amounts of manganese, phosphorus, zinc and nickel. However, it is noteworthy that copper and lead concentrations were different: enhanced in SM032 and depleted at SM007.

5.3 Sites of daily activity

The well deposits (SM006) gave a distinct chemical signature marked by enhanced levels of nutrients (Cu, Fe, K, Mn, P and Zn) and metallic elements (Al, Ba, Cr, Ni, and Pb) which point to organic input. This was better understood through the analysis of the thin section taken against the exterior wall (Table 4) which showed a matrix of medium textured sandy silty material with an iron-rich groundmass and abundant organics (plant tissues, charcoal, excremental matter) and biogenic components (shell, bone) (Fig. 5c-d). Two main anthropogenic inclusions were noted: crust fragments with micrite coating (neo-formed?) and fragments of baked reddish to yellow, silty and clay-rich matrix. In combination with potsherds, the crust fragments with thin coating may indicate some sort of finishing (whitewash?), and rock fragments and iron features indicate high temperature burning.

TABLE 3 **(suggested position)** Soil chemical analyses by contexts: pH, Electrical Conductivity (EC) and ICP-AES results.

TABLE 4 **(suggested position)** Soil micromorphology: scan images and summary description (see also Fig. 5).

FIGURE 5 **(suggested position)**: Soil micromorphology.

6 Methodological considerations

6.1.1 Sampling strategies

Field records and laboratory results obtained from the first season of work (2009) were instrumental in understanding local soils and sediments as well as ascertaining which technique provided the most useful information. Building on this, in 2011 and 2013, we focused systematic chemical mapping on buried deposits in the open areas. Similarly, higher resolution chemical mapping from occupation deposits within a wattle-and-daub structure (on a 50 x 50cm grid) enabled us to detect highly localised chemical clusters between the inner and outer spaces (cf. Middleton, 2004). The systematic collection of samples in both procedures allowed for more robust comparison of chemical concentrations between open and enclosed spaces.

The collection of micromorphology samples was particularly challenging due the nature of the deposits. These were often too sandy and unconsolidated or thin for using Kubiena/tin boxes and, even when samples were taken and carefully packaged, they could easily have been damaged during transport —via sea and rough roads. Nevertheless, a number of samples were taken by cutting a block through the section using a sharp, thick-bladed knife and firmly packed for travel.

6.1.2 Analytical techniques

The results obtained indicate both the potential of selected element analysis and soil micromorphology to address the use of space at ancient Songo Mnara. The calcitic nature of the local sediments and soils strongly influences the pH, which is moderately to strongly alkaline across the entire sample set. EC measurements were also consistently low. The most likely source of salt concentration at Songo Mnara is sea water, sea salt, and possibly urine.

Sea water is especially rich in sodium and chloride, but it also contains smaller quantities of sulphate, magnesium, calcium, potassium, and bicarbonate (cf. Milek and Roberts, 2013). pH and EC measurements, thus, provided essential information at the prospecting phase of the research to ascertain preservation conditions and site formation processes, but offered very little support in characterising archaeological contexts and possible activities.

ICP-AES analysis, instead, has offered a very informative tool to map out activities across the site. In general (House 23 is an exception), elemental clusters map out activity areas and archaeological deposits both indoors and outdoors: enhanced levels of calcium, magnesium, phosphorus, sulphur, strontium and depleted concentrations of aluminium, barium, iron, potassium, manganese, titanium, and vanadium occur across open areas, architectural contexts, and functional areas. At a first level assessment, this chemical signature seems to reflect the generalised 'impact' of human occupation and activities on the Songo Mnara landscape as preserved in the soil/sediment records. The enhanced set of elements (Ca, P, S) are those associated with archaeological sites (e.g. Milek and Roberts, 2013; Wilson et al., 2008). The depleted element group is intriguing as many of these elements (Al, Ba, Fe, K, Mn, Ti) are also usually found in elevated concentrations in archaeological sites. However, the majority of these studies related to continental/temperate regions (e.g. Milek and Roberts, 2013; Ottaway and Matthews, 1988; Wilson et al. 2008) with far fewer, though important, contributions from sub-tropical/tropical environments (e.g. Middleton, 2004; Wells, 2004). On Songo Mnara, off-site *terra rossa*-type soils and sediments are characterised by relatively high amounts of aluminium, iron, manganese, and titanium. As these elements are found in depleted levels at the site across very different contexts—from buried soils/sediments in the open areas to room fills and functional areas—, depletion due to dissolution and/or leaching seems unlikely. Also, dissolution/leaching would be expected to influence the concentrations of other elements.

Another observation can be made with reference to roofed and unroofed spaces: roofed spaces (houses, wattle-and-daub structure) show generally enhanced phosphorus and lead levels, and depleted contents of sodium, potassium, and nickel. This is particularly the case for the SM032 wattle-and-daub structure, where the 50 cm-interval chemical mapping allowed detecting changes in the concentrations of selected elements between the deposit under the daub and the space in the immediate surroundings. Similarly, the wattle-and-daub structure and the earth floor in SM007 had clusters of enhanced and depleted chemical values (enhanced Ca, Na, Mg, Sr; depleted Mn, P, Ni, Zn). Concentrations of sodium, calcium, magnesium and strontium may result from the input of sea-related resources into the system. In this respect, the findings observed in the thin sections from SM007 are indicative of domestic waste (e.g. bone and shell fragments, charcoal). However, the floor deposits from SM032 and SM007 yielded almost reverse concentrations of copper and lead: enhanced in SM032 and depleted in SM007. At the site, copper and lead were usually found in enhanced concentrations inside the houses; a finding consistent with available records of these elements concentrating in house deposits (e.g. Milek and Roberts, 2013; Wilson et al. 2008). In sum, then, chemical patterns from the two earth floors seem to reflect the presence of domestic (sea-related) waste. The difference in copper and lead concentration may be related to different depositional conditions, structural issues, and activities taking place in these spaces.

