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Mapping the Iron Age in Southern Africa: Magnetometry at two Iron Age villages in Western Zambia

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ABSTRACT

In recent years the use of near-surface geophysical survey – especially magnetometry – has been on the rise across sub-Saharan Africa, illustrating its utility at both large and/or built-up sites with stone architecture, as well as smaller and more ephemeral village sites in equatorial and sub-tropical regions of the continent. This article describes geophysical surveys and excavations at Nanga and Kanono, two Iron Age village sites in the Machile Valley, Western Zambia, undertaken between 2019 and 2022. Surveys allowed for detailed analyses of village layouts and showed the relationship between domestic areas and areas of iron production. Subsequent ground-truthing of both domestic and iron production areas elucidated differential spatial patterns of iron production stages (i.e., smelting and smithing) between village sites dating to between 800 and 1400, and allowed for the identification, excavation, and analyses of several Early Iron Age smelting furnaces.

1. Intro

Magnetic surveys have become a near-standard part of archaeologists' methodological toolbox in many parts of the world, namely Europe, parts of Eurasia, and North America. First used as far back as the 1950s (ex., Belshé 1957), magnetic survey methods are among the most developed at archaeologists' disposal, and can enable rapid surveys of archaeological sites to produce high resolution subsurface maps of archaeological features, making them – in Armin Schmidt's words – "nearly as important as the trowel" (Schmidt 2007). Due to a variety of reasons (e.g., specialized training, prohibitive costs of equipment and transport, logistical challenges, and the often-limited budgets and timelines of research projects) magnetic prospection surveys in Sub-Saharan Africa are still relatively uncommon. Moreover, since the vast majority of magnetics surveys performed have been in the Europe and North America, technical and theoretical questions remain regarding data interpretation for Sub-Saharan African sites (and for the Southern Hemisphere more generally) due to differences in the angle of inclination between the Northern and Southern Hemispheres (i.e., the angle between the earth's surface and the magnetic field lines, which varies by latitude). At the equator, this angle is particularly shallow (~0°) and increases positively or negatively the further north or south one travels. Interpretive issues can often be resolved through archaeological pattern recognition, user experience, and excavations of recorded anomalies, however the fact remains that the latitude and the angle of inclination, as well as the type of instrument used, can have a profound effect on anomaly strength and orientation (Tite 1966; Schmidt et al., 2009; Fassbinder and Gorka 2011; Ostner et al., 2019).

Notwithstanding, the past two decades have seen an increasing number of Africanist archaeologists integrating magnetic surveys into their research – either because researchers have partnered with geophysical departments and geophysical specialists in their research (e.g. Klehm and Ernenwein 2016; Oni et al., 2022; Olorunfemi et al., 2022) or because a growing number of researchers themselves are also trained in geophysical methods (Fitton and Wynne-Jones 2017; Magnavita et al. 2018). Resultingly, an increasing number of datapoints have been established around the continent since the early 2000s (Magnavita and Schleifer 2004; Gaffney et al., 2005), detailing how magnetic survey methods (i.e. magnetometry and magnetic susceptibility) can apply in a variety of different geographic regions and types of archaeological contexts – from large urban settlements with permanent stone architecture (Welham et al., 2014) to the highly ephemeral settlements of mobile pastoralists (Fitton et al., 2022; Hu et al., 2022).

This paper details fluxgate gradiometry surveys at two Iron Age village sites from the Machile Valley in Zambia's Western Province. The earlier of the two, Nanga, dates to between 800 and 1000CE (calibrated) while the other, Kanono dates from about 1300–1400CE. The spread in dates straddles a period of gradual but widespread cultural change in Zambia, and southern Africa more broadly, from a suite of Early Iron Age traditions to a set of Later Iron Age practices beginning after c.1000

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CE, represented by changes in ceramic traditions, settlement patterns, new political formations, and the expansion of long distance trade networks (Fagan 1967; Vogel 1975a,b; 1987; Huffman 1989, 2007; McIntosh and Fagan 2017; Pawlowicz et al., 2020). Because Nanga and Kanono are separated by only approximately 1 km, the two sites offer an excellent opportunity to interrogate how historical changes occurring after c. 1000CE in southern Africa played out at a local level: namely, within the Machile Valley. Geophysical surveys presented here allowed for detailed understandings of village layouts at Nanga and Kanono and identified areas of iron smelting and smithing at both sites. Ground-truthing excavations at the two sites corroborated the source of measured anomalies, clarified iron working contexts, and confirmed the chronological connections between domestic zones and areas of production. In addition to mapping the spatial layout of villages, the accuracy and precision of the methodology allowed for the identification and excavation of four *in-situ* 10th-11th century furnaces and clearly showed their place within a larger arrangement of furnace construction and use.

A major focus was to investigate changes in the organization of production – and particularly of iron production – between earlier and later Iron Age communities in southern Africa. Historically, spatial seclusion practices in Zambia and southern Africa relating to smelting have been intimately connected with gendered taboos and beliefs relating to power, secrecy, and reproduction (Huffman 2001; Musambachime 2017); by locating smelting operations away from villages, smelters could more easily control knowledge and access for whom such access would be inappropriate. The presence of iron slags (a byproduct of iron working) at Early Iron Age village sites has caused some (e.g., Fagan 1967; Inskeep 1978; Maggs 1992; Miller and Whitelaw 1994) to posit that smelting occurred in villages; thus, practices relating to seclusion and secrecy were not observed by earlier communities. Several researchers, however, (Huffman 2001; Miller and Killick 2004) have noted that archaeologists not specialized in archaeometallurgy tend to conflate smelting slags with smithing slags. Smelting (the separation of iron from the parent ore material) and smithing (the shaping of the iron bloom into a finished object) represent separate steps in the *chaîne opératoire* of iron production but can produce visually and chemically similar slags; familiarization with the two processes and understanding the full context of recovery is essential (Miller and Killick 2004; Bachmann 2016). Those arguing in support of continuity of smelting practices often tie similarities in spatial organization to similarities in worldview between the ethnographic present and Iron Age past. Greenfield and Miller (2004) point out that the temporal associations between village sites and furnace remains are often assumed. For example, furnace remains located in the center of the Ndondondwane Early Iron Age village site in KwaZulu-Natal, South Africa, were initially used to support an argument for change in spatial organization, and therefore ideology, between the Early and Later Iron Age (Maggs 1992, Loubser and Jan, 1993). Re-excavation of site, however, showed that the centrally located furnace remains significantly post-dated the site's main occupation – thereby undermining previous arguments for change in spatial practice (Greenfield and Miller 2004).

Beyond a focus on the organization of production, the fact remains that when the spatial layouts of Iron Age villages in Zambia have been archaeologically contemplated, they are often assumed or extrapolated from more limited excavations and surface artifact scatter (e.g., see Robertson 2000). Apart from a small number of extensive large-exposure excavations (e.g., Vogel 1971, 1975a, 1975b), very few detailed site plans exist for Zambian Iron Age sites. Moreover, there is not, currently, a clear understanding of the range in physical dimensions of Iron Age villages. Village extents are assumed based on the distribution of surface scatter, but survey efforts at Nanga in 2019 (McKeeby et al., 2022) showed the site to be many times larger than had been previously understood (Katanekwa 2022). This observation parallels recent geophysical work in Tanzania (Fitton et al., 2022) where researchers argue that surface survey alone is an often-unreliable indicator of a site's excavation potential. The integrated use of magnetometry surveys alongside the use of shovel-test pit (STPs), auguring, or other subsurface testing, represents a powerful approach for quickly generating a great deal of detailed spatial data about Iron Age village layouts and organization - beyond what can be gleaned from excavations, surface, and/or subsurface testing alone.

2. Background

The Machile River, located in Zambia's Western Province, is a tributary of the Zambezi and formed an important north-south corridor facilitating localized movements of iron-using Early Farming Communities (EFC) in southern Africa. From the late 1st millennium BCE and into the early 1st millennium CE iron metallurgy, new ceramic traditions, innovations in food production, and Bantu language speakers spread through eastern, central, and southern Africa along separate pathways and at different paces. Taken together, changes define a new archaeological period in regional African histories generally referred to as the Iron Age. The earliest confidently dated Iron Age occupation in the Machile Valley dates to the mid-1st millennium, and potentially even earlier (Clark and Fagan 1965; Katanekwa 1978; McKeeby et al., 2022), but most Iron Age sites in Machile range from between c.800 and 1400 CE. As indicated above, this date range straddles an important set of gradual changes in southern Africa from an Early Iron Age into a Later Iron Age period, characterized by changes in settlement nuclearization, changes in ceramic forms, increased participation in long distance exchange networks, and – to the south and north of Zambia – the establishment of centralized states.

