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The Early Iron Metallurgy of Bassar, Togo: furnaces, metallurgical remains and iron objects

Philip L. de Barros, Louise Iles, Lesley D. Frame & David Killick

Abstract

An extensive iron production industry flourished in the Bassar region of northern Togo from as early as the Early Iron Age. However, it was during the Later Iron Age that a period of rapid growth was witnessed, with locally-produced iron increasingly feeding into regional trade networks. This paper discusses the archaeology, archaeometallurgy and metallography of the earliest iron production in Bassar, through the examination of two sites. The first, BAS-252 (Dekpassanware), is a large ironworking village (in operation throughout the Early and Later Iron Ages) with six zones devoted primarily to smithing. The second, the nearby site of BAS-273, was found to be a smaller smelting site, in operation in the Early Iron Age.

This paper presents a metallographic analysis of the EIA iron artefacts excavated at BAS-252, in conjunction with an archaeometallurgical analysis of EIA smelting remains from BAS-273. The close association of smithing and smelting sites has provided an unparalleled opportunity to consider the *chaîne opératoire* of iron production in EIA Bassar, with insights into the production of iron alloyed with carbon and phosphorous, and the possible symbolic behaviours of past smelters, at a time when the foundations were being laid for Bassar to later develop into a regional hub of iron production.

Une vaste industrie de production de fer a prospéré dans la région de Bassar au Nord-Togo dès l'âge du Fer ancien (*Early Iron Age* ou *EIA*). Cependant, c'est au cours de l'âge du Fer tardif (*Later Iron Age* ou *LIA*) qu'une période de croissance industrielle a été observée, le fer produit localement étant de plus en plus utilisé par les réseaux commerciaux régionaux. Cet article traite de l'archéologie, de l'archéométallurgie et de la métallographie de la première production de fer de Bassar, à travers l'examen de deux sites. Le premier, BAS-252 (Dekpassanware), est un grand village sidérurgique (pendant l'*EIA* et le *LIA*) comprenant six zones consacrées principalement à la forge. Le second, le site de BAS-273, s'est révélé être un site plus petit spécialisé dans la production primaire du fer (réduction), en activité pendant l'*EIA*. Cet article présente une analyse métallographique des artefacts de fer de l'*EIA* découverts à BAS-252, ainsi qu'une analyse archéométallurgique des restes de réduction de l'*EIA* de BAS-273. L'association temporelle étroite des sites de forge et de réduction a fourni une occasion sans précédent d'appréhender la chaîne opératoire de la production de fer de l'*EIA* à Bassar, avec des informations sur la production de fer allié au carbone et au phosphore, ainsi que sur les comportements symboliques possibles des anciens métallurgistes à l’époque où se mettaient en place les fondements pour que Bassar devienne plus tard un centre régional de production de fer.

Keywords

Iron, archaeometallurgy, metallography, technology, Early Iron Age (EIA), Later Iron Age LIA), Bassar, Togo

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Introduction

The Bassar region of northern Togo (Figure 1) is home to rich deposits of haematite iron ores that enabled an extensive iron production industry to flourish there from as early as the Early Iron Age (hereafter EIA). Starting in the late first millennium BC, these early iron production technologies initially served local demands until the early 2nd century AD. After a long hiatus, during which no evidence of ironworking has been found in the region, Bassar ironworking reappeared in the 13th century and after the mid-16th century grew rapidly, increasingly feeding into regional and long-distance trade networks, until its abrupt decline in the mid-twentieth century. At its height at the end of the nineteenth century, analysis of ethnohistorical accounts and oral traditions estimates that the industry was providing tools to as many as 600,000 people across an area of around 100,000 km^2 (de Barros 1985, 1988).

Historical and archaeological contexts

The first author has been conducting research on the Bassar ironworking industries since 1981 (Figure 1). The region was first described by the German mining engineer F. Hupfeld (1899); following that, early research focused primarily on the Later Iron Age (LIA, AD 1200-1950) when iron ore was smelted in tall natural draft furnaces (de Barros 1985, 1986; see also Kuevi 1975; Martinelli 1982, 1984, 1992; Goucher 1984; Goucher and Herbert 1986; Hahn 1997), with a focus on the temporal and spatial extent of the iron industry, its technology and production intensity, and its demographic, economic and political effects upon Bassar society (de Barros 1988, 2000). Later research has focused on the Bassar Chiefdom in the context of regional slave raiding, Africa's internal frontier (Kopytoff 1987) and theories of political economy (de Barros 2001, 2012a, 2012b), as well as on iron bloom processing in the Bitchabe area (de Barros and Lucidi 2016) and a detailed comparison of the LIA and the EIA, as discussed below (de Barros 2013). Since 2002, the emphasis has been on the EIA predominantly smithing site of BAS-252 and the EIA smelting site BAS-273.

BAS-252 (also known as Dekpassanware) is a 27.6-ha (68 acres) ironworking village with six zones largely devoted to smithing (Figures 2a and 2b), originally recorded in 1982 as part of a regional survey (de Barros 2003, 2006, 2013). This site was occupied during the terminal Late Stone Age (hereafter LSA) and the Early and Later Iron Ages. Excavations focused on the EIA deposits. Attempts to find evidence of furnace remains at BAS-252 in 2002 and 2008 were unsuccessful due to the relative paucity of smelting activity, probably because it is 7 km west of the nearest good ore source at Bidjilib mountain (Figure 1).

The 1-ha site of BAS-273 was also first recorded in 1982. Excavations in 2013 revealed that BAS-273 was a smelting site, roughly contemporaneous with the EIA occupation at BAS-252 and underlain by an undated LSA component (Figures 3a and b). BAS-273 produced the remains of a smelting furnace that was probably bellows-driven, consisting of a subterranean slag pit and part of the base of the furnace shaft directly dated by thermoluminescence to 200 BC ± 120 years (Feathers 2015). After a period of abandonment, the site was reoccupied in the LIA, during the 15th-16th centuries AD.

