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Application of combined geophysical and archaeological survey techniques: a case study of Singida Region, Tanzania

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Abstract

The seismically active Singida region in central Tanzania lies at the edge of the East African Rift System (EARS) which is locally designated the Gregory Rift. The archaeological record of the region, especially in the eastern part of the Ikungi District, unlike that of northern Tanzania, is comparatively unknown, despite early archaeological expeditions hinting at its potential. Recent research in the eastern area suggests that it preserves a long record of hominin occupation spanning the Early to Late Stone Age. This interdisciplinary field work, carried out between August 2022 to August 2023, resulted in the discovery of a relatively deep package of Quaternary deposits, revealing assemblages of artifacts dating from Early Stone Age (ESA) to Middle Stone Age (MSA) periods. This testifies, for the first time, to a long term and more scattered human occupation in this part of this central region close to the famed Oldupai Gorge, since other sites were found across the Gregory scarp and the nearby Singida-Arusha highway. We also utilized magnetic surveys acquired with a Cesium vapor magnetometer coupled with magnetic susceptibility measurements using a SM-30 device in the sites, which revealed ancient fireplaces potteries, furnaces, Iron ore and other metallic materials of various ages, hence proving the success of multiple applications of rock magnetism combined with archaeological approaches in the region. We provide evidence of pedological and archaeological records of the end of the African Humid Period (AHP) in this eastern part of the region and possibly other later abrupt arid events which exhibit synchronicity with similar events recorded in sediment archives from Lake Victoria or further South (i.e., Lake Nyasa). This promising venue of investigation bears much potential and calls for further study. Finally, we question the potential drivers that could possibly explain human settlements or migration pathways in conjunction with the shift from hunting-gathering to pastoralism.

Keywords: Magnetic mapping; Low-field magnetic susceptibility; Archaeological sites; Heritage resources; Natural resources

Introduction

The Singida region lies at the southwestern extremity of the East African Rift System (EARS), also known as the Gregory Rift, which is characterized by raised blocks and fault scarps forming significant morphological features in the area. The depressions between the uplifted blocks contain deposits which range in age from Miocene to recent, and the youngest are the alluvial fans and talus slopes now forming the present-day landscape of the region (Schaniel 1982). In most parts of the study area, the rock shelters with archaeological artifacts

occur mainly in the highlands, and are commonly scattered along the Precambrian granite rock outcrop (Schneider 1970, Schaniel 1982, Itambu et. al. 2018). Generally, Singida's undulating landscape is punctuated by small boulder outcrops and rocky hills of granite with reliefs depicted up to 30 metres high (Oliech 1975, Ekeke 2010). These rocky outcrops, overhangs, rock shelters, and caves may have formed the canvas for prehistoric and historic painters (see Itambu 2023).

Our research focused on the Singida eastern axis in the Ikungi District, specifically in areas surrounding and adjoining the Turu/Rimi plateau in Siuyu, Mugori and Mungaa Wards. The Ikungi District is one of five forming the Singida region (Itambu et. al. 2018, Itambu 2023). The Ikungi District is within 4° to 6° latitudes south of the equator and between 34°45' to 35°45' East of Greenwich meridian (Masao1976 & 1979, Minja 2007, Ekeke 2010, Itambu and Hongoa 2016, Itambu 2023). All the archaeological sites where this research was conducted are found in the eastern part of the Ikungi District (see Figure 1a &1b).