Iron Age sites Nanga and Kanono are located circa 1 km from one another, near the current-day village of Nanga in Mulobezi District, Western Province (Fig. 1). Nanga has a long history of research, having first been documented in the 1950s (Inskeep 1962), and partially excavated in 1975 (Katanekwa 1978, 1979). However, the general village layout and site boundaries were unexplored. A return to the site in 2019 (McKeeby et al., 2022) defined the approximate site boundaries and led to the documentation of the later 14th century. Kanono site (Fig. 1). Preliminary research in 2019 showed how spatial layouts at Nanga and Kanono varied: whereas Nanga seemed to be a diffuse village covering at least 27 ha, Kanono appeared tightly nucleated with a total village diameter of only about 350–400 m. Occupation at Kanono had formed a low mound with a ~1 m thick artifact rich main cultural horizon. In 2019, members of the Machile Valley research project conducted shovel test pit (STP) surveys and limited magnetometry surveys at Nanga and Kanono; in 2022 we expanded the survey areas and increased survey resolution to better understand internal site layout and heterogeneity of craft activities occurring in and around the two villages. Magnetometry results, in combination with STP data, provided information later used to pinpoint areas of interest for formal excavations, which, recursively, helped identify the sources of recorded magnetic anomalies.

3. Geophysical methods and materials

Magnetometers measure variations in the magnetic field, caused by the magnetic properties of materials. Buried objects, human activities and landscape modifications can affect the local expression of the earth's magnetic field strength, and these departures from the earth's magnetic background field (anomalies) can be measured and mapped in a 2D space to visualize potential archaeological features within a survey area. Due to a wide variety of factors (e.g., object depth, orientation, underlying geology, surrounding matrix, natural variation in the earth's magnetic field, and competing fields) there is no 1:1 relationship between specific types of archaeological features and the strength or shape of recorded measurements. As such, the specific causes of measured anomaly are usually difficult to concretely identify without subsequent excavation or other subsurface testing to ground-truth recorded

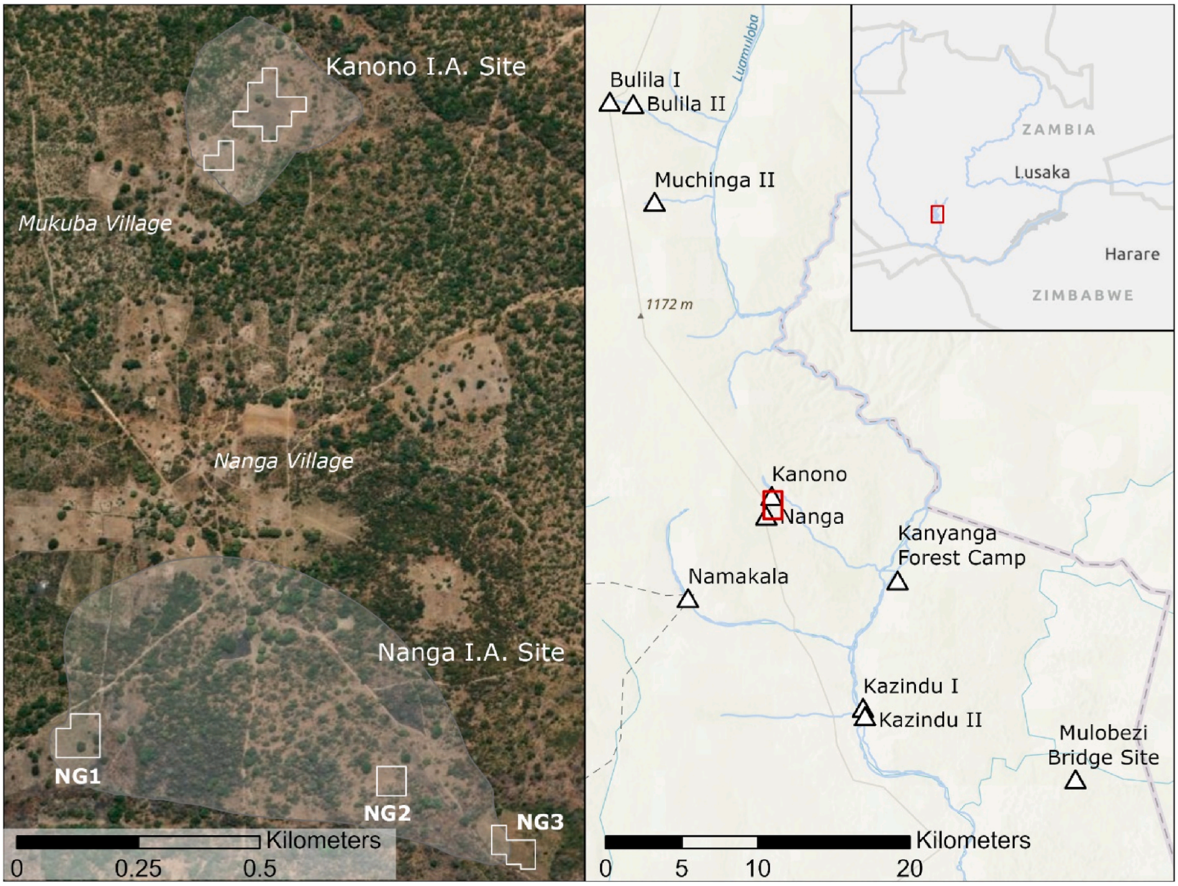

Fig. 1. Location of surveyed sites (left), and their relationships to other Iron Age (I.A.) sites in Machile (right). Light grey shading indicates approx. Site boundaries as determined through STP survey (McKeeby et al., 2022); white boxes indicate geophysical survey boundaries. Map created by the author using ArcGIS® software by Esri and are used herein under license. Sources for base maps: ESRI, NASA, NGA, USGS, HERE, Garmin, Foursquare, FAO, METI/NASA, NOAA, MAXAR. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

anomalies. Operator experience and familiarity with local archaeological patterns is crucial to interpretation, and ground-truthing of anomalous areas key.

These issues notwithstanding, general principles of magnetism offer a rough guide to identifying a range of magnetically anomalous features (Kvamme 2006; Schmidt et al., 2015; Fassbinder 2017). For example, strong (~±50 - ≥±100 nT) bipolar and dipolar anomalies indicate the presence of materials with their own magnetic fields, such as iron, iron rich materials, or soils heated above a critical point (i.e., thermoremanent magnetization). For this reason, highly heated features such as kilns, smelting furnaces, and occasionally hearths tend to be highly visible in gradiometer data, making gradiometers especially effective for identifying and mapping areas of iron production. Gradiometers are also effective at measuring more subtle induced magnetic anomalies caused by the concentration or removal of magnetic particles in the soil from human activities. Pits, ditches, earthworks, walls, and occasionally postholes and livestock pens (Olsen et al., 2006; Fitton et al., 2022; Hu et al., 2022) can be mapped in this way, allowing archaeologists to map a range of domestic structures associated with African agropastoralists.

Fieldwork took place over four weeks in July–August in 2019, and nine weeks in 2022, from mid-August to mid-October. In 2019, members of the Machile Valley Research Team surveyed 7200 m^2 at Kanono and 2800 m^2 at Nanga, recording samples at 0.125 m × 1 m intervals using a Bartington Grad 601-1 fluxgate magnetic gradiometer (1 m sensor spacing, 0.06 nT resolution; Schmidt et al., 2020). These preliminary surveys were used to establish a 30 m × 30 m grid at Kanono and Nanga in 2022. We conducted additional geophysical surveys in 2022 using the same equipment, this time recording samples at 0.125 m × 0.5 m intervals with a resolution of 0.06 nT. 2022 Survey grids overlapped and expanded on 2019 grids. In total, we surveyed 14,220 m^2 at Kanono in 2022, spread across two adjacent fields, as well as 13,100 m^2 at Nanga, split up over three locales (NG1, NG2, and NG3; Fig. 1). All data were processed and interpreted using TerraSurveyor and ArcGIS Pro.

We conducted targeted excavations and STP surveys over areas of interest and/or compared geophysical results to earlier 2019 STP survey results to best interpret geophysical anomalies. Excavations followed a single-context recording system, subdivided into arbitrary 10–20 cm spits. All excavated soils were passed through a 2 mm screen mesh to facilitate recovery of glass beads and other small artifacts, and recovery of iron fragments from smithing and/or smelting activities was aided via use of a small handheld magnet while screening. Metallurgical slags were classified, where possible, by stage of production based on a holistic physical analysis that considered size, crystal structure, slag morphology, and context of recovery (e.g., see Serneels and Perret 2003; Miller and Killick 2004; Selskienė 2007; Bachmann 2016; Bauzytė 2019; Lyaya 2019).