This paper will discuss the metallographic analysis of EIA iron artefacts excavated in BAS-252 (three iron bracelets and a knife blade fragment), in conjunction with an archaeometallurgical analysis of the EIA smelting remains from BAS-273. A separate publication will present the ethnoarchaeology of LIA smithing in the Bitchabe area (Figure 1) and the analysis of LIA, ethnographic and historic period tools (de Barros et al. in prep). It is recognised that the sample sizes of analysed EIA artefacts and EIA slags presented here are small and that future research will be needed to clarify and verify our results.

[Figure 1. Villages of the Bassar region at contact with the Germans (1890s), also indicating location of BAS-252 and BAS-273 (J. Paulson).]

[Figure 2a. Eastern half of BAS-252 facing SSE, with Mount Bassar (12 km distant) in background, from laterite road that bisects the site, near Unit 37 (Figure 2b) (P. de Barros).]

[Figure 2b. BAS-252 and its vicinity, including its six ironworking (largely smithing) zones (1-6). Both EIA (dark blue) and LIA (green) occupation areas are shown. NOTE: the larger EIA site boundary is based on a threshold surface density of ≥0.25 sherds/m^2 of the dominant Bright Mica Ware. The EIA residential area boundary (including trash dumps and burials) is based on excavated data and a Bright Mica Ware threshold of ≥0.50 sherds/m^2 (J. Paulson and P. de Barros).]

BAS-252, an EIA iron-working site (primarily smithing)

The excavation and interpretation of the site of BAS-252 have been published in detail elsewhere (de Barros 2006, 2013), but a summary is provided here to provide context for the analysed EIA artefacts. The site itself is slightly elevated within the landscape, with extensive views across the Bassar region, and it comprises residential areas alongside six zones of iron working activity (Figures 2a and 2b). Work at BAS-252 occurred in 2002, 2008 and 2013. A total of 51 units were excavated, of which most were 1 x 1 m in size. However, several 1 x 2 m units were excavated in rubbish dumps, ironworking areas and a burial area (Units 19-20, 35, 41-45), two 2 x 2 m units (Units 29 and 49) were excavated in ironworking areas and one 3 x 2 m block unit (Units 11, 14-18) was excavated in a burial area (Figure 2). None of the latter were divided by baulks, though individual unit artefact tallies and soil profiles were sometimes recorded. Units were excavated to bedrock or sterile plus a 30 cm diameter shovel test pit to a depth of 10-20 cm. Cultural deposits in residential areas ranged from 150-220 cm in depth but were less than a metre in ironworking zones. Units were excavated in 10- cm levels coupled with detailed stratigraphic profiles with Munsell soil descriptions; if features or unusual artifacts were encountered, these were pedestalled, and natural stratigraphy was respected. With burial features the focus was on the careful exposure of the human remains using dental picks and brushes with toluene added for preservation of highly deteriorated bones as needed. Some bones were removed for further study, including radiocarbon dating and isotopic analyses, but unfortunately no collagen was preserved. Soil column samples were taken from selected units for the recovery of palaeobotanical remains.

A series of radiocarbon dates give a chronological framework for the site (Table 1). Thirteen radiocarbon dates and their ironworking associated artefacts indicate an EIA period dating from 545 cal. BC to cal. AD 132. Four dates (Beta-169559, Beta-169563, Beta-173469, and Beta-173474) indicate possible occupation beginning as early as 750-509 cal. BC, though only one (Beta-173469 is associated with ironworking artefacts dating to 731-204 cal. BC. The remaining nine dates cluster between 401 cal. BC to cal. AD 70 (with one extending to cal. AD 132). Overall, this suggests the EIA occupation was primarily, if not entirely, after 401 cal. BC. A terminal LSA occupation underlies parts of the site, based on two dates (Beta-252674 and Beta-173471) indicating occupation from 1371-1051 cal. BC and 893-514 cal. BC from Units 23 and 45). A later LIA reoccupation was indicated by radiocarbon dates from two slag mound groups, dating to the late 13th thru mid-17th centuries AD (Table 1).

Ceramic typologies and ceramic chronologies for the Bassar region are primarily based on extensive and intensive surveys in the 1980s, ceramic seriation anchored by radiocarbon dating of slag mounds (and their internal ceramics) and oral traditions (de Barros 1985: 102-122, 530-694), with additional information gleaned from recent excavations at ironworking village sites in the Bandjeli and Bitchabe areas from 2015-17. Bright Mica Ware dominates the EIA and is present throughout all excavation units at BAS-252 with somewhat lower quantities in the upper 20-30 cm in areas of LIA reoccupation.

Based on 36 published dates (de Barros 1986: 157-160; Robion-Brunner 2018: 16), the LIA in the Bassar region of Togo ranges from the early 13th century to the early 1950s when iron production was outlawed by the French colonial government. At BAS-252, the LIA was indirectly dated by two radiocarbon dates from two LIA slag mound groups (A and B) indicating the late 13th to mid-17th centuries (Table 1 and Figure 2). Site ceramics indicate roughly similar periods. Burnished Fine Mica Ware is diagnostic of the early LIA and occurs primarily in the upper 40 or 50 cm at BAS-252 and it dates to the 14th-15th centuries AD. The area of less intensive LIA occupation north of the main site (Figure 2) contains both Fine Mica and Incised Thin Fine Micaceous wares, the latter dating to the mid-16th to 18th centuries (de Barros 1985: 122, 684). No additional LIA radiocarbon dates were obtained from excavations at the main site for several reasons: 1) the relative similarity between the LIA slag mound dates and the ceramic dates noted above; 2) emphasis on the accurate dating of the EIA; and, 3) the potential of disturbance by recent farming in the upper LIA levels.

Bassar Ware is relatively uncommon during the EIA and more common during the LIA, but it is present in virtually all excavation units. In fact, Bassar Ware has been present for millennia. Its various, largely undated, sub-categories are based on differences in surface treatment and sparse design elements (primarily from surface collections) and as a result they are difficult to use for dating purposes (de Barros 1985: 541-559, 647-684). However, excavated data from BAS-273 indicate that grooves and twisted cord roulette are the predominant decorative motifs with occasional comb stamping during the EIA.

