Archaeological Prospection
Archaeol. Prospect. **21**, 255–262 (2014)
Published online 1 May 2014 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/arp.1487

Geophysical Survey in Sub-Saharan Africa: magnetic and Electromagnetic Investigation of the UNESCO World Heritage Site of Songo Mnara, Tanzania†

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ABSTRACT Magnetometry and Slingram electromagnetic surveys were conducted at the UNESCO World Heritage Site of Songo Mnara, Tanzania, as part of a multinational programme of investigation to examine the uses of space within and outside of this stonetown. The town was a major Islamic trading port during the fourteenth and fifteenth centuries. The surveys detected significant evidence for the containment of activities within the town walls, and previously unknown anthropogenic activity was revealed between the existing coral rag buildings, as well as within the open areas inside the town. Over 40 areas of magnetic disturbance were identified that corresponded directly with areas of high magnetic susceptibility in the Slingram electromagnetic in-phase responses. On excavation many of these anomalies were found to correlate with wattle and daub structures, indicating a hitherto unidentified population, and the location of the anomalies also suggests a potentially deliberate delineation of space within the open areas of the stonetown. The combined results of the three geophysical data sets indicate that there are clear delineations in the use of space within Songo Mnara. This, coupled with the presence of industrial activities and evidence of more ephemeral occupation, neither of which had previously been recorded at the site, indicates that the pre-existing town plan is in need of significant reappraisal. The current plan, based upon the remains of extant and collapsed coral buildings, can now be updated to incorporate the more ephemeral aspects of Swahili sites, including activity areas, and notably, the homes of the 'hidden majority' of the population. The results establish the benefit of a combined approach at these sites, and demonstrate that further invasive and non-invasive exploration is required in order to fully exploit the significance of the role of geophysical techniques in understanding Swahili towns. © 2014 The Authors. *Archaeological Prospection* published by John Wiley & Sons Ltd.

Key words: conductivity; coral architecture; magnetic susceptibility; magnetometry; Slingram electromagnetic; Swahili

Introduction

Sites of the East African Swahili coast offer a real opportunity for transformed understandings through geophysical survey techniques. Yet the use of archaeological geophysics is only just beginning in the region, as on the African continent more generally (Fleisher *et al*., 2012). This paper reports on magnetometry and Slingram electromagnetic survey at the UNESCO World Heritage Site of Songo Mnara in southern Tanzania, conducted as part of a multinational programme of investigation that explores the uses of space within and outside the structures of the town. Activities across the urban space of Songo Mnara are being sought through a combination of traditional archaeological excavations and site surveying, as well as a set of scientific approaches including geophysical surveys, soil-chemistry studies,

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† Correction added on 12 June 2014 after original publication: the copyright line and license terms have been amended.

Received 1 October 2013
Accepted 21 March 2014

microstratigraphic analysis, environmental coring and flotation (Wynne-Jones and Fleisher, 2010, 2011). Geophysical survey was conducted to examine the use of open spaces and the boundaries of anthropogenic activity within and outside the stonetown at Songo Mnara. In this paper we discuss the methodological approach and results as part of a consideration of the potential of geophysics to add to our understandings of urban forms in this region. Our results from Songo Mnara suggest both great possibilities for augmenting current archaeological interpretations of Swahili towns, and a number of challenges presented by the environment and the nature of archaeological remains here. We therefore highlight the importance of using geophysical survey in conjunction with other techniques, particularly excavations and geochemical studies.

Archaeological and environmental context

Songo Mnara is an extremely well preserved example of a coral-built Swahili stonetown (Garlake, 1966). The site is situated on an island in the Kilwa archipelago of southern Tanzania, approximately 9 km south of the prominent and long-lived town of Kilwa Kisiwani (Figure 1), which was at the forefront of coastal and intercontinental trade in the medieval Islamic world (Chittick, 1974; Sutton, 1998; Fleisher, 2004; Wynne-Jones, 2007). The geology of the Kilwa archipelago is composed of bedrock of Upper Cretaceous to Lower Miocene claystones and clays with secondary lithologies of limestone and sandstone (Nicholas *et al*., 2007). On Songo Mnara Island, the coral bedrock is covered with shallow subsoils of degraded coral sands.