4. Results

Fig. 2 shows the processed and interpreted results of the gradiometer surveys at Kanono, NG1 and NG2. Locale NG3 (the easternmost portion of the larger site at Nanga) was determined to be a more recent 17–19th century site; results are not included in this paper. Characterization of anomalies by type were based on basic magnetic principles of gradiometric surveys (above) following a typology used by Fitton et al. (2022) and were aided by STP and surface surveys. Based on these results, I

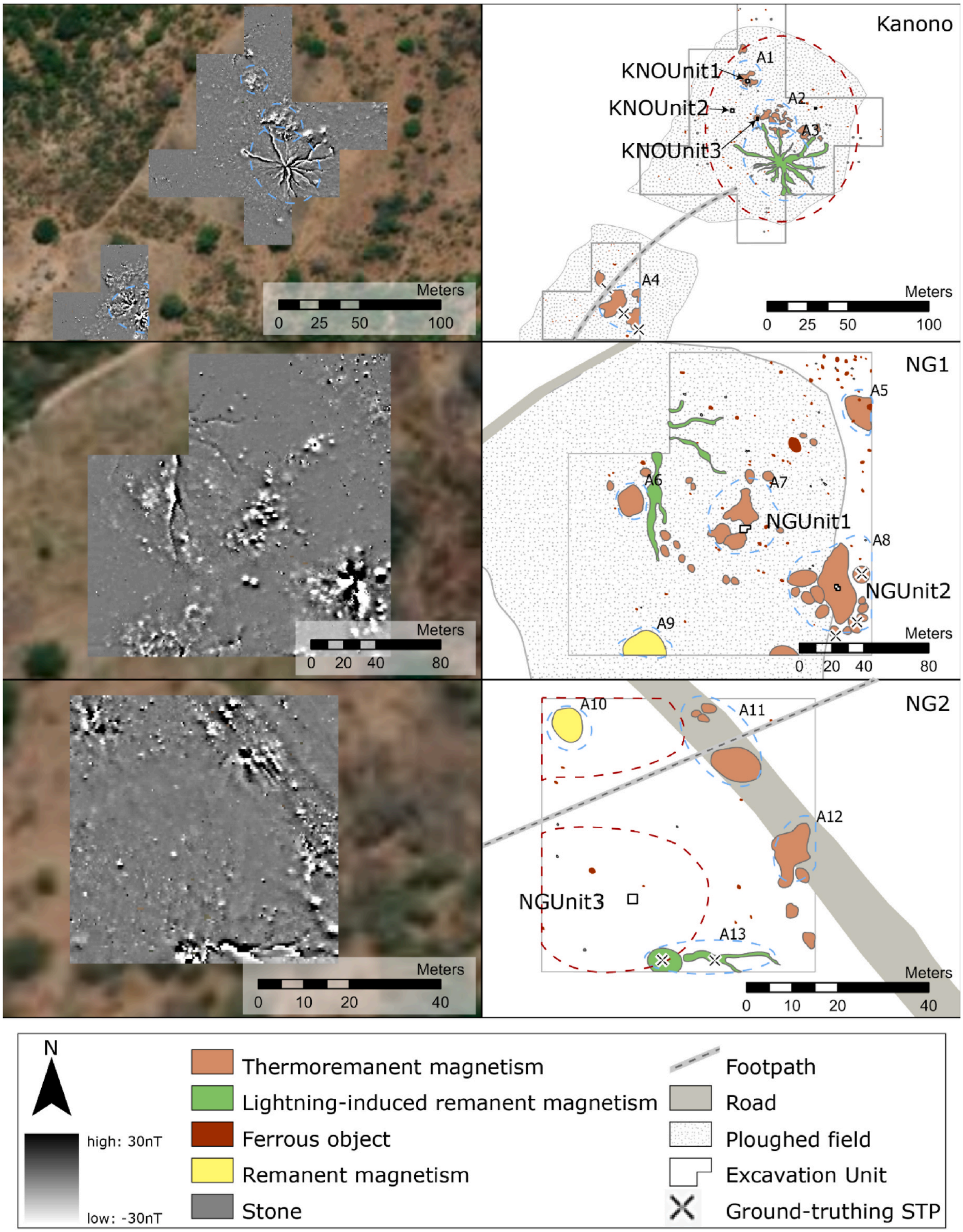

Fig. 2. Geophysical survey data (left) and interpretation (right) from Nanga and Kanono. Red dashed area demarcates diffuse anomalous areas. Blue dashed areas labeled A1-A13 show areas of interest (discussed more fully below). Data processed with TerraSurveyor. Data were de-striped and clipped to 2 standard deviations of the mean. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

identified 13 magnetically anomalous areas of interest (A1-A13, Fig. 2), as well as a several areas of more diffuse spreads of magnetic anomalous scatter that cover significant portions of the surveyed areas at Kanono and NG2. Six of these areas of interest (A1, A2, A7, A8, and A13) were excavated. Additional STPs and surface inspection helped characterize areas A4, A11, A12, and the more diffuse anomalous areas at Kanono and NG2. Investigated areas are discussed in detail below. Areas A1-4 are from the later site at Kanono; areas A7, A8, A11, A12, and A13 are from NG1 and NG2 Area A1 represents a cluster of strong (>±100 nT) overlapping dipolar anomalies, each about 3 m across, with a total diameter of about 15 m. Individual anomalies within the cluster all share a similar NW-SE orientation, and anomaly strength gradually decreases toward the edges. In 2019, we hypothesized the area was related to iron production activities, based on nearby surface slags. Unit KNOUnit01

(2mx2m) was placed toward the center of the anomalous area to assess hypotheses and potentially identify stage of production (smelting vs. smithing).

4.1. A1

Unit 1 contained several successive cultural horizons extending roughly 75 cm below datum, before transitioning rapidly into the sterile basal sands. Several pits such as those seen in profile (Fig. 3) cut down a further 15–20 cm into the sterile sands. Small pieces of iron (~2–5 mm) and iron scale (both byproducts of blacksmithing), as well as of charcoal and metallurgical smithing slags (crushed slags and planoconvex hearth bottoms, or PCBs; Fig. 4) were common within the main cultural horizons (contexts 003, 005, and 006). Whereas contexts 003 and 005 extended across the entirety of the unit, 006 was restricted to the southeastern quadrant, sandwiched between 003 and 005. It was noticeably more compacted, consistent with a burned earth feature. Given the frequencies of crushed and planoconvex slags, iron, scale, and charcoal from 006 and adjacent contexts, context 006 is interpreted as a baked earth feature from a nearby smithing hearth, presumably located just beyond the boundaries of the excavation unit.

A1 contains several discrete anomalies that make up the larger thermoremanent feature; unit 1 lays in-between several of these and clips the edge of at least one in such a way that the clipped area coincides directly with context 006. It is likely, then, that smithing hearths/baked earth features such as context 006 are the source of the recorded magnetic anomalies. The gradual fall-off in anomaly strength from the center of anomalies to the edges would correlate with decreased thermoremanence from the dissipated heat intensity as one moved away from the center of the heated features. The permanent, stationary nature of a burned earth feature would explain the uniform polarity at A1. A1, then, represents an area of iron working; likely smithing, judging by the frequency of excavated materials associated with smithing (i.e., iron scale, planoconvex slags, and crushed slag) and relative lack of materials associated with smelting such as furnace walls, reduced ore, or diagnostic smelting slags.

4.2. A2

A2 is similarly an area of strong (≥100 nT) dipolar anomalies consistent with ferrous material and/or thermoremanence. STPs in 2019 from A2 contained large amounts of iron fragments and slags, suggesting

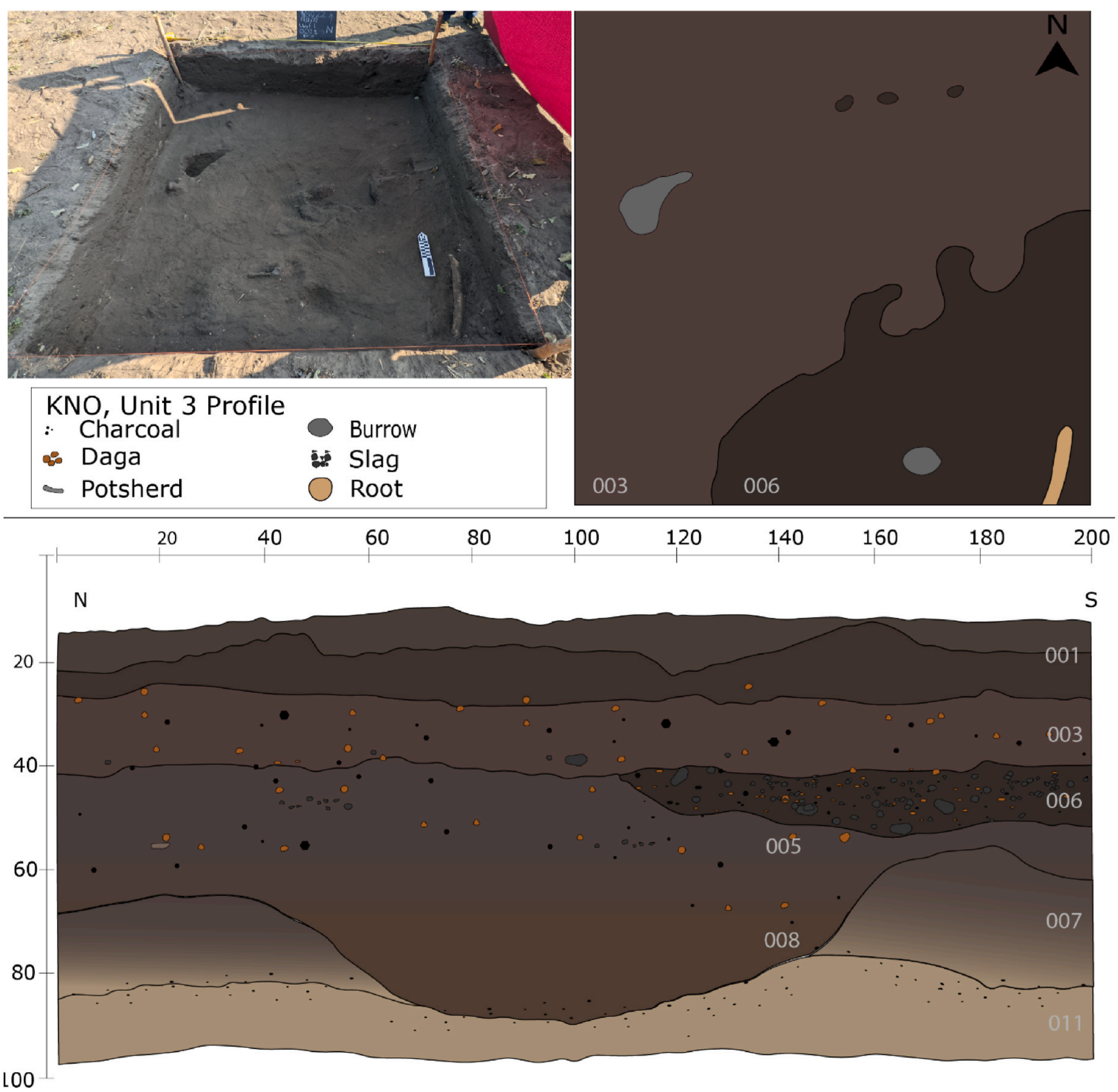

Fig. 3. Kanono Unit 1 east wall profile and mid-excavation plan, with contexts labeled. Soil colors reflect recorded Munsell codes. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