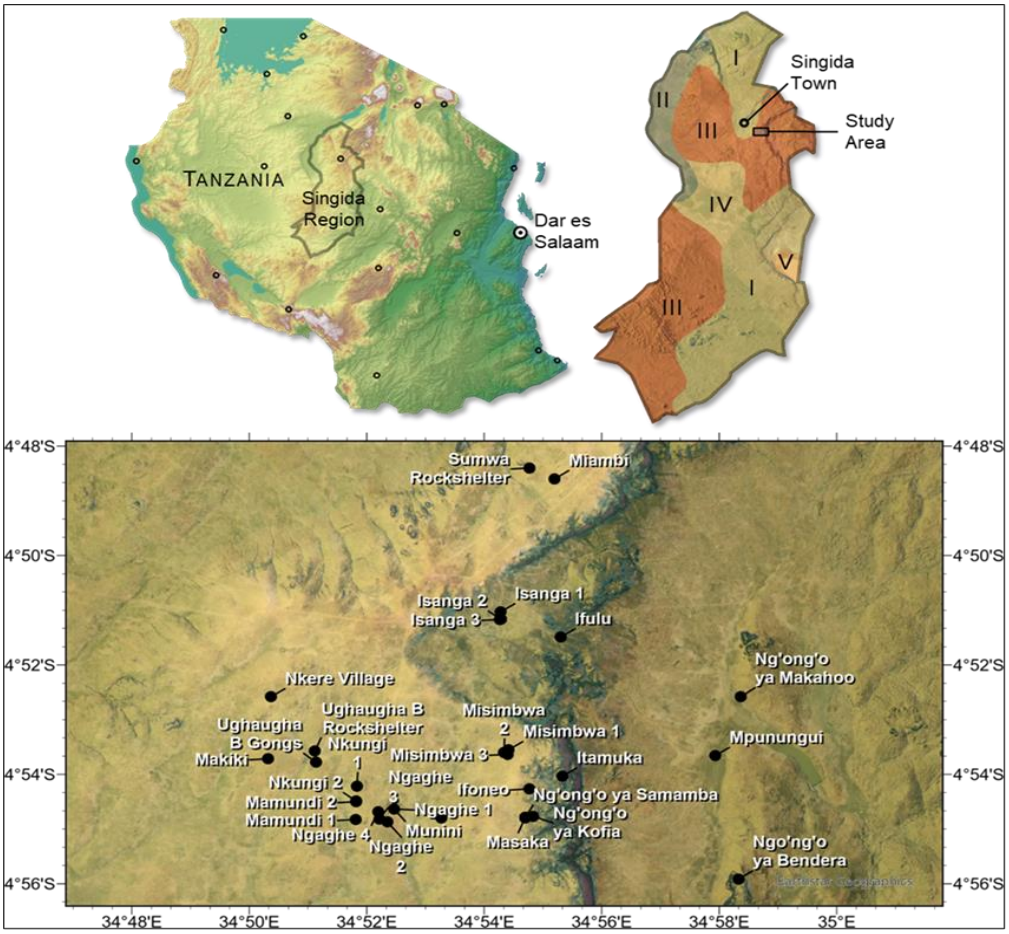

Figure 1a: Map of Tanzania showing the location of Singida (Source: Modified from Itambu and Patalano 2022).

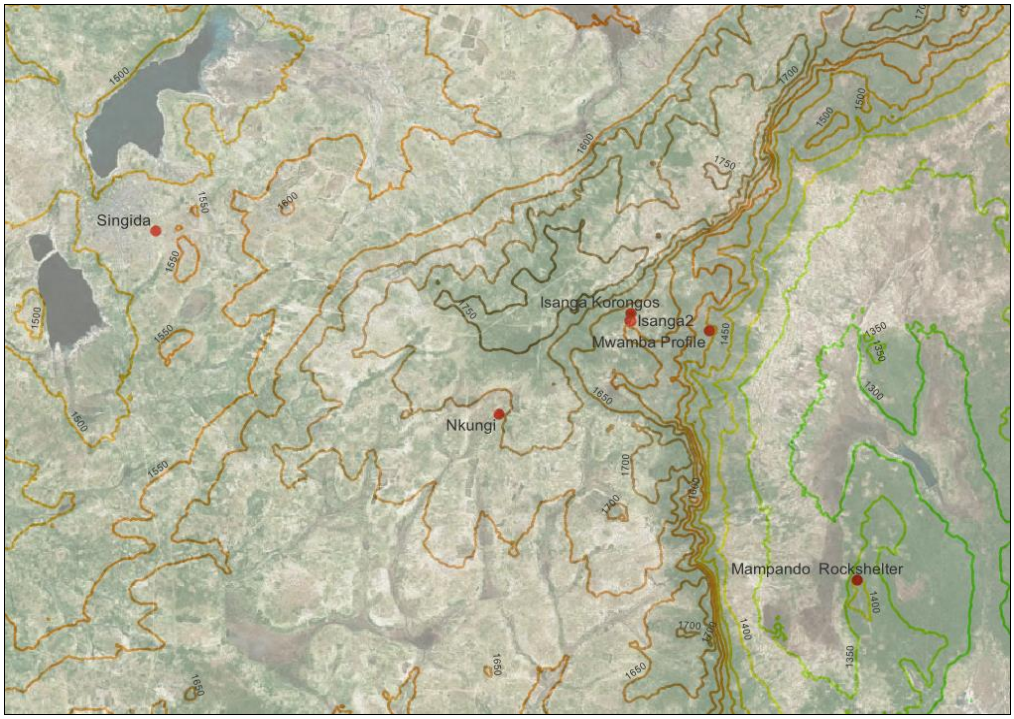

Figure 1b: A contour map for the studied sites in 2023 at Ikungi District, Singida Region.

In this paper, we present magnetic surveys form two archaeological sites where an *in situ* hearth is suspected: one open air site and one rock shelter with charcoal and rock paintings. We generated low-field magnetic susceptibility data from six sites that contain rock paintings, ESA-MSA stone tools or soil profiles and soil surfaces, thus evidencing landscape changes due to varying weathering and erosion dynamics. We also investigated the origin of the artefacts collected in the field or at the Singida Regional Ethnographic Museum in order to get a preliminary understanding of their origin and determine if these artefacts can be magnetically detected. Potential supergene ores resulting from palaeoweathering that correspond to silcretes, ferricretes (with suspicions of mixed manganese or copper phase) and so-called mottle clays or kaolinic horizons were analysed.