Until recently only survey of the standing structures had been undertaken at Songo Mnara (Dorman, 1938; Mathew, 1959; Garlake, 1966), supplemented by minimal test excavations which had established a short occupation in the fourteenth and fifteenth centuries (Chittick, 1961; Pradines and Blanchard, 2005). This short period of occupation, which contrasts with a millennium of settlement at nearby Kilwa Kisiwani, makes Songo Mnara the ideal site at which to explore spatial activity, and an excellent candidate for pioneering geophysical survey as part of that exploration.

The standing architecture at Songo Mnara is particularly noteworthy, with over 40 domestic room blocks enclosing an open central area where a walled cemetery, tombs and a small mosque are located (Figures 2 and 3). As such, it is a grand example of the Swahili style of building using locally mined coral rag bonded with lime mortar. Both plaster and mortar were prepared by burning coral in open pits, and modern

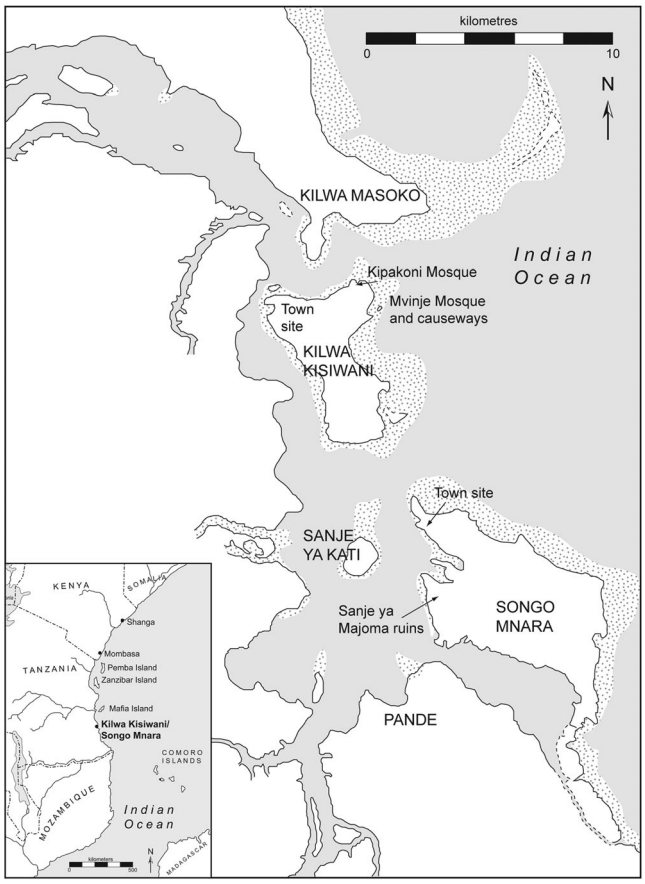

Figure 1. Location map of Songo Mnara and the surrounding sites on the Swahili Coast. (After Chittick, 1974, figure 1).

evidence of similar activities can still be observed in the area today. These buildings developed on this coast from the early second millennium AD, supplementing townscapes that had previously consisted only of wattle-and-daub structures.

The 'stonetowns' that were thereby created along the Swahili coast were cosmopolitan places, home to Islamic populations involved in Indian Ocean trade, but always based on a small-scale agricultural economy of farming and fishing (Kusimba, 1999; Horton and Middleton, 2000; LaViolette, 2008). Excavations within the structures and mosques of these towns have revealed a complex material assemblage relating to an African population, deeply interconnected with a wider world both in the African interior and overseas (Chittick, 1974, 1984; Horton, 1996). The sites themselves are often clearly delineated by their coral structures, with coral-built mosques adorning sites from the eleventh century onwards, and coral-built domestic structures or 'stonehouses' becoming common from the fourteenth century (Allen, 1974).

The area of stonetowns is often delineated by a town wall, enclosing the structures and associated