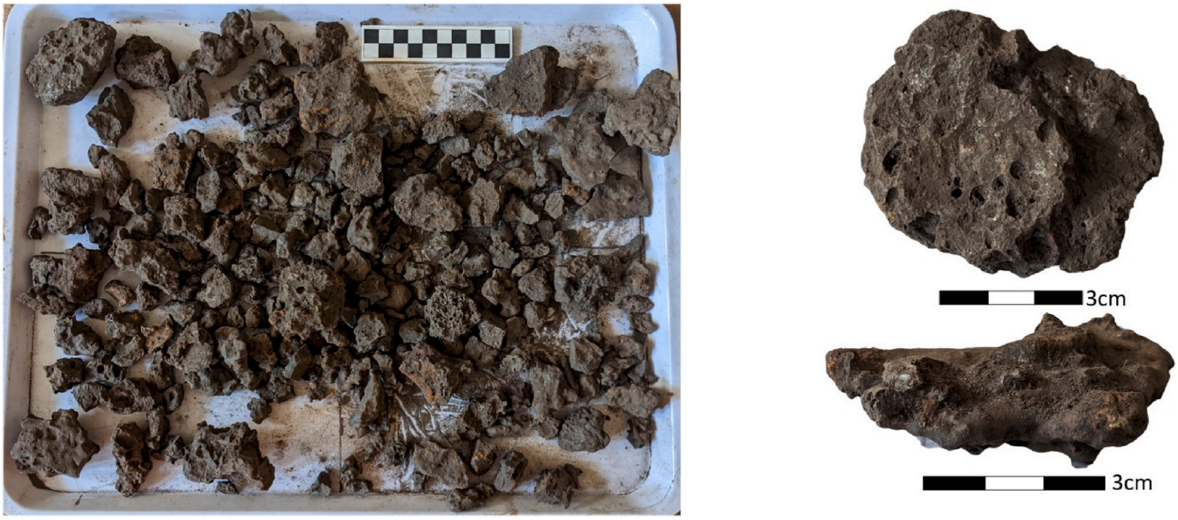

Fig. 4. Smithing slags from Unit 1, context [003], directly above [006]. (Left) a 50% subsample of excavated slags. With the exception of several complete and partial planoconvex smithing slags, the vast majority by volume are ≤2 cm in diameter and broken, indicating manual breaking up of slags during smithing. (Right) two characteristic plano-convex smithing hearth slags from the same context. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

a second area of iron production. To confirm the causes of recorded anomalies, we excavated a 2 m by 1 m unit (KNOUnit 3; Fig. 5) over the western side of the anomalous area.

Iron Age artifacts (slags, daga, diagnostic potsherds, etc.) began near the surface. Below the plow zone, at about 30 cm below datum, excavators encountered a 5–10 cm lens of iron slag (context 002) that formed a pavement capping an underlying sequence of Iron Age pits, a house floor or collapsed wall, and other cultural deposits. Slag morphologies ranged from smaller crushed slags, PCBs, and some larger possible furnace slags. Iron fragments were less common than in Unit 1 but were still plentiful. STPs from nearby contained copious amounts of iron and slags suggesting that context 002 extended over a larger area. A hearth and several ashy pits were excavated as well from Unit 2, but these are unlikely to cause in the strong anomalies recorded. Given 002's quantity

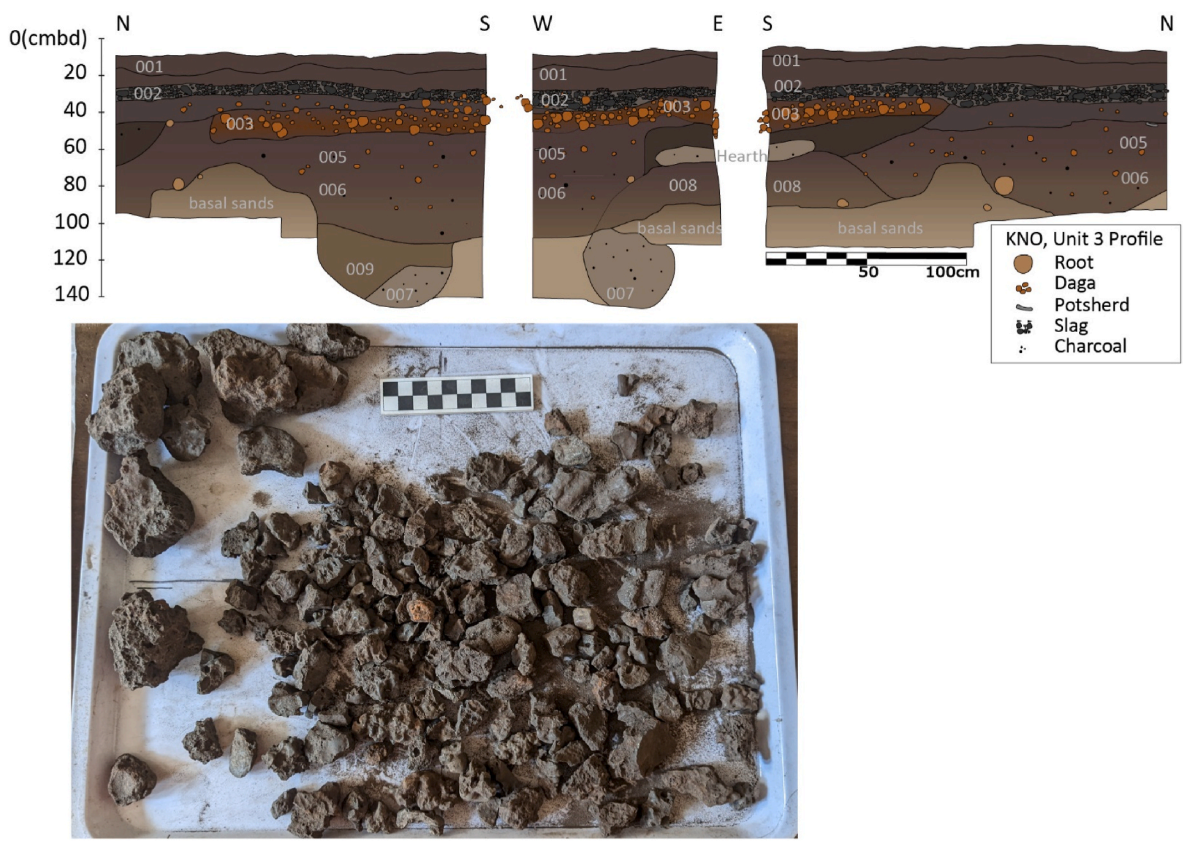

Fig. 5. top: Kanono Unit 3 West, South, and East Wall profiles with contexts labeled. Soil colors reflect recorded Munsell codes.left: Subsample of smithing slags from Unit 3, context 002 showing a majority of crushed slag (by volume) and several large partial PCBs and/or pieces of furnace slag. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

of iron slags and the lack other likely sources excavated features, context 002 is undoubtedly the most likely source of anomalies at A2. From this, we are interpreting A2 as a slag dumping area likely associated with nearby smithing locations.

4.3. A4

A4, situated to the southwest of the main portion of the site, shows two areas of particularly strong, but highly jumbled, dipolar anomalies. A SW-NE linear arrangement of more subtle negative anomalies (white) passes to the immediate west of the stronger anomalous areas and corresponds to a contemporary footpath used by farmers and livestock moving between the two ploughed fields. We didn't have time to excavate a full unit over A4, but two STPs dug toward the center of the two main anomalies both yielded large assemblages of large furnace and tap slags, ore (Fig. 6), chunks of daga (a.k.a. daub; likely furnace wall remains), tuyere fragments, and charcoal - but very few artifacts associated with domestic areas such as ceramics or faunal remains. A charcoal sample taken from the western A4 anomaly yielded a date of 780BP ±15 (1229–1294 cal), virtually identical to dates gathered from excavation units from the main part of the site. Given the nature of the artifacts recovered, the measured anomalies are most likely caused by the remains of ancient smelting furnaces. The breakdown and scattering of ferromagnetic furnace remains and iron slags would explain the jumbled polarity seen at A4.