Materials and Methods

During the sampling of three sites of Ikungi District, the *in-situ* field susceptibility measurements were performed with a SM-30 device from ZH-Instruments; SM-30 being volumetric measurements. The measurements are dependent on factors such as the roughness, shape, and thickness of the materials measured and penetrating depths depend on the magnetic properties of the raw materials. Therefore, the soil profiles were smoothed as much as possible to limit bias due to differential roughness and top soil was smoothed after gently removing the litter from the surfaces. K measurements and tests on shape and mineralogy were performed on various pottery and metallic objects stored in the Singida Regional Ethnographic Museum. This must be interpreted with caution since they are uncorrected for shape and thickness of the various objects, which requires a much more systematic cross-checked modelling, especially for iron or metallic tools where Eddy currents may interfere with the device. Systematic measurements were performed at archaeological trenches dug at these sites, as well as on present day surface soil or soil profiles of unknown age, possibly Holocene, in order to collect magnetic rock and ecological data.

Magnetic surveys were performed with a Caesium Vapor magnetometer G858 from

Geometrics used in pseudo-gradient configuration (1 m between the top and bottom probe, bottom probe at 40 cm from the soil surface) to avoid diurnal variation of the magnetic field. Our multidisciplinary survey methods aims were to: a) better constrain human occupation in this region, b) get a more definitive understanding of the drivers of landscape dynamics in this region of most likely complex palaeoclimatic records, that in turn could aid in locating other archaeological sites, c) to collect samples for paleoenvironmental and heritage reconstructions based on further multiproxy analyses in the laboratory, d) find *in-situ* burnt clays which are presently exhibiting a Thermo-Remanent Magnetization (TRM) acquired upon cooling; this is promising as it is suitable for archaeomagnetic dating in order to better constrain the predictively modelled behaviours of the South Atlantic Anomaly (SAA) of the Earth's magnetic field (F) in this poorly documented region of East-Africa.

We conducted a systematic study of remains located in the fields of the Nkungi landscape and those found within excavated trenches as well as on traditional-cum-cultural objects stored in various collections such as materials stored and curated in the Singida Regional Ethnographic Museum (Itambu 2023). This was done in order to check whether the susceptibility contrasts between the various artifacts and the soils that contain them were sufficient to be detectable during magnetic surveys. We took measurements from traditional tools such hand hoes, axes, machetes, spears, and arrows that were used by the indigenous tribes of Singida before colonial contact.

Results

Isanga Korongos (Gullies 1-3: Elevation, 1607 m, S 04° 51'1.8" & E 034° 54' 16.8").

At the archaeological sites of Isanga village, we conducted extensive pedestrian surveys, recording and geo-mapping across the open landscapes, plant landscapes, gullies and erosional features of the village and neighbouring villages in order to discover potential archaeological sites.