Analysis of the microstratigraphy was instrumental in characterising house deposits as well as activities in open areas. In the houses, excavation records and chemical mapping provided suggestive but ambiguous information on the nature and possible uses of floor deposits. In House 23, microstratigraphic analysis allowed us to characterise a packed-earth floor as composed of mixed fabric materials, abundant organics and burning features, suggestive of processing and/or consumption of food (cf. Matthews et al., 1997). Thin section analysis of the hearth at House 44, in contrast, revealed that this deposit was not associated with food processing/consumption (Sulas and Madella, 2012). In the open areas, micromorphological analysis of the well deposit (SM006) showed *terra rossa*-type sediments modified by human activities outdoors. Here, mineral rich sediments mixed with burnt remains, cultural refuse, and organics, and some indication of trampling may be associated with an unroofed, busy area with people using and standing around the well (cf. Matthews et al., 1997).

7 Conclusions and future research directions

Research at Songo Mnara demonstrates the possibility of using geoarchaeological techniques in a tropical urban environment. The project has benefited from a multi-pronged research strategy in which all types of evidence are marshalled toward a common goal of reconstructing the use of space. Thus, it has been possible to move between traditional archaeological data (artefact concentrations, structural information) and geoarchaeological data (pH, EC, soil chemistry and micromorphology). There are other layers of data that have not been discussed here, including macrobotanical and phytolith data, from systematic sample grids and from bulk archaeological contexts, and geophysical survey data. These layers of information inform each other and make specific interpretations more possible to achieve.

Beyond interpretation of the site of Songo Mnara, the results discussed here show some interesting trends that might be applied elsewhere. For tropical island environments, the ICP-AES results from Songo Mnara demonstrate that measurements of calcium, magnesium, phosphorus, sulphur and strontium levels can help discriminate occupation/activity areas. They also indicate that the depletion of certain elements (Na, K, Ni) should be considered as a means of differentiating between roofed and unroofed spaces.

As discussed above, the stonetowns of the eastern African coast are special in that they represent bounded, intensively occupied locales with relatively clearly defined structures built in coral and lime mortar. Some of the results from Songo Mnara suggest that the insights developed here might be applicable beyond this subset of African urban sites; in particular, the successful identification and sampling of wattle-and-daub structures points to the possibility of using geoarchaeology to give resolution to sites of ephemeral architecture which are currently poorly understood. Yet, the results from this programme do not give a blueprint for identifying impermanent architecture elsewhere, or understanding the internal spaces of every tropical urban site. Instead, the results at Songo Mnara clearly point to the importance of interpolating between different sources of data and remaining flexible in interpretation of geoarchaeological results.

Urban sites in tropical environments will remain a challenge for archaeological interpretation. This is even more complicated in island environments, where seawater and tidal processes create new pathways for contamination or degradation of certain elements. Nonetheless, it has been shown at Songo Mnara that a project incorporating geoarchaeological testing from the start can overcome some of the obstacles to understanding those sites. By allowing geoarchaeology and other methodologies to work in parallel, with constant interaction and readjustments, it is possible to develop a more coherent and richer understanding for all concerned in trying to unravel the history of these important sites.

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Fig. 4 Composite map of open areas showing key clusters of chemical concentrations (calcium, magnesium, sodium and strontium) in the buried cultural layer, detected via shovel test pits (STPs) dug on a staggered 5m grid; the background shows magnetic susceptibility anomalies.

Fig. 5 Soil micromorphology: a.-b. micrographs from House 23 (SM0015/1) showing the fine groundmass with fresh and burnt bone fragments (B); c. detailed scan image of crust fragment from the Well deposit (SM006) with thin coat of micro-sparite (arrow); d. micrograph from the same deposit (SM006) showing charcoal-rich fabric (C=coarse charcoal) and spore (S) micrographs from thin sections; e. micrograph of deposit from Trench SM007 showing porosity and groundmass and a relict pedofeature (SMT2); f. micrograph from the same deposit (SM007) showing shell fragments and a calcite spherulite (arrow).

Table 1 Local soils and sediments (Sulas and Madella, 2012; Fleisher and Sulas, 2015).

Table 2 Summary data on the number of samples examined by context (see also full data in Tables 3 and 4).

Table 3 Soil chemical analyses by contexts: pH, Electrical Conductivity (EC) and ICP-AES results. The following elements yielded the same concentrations across the entire sample set: Cd (ppm <0.5), Ti (%<10), U (ppm<10), and W (ppm <10).
Legend: RG=regional sediment in and around the site; Lime pit=sample from a modern lime-processing pit; ST1/3=anthropogenic sediment; ST2= *terra rossa*-like sediments; GT DC=Open area with daub concentrations; PS=Public space; GT ES=East samples; WD=Wattle-and-daub structure; Ext wall=external wall; Int c-yard=internal courtyard; Ext Stc=external staircase. Colour shading to show element enhancement/depletion against the regional sediment only: ■=general enhancement; ■=very high/double enhancement; ■=generally depleted level; ■=much depleted/halved levels.

Table 4 Soil micromorphology: scan images and summary description (see also Fig. 5).