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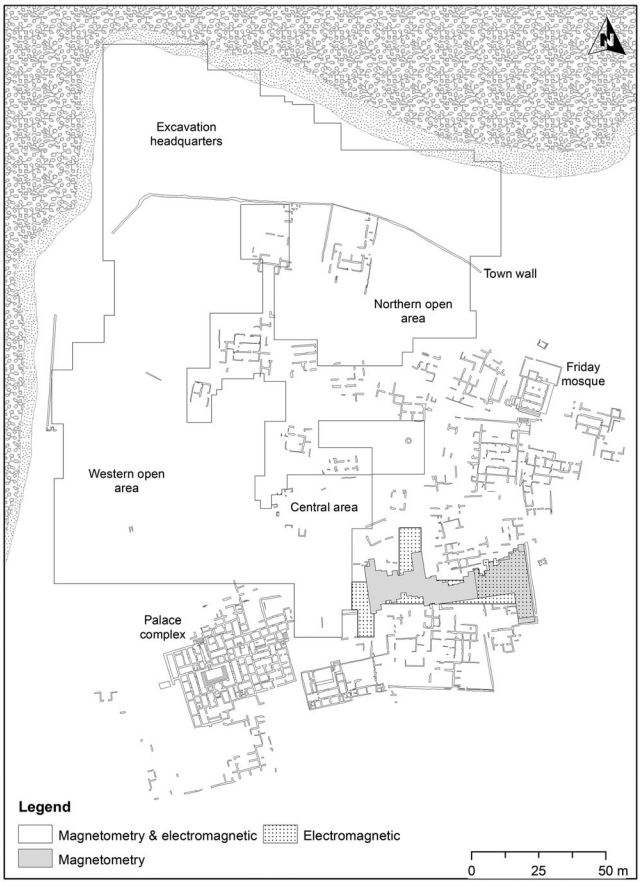

Figure 2. Map of the known building structures at Songo Mnara and areas surveyed.

activity areas such as middens and zones related to craft-working; this contrasts with sites elsewhere in sub-Saharan Africa where a preponderance of ephemeral architecture means much hazier site boundaries and less definition of site layout. A recent movement in the archaeology of the Swahili coast has argued for the recognition of the 'hidden majority' of coastal inhabitants, who would have dwelt within such wattle-and-daub architecture positioned in and around the more visible components of the stonetowns (Fleisher and LaViolette, 1999). The combination of a clearly defined survey area and the recognition of the partiality of a site layout based only on stone components means that Swahili towns are ripe for re-evaluation using geophysical survey, which has the potential to explore more ephemeral aspects of the sites.

Songo Mnara, with its relatively shallow (~ 0.7–0.9 m) stratigraphy and clear town plan, is especially well suited to geophysical exploration. It is perhaps surprising that there has been very limited archaeological geophysical survey on the East African coast. GSB Prospection (2008) conducted a season of magnetometry

Figure 3. View of Songo Mnara stonetown during the 2009 Slingram electromagnetic survey. This figure is available in colour online at wileyonlinelibrary.com/journal/arp

and magnetic susceptibility survey at the fourteenth to fifteenth century site of Vumba Kuu on the south Kenyan coast on behalf of one of the authors (Wynne-Jones, 2012). The magnetometry results were used to establish the extent and layout of the site. Large areas of magnetic disturbance were detected, which were shown by excavation to represent large quantities of iron slag, iron-working deposits and burnt daub. Topsoil magnetic susceptibility survey confirmed the size of the town and concentrated anthropogenic activity across the site. Earth resistance and electromagnetic surveys were also undertaken at the first-millennium site of Unguja Ukuu, on Zanzibar (Juma, 2004) as part of a suite of techniques to guide the positioning of trenches for excavation. The current authors have also conducted survey using magnetometry, magnetic susceptibility and ground-penetrating radar at the site of Kilwa Kisiwani. The results were encouraging, and indicated that the site was heavily robbed of building material, most probably in the eighteenth century (Fleisher *et al.*, 2012). Yet, the many phases of activity at Kilwa Kisiwani present a challenge when trying to reconstruct the town plan.

In part, the lack of previous geophysical studies reflects an ongoing commitment to traditional stratigraphic excavation in the archaeology of the region, where the establishment of a baseline chronology remains the first priority of most archaeological work. Stratigraphic complexity has been emphasized at the expense of exploring the spatiality of stonetown sites (Wynne-Jones and Fleisher, 2014). Yet it is also an effect of the general dearth of geophysical survey equipment and expertise in eastern Africa more generally, which has resulted in a lack of appreciation of what the various techniques might offer.