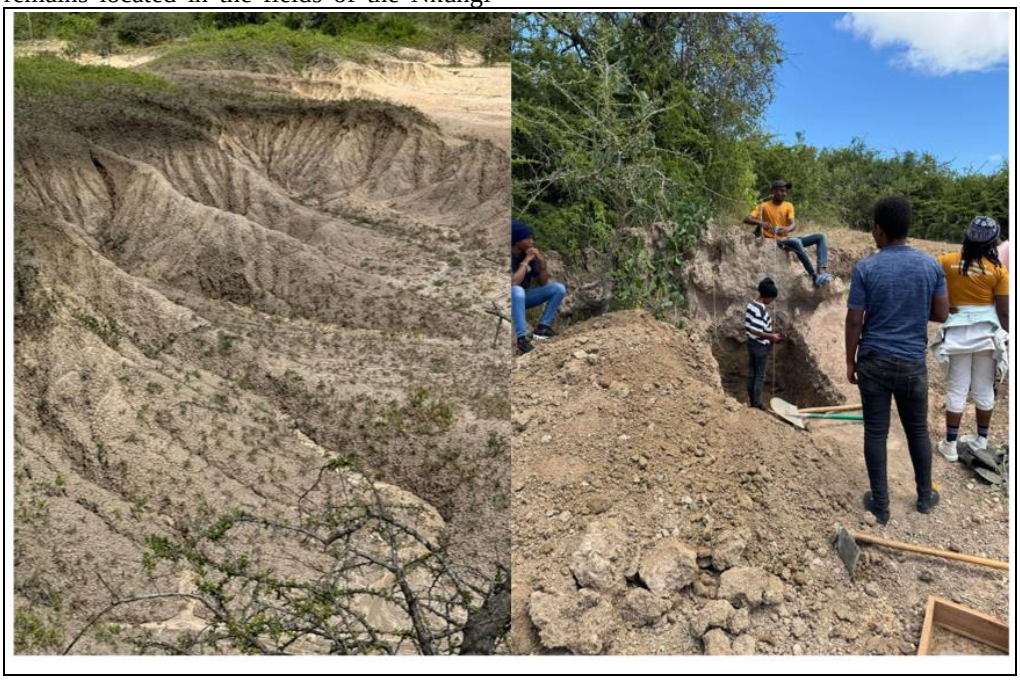

Figure 2: Isanga Korongos (Gullies) where ESA-MSA stone tools were discovered

During this exercise, we systematically recorded all discovered artifacts and

conducted surface collection of some of the materials. We covered approximately 100 km in the Ikungi District around the Siuyu, Isanga, Mampando and Mwamba Villages. Through pedestrian surveys, we were able to discover both ESA and (MSA) materials in Isanga village. The lithic artefacts from the Isanga sites were naturally exposed at the palaeosoils by erosion via rain water in the gullies (Figure 2-3). These materials are the first concurrently and congruently ESA-MSA stone tools reported in Central Tanzania and were collected for further analysis.

Also, adjacently and in the proximities of Isanga 1, about 20–30 m on the eastern side, there is another gully (Isanga 2, Elevation 1610 m, S 04°51'9.9" & E 034° 54' 17") with similar lithic assemblages to the Isanga 1 gully (Figures 2-3), which includes: pebbles, spheroids, polyhedrons, choppers, handaxes, cleavers, flakes, blades and scrapers made from a variety of raw materials such as cherts, quartzite, quartz, basalts, and obsidians. The same lithic industries were also spotted at Isanga 3 (Elevation 1612 m, S 04° 51'10.1" & E34° 54' 16.1").

Figure 3: Some of ESA artefacts: choppers, handaxes and cleavers discovered in Isanga I and II Korongos.

Nkungi sites (S 5˚ 07'59. 00", E 39˚ 46'0. 01")

At the Nkungi landscape, specifically in trench 2, we identified and described soil types and textures, colour and fabric-structure patterns using a Munsell colour chart, while also taking sediment samples for archaeomagnetic analyses and dating purposes from the column sampling at the trench (Figures 4-6).

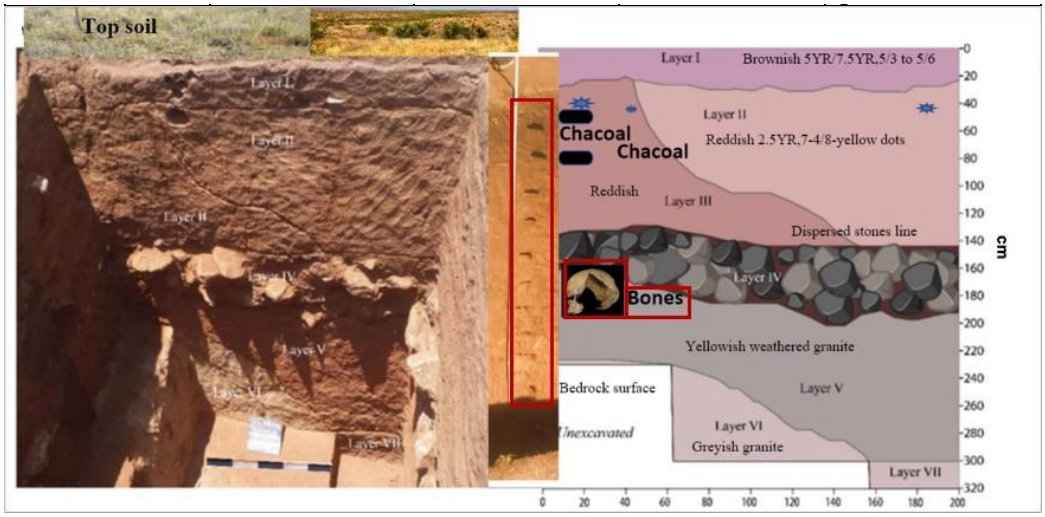

Figure 4: Nkungi 2 trench column sampling for archaeomagnetic susceptibility.