TABLES 1 and 2

Types	*Field observations*	*Key chemical values* (pH, EC and ICP-AES)
Regional soils/sediments		
Terra rossa		
on site	Reddish brown (7.5YR 4/4) medium/fine textured sandy loam (coral, quartz); rich in organic matter, occasional microcharcoal, medium-sized shells; loose, slightly moist or dry.	**pH**: >8; **EC**: >100ms/cm **ICP-AES**: Al 0.57-2.5,ppm, Ba 60-170ppm, Ca 11.9-23%, Cr 8-30ppm, Fe 0.39-0.94%, K 0.17-0.42%, Mg 0.17-0.63%, Na 0.12-0.2, Mn 76-224, P 1090-5120ppm, Sr 1995-3880ppm, Z 5-20ppm
off site on farmland	As above	**pH**: >8; **EC**: >100ms/cm **ICP-AES**: Al 3.5%, Ba 280, Ca 0.4%, Cr 39, Fe 1.7%, Mn 474, P 330, Sr 57, Zn 10
Anthropogenic sediments		
Dark brown fine sand silty loam	Dark brown/ashy (10YR 4/3 and 3/1) fine to very fine sand silty loam with few medium sands (coral, quartz); common rooting, rare charcoal, medium to very fine shell fragments; loose, dry.	**pH**: >8; **EC**: <100 ms/cm **ICP-AES** against *terra rossa* soils/sediments: Ca >20%, P and Sr >3000 , K >0.18%, S >0.1%

Table 1 Local soils and sediments (Sulas and Madella, 2012; Fleisher and Sulas, 2015).

Year	*Context*	*Number of samples per technique*		
		ICP-AES	*pH & EC*	*Thin section*
2009	**Background *terra rossa*-type sediments**	2	2	
2009	**Modern lime-processing pit**	1	1	
	OPEN AREAS			
	5 m-interval transect; sampling at 10cm depth			
2009	NOA soil types 1 & 3	22	27	
2009	SOA soil types 1 & 3	9	25	
2009	NOA soil type 2	1	16	
2009	SOA soil type 2	8	8	
	5 m-interval transect; sampling of cultural deposit			
2011	GT Daub concentrations	17		
2011	GT Public space	56		
2011	GT East Samples	29		
2009	**FUNCTIONAL AREA**			
	Sampling by context			
	Well (SM006, #6002, 6003, 6004)	3	3	2
	ARCHITECTURAL CONTEXTS			
	Sampling by context			
2009	**House 44**			
	House 44 floor deposits (SM003/3002, SM004/4005)	2	2	
	House 44, hearth (SM004/4009)	1	1	1
	House 44, indoor midden (SM010/10002)	1	1	
	House 44, external N wall (SM002/2003)	1	1	
2009	**House 23**			
	House 23, packed-earth floor (SM015/15002)	2	1	1
	House 23, inner courtyard (SM014/14004)	1	1	
	House 23, external staircase (SM013/13004 and 13007)	2	2	
2009	**Trench SM007**			
	Soil profile with wattle-and-daub floor (#7002 and 7003)	2	2	1
	Sampling at 50 cm-interval			
2013	**Wattle-and-daub structure** (SM032)	275		

Table 2 Summary data on the number of samples examined by context (#) (see full data in Table 3).

Table 3

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Table 3 Soil chemical analyses by contexts: pH, Electrical Conductivity (EC) and ICP-AES results. The following elements yielded the same concentrations across the entire sample set: Cd (ppm <0.5), Ti (%<10), U (ppm<10), and W (ppm <10).

Legend: RG=regional sediment in and around the site; Lime pit=sample from a modern lime-processing pit; ST1/3=anthropogenic sediment; ST2= *terra rossa*-type sediments; GT DC=Open area with daub concentrations; PS=Public space; GT ES=East samples; WD=Wattle-and-daub structure; Ext wall=external wall; Int c-yard=internal courtyard; Ext Stc=external staircase. Colour shading to show element enhancement/depletion against the regional sediment only: ▪=general enhancement; ▪=very high/double enhancement; ▪=generally depleted level; ▪=much depleted/halved levels.

	CONTROLS		OPEN AREAS					ARCHETECTURAL CONTEXTS									WELL
	RG	*Lime pit*	*ST1/3*	*ST2*	*GT DC*	*PS*	*GT ES*	*House 44*				*House 23*			*WD*	*SM007*	*SM006*
								Floors	*Hearth*	*Midden*	*Ext wall*	*Floor*	*Int c-yard*	*Ext Stc*			
pH	8.2	7.9	8.3	8.3	n/a	n/a	n/a	8.4	8.2	8.3	8.5	8.5	8.3	8.4	n/a	8.3	8.2
EC ms/cm	104	86	101	107	n/a	n/a	n/a	143	245	103	126	136	113	136	n/a	113	97
ICP-AES																	
Ag ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	<0.5	<0.5	<0.5	<0.5	3.1	<0.5	<0.5
Al %	1.8	<0.1	1.3	0.9	2.0	0.7	0.2	0.3	0.7	1.0	0.5	4	2.2	1.2	1.1	1	1.4
As ppm	10	<5	6.5	5	7	<5	8	<5	11	8	7	18	16	11	2.3	11	10
Ba ppm	122	10	100	90	110	70	110	20	40	60	60	135	100	125	113	80	100
Be ppm	0.7	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.7	<0.5	<0.5	0.5	<0.5	<0.5
Bi ppm	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	4	<2	<2	<2	<2	<2	<2
Ca %	14	34	16	20	27	29	25	25	24	20	22	8	14	11	20	22	16
Cd ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Co ppm	3	<1	1	1	4	2	3	<1	<1	1	<1	6	2	3	4	1	1
Cr ppm	23	2	18	13	30	13	25	7	10	15	9	49	31	31	15	14	21
Cu ppm	2	<1	2	4	4	4	5	<1	4	4	<1	2	2	3	5	<1	3
Fe %	0.8	<0.1	0.6	0.4	0.9	0.3	0.7	0.1	0.4	0.5	0.3	1.9	1.0	1.0	0.5	0.4	0.7
Ga ppm	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	10	<10	<10	<10	<10	<10
K %	0.3	<0.1	0.3	0.2	0.3	0.2	0.3	0.7	0.1	0.2	0.1	0.5	0.3	0.3	0.3	0.2	0.3
La ppm	18	10	15	15	10	<10	10	10	20	20	20	20	30	20	<10	20	20
Mg %	0.3	0.3	0.3	0.4	0.6	0.8	0.6	0.5	0.6	0.4	0.7	0.3	0.3	0.2	0.5	0.8	0.3
Mn ppm	193	<5	153	100	219	70	137	73	60	132	90	408	250	283	114	95	160
Mo ppm	1	<1	<1	<1	<1	1	1	<1	1	1	<1	1	1	<1	<1	<1	<1
Na %	0.1	<0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	<0.1	<0.1	<0.1	0.2	0.2	0.1
Ni ppm	12	1	9	7	14	4	10	4	8	9	5	29	14	14	6	6	12
P ppm	1690	110	2570	2525	1890	1280	2190	2160	2520	2690	3210	1600	1950	3150	1080	1240	2690
Pb ppm	5	<2	5	4	5	6	6	3	5	9	2	13	6	8	7	4	6
S ppm	<0.1	0.3	<0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.1
Sb ppm	5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sc ppm	3	<1	2	2	3	1	2	1	1	2	1	6	4	3	2	1	2
Sr ppm	2237	8550	2525	3155	3820	4520	3640	4350	4190	3330	3400	1250	1840	1460	2740	3250	2280
Th ppm	20	30	18	20	20	20	<20	20	20	20	<20	<20	20	<20	<20	20	<20