The creation and division of the LIA reoccupation boundaries at BAS-252 were originally based on Burnished Fine Mica Ware surface densities (de Barros 2013: 16). However, while the total area of LIA reoccupation extends as indicated in Figure 2, an additional study of excavated Fine Mica Ware densities in the upper 50 cm indicates there is a small core area of intense LIA occupation where Fine Mica densities are 10-20 times higher (106-238/m^3) than for the rest of the LIA reoccupation (<1-28/m^3). Surface sherd densities suggest this core area might extend further south but time constraints and land under cultivation west of the main road prevented excavation there (Table 2).

The six zones of iron working activity at BAS-252 comprise evidence mostly for smithing (see Pleiner 2006 for a discussion of archaeological indicators of smithing activity), including abundant smithing hearth bottom slags and other smithing-related slag (particularly hammerscale), as well as tuyère fragments in all six zones. Additionally, a few stone hammer fragments were found in Zone 4, and an area with two large stationary stone anvils, with associated hammerscale and microspatter produced from hot forging, and nine iron bloom crushing mortars were found in Zone 1 (Figure 2b).

Smelting evidence at BAS-252 is limited, appearing in only three of the iron working zones. In Zone 1, a smelting type tuyère (see later discussion of tuyère types) was found with a slag-filled entry way, and four pieces of vesicular smelting slag were found in three excavation units (Units 26, 30, 31), similar to those found at the smelting site BAS-273. In Zone 2, quite a bit of slag suggesting a smelt had had taken place was found in Unit 29, a 2 x 2 m unit 90 cm in depth, dating to 387-2 cal. BC (Table 1), along with a partially clogged smelting tuyère and a piece of vesicular smelting slag from Unit 35, and a possible furnace fragment on the surface. In Zone 4, a group of four very small mounds of possible smelting slag were found near two units (Units 25 and 43A) which produced several large pieces of vesicular and other smelting slag. A probable furnace fragment was also found on the surface in Zone 4. However, no evidence of in-situ furnace locations or clear-cut furnace fragments were observed.

No pronounced separation between iron working areas and living areas seemed necessary at this time given the relative proximity of Zones 1, 2, 4 and 5 to habitation areas. However, except for a pair of adjacent units west of Zone 4 (10 and 51), smithing furnace bottoms were rarely recovered from excavated units in residential areas. In addition, no anvils, large hammer fragments or iron bloom crushing mortars of any size were recovered within residential areas, as is typical of archaeological and ethnographic smithing sites in the Bitchabe zone during the LIA (Figure 1). A hiatus in deposits is followed by reoccupation of BAS-252 during the LIA (Figure 2), as indicated by the importance of Fine Mica Ware, indirectly dated through its association with the slag mounds to between cal. AD 1281 to 1400 (Zone A) and cal. AD 1477 to 1642 (Zone B; see Table 1), at which point separation between smelting areas and residential areas was more apparent. In contrast to the smelting remains present at BAS-252 in the LIA, no smithing remains were associated with the LIA period, which might be indicative of the later emergence of technological specialisation in the region (de Barros 1986).

BAS-273, a late first-millennium BC iron smelting site

The presence of surface slag and tuyères, the domination of Bright Mica Ware ceramics, and its location about 1100 metres north of the Bidjilib ore body indicated that BAS-273 was probably a smelting site contemporaneous with the predominantly smithing site of BAS-252 (Figures 3a and 3b). The subsequent excavation of fourteen 1 x 1 m excavation units delineated three major activity areas: a residential zone with deposits ranging from 70-110 cm in depth; a waste dump (slag, furnace remains and tuyères) ranging from 110-160 cm; and a mixed waste/furnace zone area from 70-110 cm (Figure 3). Note that the smelting and associated dump areas are adjacent to the residential area, much as we see with BAS-252.

Like BAS-252, BAS-273 has three principal temporal components. The first is an LSA deposit found at the base of the site indicated by the highest per-level quantities of Bright Mica Ware ceramics and very low levels of slag and tuyères (Table 2), along with a polished stone axe (Unit 4, 100-110 cm), quartz cores and flakes, a jasper flake, a few grindstone and hammer fragments, a broken polishing stone, some domesticated cattle teeth and long bone fragments, and a thin, ovoid, red and white quartz bead (Unit 6, 130-140 cm). In the non-residential areas LSA deposits underlie EIA deposits from 70-170 cm in depth depending upon site activity area and unit. In the residential area, LSA deposits underlie the EIA from 30/40 to 100/110 cm (Table 2). However, debitage, which is more easily dispersed upward over time by burrowing animals, worms and insects, is found mixed in with EIA deposits as high as 20-40 cm in Units 7 and 9. Units with clearly disturbed stratigraphy (Units 8, 10 and 12, and 18) were not considered (Figure 3b). Site radiocarbon dates did not capture the time span of this LSA deposit, in part due to charcoal samples lost to mould.

The second is an EIA deposit characterised by lower quantities of Bright Mica ceramics and large quantities of slag and tuyère and furnace fragments, with deposits ranging from 10 to 130 cm in depth (Table 2). If we exclude the upper 30-40 cm which are stratigraphically mixed due to hoe agriculture and the 15th-16th century LIA re-occupation, the EIA deposit also contains occasional sherds of Fine Mica and Brownware ceramics, an upper grinding stone, an edge-polished stone axe fragment (Unit 5, 40-50 cm), a quartz core and some quartz flakes, some stone hammers, a cattle tooth, a few probable cattle long bone fragments, a pounder or club made of quartzite or micaceous schist, a round hammer made of iron ore, and iron tools (probable hoe, bracelet and knife fragments). Four calibrated radiocarbon dates are associated with the EIA deposits ranging from 371 cal. BC and cal. 20 AD. Three dates range from 371-168 cal. BC and the fourth extends from 166 cal. BC to 20 cal. AD (Table 3).