Magnetic Susceptibility results

Susceptibility measurements

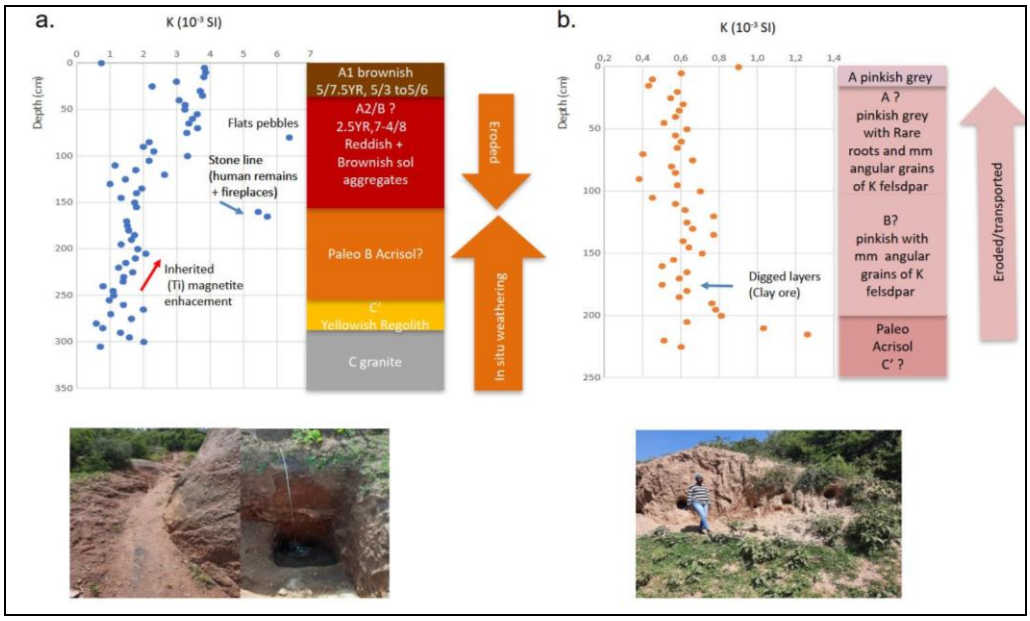

Figure 5: Comparison of K profile from : a) Nkungi 1 trench one, and b) Mwamba site including a brief description of horizons and pictures of the profiles with evidence of preserved and transported magnetite accumulated in black placers near the Nkungi rock shelter.

The *in-situ* K profile at the Nkungi 1 trench (Figure 5) evidences the preservation of ferrimagnetic minerals e.g. magnetite (see Hunt et al. (1995) for reference K of minerals) through *in-situ* weathering of the fresh granite with an increase upwards due to

the differential leaching of a relict feldspar (Mathé et al, 1999, Tchibinda et al, 2020, Amandine, 2020, Lund et al, 2022). K remains constant up to the stone line where human remains and a fireplace were uncovered, suggesting the attainment of weathering and inheritance of the ferrimagnetic fraction in the upper horizons. The stone line itself corresponds to the highest value, indicating a major erosional process to be linked with the end of the AHP (locally dated c.a. 1 kya BP (Itambu, in press.) according to radiocarbon dates of the sampled bone collagen.

The highest values of the profile correspond to a stone line, suggesting that erosional and transport processes could be possibly suggestive of a temporal hiatus of sedimentation/pedological processes in this profile. The upward increase of K with more dispersed values is a possible proxy as enhancement of transported preserved magnetic minerals through preferential paths of runoff (as observed today, left-hand picture in fig.3a) consistent with a tiny level of pebbles. K is multiplied by a factor of 2 from the bottom to the top of this horizon. With evidence of firing indicated by the brownish aggregates, it may suggest an increase of the frequency of fires (either natural or induced by land-use) well known to enhance the susceptibility caused by mineralogical transformation upon heating (e.g. from hematite or goethite to magnetite, see also this study). This horizon is truncated to a depth quite classical (30 cm) for traditional tillage (Figures 5-7).

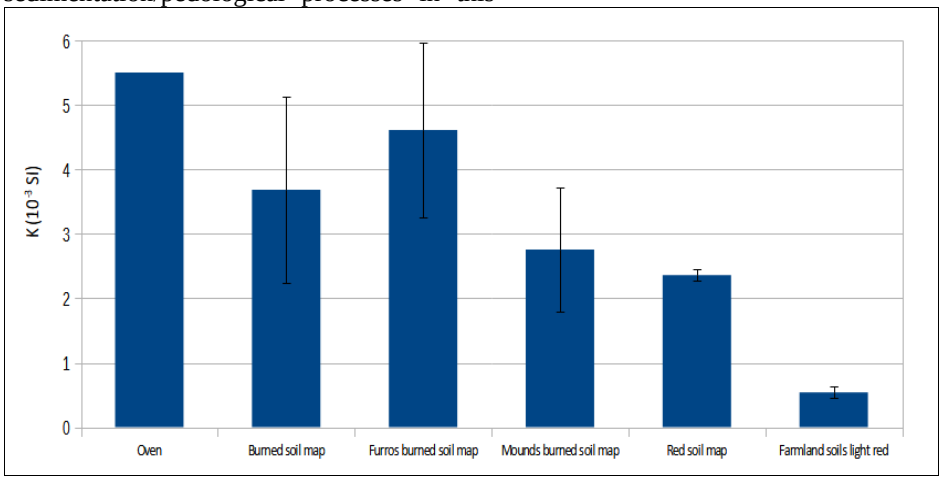

Figure 6: Comparisons of K on various surficial soils at Nkungi 1 site, nearby farmlands and an Iron Age furnace. Data labelled soil map corresponds to data also documented by the magnetic anomalies on the magnetic surveys (see Fig. 8).

Mwamba Village Soil Profile (Elevation 1513 m, S 04°51' 20.9" & E 034°55' 41.8).