4.4. A7 and A8

Areas A7 and A8, at NG1, appear as a particularly strong set of dipolar anomalies arranged in rough circular formation (Fig. 7), with negative poles (white) consistently located to the north of their adjacent positive poles (black). In A8, this ring of dipoles surrounds a large irregular anomalous area. The strength and uniform polarity present suggested the presence of permeant thermoremanent features, and STPs from the general area contained large amounts of slags and some diagnostic Early Iron Age pottery. One unit was excavated over each area of interest (NG Units 1 and 2) to identify the causes of recorded anomalies. Unit 1 was carefully placed to run perpendicular to the circular arrangement at A7, completely overlaying one dipole and clipping the edge of another; Unit 2 was placed toward the center of the large irregular anomaly at the center of A8. We also excavated 3 additional STPs over 3 dipolar anomalies making up the ring formation at A8.

Excavation of both units resulted in the exposure of two Iron Age smelting furnaces (FRN1, FRN2; Fig. 7), beginning between 55 and 75cmbd (context 004). A full archaeometallurgical description and analyses of the smelting technologies employed is beyond the scope of this paper and will be described elsewhere. In brief, however, both represent domed bowl, non-tapping smelting furnaces powered through forced draught. In a highly satisfying way, the location of FRN1 matched precisely onto the location of the dipolar anomaly overlayed by Unit 1. The remains of an additional 2 furnaces (FRN3 and 4) were partially exposed within Unit 1's SW corner: precisely where the corner of Unit 1 clipped the edge of another dipolar anomaly. A massive piece of slag weighing over 70 kg was left in the base of the FRN1 and slag caught in the south wall profile suggests a similar pattern of abandonment at FRN3. Three radiocarbon dates taken from inside the collapsed furnaces (one each from FRN1,2, and 4) returned a consistent sequence dating the furnaces to the late 1st millennium after calibration (Table 1), showing that furnaces not only dated to roughly the same period but allowing for them to be put into a sequence of use, abandonment, and reconstruction. Importantly, dates from furnaces were consistent with earlier dates from Nanga (Katanekwa 1979) and with new dates gathered from NG2, located appx. 100 m from Katanekwa's 1975 excavations, indicating that the furnaces at NG 1 can be directly attributed to smelters living at the Nanga Iron Age village.

Two of the three STPs dug at A8 also yielded substantial amounts of furnace slags, tuyere fragments, and massive chunks of daga identical to recovered furnace wall fragments from units 1 and 2, indicating the presence of two more furnaces. The third STP contained similar amounts and morphologies of slags, but less daga. It's likely then that this third STP was placed near to, but slightly missed, an additional furnace. The success rate between recorded anomalies and evidence of furnaces confirmed through ground-truthing indicate the presence of approximately fifteen additional furnaces at A7 and 8, constructed sequentially

Fig. 6. Smelting debris from A4. (Left) top and side view of tuyere-tapped slag. (Right) large piece of ferricrete ore.(For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

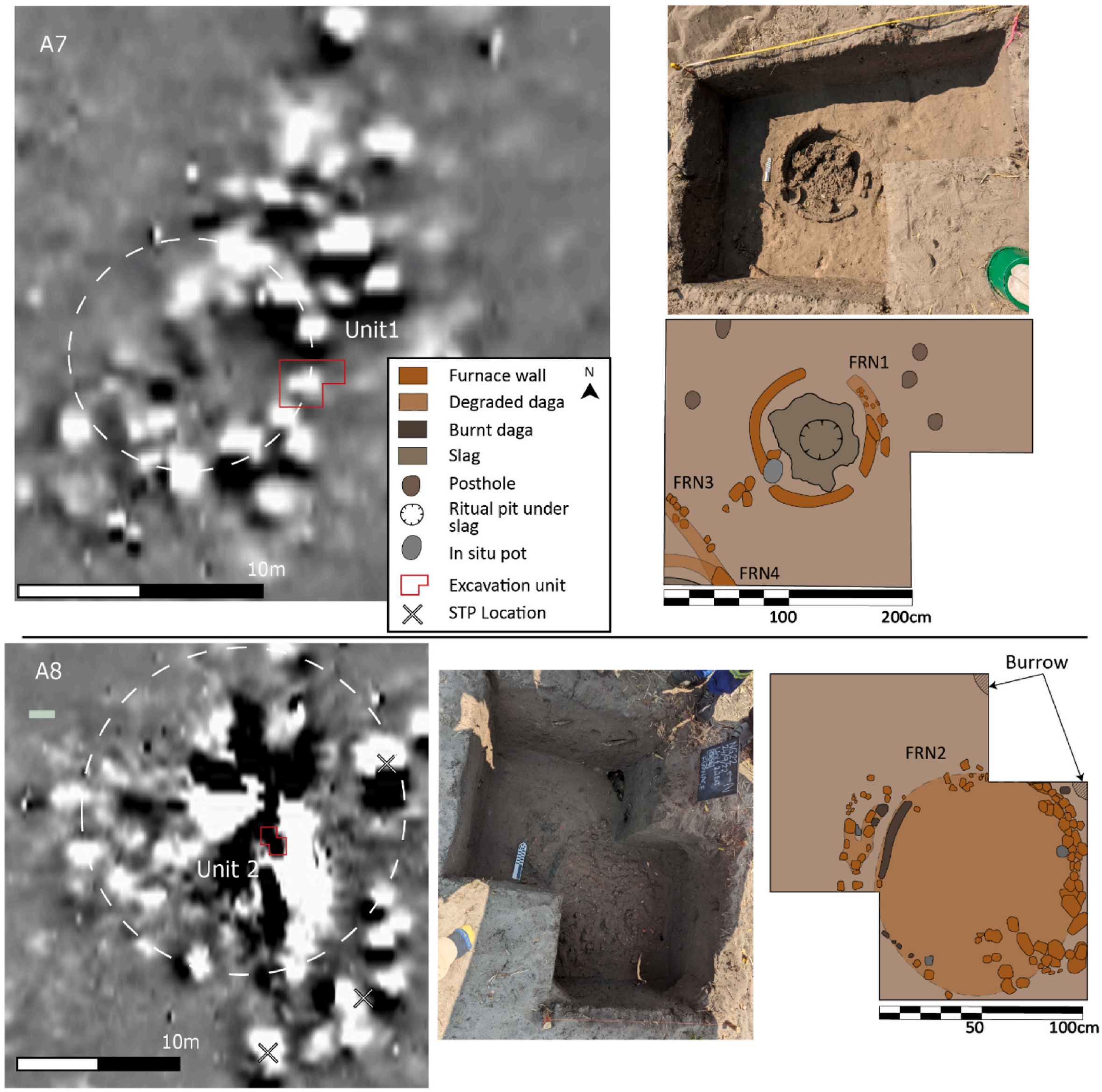

Fig. 7. Magnetometry data and excavations at A7 and A8 (NG1). Strong dipolar anomalies directly correspond with excavated furnace locations. Dashed white circle indicates hypothesized arrangement of smelting furnaces based on excavations of anomalies. Soil colors in plan illustrations reflect recorded Munsell codes. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

within a circular or semi-circular arrangement.

4.5. A11 and 12

A11 and A12 (NG2) both consist of sets of dipolar anomalies of varying polarity, consistent with ferrous material and/or thermoremanence. A deep roadcut (~1.5 m), now disused, bisects the areas and exposes the cultural horizon, facilitating interpretation. Concentrations of iron slags on the surface that had eroded from the nearby roadcut coincided with the location of recorded anomalies. Several classic smithing PCBs were collected (Fig. 8), indicating that the road had cut through at least one, perhaps two, smithing area(s) located within several meters of other domestic areas, judging by excavated assemblages from NGUnit 3 (~25 m to the SW) and nearby STPs.

4.6. A13

A13 contains a strong linear bipolar anomaly with its positive pole to the north – a pattern that stood at variance to other confirmed permanent thermoremanent features that all consistently displayed a positive polarity to the south. We dug three STPs along the anomaly to identify the source but all STPs were sterile apart from a few isolated potsherds or small (<1 cm) pieces of slag, i.e., nothing that would obviously cause such a strong (≥±100 nT) linear reading. Given the shape, strength, locally unusual polarity, and lack of obvious cause, we are interpreting A13 as an example of lightning-induced remanent magnetism (LIRM). Lightning strikes represent massive exchanges of heat and electromagnetic energy, resulting in strong anomalies forming either dendritic (such as the one seen at Kanono), radial, or linear forms. Linear components of LIRM are dipolar and perpendicular to the path of energy transfer through the ground, with a result that the positive pole most often is to the right when facing toward the point of initial contact with the ground (Jones and Maki 2005); this exact configuration is present at A13.

4.7. Diffuse anomalous areas

Lastly, several general areas at Kanono and NG2 (circled in red;

Table 1
Radiocarbon dates from Nanga. Birm-series dates were collected during N. Katanekwa's 1975 excavations, first reported in Katanekwa (1978), 1979 and calibrated in McKeeby et al., (2022). All other dates were obtained during the 2022 field season. NG-series AMS dates were analyzed at Woods Hole Oceanographic Institute. All dates calibrated in OxCal (v.4.4, Bronk Ramsey, 2009) using the SHCal20 calibration curve developed for the southern hemisphere (Hogg et al., 2020).