The third depositional period represents a LIA reoccupation of the site during the 15th-16th centuries found primarily in the upper 30-40 cm. Bright Mica ceramics are relatively uncommon, especially in the upper 20 cm, and their presence is almost certainly due to stratigraphic mixing by the farmer's hoe, as Bright Mica ceramics are found only in association with terminal Late Stone Age and EIA sites in the Bassar region (de Barros 1985, 2013). Bassar Ware ceramics dominate, followed by Burnished Fine Mica Ware (including a few sherds with random criss-cross burnishing marks similar to a smudged variety dating primarily to the late

15th-16th centuries) (de Barros 1985: 122, 558-579), as well as a few sherds of largely smudged Thin Fine Micaceous Ware with traces of a white wash or sheen that is tentatively dated from recent excavations to the 16th century. Some of the site's iron objects and two stone ornaments made of facetted white quartz (possible bead blank) (Unit 10, 20-30 cm) and a dark brown to black spheroid as well as a rose quartz bead (Unit 10, 30-40 cm) may also be a part of this reoccupation but are in a disturbed context (Figure 3). Three major features are also present: 1) a probable refilled borrow pit in Unit 8 (where material has been removed in antiquity for use elsewhere); 2) a piled-stone subterranean structure of unknown function, about a metre deep and more than a metre across, containing many recycled lower and upper grindstones and stone hammer fragments, which dominates Unit 10 and extends into Unit 12; and, 3) an extended (probable) female burial without grave goods in Unit 18 that is thus far undated due to the lack of bone collagen.

The EIA assemblage at BAS-273 strongly suggests that the site specialised in smelting. Evidence for smithing is largely absent with no stone anvils or large stone hammers (or fragments thereof) used in crushing iron bloom or shaping iron tools and no iron bloom crushing mortars (*likumanjool*) (Figure 4) at the site or in the general vicinity. Finally, selected surface and subsurface soil samples detected no hammerscale or microspatter that would indicate hot forging activity (Dungworth and Wilkes 2009; de Barros 2011). A small *likumanjool* measuring 42 x 33 x 17-18 cm was found in Unit 15A at 40-58 cm that has 11 small cupules or pits indicating the pulverising of small bits of bloom and/or bloom-slag mix that could have been used in the iron refining process and/or added to courtyards and house walls to harden them (Dugast 2013: 28-36; de Barros and Lucidi 2017: 65-69). Such small *likumanjool* were not found in EIA deposits at BAS-252 and the one at BAS-273 may be associated with the c. 15th-16th LIA reoccupation. Finally, as discussed below, the tuyères at BAS-273 are different from those at BAS-252, which focused primarily on smithing.

While BAS-273 was reoccupied during the LIA, it appears that its later inhabitants did not practice smelting. No evidence of LIA smelting furnaces or slag was noted in the vicinity of the site. BAS-273 lies within a 5 km^2 intensive survey zone that in 1982 recorded all slag mounds encountered. However, there are two LIA slag mound sites that might have been possible candidates for association with BAS-273. The first, BAS-228, was ^{14}C dated in 1982 (de Barros 1986: 158) and recalibrated in 2018 (with INTCAL13 using BetaCal 3.21) to 1294-1425 cal. AD (94.5% probability), essentially the 13th-early 14th centuries. This is a bit early compared to the LIA at BAS-273 and the site is 575 m to the west, which makes it unlikely that it is associated with the reoccupation of BAS-273. Second, BAS-269, while only 185 m to the west, dates to <300 years ago (de Barros 1986: 158) and thus, it very likely post-dates the LIA occupation at BAS-273. The slag mounds at BAS-269 are also near several 17th-18th century habitation sites, and both the mounds and the habitation sites are dominated by Thin (smudged) Fine Micaceous Ware, which is quite rare at BAS-273. In short, while BAS-273 was occupied during the LIA its inhabitants do not appear to have practiced iron production.

[Figure 3a: View from site BAS-273 before excavations, facing south toward the Bidjilib mountain iron ore source in background (Figure 1) (P. de Barros).]

[Figure 3b: Site BAS-273, east of Nababoun between Bassar and Kabu (J. Paulson).]

[insert Table 1 here]
[Table 1: ^{14}C dates on charcoal samples from BAS-252 (Dekpassanware), obtained between 1982 and 2013, recalibrated using BetaCal 3.21 and INTCAL13 (Reimer et al. 2013) in 2018, which explains differences with prior published date ranges (de Barros 2013: 13.]

[insert Table 2 here]
[Table 2: Distribution of Bright Mica Ware fragments (B) associated with LSA deposits, alongside excavated slag weights (S, in kg) and tuyère fragments (T) associated with EIA deposits, at BAS-273. Levels with ^{14}C dates are indicated by a star (*) in column C (see associated dates in Table 3). Shading broadly indicates the dominance of LSA vs EIA material through the levels in each unit. Refitting attempts using tuyère and ceramic fragments to establish vessel counts were not productive.]

[insert Table 3 here]
[Table 3: ^{14}C dates on charcoal samples from BAS-273, calibrated using BetaCal 3.21 and INTCAL13 (Reimer et al. 2013).]

[Figure 4. Iron bloom crushing mortar site (*likumanjool*) at BAS-299A at Upper Bidjomambe (BAS-322) near Bitchabe (P. de Barros).]

Smelting remains at BAS-273

Tuyères

In addition to the relative scarcity of smelting slag and furnace remains at BAS-252, and the paucity of smithing remains at BAS-273, the differences in the tuyères at the two sites supports the supposition that the former site specialised in smithing and the latter in smelting. The ends and lower portions of both smithing and smelting tuyères would have been subject to considerable heat during use which would have turned the clay to fired clay, like pottery.

However, we suggest that a greater proportion of a tuyère would have become fired or vitrified in a smelting furnace than a similar tuyère would in a smithing forge, due to tuyères being inserted further into smelting furnaces than into the forge. The subsequent differential firing impacted the preservation rate of the tuyères themselves, as only the fired or vitrified portions of the tuyères survived in the archaeological record.

As such, length of tuyère fragment might be useful as an indicator of technological process in Bassar. Only 1.2% (2/344) of the BAS-252 tuyères are ≥ 10.5 cm in length. In a study of the length of 132 tuyère fragments from Units 43A1 and C1 excavated in ironworking Zone 4 (Figure 3), an area dominated by smithing debris, especially smithing furnace bottoms (cf. Pleiner 2006), the mean tuyère length was 4.6 cm (SD = 1.1 cm) and none were > 9.0 cm.