Ti %	0.2	<0.1	0.1	<0.1	0.2	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	0.3	0.2	0.4	<0.1	<0.1	0.1
Tl ppm	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
U ppm	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
V ppm	19	2	13	8	3	5	13	4	7	10	7	45	22	25	12	10	16
W ppm	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Zn ppm	10	<2	7	10	14	6	12	6	12	11	11	15	16	14	8	3	15

Table 4

Table 4 Soil micromorphology: scan images and summary description (see also Fig. 5).

INSERT **T4_ FIGa.jpg** **here**	**House 23** Slide: SM015/1, #15001/15002 Unconsolidated iron- and organic-rich material with two different microfabric types (SMT). SMT1 (~ 70% of the slide): medium to fine sand (coral/calcite, quartz) with little clay; crumb microstructure; undifferentiated to crystallitic b-fabric; 15% porosity (complex packing voids, channels); strongly iron-impregnated groundmass with predominant amorphous organic matter, little microcharcoal and ash; abundant charcoal; rare iron-replaced plant tissue remains and roots; rare fresh fragments of straw; pollen and fungal spores; common (fish) bone fragments (fresh and burnt); medium to coarse fragment of burnt soil. SMT2 (~ 30% of the slide): very fine iron-rich material; rare coarse to medium coral pebbles; granular to crumble microstructure; high amounts of charcoal, microcharcoal, pollen and fungal spores (Fig. 5 a-b). Deposit characterised by mixing of materials very rich in organic matter and strongly iron-impregnated suggestive of burning and processing/consumption of food.
INSERT **T4_ FIGb.jpg** **here**	**Well** (SM006) Slide: SM006/7, # 6004 Sandy silty loam with dominant fine and very fine, angular sand (coral/limestone, quartz), few coarse sand, rare silt and clay; crumb microstructure; crystallitic b-fabric; 10% porosity (complex packing voids, channels and vughs); the groundmass is strongly impregnated by amorphous iron and organic matter.; abundant excremental matter, microcharcoal, very fine charcoal; shell and bone fragments (burnt and fresh); (iron-replaced) plant tissue remains; fungal spores (Fig. 5d), pollen and phytoliths; coarse to medium organo-mineral spheres are also present and results from earthworm activity; fragments of crusts, daub (DF), and potsherds. The matrix is a darkish brown silty loam, significantly similar to the terra rossa-type soil recorded across the open areas. In addition to potsherds, the presence of crust fragments with thin micro-sparite and iron-manganese coatings (Fig. 5c) on one side may indicate some sort of finishing (white wash?). The rock fragments and iron features seen within the crust fragments indicate high temperature burning.
INSERT **T4_FIGc.jpg** **here**	**Trench SM007** Slide: SM007/3, #7003 Medium textured sandy loam with dominant fine and very fine, angular sand (coral, quartz), few coarse sand, and rare silt and clay; crumb microstructure; 20% porosity (complex packing voids, channels, vughs; Fig. 5e); groundmass consists of organic matter, amorphous iron and common micro-charcoal and is moderately iron-impregnated; abundant shell fragments (gastropod/bivalve, Fig. 5f), amorphous excremental matter, coarse to fine charcoal and microcharcoal; coarse to medium plant roots and tissue fragments (fresh and iron-replaced); rare bone fragments (fresh and burnt); rare organo-mineral spheres and calcite spherulites (Fig. 5f). A few relict matrix fragments are present: - SMT1: sub-rounded iron- and organic-rich aggregates (500-300 μm) with sharp boundary and undifferentiated b-fabric; the internal microstructure exhibits no pores, rare very fine sand and micro-charcoal; - SMT2: sub-rounded clay-rich aggregates (1000 μm) with abundant silt and high degree of iron-impregnation; rare fine sands (quartz and coral); rare vughs; fine charcoal and microcharcoal (Fig. 5e). - SMT3: tabular, layered iron- and organic-rich fragments (crust?) (500-300 μm) with no pores and abundant microcharcoal; rare very fine quartz.