As opposed to the Nkungi trench and Nkungi landscape susceptibility tests, the Mwamba clays susceptibility profile exhibits lower and more uniformed values with no clear differentiation except in the upper organic layer (the first centimetre with grey colours imparted to MO, the presence of roots and a clay content around 10% and the so called parallel "magnetic susceptibility enhancement"). The angular shape of mm gravels (mostly orthose, K feldspar, if only considering colour) clearly indicates short distance transport. The authors and local villagers believe that these modern clay soils developed as the result of a termites' mound, suggesting that the origin of clays could correspond to remobilized mottled clays underneath.

Mampando (Ng'ongo a Bendea Rock Shelter: *S 04°55' 54.8" & E 034°58' 19.8"*).

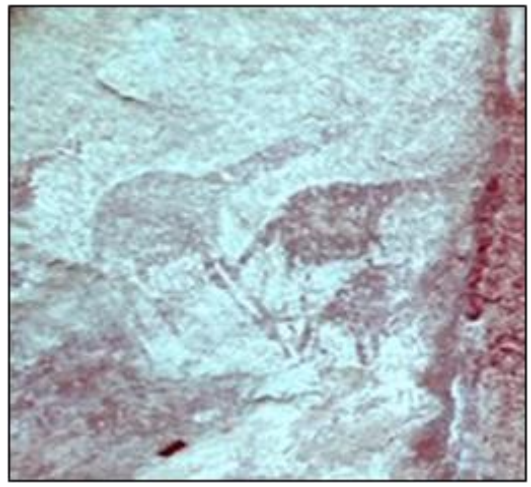

Figure 7: Burnt soils and fireplaces under the rock painting at a site in the Mampando area: Ng'ongo a Bendea rock shelter magnetic evidence at the floor of the rock shelter.

All soil horizons sampled in the immediate vicinity of the granitic shelter exhibit at relatively high susceptibilities at Ng'ongo a Bendea rock shelter in Mampando Village as opposed to modern agricultural soils sampled several hundred metres away from the Nkungi boulder or at the Mwamba site. The magnetic susceptibility situation here suggests *in situ* inheritance of magnetic minerals from the parent gneiss or granite, although these magnetic materials may have been transported before redeposition to some extent, as suggested by the magnetite placers observed near the rock shelter (Figures 6-7).

Magnetic surveys

Both sites show high magnetic dipolar anomalies (several hundred of nT/m), more than 1000 nT At Nkungi 1, about 200 nT at Ng'ongo a Bendea rock shelter for the top (A labels iin Figure 6a and 6b), in agreemennt with K values and confirming the presence of ferrimagnetic grains such magnetite, either inherited from the parent rock or neo-formed from goethite or hematite upon heating.

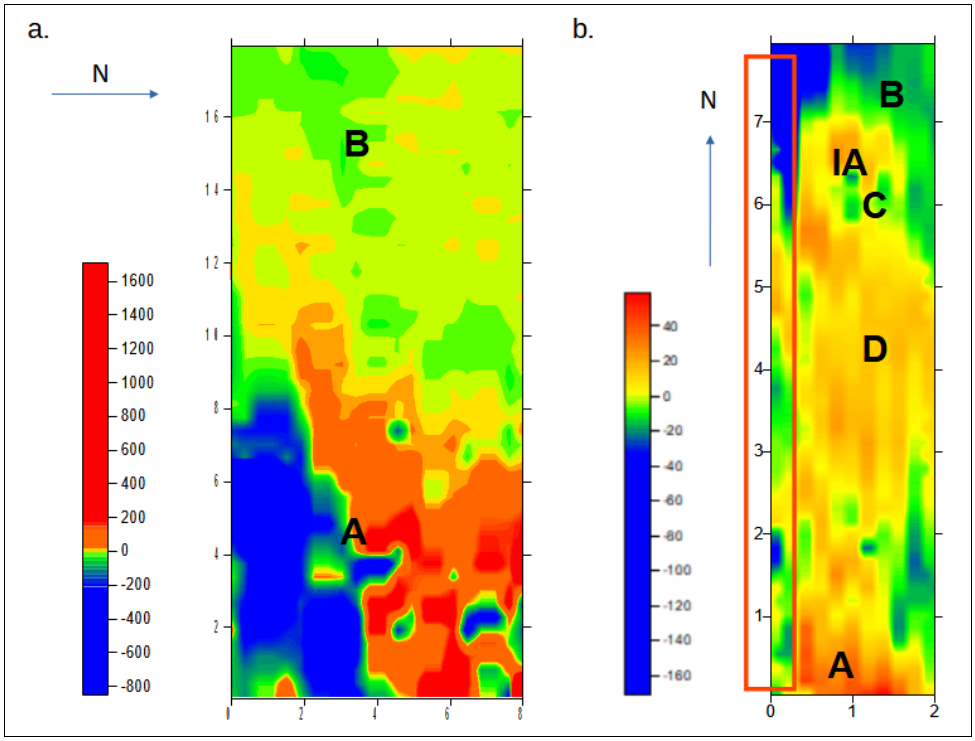

Figure 8: Magnetic maps of pseudogradient with scale bars scale bars in nT/m, axes : distances (m). blue arrows: actual North. a) Nkungi 1: A: huge anomalies deviated from present field direction and attributed to a TRM acquired by fireplace and burned soils B: Elongated anomalies linked to the mound culture. Note that the anomalies in this part of the map are lower, in agreement with the lower K values of light red soils. b) rock paintings site in Mampando area: Ng'ongo a Bendea rock shelter. Red rectangle: «magnetic shadow» due to the differential magnetic effect created by the curvature of rockshelter on top and bottom probe. A: potential fireplace, B: excavated area with pottery fragments, C: potential pottery or IA: iron age smelting remains; D: possible other in situ fireplaces.