DOI: 10.1002/arp

Methods

Survey grids were set out using a Leica Viva differential Global Positioning System (dGPS) wherever possible. In areas where the signal was degraded due to tree cover or buildings, grids were set out using tapes offset from the dGPS grid. Magnetometry survey was conducted using a Bartington Grad 601-2 (dual 1-m fluxgate gradiometers) over 20 m by 20 m and 10 m by 10 m grids, with readings taken at 0.125 m intervals along north–south zigzag traverses spaced 1 m apart, at a resolution of 0.1 nT. The Kilwa archipelago is south of the magnetic equator, and therefore the data from the magnetometry survey will have a reversed anomaly from that found to the north (Tite, 1966). The plots of the magnetometry results have black for enhanced magnetism, and white for reduced magnetism, both relative to the background value (Figure 4).

Electromagnetic survey was undertaken using a Geonics EM38B conductivity meter in vertical magnetic dipole mode with an intercoil spacing of 1 m and an operating frequency of 14.6 KHz. Both in-phase and quadrature measurements were recorded. Surveys were carried out over 20 m by 20 m and 10 m by 10 m grids, with readings taken at 1 m intervals over traverses spaced 1 m apart. Electromagnetic survey was applied over the same area as the magnetometry survey, where masonry and vegetation permitted (Figures 5 and 6).

Results and discussion

The magnetometry data and in-phase response from the electromagnetic survey (Figures 4 and 5) have provided the clearest indications for what appears to be high levels of anthropogenic activity within and around the existing coral-rag-built structures in the town. In contrast, the conductivity response (Figure 6) is more complex to interpret, and the majority of the discussion therefore focuses on the magnetic anomalies observed.

The majority of the geophysical anomalies detected at Songo Mnara were present in both the magnetometry

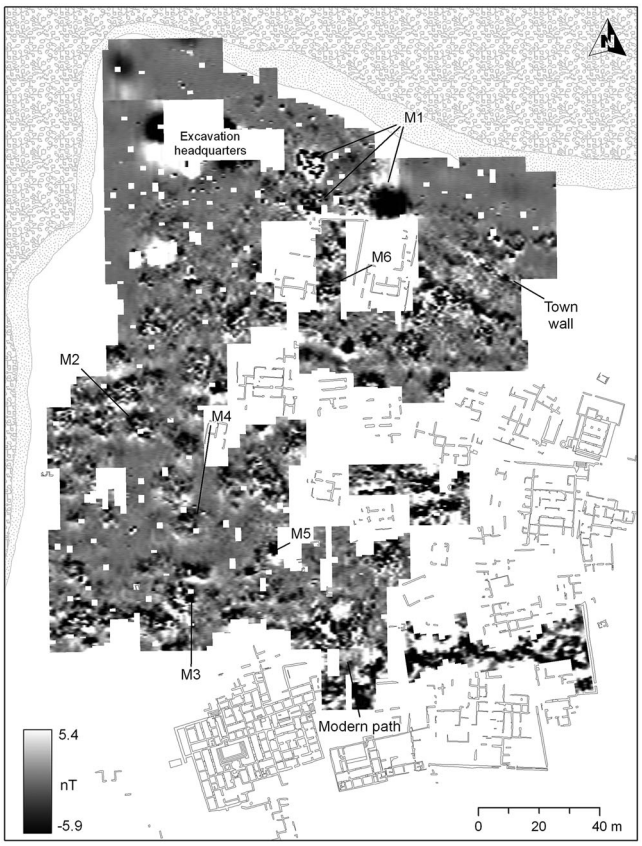

Figure 4. Enhanced magnetometry data (de-striped, clipped and interpolated).