Figure 1
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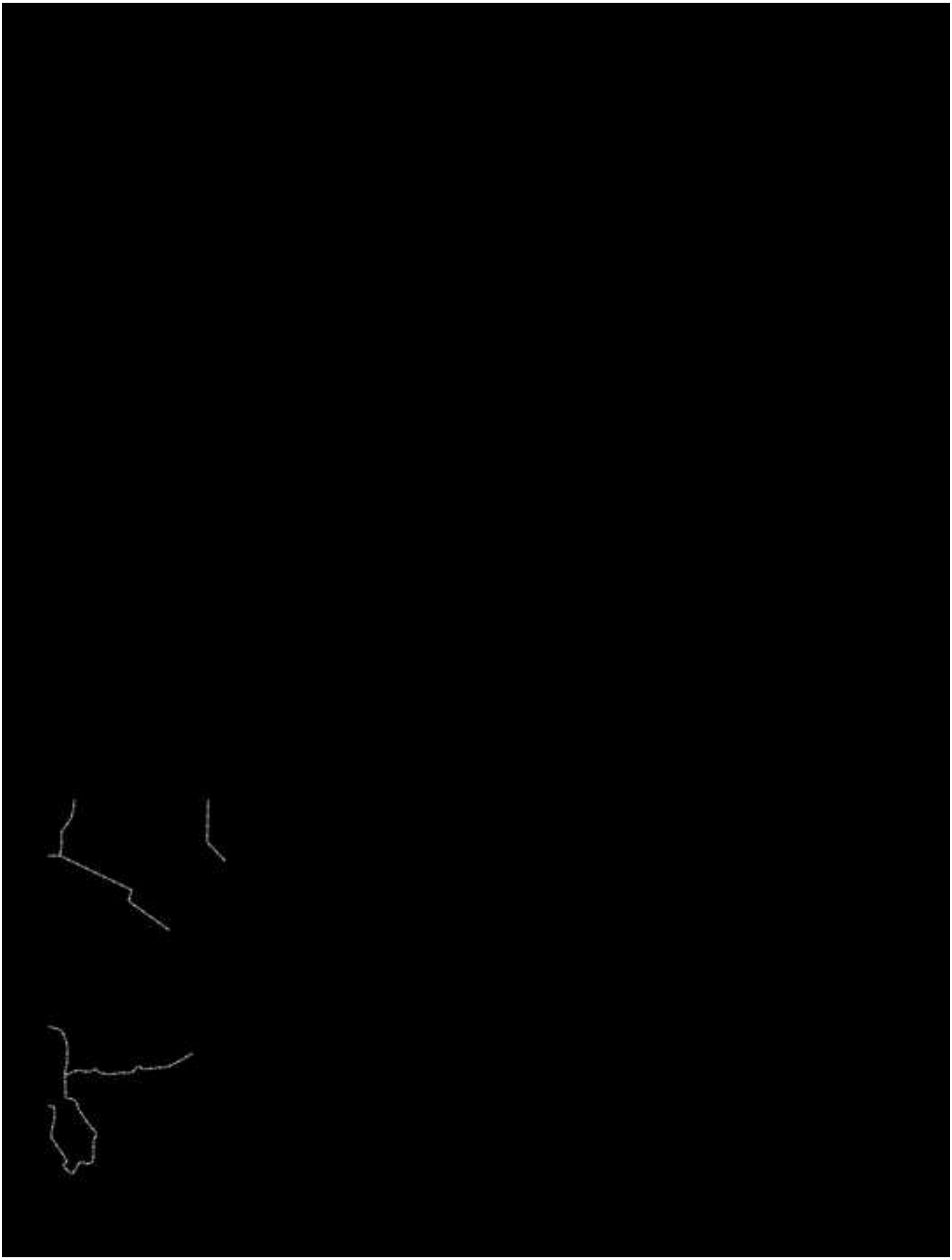

Figure 2
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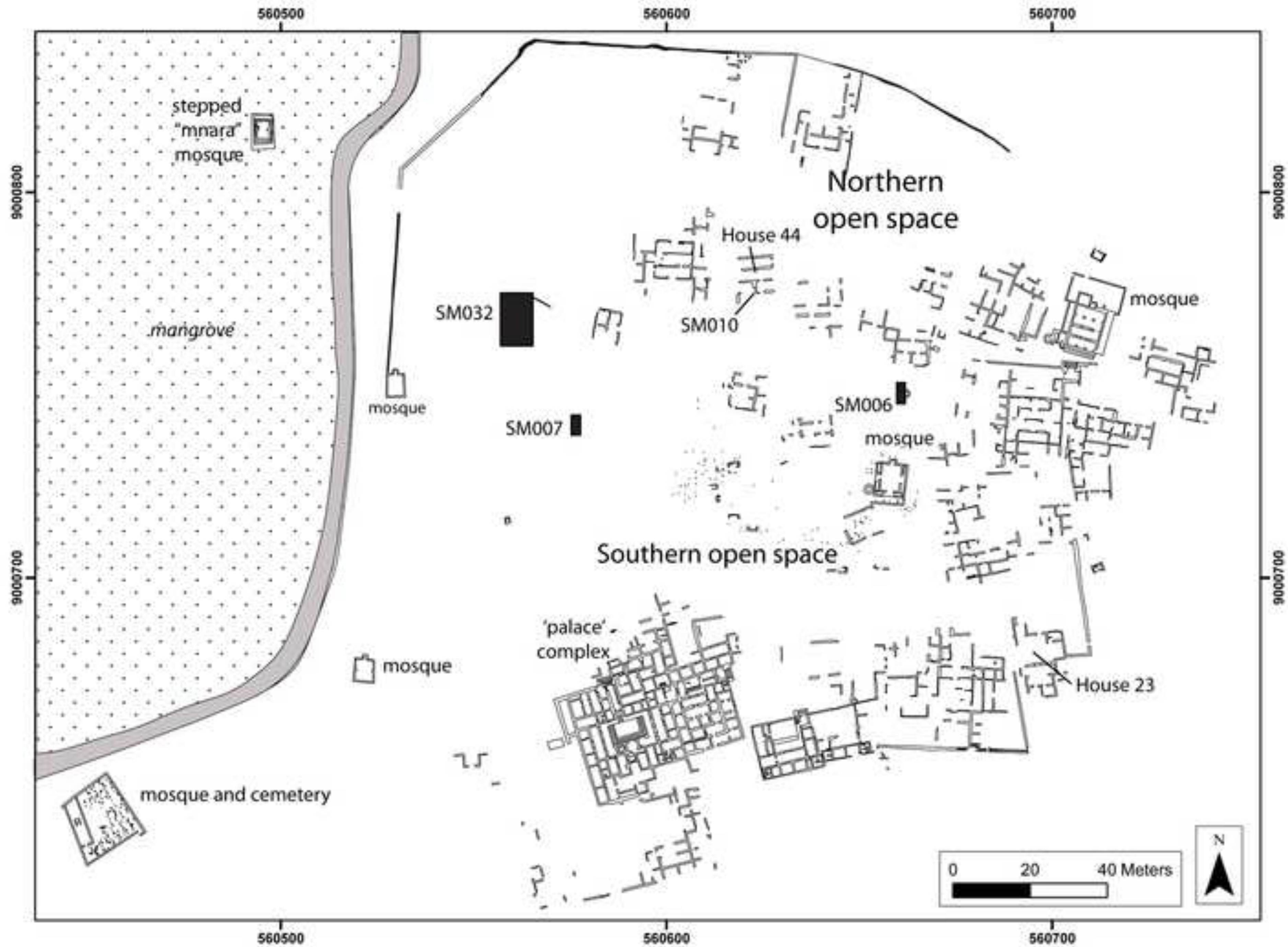