Sample	Unit	Context	Material	Lab number	UNCAL. BP	CAL. CE
NG.1029	1	002.2 (above FRN1)	charcoal	OS-171059	1130 ± 15	895–1020
NG.1036	1	004 (FRN1)	charcoal	OS-171060	1150 ± 15	890–995
NG.1039	1	005 (FRN3)	charcoal	OS-171061	1210 ± 15	770–965
NG.1221	2	003.2 (above FRN2)	charcoal	OS-171062	980 ± 15	1030–1155
NG.1228	2	004 (FRN2)	charcoal	OS-171063	1170 ± 15	890–990
NG.1608	3	002	charcoal	OS-171064	1190 ± 15	770–985
NG.1625	3	004	charcoal	OS-171065	1190 ± 15	770–985
NG.1641	3	004.3	charcoal	OS-171066	1250 ± 15	770–885
Birm-836	unreported		charcoal	Birm-836	1240 ± 100	655–1025
birm-835	unreported		charcoal	Birm-835	1190 ± 100	665–1135
birm-837	unreported		charcoal	Birm-837	1070 ± 120	690–1265
birm-834	unreported		charcoal	Birm-834	980 ± 120	770–1295

Fig. 2) are characterized by numerous small, heterogenous, mostly subtle positive and negative magnetic anomalies. From comparing the gradiometer data to STP results, excavations, and surface scatter, these areas of magnetic disturbance map onto the general spread of the main village cultural horizons at Nanga and Kanono, i.e., STPs located outside these circled areas contained far fewer artifacts than STPs from within the circled areas. Apart from small dipoles interpreted as small iron objects, it is currently difficult to attribute specific anomalies to specific features or objects. Some anomalies form partial linear arrangements that might relate to postholes from house walls, however without larger exposure excavations to expose entire houses this is speculative. Notwithstanding, the areas of general magnetic disturbance represent palimpsests of village life showing the main nucleus of peoples' daily actions. At NG2, anomalous areas also coincide with two slight rises in the ground surface - with a lower, artifact poorer area passing between them. This would support the hypothesis that the Nanga village layout consisted of a network of small, dispersed homesteads (McKeeby et al., 2022).

5. Discussion

Though outside the scope of this paper, the mapping and subsequent excavation of smelting furnaces arrangements at Nanga has implications for understandings of technical practices in the Early Iron Age – a period for which few smelting furnaces have been found anywhere in sub-Saharan Africa, and none for Zambia: to the author's knowledge, all furnaces in Zambia that have been dated and published all date to either the Later or Recent Iron Age. This has affected the abilities of archaeologists to reconstruct social and technical practice in the more distant past, necessarily interjecting a note of speculation into past reconstructions that rely to varying degrees on the ethnographic record. Not only do the furnaces excavated at Nanga allow for the reconstruction of iron smelting practices in the late 1st millennium, but they show how smelters returned to a single location year after year and over generations of smelters, probably operating multiple furnaces at once.

At a broader scale, however, these spatial data give a clearer picture of what two types of Iron Age villages in Zambia "look like". Despite the lack of permanent stone architecture, craft production activities and the general archaeological scatter of village life at Kanono and Nanga created clear magnetic signatures that contrast with the deep Kalahari sands that typify the geology in western Zambia. Moreover, spatial data

Fig. 8. Characteristic plano-convex hearth base. Top view (left) and profile (right). Found on surface at NG2 within A12 (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

show how settlement patterns changed in Machile between the late 1st/early 2nd millennium. Ground-truthed geophysical results thus carry important implications for our understandings of the southern African Iron Age craft, lifeways, and for regional interpretations of geophysical surveys.

As stated at the outset, a persistent question in southern African Iron Age archaeology had been regarding long term change vs continuity in cultural practice and village organization; these data, however, show neither a simple change in worldview between the Early/Middle and Later Iron Age, nor cultural continuity. Iron smelting at Nanga was located roughly a half-kilometer away from the main village and, presumably, away from public gaze. Smithing was likely a household-based craft, although houses at Nanga seemed widely spaced. By comparison, the spatial layout at Kanono represents a reorganization of village life from dispersed villages made up of individual homesteads to tightly nucleated villages with a clear village center. The large anomalous area at A2 and complex stratigraphy at Unit 3 paints an evocative picture of early 2nd millennium village expansion and change during which the village center becomes established as a designated smithing area. This spatial layout more resembles other more recent ethnographically and archaeologically documented spatial patterns, from South-Central Africa, such as the Central-Cattle Pattern (Huffman 2001) where the village center was an area of iron working, public life, settling disputes, and livestock herding. However, in variance with a normative CCP pattern where smelting activities are secluded and secret, smelting activities at Kanono occurred well within view of the village, judging the proximity of A4 to the rest of the village scatter. It's unlikely, then, that cultural practices related to iron working went through a straightforward set of evolutionary changes between the first and second millennium. Rather, these data underscore the historically contingent and locally specific nature of southern African iron working practices and of the cultural contexts in which they are performed.

On a technical level, these data offer some clues as to how the effect of the Southern Hemisphere's high negative angle of inclination impacts gradiometric magnetic data. At ~16°S, the Machili Valley has a magnetic declination of ~ -56°, or roughly the magnetic inverse of southern Europe and Turkey (~40°N; NCEI Geomagnetic Modeling Team and British Geological Survey, 2019). As has been noted by others (e.g. Tite 1966; Welham et al., 2014), the magnetic polarity of recorded anomalies in the Southern Hemisphere is reversed relative to how they might typically appear in the Northern Hemisphere. The locations of furnaces excavated at A7, for example, directly correspond to strongly *negative* values seen in the gradiometry data; by comparison, magnetic surveys of smelting furnaces from Northern Hemisphere sites (e.g. Powell et al., 2002; Stamnes et al., 2019), show strong *positive* values closest to smelting furnace locations. Aside from this inversion, however, anomaly shapes seem comparable to magnetic results from Northern Hemisphere sites with similar, albeit positive, inclination angles, and data clarity seems unaffected by issues seen more commonly in equatorial regions as described by Fassbinder and Gorka, 2009; 46–48). An important caveat to these observations, however, is that the data presented here were collected using a Bartington fluxgate gradiometer whereas most other discussions of anomaly shapes and intensity from Equatorial and Southern Hemispheric sites were analyzed from total-field magnetometry data. It is anticipated that different instrumentation would result in different operator experiences.

Due to varying survey conditions between sites, survey grid orientations between survey sites varied (e.g. E-W transects at NG1 vs. N–S transects at Kanono). With frequent and carefully orientated gradiometer calibration, however (we recalibrated after about every two grids), there were no noticeable differences in the quality of results between different survey orientations. Analyses of magnetic profiles across recorded anomalies at Nanga show somewhat stronger negative signal intensity relative to the magnetically positive portion of recorded dipoles (Supplemental Fig. 1). More field and lab analyses need to be conducted to determine the offset distance caused by the inclination angle between recorded anomalies and the true locations of buried features, but excavations of furnaces at NG1 suggest that the difference was ≤.5 m and most offsets can thus be accounted for through excavation strategy. Use of STPs to ground-truth anomalies had mixed success due to the smaller size of STPs (~30–50 cm in diameter) vs. excavation trenches.

Lastly, the frequency of anomalies from lightning strikes at surveyed sites is notable. As discussed above, both Kanono and Nanga contain LIRM; an additional LIRM anomaly might be present at NG1, partially measured in the NW corner of the survey area, judging by its shape and strength. In writing about LIRM from sites in the American Plains region, numerous researchers (e.g. Maki 2005; Jones and Maki 2005; Burks et al. 2015) have noted that LIRM are common at archaeological sites in the Plains region due to the frequency of thunderstorms, but often go undiscussed or are misinterpreted as ferrous objects. In southern Africa, the N–S movement of the ITCZ similarly brings with it biannual bands of intense rain and thunderstorms throughout the region, coinciding with the onset of the short and long rainy seasons. Put within this context, it would be unsurprising that these seasonal bands of thunderstorms seemingly create a high frequency for LIRM at southern African sites. As very few magnetics surveys have been performed in southern Africa, however, this remains a working hypothesis.

6. Conclusion

The results of gradiometer surveys at Nanga and Kanono underscore the value of using geophysical methods – particularly gradiometry – to better understand Iron Age village life in southern Africa with impermanent architecture. This research adds to a growing body of work showing the application of magnetic survey methods for mapping and interpreting ephemeral sites in Africa (Fitton et al., 2022; Hu et al., 2022). In the case of Kanono, site identification was facilitated by agricultural activities that kept the surface free of groundcover and brought some artifacts to the surface, but there is little on the surface at Nanga today to suggest the presence of such a large ancient village. Even at Kanono, there is no clear relationship between the surface material and subsurface deposits: surface artifacts are restricted to the actively ploughed areas of the site, which makes up only a portion of the total area. Ploughing scatters surface artifacts, further obscuring surface/-subsurface relationships. Maps generated by the geophysical data, however, clearly show a heterogenous village layout at Kanono and offer a guide through which to approach other Zambian and southern African Iron Age sites; the overlaps and discrepancies between Nanga, Kanono and other village sites - after correcting for the palimpsest nature of magnetics data - can only further clarify understandings of the cultural heterogeneity in south-central Africa during the 1st and 2nd millennium.