By contrast, at BAS-273, 29.1% (43/148) of the tuyère fragments were ≥ 10.5 cm in length, with a mean of 16.6 cm, with the longest at 23 cm. This is comparable to one of the four probable smelting tuyères from BAS-252 (associated with smelting as the entry-way was clogged with slag), whose length is 20.5 cm. Moreover, many of the BAS-273 tuyères have a glazed and/or lustrous appearance for at least 10-19 cm of their length, with a mean of 11.7 cm. BAS-252 tuyères sometimes have a melted end but glazed or lustrous portions extend only a few cm or are absent. The greater extent of vitrification on the BAS-273 tuyères is potentially due to the greater sustained temperatures achieved in a smelting furnace rather than a smithing forge.

In addition, a study of 334 tuyère fragments at BAS-252 and 148 tuyère fragments at BAS-273 indicates that both smelting and smithing tuyères were conical rather than cylindrical in shape during the EIA. Further study of 135 probable smithing tuyères at BAS-252 and 128 smelting tuyères at BAS-273 suggests that the internal diameters of the tuyères are slightly different at the two sites: at BAS-252, for 132 excavated tuyères from Units 43A1 and C1 in Zone 4 (Figure 3), the mean is 4.5 cm (SD = 0.67; range = 3.3-6.0); at BAS-273, for 63 excavated tuyères where the internal diameter could be satisfactorily estimated, the mean was 4.1 cm (SD = 0.32; range = 3.25-5 cm). The somewhat larger mean internal diameter of smithing tuyères at BAS-252 may indicate either that the conical smithing tuyères flared out more widely than did the BAS-273 smelting tuyères, or that a different bellows/tuyère system was used to introduce air into the furnace at different rates.

It is also feasible that some of the tuyères at BAS-273 had additional socio-cultural meanings related to the smelting activity carried out at that site. In Unit 1 at BAS-273, a previously used (fired) tuyère fragment 22.5 cm in length and 10-11 cm in diameter was found placed vertically in the ground at a depth of 80-103 cm. Other examples of buried, upright tuyères are sparse, and are more usually associated with furnaces themselves. Examples from Kasungu National

Park, Malawi, saw one or two used tuyères set vertically and sealed in pits beneath the furnace floors of small, conical, slag-tapping furnaces of the nineteenth century AD (Killick 1990: 170, 178, 189, 190). In southeastern Gabon, an upright tuyère was found buried beneath an EIA tall shaft furnace (Digombe et al. 1988; Schmidt 1998). Closer to Bassar, 14 near-vertical, unused (and unfired) tuyères were found buried beneath the combustion chamber of a natural-draft furnace in Tora-Sira-Tomo 1, Burkina Faso (Holl and Lassina 2000; Holl 2009). There is no evidence that the buried tuyère at BAS-273 was placed at the base of a furnace (Figures 5a and 5b), however, it is unlikely this tuyère occurred in this position at random, and does suggest a symbolic element, perhaps to help ensure successful smelting at the site.

These kinds of symbolic actions are not uncommon in the more recent smelting technologies of sub-Saharan Africa. For example, medicines – in the form of plant or animal products – were seen as indispensable for the successful construction and operation of the smelting furnace in many areas (Herbert 1993: 55-116; Schmidt 1996, 1997; de Barros 2000: 167). Such medicines were sometimes buried in a hole or depression, sometimes in a pot, directly beneath the furnace (de Maret 1980; Fowler 1990: 222; Essomba 1992; de Maret and Thiry 1996; Schmidt 1997; Schmidt and Mapunda 1997); there is abundant ethnographic and archaeological evidence for this practice (de Barros 2000: 167-168). Thus, the upright tuyère at BAS-273 may conceivably represent a similar behaviour.

[Figures 5a and 5b. Vertically placed tuyère in BAS-273 Unit 1, 80-103 cm, prior to its removal (P. de Barros).]

In addition, several tuyères were recovered with unusual shallow channels or grooves or incisions parallel or slightly oblique to its length (n=2) or to its width (n=4), including two that are spiral-like. With one exception, these marks do not cover the entire circumference of the tuyère (Figures 6a-d). Their function is unknown. Some may be the result of forcing the tuyère into a furnace tuyère hole, perhaps with a twist to create a secure and tight fit, thereby creating incisions or grooves. In the case of the deep, spiral-like set of grooves that cover the entire tuyère surface, it may be an idiosyncratic stylistic element of a particular tuyère maker or it may be associated with a specific ritual. Whereas examples of decorated tuyères are rare, examples of decorated iron smelting furnaces have been documented in eastern (e.g. Schmidt and Childs 1985; van Grunderbeek et al. 2001; Barndon 1996) and southern Africa (e.g. Chirikure and Rehren 2004). However, most tuyères from BAS-273 do not have such marks: only 6/43 (14.0%) tuyères ≥10.5 cm in length have them and only two tuyères ≤10.5 cm exhibit traces (thus 8/148 tuyères, or 5% of the tuyère assemblage). No tuyère from BAS-252 displayed similar marks.

[Figure 6. a) BAS-273 Unit 6, 78-86 cm, Tuyère 1, grooves parallel to width; b) BAS-273 Unit 5, 90-100 cm, spiral-like grooves; c). BAS-273 Unit 6, 89-100 cm, Tuyère 4, grooves/incisions parallel to width; d). BAS-273 Unit 6, 95-113 cm, Tuyère 6, partial grooves parallel to length (after P. de Barros).]

Furnace Remains

After determining the approximate locations of the residential zone and the smelting trash dump (Figure 3), it was decided the most likely place to find intact furnace remains would be south of the dump, away from residential houses. Unit 11 produced what was initially thought to be a furnace wall fragment measuring 48 x 20 cm and c. 9-10 cm in thickness (Figure 7).

[Figure 7. BAS-273 Unit 11, 50-70 cm near south wall: oxidised slag pit wall fragment, 48 x 20 x 9-10 cm; initially thought to be a wall fragment from the furnace shaft (P. de Barros).]