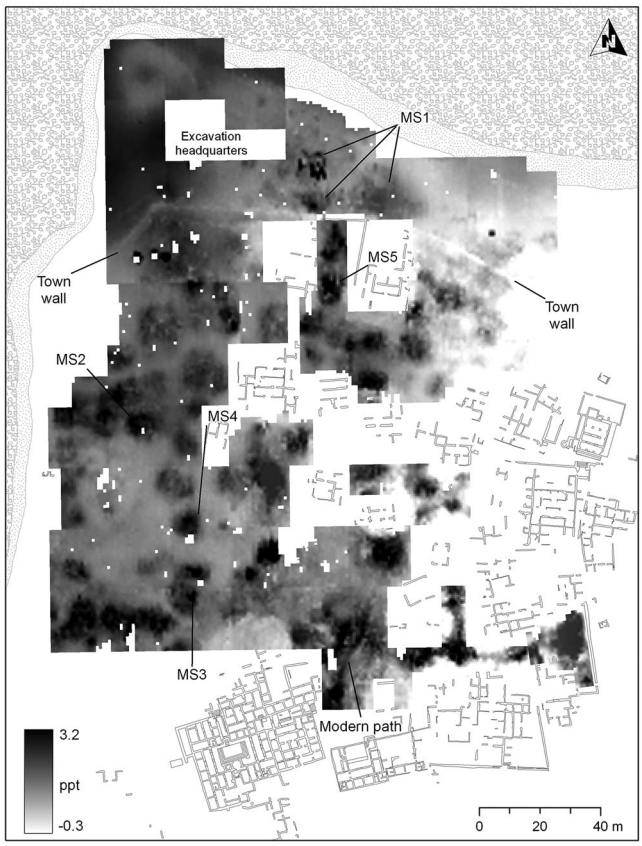

Figure 5. Enhanced in-phase data (edge matched, de-sloped, clipped and interpolated).

DOI: 10.1002/arp

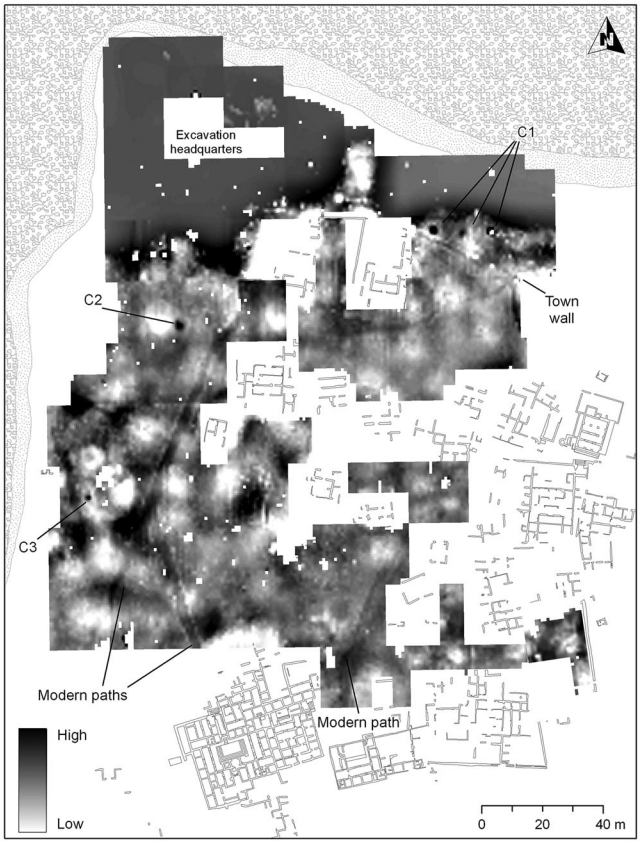

Figure 6. Enhanced quadrature data (edge matched, clipped, high-passed filtered and interpolated).

and electromagnetic in-phase data and were circular or subcircular areas, approximately 10–15 m in diameter. Although some anomalies are clearly related to the upstanding remains, of greater significance are the large number of anomalies that are situated within open areas that are not related to any extant structures. These will be discussed in detail below. Although the site is largely devoid of modern contamination, there are a few features that relate to very recent activity, including the excavation headquarters and paths through the site to a mooring point and local village on the other side of the island. North of the town walls, modern disturbance including rubbish pits and burning are responsible for the presence of the three small, discrete high-conductivity anomalies (C1), areas of high susceptibility (MS1) and the large, irregular areas of magnetic disturbance (M1).

Outside the town walls

The town walls can still be traced around a significant proportion of the stone town at Songo Mnara, and the geophysical data suggest that these acted as a definite boundary, with many activities constrained within them. This interpretation is supported by the magnetic data, where in the northern part of the site it can be seen that there is generally less magnetic disturbance outside, than within the town itself (Figures 4 and 5). In addition, when moving beyond the northern town boundary the conductivity levels increase, reflecting the rising salinity of the soil where the mangrove and seawater approach the site at high tide (Figure 6).