While we didn't have time to ground-truth all areas of interest, by conducting simultaneous geophysical surveys and excavations we were able to target subsurface investigations with great precision and place those data into a larger spatial, and therefore social, context. Remaining and additional areas of interest can become the focus for future work. While our survey data were highly effective at mapping the organization of production within Iron Age villages, there are some shortfalls with gradiometric surveys: more subtle traces of human occupation are difficult to detect with gradiometers. Livestock corralling, for example, can be sometimes detected in gradiometer surveys (Olsen et al., 2006; Smekalova et al., 2021; Hu et al., 2022), but doing so is difficult – especially if corrals are constructed with thornbushes or other organic materials, or if corrals are overlaid by materials with stronger magnetic effects (such as iron slags). The application of additional geophysical and/or geoarchaeological survey methods – particularly magnetic susceptibility (e.g., see Klehm and Ernenwein 2016) - may help identify some of these harder to see features.

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CRediT authorship contribution statement

Zachary McKeeby: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary datae

The following is the Supplementary data to this article.

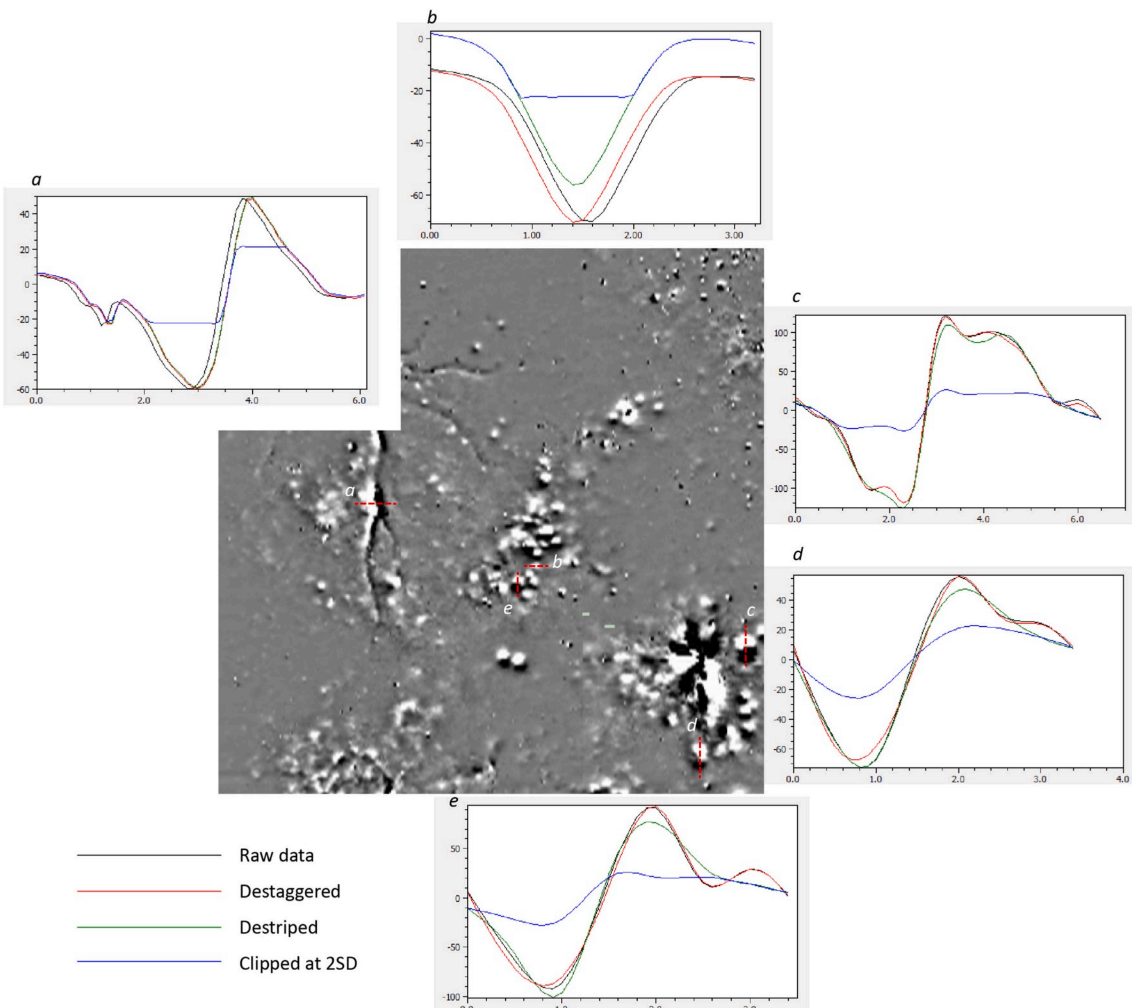

Fig. S1. Magnetogram of NG1 (Nanga) with selected magnetic profiles across archaeological anomalies. labeled dotted lines on magnetogram denote profile axis represented, while color-coded profile lines show measurement readings at different stages of data processing. Data gathered with a Bartington Grad 601-1 fluxgate gradiometer. Image shows data destripped, destaggered, and clipped to 2 SD.

Appendix A. Supplementary datacs

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jas.2024.105937.