It was later realised that it was probably a rather fragile, partially oxidised sidewall fragment of the slag pit later exposed in the unit's south wall which had been protected from the farmer's hoe by a relatively dense layer of large pieces of smelting slag (Figures 8a and 8b). Leaving a 20-cm baulk, Unit 17 was excavated directly to the south to come down on the slag pit from above (Figure 9). This excavation encountered solid remnants of the base of the furnace shaft that extended above the slag pit (Figure 10), a part of which was removed for thermoluminescence dating. Figure 11 illustrates the overall configuration of the slag pit and shaft base.

[Figure 8a. Slag pit profile exposed in south wall of BAS-273 Unit 11; slag at bottom right of pit was analyzed as sample #800 discussed latter; see Figure 8b for scaled profile (P. de Barros).]

[Figure 8b. Stratigraphic profile of south wall of 1 x 1 m Unit 11 at BAS-273 showing slag pit (scale in cm) (J. Paulson and P. de Barros).]

[Figure 9. Opening BAS-273 Unit 17, 20 cm south of Unit 11, to expose top of slag pit (P. de Barros).]

[Figure 10. Discovery and excavation of BAS-273 slag pit surrounded by remains of the base of the furnace shaft; see Figure 11 for scaled view (P. de Barros).]

[Figure 11. Plan of the base of the furnace shaft and the slag pit, BAS-273 (J. Paulson).]

The slag pit was at least 45-50 cm in depth and was probably dug with a hoe. It also did not have a special lining made of clay or other material. With use, its sidewalls became slightly- to partially- to fully-oxidised, which allowed an estimation of its internal diameter. Its internal diameter along N-S and E-W varies from 60-63 cm and from 62-64 cm, respectively. Thus, the slag pit is more of an ellipsoid with a longer N-S axis with its ends somewhat flattened (Figure 11). The thickness of the oxidised layer varies from 2-4.5 cm in the profile exposed in Unit 11; however, the slag pit wall fragment (initially thought to be a furnace fragment) recovered in the same unit was 9-10 cm thick (Figure 7), suggesting the thickness range of the pit profile may not be fully representative. In addition, the excavation of the slag pit in Unit 17 revealed that its thickness, as it nears the surface, becomes much thinner, varying from <1 cm to 1.5-2 cm. A partial excavation of the slag pit (Figure 10) produced 10 pieces of slag of different types along with tuyère fragments, but no iron ore, charcoal, ceramics or other artefacts; in addition, two pieces of slag were noted in the Unit 11 pit profile (Figure 8b).

The base of the furnace shaft exposed around the slag pit was generally placed about six cm away from the slag pit (Figures 10 and 11). Using the diameter of the slag pit (see above), the distance between the pit and the shaft base, and the thickness of the shaft base (10-12 cm) its external circumference was estimated to be 96-104 cm. Interestingly, a curved piece of furnace wall measuring 20 x 9.5 x 6.5-7 cm was recovered from 35-42 cm in Unit 15A (Figure 12). Using the lengths of its arc and chord, it was estimated to have a circumference of only 45-55 cm, indicating the furnace shaft was conical in shape. The height of the furnace is unknown, but it was probably bellows-driven, given the shape and number of tuyères and the EIA date. The earliest evidence of natural draft furnaces yet recovered in West Africa dates to the eighth century AD (Serneels et al. 2013).

[Figure 12. Portion of upper part of a furnace shaft, BAS-273; its estimated circumference based on arc and chord lengths suggests that this Bassar EIA furnace was conical in shape (P. de Barros).]

Dating the furnace remains

There are several features of the excavated furnace that suggest it is associated with an EIA technology. Firstly, the use of a furnace shaft with slag pit is unknown during the LIA (1200-1950 AD) in the Bassar region. In addition, the natural draft furnaces of the LIA are equipped with tuyères that are cylindrical, not conical. Air flow into the furnace is controlled by partial or full closure of the tuyères from the exterior using a piece of kneaded clay (Kuevi 1975: 40; Goucher 1984, 1996; de Barros 1985: 138; Hahn 1997: 60). Thus, we can infer that the furnace technology at BAS-273 does not date to the LIA, as currently defined for the region.

Furthermore, the depositional layer associated with slag and tuyères at BAS-273 is almost entirely dominated by Bright Mica Ware ceramics which are associated at BAS-252 with radiocarbon dates from 893-514 cal. BC until 211 cal. BC-cal. AD 132 (Table 1) and are never present within LIA sites or site components. The ceramics associated with the c. 15th-16th century LIA reoccupation of BAS-273 occur primarily in the upper 40 cm, except in areas of intense disturbance, such as the borrow pit, stone structure, and an undated burial in Units 8, 10 and 12, and 18, respectively (Figure 3). The furnace remains in Units 11 and 17 begin at a depth of about 38 cm, which does not clearly set them apart from the 15th-16th century occupation layers, but the furnace technology does, as discussed earlier.

These inferences are upheld by the absolute dates obtained from the furnace and the associated remains. Four charcoal-based radiocarbon dates were obtained from BAS-273 (Table 3). Three of the dates, from Units 5 and 6 in the dump area and from Unit 14 in the residential area, range from 371-168 cal. BC; the fourth date from Unit 5 dates just after this period from 166 cal. BC to cal. AD 20. All four dates are contemporaneous with the EIA deposits at BAS-252 (Table 1). Finally, a very highly-fired piece of furnace shaft base (Figure 11) along with associated soil samples, slag and tuyère fragments from within the pit were sent to James Feathers at the University of Washington. A thermoluminescence date of 200 BC ± 120 years (Feathers 2015) or 320 to 80 BC was obtained, which matches quite well with the site ceramics and ^{14}C dates. In short, BAS-273 was a smelting site contemporaneous with BAS-252.

Optical microscopy of ore and slag samples from BAS-273

Polished thin sections were prepared of two ore and five slag samples, which were then subsequently examined in reflected and transmitted light by David Killick at the University of Arizona. Four slag samples originated from EIA contexts at BAS-273. The fifth slag sample is from a LIA natural draft furnace and is included for comparative purposes. The results are presented below.

Ore samples

The two ore pieces, which weighed 118.5 and 70 g respectively, were recovered from the 30-40 and 40-50 cm levels of Unit 1 at BAS-273. They were determined to be hematite of a very good quality, probably close to 100% Fe_2O_3.