Figure 3
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Figure 3b
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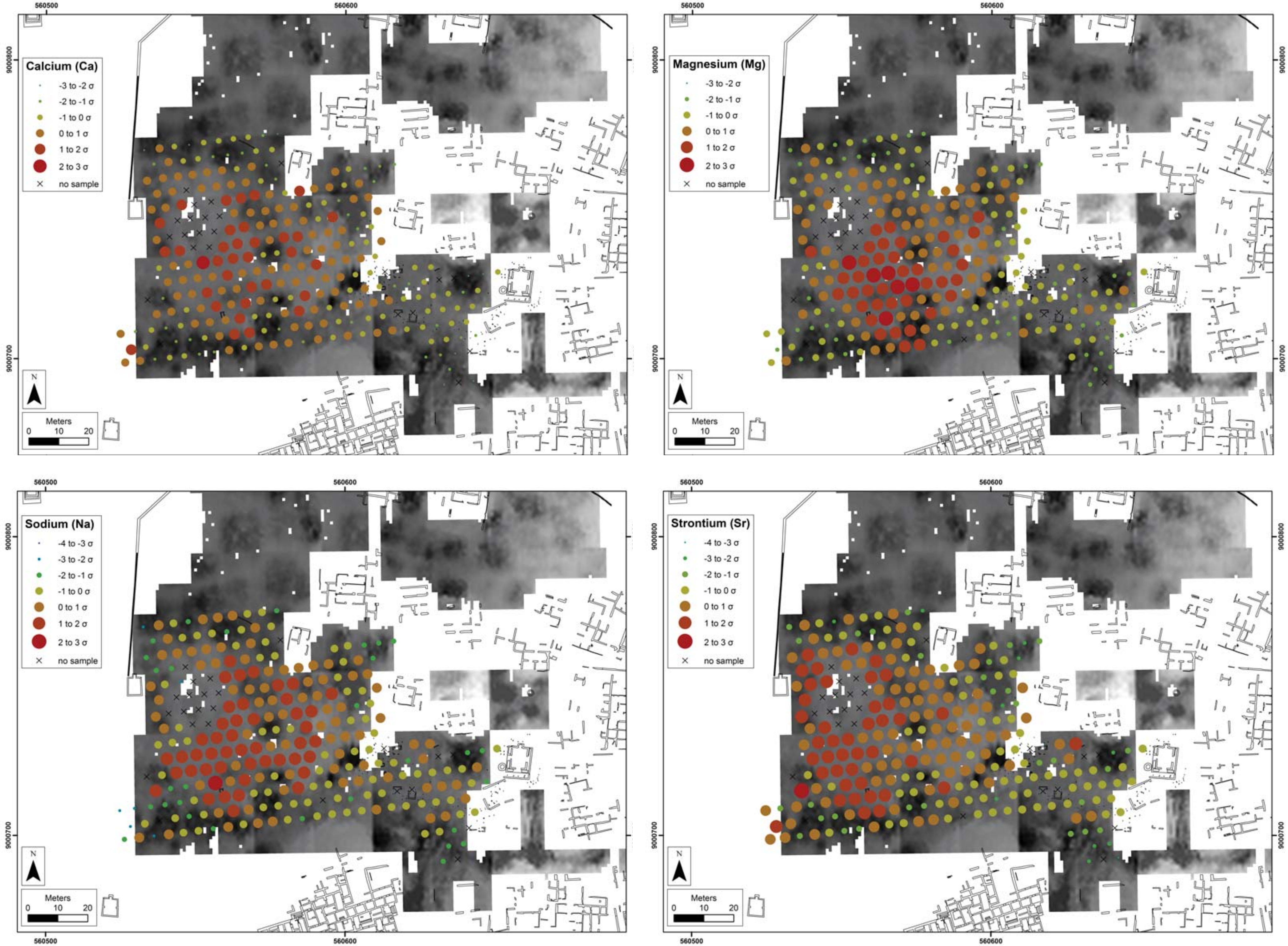
Figure 4