Activities within the town walls

Within the town the most striking feature of the results was the recurring circular magnetic anomalies seen within the open spaces between buildings. Ground-truthing was carried out to determine the exact source of these, and on removal of the surface vegetation it was found that many related directly to patches of soil that had a marked red colour when compared with the surrounding environment. Anomalies MS2/M2, MS3/M3 and MS4/M4 (Figures 4 and 5) were excavated, and both were found to be the probable remains of wattle-and-daub structures. Anomalies MS2/M2 were revealed to be indicative of the remains of a collapsed wattle-and-daub building; large exposure excavation over these anomalies has revealed dense deposits of daub, pottery and other artefacts (Figure 7). Artefacts were found within and below the daub mound, suggesting that after the building collapsed, it was left exposed and thus the daub was partially melted. Although the anomalies are circular in shape, it was not possible to determine the shape of the earthen structure as no wall stumps or posthole patterns were identifiable; the artefact assemblage, however, suggests a domestic use. The trench over MS3/M3 exposed a fifteenth to sixteenth century floor surface, with a layer of *in situ* ceramic vessels and a terracotta stove, as well

Figure 7. Excavation of anomaly M2/MS2 showing daub and pottery scatter. This figure is available in colour online at wileyonlinelibrary.com/journal/arp

DOI: 10.1002/arp

as coins, glass beads and other debris. The remains of MS4/M4 were less apparent, but excavation uncovered a 'disintegrated' wattle-and-daub structure. The exact shape of the features was difficult to ascertain due to the effects of drying, the subtle gradations of colour between the disintegrated daub and surrounding sediments and the sandy nature of all of the soils. It was only in combination with geophysical survey data that their attribution to former structures was possible (Fleisher and Wynne-Jones, 2010). The discrete, homogeneous response of daub structures MS2/M2 and MS4/M4 in the in-phase data is further illustrated in Figure 8, as is the localized, disturbed response in the magnetometry data. The quadrature anomaly response is more variable and is offset from the magnetic results. This may indicate that the physical structure does not directly correlate with the activity that has produced the magnetic response.

It is thought very likely that many of the other oval and suboval areas of high susceptibility across the survey, the majority of which correspond with areas of magnetic disturbance and partially with areas of low conductivity, may be representative of further wattle-and-daub buildings. In support of this hypothesis, further test-pitting did reveal high concentrations of burned daub associated with many of them (Fleisher and Wynne-Jones, 2010). Some are located within the tight spaces between buildings, but others appear to be present in the larger areas of open space, particularly in the southwest corner of the survey area, in the western open area to the west of the extant town buildings. Here a collection of these anomalies appears to delineate an ovoid area, ca. 50 m by 50 m, with a line of more circular anomalies running north–south across it (including MS2/M2, MS3/M3 and MS4/M4) (see Figures 4 and 5). This space is comparatively magnetically quiet (broadly in the range of −2.7 to +2.4 nT) when compared with the rest of the town (mainly in the range of −5.92 to +5.49 nT), and it would appear that this area may have been deliberately orchestrated as an entrance into the town and public space.

Two small, discrete, high-conductivity anomalies, C2 and C3 (Figure 6), are present in the west of the town. These may indicate the presence of wells, which can be highly variable in size and shape – or features such as latrines, which have a corbelled substructure beneath the ground. Both features have previously been identified and excavated elsewhere on Songo Mnara, although latrines are associated exclusively with houses (Fleisher and Wynne-Jones, 2010). In addition, evidence for industrial activity was also identified within the town. The intense magnetic response (maximum 5.49 nT) exhibited by M5 is indicative of iron working and high-temperature activities. Excavation over this feature showed it to be the site of smithing activity, with great quantities of hammer scale and iron