Slag samples

Four samples of slag (#800, #812, #808, #802) from EIA contexts were examined (Table 4). These samples were recovered from the slag pit below the furnace superstructure. The slags analyzed are representative of what was found in the pit. However, some heavier (though not large) pieces of flow slag noted during excavation of site BAS-273 were not recovered from the pit. It is also possible the furnace was reused, and it is uncertain whether it was fully cleaned after each smelting operation. Thus, we cannot be certain the samples are typical of a given smelt.

Slag sample #800 (shown in Figure 8b) comprised three conjoined pieces of slag with a total mass of 280 g. Its microstructure (Figure 13) indicates that this wüstite-rich slag was quite fluid as it drained freely from the bloom and ran into the slag pit. The geometrically perfect dendrites of wüstite (FeO) were the first to crystallise from the liquid slag, followed by large, well-formed blocks of what appear to be fayalite (Fe_2SiO_4) that grew around the wüstite dendrites (Figure 13). In between these silicates are dark areas of kalsilite ($KAlSiO_4$) or leucite ($KAlSi_2O_6$) enclosing tiny white sprays of wüstite (Figure 14). The slag solidified against the base of the furnace slag pit, which was concave and unlined, providing a macroscopic impression of the furnace base. The abundance of wüstite and the absence of phases with substantial alumina, such as hercynite ($FeAl_2O_4$), indicate the use of rich, pure ores, such as the hematite ore discussed above. The sample is nearly free of metallic iron and no partly reduced ore was noted.

[insert Table 4 here]
[Table 4. Analysed ore and slag samples from BAS-273 and BAS-252.]

[Figure 13. Sample #800 viewed in reflected light. Fayalite crystals (light grey) and wüstite dendrites (white) in reflected light. The darker grey groundmass is not resolved at this magnification – see Figure 14. The black areas are empty pores. Width of field is 1.25 mm.]

[Figure 14. Sample #800 viewed in reflected light at higher magnification. A cotectic intergrowth of tiny white wüstite dendrites with black kalsilite or leucite has formed in the spaces between larger proeutectic fayalite crystals (grey) and wüstite dendrites (white). The rest of the area between the larger crystals is a mixture of small fayalite crystals (light grey) and glass (dark grey). Width of image is 375 microns.]

Sample #812 is a clay-sand slag (140.1 g) that fused together in the bottom of a furnace pit. A study of the thin section in reflected light at high magnification revealed several small pieces of partly-reduced ore, slag and metallic iron attached to its upper surface, including a fragment of unreduced hematite, a piece of ore fully reduced to wüstite, and a piece of wüstite being reduced to metallic iron. It is probable that this slag was originally part of the furnace pit floor made of clay with quartz grains. It was converted to a partially-to-fully molten glass when it came into contact with molten iron slag descending from the bloom. This contact resulted in the rapid diffusion of iron and calcium into the glass, with the additional effect of lowering the melting temperature; the longer the high temperature persisted, the more deeply the clay-sand mix was altered.

The small samples of #808 and #802 weigh 28.8 g and 73.4 g, respectively. Both represent slag that solidified among pieces of charcoal fuel (up to 1.0 cm in length) during the smelt. They are both highly corroded, with a pumice-like texture due to many entrapped bubbles of gas.

The microstructure of sample #808 is similar to sample #800 in terms of the relative order of crystallization of its constituents. While a few small grains of metallic iron are present, about 50% of its surface area is made up of wüstite and about 30% of fayalite that enclosed the wüstite dendrites. In the spaces between crystals are rounded patches of a cotectic intergrowth (i.e. two solid phases crystallizing simultaneously) of either kalsilite ($KAlSiO_4$) or leucite ($KAlSi_2O_6$) with tiny white sprays of vermicular wüstite (Figure 15). The cellular structure of entrapped charcoal pieces is clearly visible, preserved by the conversion of the wood to graphite. The high-volume fraction of wüstite shows that this slag derived from a high-grade ore.

Sample #802, however, is richer in wüstite than the other studied samples. This slag clearly flowed less readily, oozing between and eventually solidifying around charcoal pieces. This sample instead exhibits two separate slag flows, with 25% of the sectioned area consisting of rounded voids. It exhibits a very high concentration of wüstite (60%) with minor glass and fayalite. Like sample #808, it also has a few rounded dark gray areas of late-forming kalsilite or leucite cotectic with wüstite. There is no hercynite ($FeAl_2O_4$). Once again, the ore used is inferred to have been of high-grade.

[Figure 15. Sample #808 viewed in reflected light. The first phase to crystallise was metallic iron (white), followed by wüstite (off-white) and fayalite (light gray), with some late-forming wüstite-kalsilite/leucite cotectic between larger crystals in upper right (blue arrow). The large rounded areas were entrapped gas bubbles, now partly filled with epoxy resin. Width of field is 1.25 mm.]

The microstructural analyses of these slag samples confirmed that the EIA furnace that they derived from was not a slag-tapping furnace. For comparison, a slag sample was also analysed from excavation Unit 32, a LIA slag mound from BAS-252 associated with natural draft furnace remains dating to cal. AD 1281-1400 (Table 1). The 320 g piece of slag was clearly broken from a larger piece, and the curvature of the unbroken side was suggestive of a pit c. 50 cm in diameter. This is too small to be the wall of a furnace but could be that of an external pit into which slag was tapped. The physical characteristics of the slag include its homogeneous gray color without visible crystals and almost no entrapped air bubbles; visible boundaries between separate slag flows; and the lack of magnetism in the interior but its presence in the exterior, suggests that some iron has oxidised to magnetite at the contact zone between the slag and the soil. Together, these features suggest that this was fully molten slag that had been tapped into an external slag pit. These deductions are in agreement with archaeological and ethnographic data that LIA natural draft furnaces in this region tapped slag into an external pit (Goucher 1984, 1986; de Barros 1985; Hahn 1997).