In both cases the magnetic meridian deviated from the local magnetic North, excluding the dominance of induced magnetization in the present F. This feature (high intensities, deviated North) which is attributed to the record of a ThermoRemanente Magnetization (TRM) or partialTRM (pTRM)) of different ages between the two sites on the basis of archaeological evidence of firing (c.a 5000 Kya BP) for a fireplace and burned soils at Nkungi1, surficial charcoals at Ng'ongo a Bendea thought to be Iron Age or later. By comparison, at this latter site, induced anomaly due to « natural soil » can be seen in B where surficial soils were previously excavated and refilled, showing the loss of the NRM signal. In the C area, and to a lesser extent in between A and D, small dipolar anomalies might correspond to pottery fragments or iron smelting, depending on their intensity. The D area is interpreted as a zone of other potential fireplaces.

Discussion

Our multiproxy sampling and surveys across the exposed gullies facilitated the discovery of ESA sites for the first time in the Central Tanzanian Gullies. They are exhibiting superimposed paleoweathering

features with several generations of silcretes and ferricretes which would mean that the region has undergone dramatic paleoclimatic changes, with possibly several episodic trends of aridification. This system might be still chemically functional, as suggested by the chemistry of both surface water (e.g., Singida saline lakes) and underground waters (Appendix 5). Our research in Singida must be refined with the supplementation of more extensive geological surveys in order to better understand the role of tectonics in the relative chronology exhibited in this stratification (Appendix 3-5), since in this region of boulders, the rate of uplift leading to run off and erosion is clearly higher than weathering rates. Some ESA surface artefacts are enclosed in layers of mottled clays generally associated with seasonality of watershed levels. In the absence of more precise age constraints from absolute dating methods, the age of these formations testifies to an extensive humid period and can be temporarily attributed to Oldowan and Acheulean time frames, that is, from millions to hundreds of thousands of years.

Our fieldwork data show that rock shelters with quartz veins, mottled clays or duricrusts (sometimes with associated copper or manganese in nearby locations), nowadays mined as ores of iron aluminium and silica over the world, were also possible resources for Stone and Iron Age industries, as they remain for present-day populations (e.g., using quartz to make fire). The poly-phased processes (climate or tectonic driven or both) suggest that varying concentrations of these metals may have accompanied or even driven the Stone Age to Iron Age transition in the region. The magnetic susceptibility mapping results show some clear anomalies which suggest fireplaces; sediment discolorations that are indicative of hearths and magnetic anomalies, though from the geometry it is not clear if the materials have remained in situ and for how long since cooling (Figure 7). This research indicates that the magnetic signals we collected from these materials in the field are dominated by thermoremanent magnetization which was probably acquired upon cooling or was an induced magnetization in the ambient field in the past (Figures 6-8).

Conclusion and future directions

We report here the first ESA sites ever discovered in this part of Central Tanzania, near the Isanga village which shows a variety of artefacts made from a variety of raw materials. Their geological origin is yet to be investigated more intensively in terms of raw material sourcing, migrations and trading pathways. ESA-MSA assemblages found at Isanga clearly point out a much longer human occupation than previously thought in the region, possibly because of the outstanding conditions of settlement such as multiple primary natural resources, i.e. mining ores and necessary water sources. Evolution of rock paintings at rockshelter sites illustrating abundant and varying fauna from humid zones possibly existing at the AHP, together with iron smelting sites, further indicates a long term occupation of the region until now under ever dynamic, changing environmental conditions. The varying stone tool assemblages in the region, as well as the transition from hunting to a domestication and pastoralism based subsistence system, might have had a significant imprint on past and present day ecosystems, especially during the settlement of iron smelting industries which required adequate amounts of wood for firing in the furnaces.

The field work shows the relevance of coupling of geophysical and archaeological approaches to reconstruct palaeoenvironment and heritage evolution through past and present landscape dynamics and also raises questions as to the role of human occupation on an environment with unpredictable climate and erosion retroactions as illustrated by the burnt soils evidenced at Nkungi 1 sites. This could indeed be imparted either to bushfires taking place more extensively during arid periods as well as to changes in local land use and culturally induced practices shifting from a focus on hunting to pastoralism. This is in regards to an extension of herding practices following the shift of the monsoon belt southwards (Critz et al, 2019), accompanying vegetation shifts from theorized abundant C3

trees and shrubs (dominated by Moraceae) during the warm, wets intervals of the mid-Holocene, to C4 grasses (Poaceae) during cooler, drier episodes of the latest Pleistocene and late Holocene (Berke et al, 2012) across the eastern Africa region.