560500
560600
9000800
9000700
Calcium (Ca)
-3 to -2 σ
-2 to -1 σ
-1 to 0 σ
0 to 1 σ
1 to 2 σ
2 to 3 σ
no sample
Magnesium (Mg)
-3 to -2 σ
-2 to -1 σ
-1 to 0 σ
0 to 1 σ
1 to 2 σ
2 to 3 σ
no sample
Sodium (Na)
-4 to -3 σ
-3 to -2 σ
-2 to -1 σ
-1 to 0 σ
0 to 1 σ
1 to 2 σ
2 to 3 σ
no sample
Strontium (Sr)
-4 to -3 σ
-3 to -2 σ
-2 to -1 σ
-1 to 0 σ
0 to 1 σ
1 to 2 σ
2 to 3 σ
no sample
N
Meters
0 10 20

Figure 5

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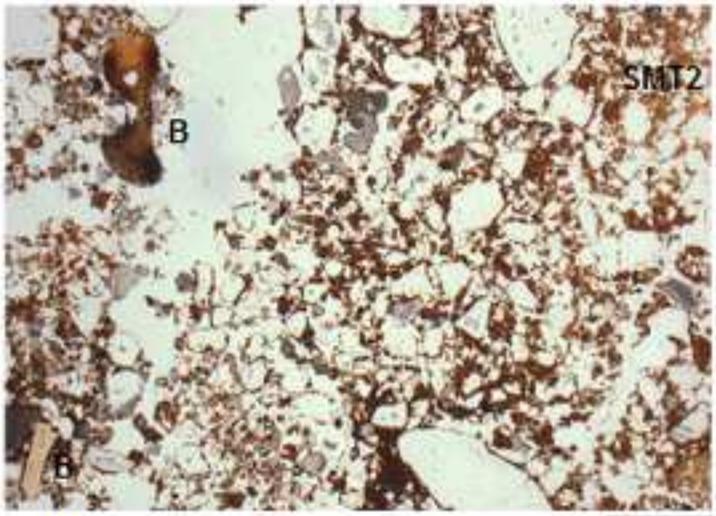
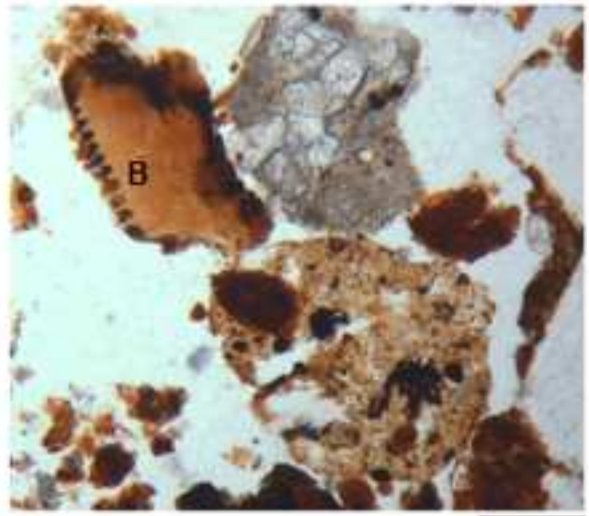
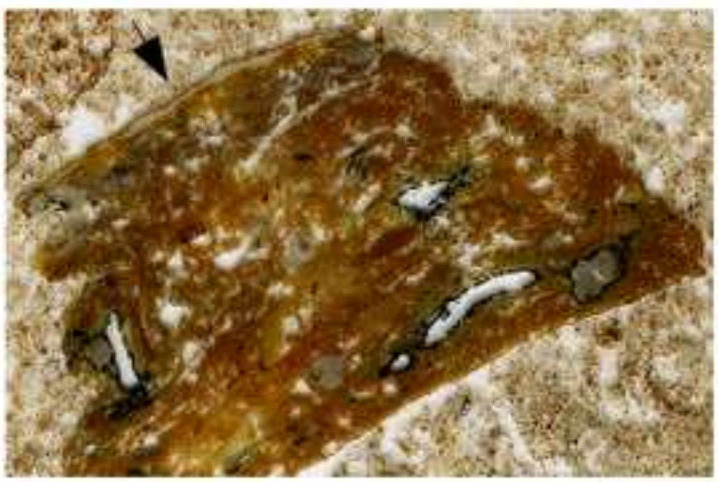