References

Bachmann, H.-G., 2016. The Identification of Slags from Archaeological Sites, vol. 6. Routledge.
Bauzytė, E., 2019. Making and trading iron in the Swahili world: an archaeometallurgical study of iron production technologies, their role, and exchange networks in 500 - 1500 CE Coastal Tanzania. In: PhD Thesis, Denmark. Aarhus University.
Belshé, J.C., 1957. Recent magnetic investigations at Cambridge University. Adv. Phys. 6 (22), 192–193. https://doi.org/10.1080/00018739700101561.
Bronk Ramsey, C., 2009. Bayesian analysis of radiocarbon dates. Radiocarbon 51 (1), 337–360.
Burks, J., Viberg, A., Bevan, B., 2015. Lightning strikes in archaeological magnetometry data. A case study from the high bank works site, Ohio, USA. Arctic 61 (4), 4o7–425.
Clark, J.D., Fagan, B.M., 1965. Charcoals, sands, and channel decorated pottery from northern Rhodesia. Am. Anthropol. 67 (2), 354–371. https://doi.org/10.1525/aa.1965.67.2.02a00040.
Fagan, B.M., 1967. Iron age cultures in Zambia. In: *Kalomo And Kangila*. The Robins Series 5, vol. 1. Chatto & Windus, London.
Fassbinder, J., 2017. Magnetometry for archaeology. In: Gilbert, Allan S. (Ed.), Encyclopedia of Geoarchaeology. 499–514. Encyclopedia of Earth Sciences Series. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-1-4020-4409-0_169.
Fassbinder, J., Gorka, T. (Eds.), 2009. Beneath the Desert Soil – Archaeological Prospecting with a Caesium Magnetometer." In *New Technologies for Archaeology: Multidisciplinary Investigations in Palpa and Nasca, Peru*, edited by Markus Reindel and Günther A. Wagner, 49–69. Natural Science in Archaeology. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-87438-6_4.
Fassbinder, J., Gorka, T., 2011. Magnetometry near to the geomagnetic equator. In: Archaeological Prospection: 9th International Conference on Archaeological Prospection. Istanbul: Archaeology and Art Publications, pp. 45–48.
Fitton, T., Contreras, D., Gidna, A., Mabulla, A., Prendergast, M., Grillo, K., 2022. Detecting and mapping the 'ephemeral': magnetometric survey of a pastoral neolithic settlement at Luxmanda, Tanzania. Antiquity. https://doi.org/10.15184/aqy.2021.59. February, 1–21.
Fitton, T., Wynne-Jones, S., 2017. Understanding the layout of early Coastal settlement at Unguja Ukuu, Zanzibar. Antiquity 91 (359), 1268–1284. https://doi.org/10.15184/aqy.2017.141.
Gaffney, C., Hughes, G., Gater, J., 2005. Geophysical surveys at king Lobengula's Palace KoBulawayo, Zimbabwe. Archaeol. Prospect. 12 (1), 31–49. https://doi.org/10.1002/arp.241.
Greenfield, H.J., Miller, D., 2004. Spatial patterning of early iron age metal production at Ndondondwane, South Africa: the question of cultural continuity between the early and late iron ages. J. Archaeol. Sci. 31 (11), 1511–1532. https://doi.org/10.1016/j.jas.2004.03.014.
Hu, L., McKeeby, Z., Muia, M., Munyiri, J., Nelson, C.M., 2022. Examining late pastoral neolithic settlement at Silanga (GvJm52), Lukenya Hill, Kenya. In: *Azania: Archaeological Research In Africa*, March. https://www.tandfonline.com/doi/abs/10.1080/0067270X.2022.2050566.
Hogg, A.G., Heaton, T., Hua, Q., Palmer, J., Turney, C., Southon, J., Bayliss, A., Blackwell, P., Boswijk, G., Bronk Ramsey, C., 2020. SHCal20 southern hemisphere calibration, 0–55,000 years cal BP. Radiocarbon 62 (4), 759–778.
Huffman, T.N., 1989. Ceramics, settlements and late iron age migrations. Afr. Archaeol. Rev. 7 (1), 155–182. https://doi.org/10.1007/BF01116842.
Huffman, T.N., 2001. The central cattle pattern and interpreting the past. South. Afr. Humanit. 13 (1), 19–35.
Huffman, T.N., 2007. Handbook to the Iron Age: the Archaeology of Pre-colonial Farming Societies in Southern Africa. University of KwaZulu. Natal Press, Scottsville.
Inskeep, R.R., 1962. Some iron age sites in northern Rhodesia. S. Afr. Archaeol. Bull. 17 (67), 136. https://doi.org/10.2307/3887543.
Inskeep, R.R., 1978. An iron-smelting furnace in southern Zambia. S. Afr. Archaeol. Bull. 33 (128), 113. https://doi.org/10.2307/3888148.
Jones, G., Maki, D., 2005. Lightning-induced magnetic anomalies on archaeological sites. Archaeol. Prospect. 12 (3), 191–197. https://doi.org/10.1002/arp.257.
Katanekwa, N.M., 1978. Some early iron age sites from the Machili Valley of southwestern Zambia. Azania 13 (1), 135–166. https://doi.org/10.1080/00672707809511636.
Katanekwa, N.M., 1979. Namakala and Nanga sites and the chronology of the early iron age in southern & south-west Zambia. S. Afr. Archaeol. Bull. 34 (130), 120. https://doi.org/10.2307/3887871.
Katanekwa, N.M., 2022. Barotseland and Western Zambia: the Bantu Destination. CreateSpace Independent Publishing Platform.
Klehm, C., Ernenwein, E., 2016. Iron age transformations at Mmadipudi Hill, Botswana: identifying spatial organization through electromagnetic induction survey. Afr. Archaeol. Rev. 33 (1), 45–59. https://doi.org/10.1007/s10437-016-9213-3.
Kvamme, K.L., 2006. Magnetometry: nature's gift to archaeology. In: Johnson, Jay K. (Ed.), In Remote Sensing in Archaeology: an Explicitly North American Perspective, 205–33. The University of Alabama Press, Tuscaloosa.
Loubser, Jan, H.N., 1993. Ndondondwane: the significance of features and finds from a ninth-century site on the lower Thukela river, natal. South. Afr. Humanit. 5 (10), 109–151.
Lyaya, E., 2019. An identification guide for metallurgical sites in Tanzania. Afr. Archaeol. Rev. 36 (2), 193–209. https://doi.org/10.1007/s10437-019-09334-0.
Maggs, T., 1992. My father's hammer never ceased its song day and night': the Zulu ferrous metalworking industry. South. Afr. Humanit. 4 (10), 65–87.
Magnavita, C., Lüth, F., Appiah-Adu, S., 2018. First trial geophysical surveys at Kintampo open-air sites: results, recommendations, research prospects. J. Afr. Archaeol. 16 (1), 105–115. https://doi.org/10.1163/21915784-12340013.
Magnavita, C., Schleifer, N., 2004. A look into the earth: evaluating the use of magnetic survey in African archaeology. J. Afr. Archaeol. 2 (1), 49–63. https://doi.org/10.3213/1612-1651-10018.
Maki, D., 2005. Lightning strikes and prehistoric ovens: determining the source of magnetic anomalies using techniques of environmental magnetism. Geoarchaeology 20 (5), 449–459. https://doi.org/10.1002/gea.20059.
McIntosh, S., Fagan, B.M., 2017. Relocating Ingombe Ilede in the history of South-Central Africa. Antiquity 91 (358), 1092–1094. https://doi.org/10.15184/aqy.2017.120.
McKeeby, Z., Hu, L., Mundiku, W., Mbewe, R., 2022. Archaeological survey in the Machili Valley, Zambia: a report on the 2019 preliminary field season. Azania 0 (0), 1–28. https://doi.org/10.1080/0067270X.2022.2078577.
Miller, D., Killick, D., 2004. Slag identification at southern African archaeological sites. J. Afr. Archaeol. 2 (1), 23–47. https://doi.org/10.3213/1612-1651-10017.
Miller, D., Whitelaw, G., 1994. Early iron age metal working from the site of KwaGandaganda, natal, South Africa. S. Afr. Archaeol. Bull. 79–89.
Musambachime, M.C., 2017. Fire-Eaters: Blacksmiths and the Products of the Forge in Pre-colonial Zambia. Xlibris Corporation.
NCEI Geomagnetic Modeling Team and British Geological Survey, 2019. World Magnetic Model 2020. NOAA National Centers for Environmental Information. https://doi.org/10.25921/11v3-da71.
Olorunfemi, M., Oni, A.G., Fadare, T., 2022. Geoelectric characterisation of furnace and slag trench structures: case study Obafemi Awolowo University ancient iron smelting site, Ile-Ife, southwest Nigeria. NRIAG J. Astron. Geophys. 11 (1), 1–20.
Oni, A.G., Olorunfemi, M., Ogunfolakan, B., Okunubi, O., 2022. Archaeo-geophysical investigation of Ife city Grand Resort iron smelting site at Ile-Ife, southwest Nigeria. J. Afr. Archaeol. 20 (February), 40–56. https://doi.org/10.1163/21915784-bja10010.
Olsen, S., Bradley, B., Maki, D., Outram, A., 2006. Community organisation among copper age sedentary horse pastoralists of Kazakhstan. Beyond Steppe Sown: Proc. 2002 Univ. Chicago Conf. Eurasian Archaeol. 89–111.
Ostner, S., Fassbinder, J., Parsi, M., Gerlach, I., Japp, S., 2019. Magnetic prospection close to the magnetic equator: case studies in the tigray plateau of Aksum and Yeha, Ethiopia. In: New Global Perspectives on Archaeological Prospection. 13th Int. Conf. On Archaeological Prospection. Archaeopress, Oxford, pp. 180–183.
Pawlowicz, M., Fleisher, J., de Luna, K., 2020. Capturing people on the move: spatial analysis and remote sensing in the Bantu mobility project, Basanga, Zambia. Afr. Archaeol. Rev. 37 (1), 69–93. https://doi.org/10.1007/s10437-020-09363-0.
Powell, A.J., McDonnell, J.G., Batt, C.M., Vernon, R.W., 2002. An assessment of the magnetic response of an iron-smelting site. Archaeometry 44 (4), 651–665.
Robertson, J.H., 2000. Early iron age archaeology in Central Zambia. Azania 35 (1), 147–182. https://doi.org/10.1080/00672700009511600.
Schmidt, A., 2007. Archaeology, magnetic methods. Encycl. Geomagn. Paleomagn. 23–31.
Selskienė, A., 2007. Examination of smelting and smithing slags formed in bloomery iron-making process. Chemija 18 (2), 22–28.
Serneels, V., Perret, S., 2003. Quantification of smithing activities based on the investigation of slag and other material remains. Archaeometall. Eur. 1, 469–478.
Schmidt, A., Coningham, R., Gunawardhana, P., 2009. At the equator: making sense of magnetometer data. ArcheoSci. Rev. Archéom. 33, 345–347. https://doi.org/10.4000/archeosciences.1815 suppl.) (October.
Schmidt, A.R., Linford, P., Linford, N., David, A., Gaffney, C.F., Sarris, A., Fassbinder, J., 2015. In: *EAC Guidelines For the Use of Geophysics In Archaeology: Questions To Ask And Points To Consider*. EAC Guidelines 2. Namur, Belgium: Europae Archaeologia Consilium (EAC), Association Internationale Sans but Lucratif (AISBL), 978-963-9911-73-4. 135.
Schmidt, A., Dabas, M., Sarris, A., 2020. Dreaming of perfect data: characterizing noise in archaeo-geophysical measurements. Geosciences 10 (10), 382. https://doi.org/10.3390/geosciences10100382.
Smekalova, T., Bevan, B., Kashuba, M., Lisetskii, F., Borisov, A., Kashirskaya, N., 2021. Magnetic surveys locate late Bronze age corrals. Archaeol. Prospect. 28 (1), 3–16.
Stamnes, A., Stenvik, L., Gaffney, C., 2019. Magnetic geophysical mapping of prehistoric iron production sites in Central Norway. Trans. Roy. Norweg. Soc. Sci. Lett. 2, 71–113.
Tite, M.S., 1966. Magnetic prospecting near to the geomagnetic equator. Archaeometry 9 (1). https://doi.org/10.1111/j.1475-4754.1966.tb00903.x, 24–24.
Vogel, J.O., 1971. Kamangoza: an introduction to the iron age cultures of the Victoria falls region. Zambia Museum Papers, an Introduction to the Iron Age Cultures of the Victoria Falls Region. Oxford University Press for the National Museums of Zambia, London, New York.
Vogel, J.O., 1975a. Kabondo Kumbo and the early iron age in Victoria falls region. Azania: J. Brit. Inst. E. Afr. 10 (1), 49–75.

Vogel, J.O., 1975b. Simbusenga: the Archaeology of the Intermediate Period of the Southern Zambian Iron Age, vol. 4. Oxford University Press published on behalf of the National Museums of Zambia by.

Vogel, J.O., 1987. Iron age farmers in southwestern Zambia: some aspects of spatial organization. Afr. Archaeol. Rev. 5 (1), 159–170. https://doi.org/10.1007/BF01117090.

Welham, K., Fleisher, J., Cheetham, P., Manley, H., Steele, C., Wynne-Jones, S., 2014. Geophysical survey in sub-Saharan Africa: magnetic and electromagnetic investigation of the UNESCO world heritage site of Songo Mnara, Tanzania. Archaeol. Prospect. 21 (4), 255–262. https://doi.org/10.1002/arp.1487.