Most of these archaeological sites are being vandalized by looters who subscribe to the popular myth that the rock paintings were made by the Germans during the colonial period to locate their cache of precious gems and coins after they were defeated during the World War II. Vandalism is a critical problem, and as such we conducted community engagement programs (mostly with village local leaders such as the village chairpersons and ward councilors) during our surveys in order to raise awareness on the importance of conservation and protection for these integral archaeological sites. We envision a multiproxy collaborative research project that could act as a pilot study, resulting in a major collaborative international, cross-disciplinary work in the future. These studies would be incredibly useful and applicable in both the social and educational sciences to aid in the prevention of and raise raise awareness on issues pertaining to land use, archaeomagnetism, conservation, site preservation, best configuration responding to local/regional climatic changes, and adaptability to unpredictable environmental and climatic stress in the past.

All of these magnetic datasets, when they are combined with archaeological practices in the field and lab, would facilitate to constrain sites' taphonomy, tools classifications, absolute dating (on bone collagens samples from both human and animal remains) and will help to reconstruct a complete picture of ancient climates and environments of Singida during the Pleistocene, the historical period, and contemporary times. Similarly, these approaches be utilized in tandem with magnetic susceptibility survey, archaeometry and environmental reconstitution proxies such as rock magnetism, XRF, and XRD on rocks minerals and artefacts, analyses of ancient charcoals, phytoliths and other methods which are suitable for constraining both absolute and relative chronologies as well as cross-calibrate archaeomagnetic ages of *in situ* fireplaces or baked clays such as ^{10}Be, ^{40}K/^{40}Ar or ^{40}Ar/^{39}Ar, OSL, on silcretes, ferricretes, stone lines and stone tools.

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Competing interests:

No conflict of interest to be reported by the authors.

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Appendices

Appendix 1: Nkungi landscape with rock shelter showing congruent weathering features and various color of soils (from redish left to pinkish righ).

a) b)

Appendix 2: a: Re-Opening of Nkungi Trench to take magnetic sample and in sotu K measurements b: low suscpetibility ferricretes at Isanga Korongos. Whitish waters (Magadi soda) in a local well in Siuyu Village showing undergoing chemical weathering.

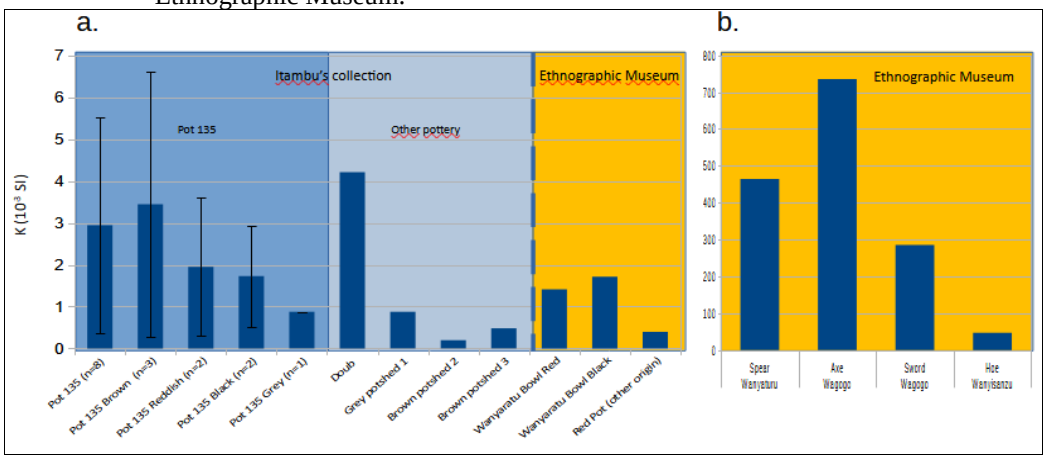
a. High susceptibility tools from Wanyaturu and Wagogo
K = 464 and 735. 10^{-3} SI

b. Low susceptibility Wanyisanzu Hoes
K = 33 to 63.10^{-3} SI

c. Wanyaturu pottery
K= 1.41. 10^{-3} SI

d. ? K= 0.396. 10^{-3} SI.

Appendix 3: Magnetic susceptibility: an experimental study at the Singida Regional Ethnographic Museum.



Appendix 4: comparative diagram of K values measured on a) Pottery. Background fill color: dark blue: measures on Pot 135 from Itambu's collection classified by areas of distinct colors; light blue : other pottery from this collection; c) orange : measure realized at the regional ethnographic museum; b) Metallic tools from the museum

Appendix 5: Lake Singidani at the Singida Municipality (a saline lake in the region) is one of three saline lakes of the region; with green waters and plenty of rocky spots along its shores.