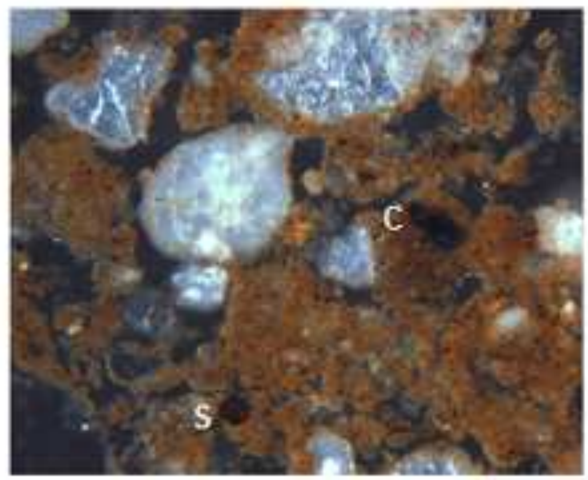
a. PPL x8. Scale bar: 1 mm — 1 mm



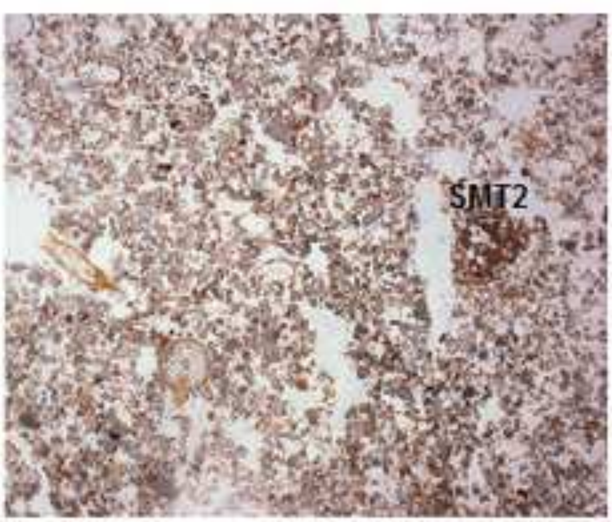
b. PPL x10. Scale bar: 100 µm — 100 µm



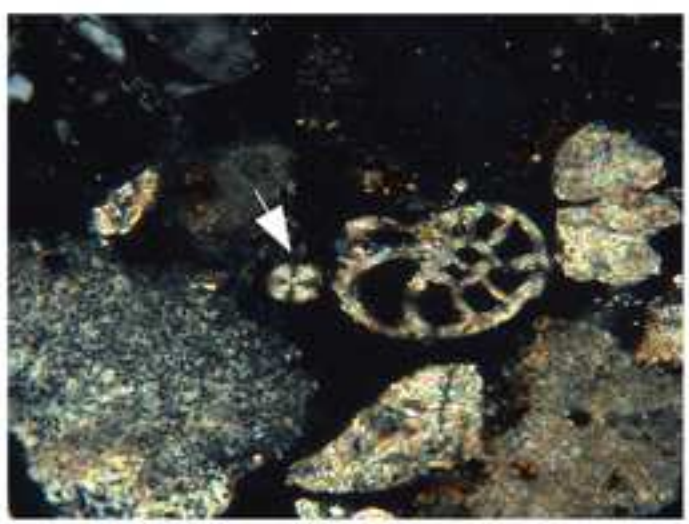
c. Scan of slide. — 1 cm



d. OIL x10. Scale bar: 100 µm — 100 µm



e. PPL x8. — 1 cm



f. XPL x4. — 250 µm

Fig a for Table 4
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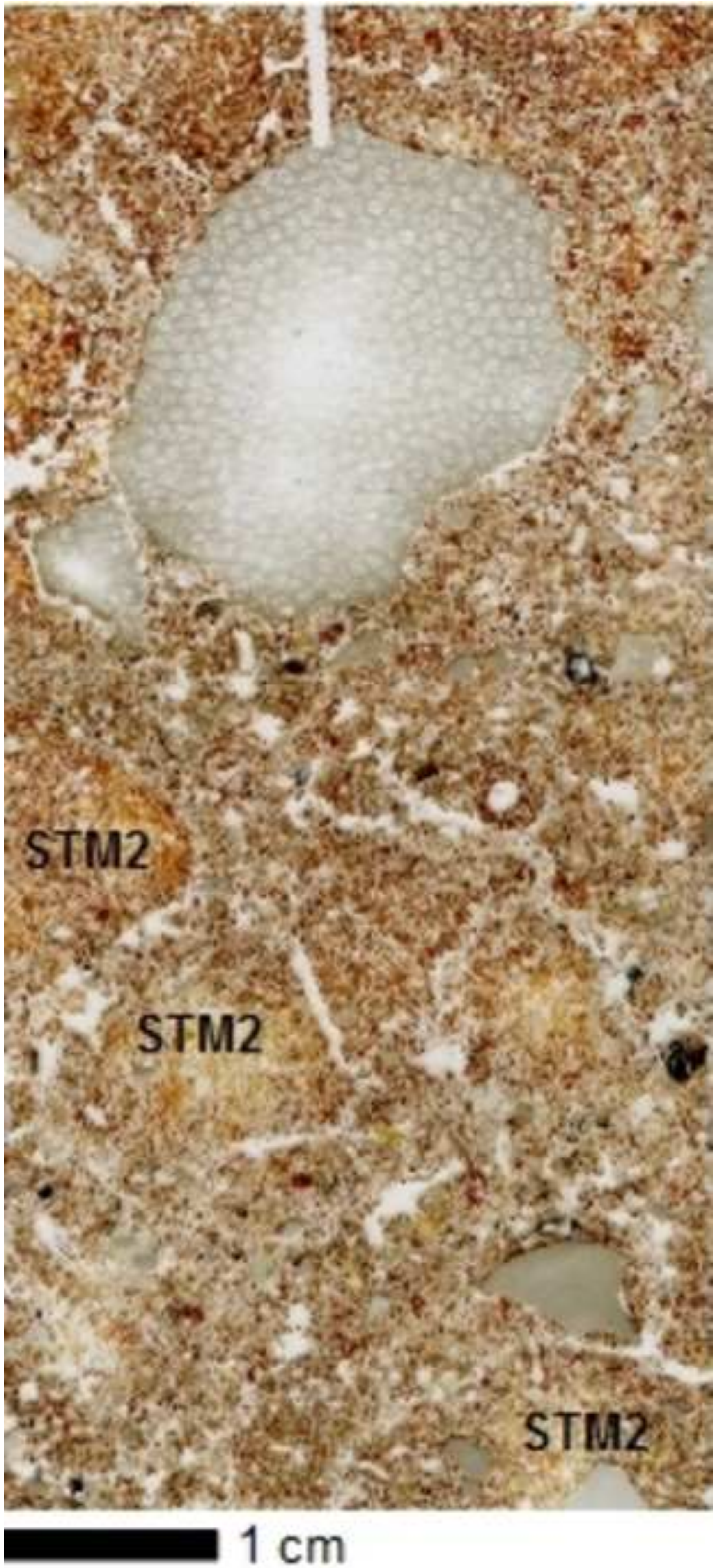

Fig b for Table 4
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Fig c for Table 4
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