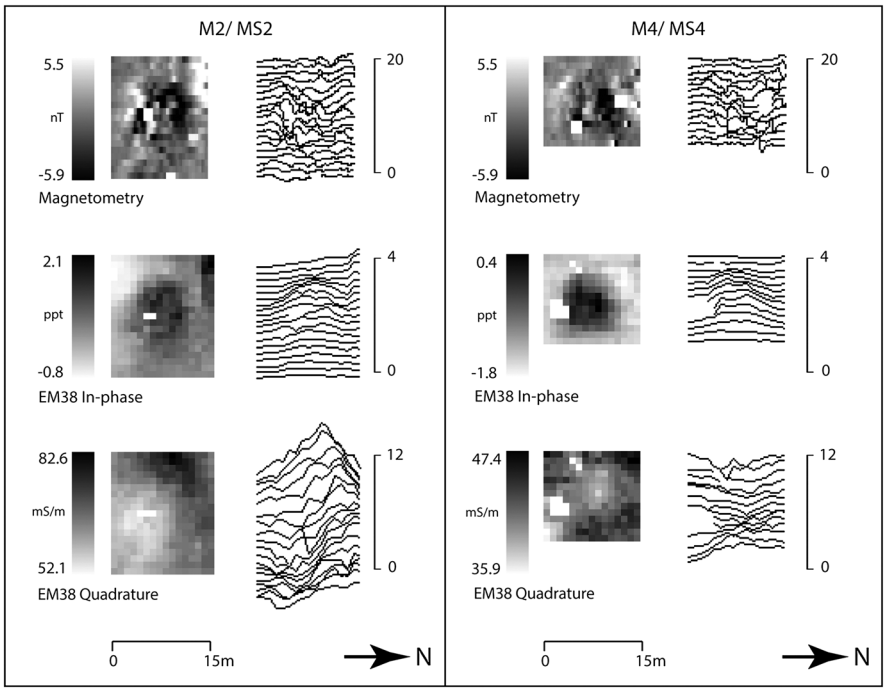

Figure 8. Shade and trace plots of raw data for anomalies M2/MS2 and M4/MS4 for comparison. Note the similarity of responses between the magnetometry and in-phase response for both anomalies.

DOI: 10.1002/arp

droplets, as well as quantities of slag (Fleisher and Wynne-Jones, 2010). Iron working is well-attested in Swahili settlements (Kusimba, 1993; Mapunda, 2002; Wynne-Jones, 2012), although this activity has often been seen on the outskirts of settlements, a pattern that has been suggested as reflecting a desire for secrecy among smiths, as well as taboos surrounding the craft (Kusimba, 1996). Here, the activity occurs in the centre of the southern open area, near a series of monumental tombs. In addition to iron working, excavation of the magnetic anomaly M6/MS5 to the north of the survey was found to be in the location of a lime kiln (Fleisher and Wynne-Jones, 2013). The preparation and use of lime was prevalent in Swahili society (Sulas and Madella, 2012) and the buildings within Songo Mnara would have required substantial quantities of this material. It is thought likely that a proportion of the other magnetic anomalies may also be related to lime kilns and further ground-truthing will help to elucidate fully the differences between the different magnetic responses on site.

It is worthy of note, that a Slingram electromagnetic survey at Songo Mnara has provided valuable data in our understanding of the archaeological remains. The increasingly positive contribution being made by these techniques to archaeology can be seen here, as well as in recent studies by Bonsall *et al*. (2013) and Saey *et al*. (2013), and in a comparative study by Cheetham *et al*. (2005) comparing the EM38B with a range of geomagnetic and geoelectrical methods.

Conclusions

The combined results of the three geophysical data sets indicate that at Songo Mnara there are clear delineations in the use of space within the town, coupled with the presence of industrial activities and occupation, neither of which had previously been recorded at the site. The pre-existing town plan, based on the remains of the extant and collapsed coral buildings, can now be seen to require a significant reappraisal, with the ability to include more ephemeral aspects of Swahili sites that represent activity areas or the homes of the 'hidden majority' of the population. Further work is being undertaken to understand the wattle-and-daub structures and the industrial remains in greater depth. The results of an extensive geochemical and test-pitting survey will enable both the geophysical signatures to be better understood and further insight into these enigmatic remains. In conclusion, it is hoped that the work here will encourage and inform future survey on the East African coast, where these techniques have great potential to enhance our understandings of Swahili towns and the lives of their inhabitants.

Acknowledgements

The project was generously supported by a Minor Research Grant from the Society of Antiquaries of London and is part of the Songo Mnara Urban Space and Materiality Project jointly funded by the National Science Foundation (BCS 1123091) and the Arts and Humanities Research Council (AH/J502716/1). The authors would also like to thank the Department of Antiquities of Tanzania, and in particular Benson Kimeu from the British Institute in Eastern Africa for their help and support.

The surveys presented here were carried out with support from participants of the Archaeological Field School, Department of Anthropology, Rice University, USA. The topographic survey and mapping was undertaken by Mark Dover, and we would like to thank Professor Heinz Rüther and the Zamani Project, University of Cape Town, for allowing access to digital mapping. Thanks are also due to Dr Haskel J. Greenfield, Professor Kevin MacDonald and Professor Paul Sinclair for kindly sharing their data and knowledge of geophysical survey in sub-Saharan Africa.

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