Analysis of a thin section of the interior of the slag indicated that the microstructure is homogenous across the section, comprising mostly bulbous single crystals and short stubby dendrites of wüstite, occupying >75% of its surface area (Figure 16), with rare anhedral crystals of gray silicate (likely fayalite) and glass around the wüstite. There are no distinctive kalsilite/wüstite eutectic (joint) intergrowths, and there is no metallic iron. The microstructure of this sample was thus very different from the EIA slag samples previously analysed. In conclusion, this appears to be the product of a slag tapping furnace using very high-grade ore, as shown by the predominance of wüstite in the microstructure. There are as yet no published studies of the chemistry or microstructure of Late Iron Age slags from Bassar, so we cannot say whether this sample is representative of LIA slag in the Bassar region. However, it is clearly a tapped slag, and very different from the Early Iron Age slags described above.

[Figure 16: LIA sample from Unit 32, BAS-252, in reflected light. Large bulbous crystals of wüstite (light gray) are dominant, with some interstitial glass (mid gray); voids are black. Width of field is 2.5 mm.]

Metallographic analysis of EIA iron artefacts from BAS-252

Metallographic analysis was undertaken on several artefacts selected from secure EIA contexts at BAS-252 (Table 5) by Lesley Frame, David Killick and Louise Iles at the University of Arizona (and subsequently by Iles at the University of York). Samples were removed manually from these artefacts using a fine jeweller's saw with hardened steel blades and a Buehler Isomet slow-speed saw with a diamond wafering blade. Each sample was then mounted in a low-viscosity epoxy resin to form cylindrical blocks, which were then ground and polished using progressively finer grades of silicon carbide abrasive papers (240 to 400 grit), abrasive diamond suspensions (15 to 1 micron) and finally, colloidal silica. The polished samples were studied in reflected light with an Olympus BX51 microscope at the University of Arizona, or a Leica DM1750 M microscope at the University of York. Samples were examined as polished to show the distribution of slag inclusions, empty spaces (voids) and corrosion, and again in Nomarski differential interference contrast (DIC) to check for variations in topography that might show regions hardened by elements dissolved in iron (typically phosphorous or arsenic). The samples were then etched lightly in nital (a 4% solution by volume of nitric acid in ethanol) to show the distribution of carbon across the surface and the size and shape of the grains of metal. The Vickers microhardness (HV) of the mounted sample of the only forged implement in the assemblage (the knife) was measured with a Buehler Micromet 3 semiautomatic microhardness tester with a diamond pyramid tip, at 200 g force and 10 seconds dwell time.

[insert Table 5 here]
[Table 5. Excavation and analysis summary of iron artefacts from BAS-252.]

Bracelets

Three iron bracelets or bangles that had been excavated from BAS-252 were analysed as part of this research. Two were child's bracelets derived from burial contexts at BAS-252 excavated in 2002; one was associated with the partial excavation of remains belonging to what is probably a single individual (#1011, Figure 17a) and the other was found in a communal burial (#1010, Figure 17b). The third bracelet, from the same excavations at BAS-252 (#1006), was significantly larger in diameter (Figure 17c), and was found in the same communal burial. In all three cases, the bracelets were worn by the individuals buried. These bracelets were assigned to the EIA for several additional reasons:

1) As discussed earlier, both the ceramics and radiocarbon dates indicate only three periods of occupation at BAS-252: the later LSA, the EIA, and the LIA. The three bracelets were found in burial contexts (adjacent Units 19-20 and Unit 39) dominated by Bright Mica Ware of the EIA with some Burnished Fine Mica from the LIA. The latter was found at deeper levels than usual due to the disturbance caused by the repeated addition of individuals to the communal burial. In addition, no indication of ceramic wares not usually associated with the EIA and LIA were recovered, such as Smoothed Fine Micaceous in association with Unsmoothed Brownware, which, based on seriation results, directly precedes the LIA which begins in the 13th century (de Barros 1985: 122, 628, 648-651; de Barros 1986: 157-160; Robion-Brunner 2018: 16).

2) No surveys or excavations to date have found ceramic evidence or radiocarbon dates of ironworking from the late 2nd through 12th centuries AD in the Bassar region, though this does not exclude that iron objects were obtained from trade with other regions.

3) Except for the highly disturbed human remains of what appears to be a single individual recovered from Units 11 and 14-18 (Figure 2b), burials are adorned with iron bracelets (or anklets or necklets).

4) Two of the bracelets (#1006 and #1010) were found in Unit 19 in the communal burial, which included at least four (possibly five) individuals, with evidence of four skulls or partial skulls, two of which were exposed in the sidewalls and were not excavated. While we do not know how far back in time this practice began, the Bassar, based on ethnographic data collected by the author, do not bury their dead in communal burials and they do not use grave goods (de Barros 2012a: 265-66, 2013: 19). This communal burial is dominated by Bright Mica Ware which dates from 893 cal. BC to 132 cal. AD (Table 1) and does not occur during later time periods.

5) Finally, a probable juvenile's skull in Unit 19 attached to the inside of a large sherd from a Bright Mica ware jar with knotted cord roulette decoration was encountered at 77-78 cm, suggesting the remains of a pot burial, a present-day mortuary practice of some peoples of northern Togo, such as the neighboring Konkomba (de Barros 2006: Slides 20-22). This direct association between human remains and Bright Mica Ware confirms an EIA context for this burial and supports other evidence presented for the EIA context of the bracelets within the communal burial.

[Figure 17. Three EIA bracelets recovered from burial contexts at site BAS-252: 17a. Child's bracelet #1011; 17b. Child's bracelet #1010; 17c. Large bracelet #1006 (after P. de Barros).]

The two child's bracelets are remarkably similar in terms of their dimensions: one has a diameter of 70 mm and the other 72 mm, while the circular cross-sections were approximately 10 mm in each. Each weighed 80 g. The bracelets had been formed by bending a cylinder of iron, and in both cases the join where the two ends met had not been welded shut. The third bracelet (Figure 17c) was much larger – with an external diameter measuring 116-122 mm – and with a roughly circular cross-section measuring c. 11-15 mm (including the amassed corrosion product) and a mass of 220.1 g. This item also had not been welded shut.

When examined in unetched polished section under the microscope, all three samples displayed a significant proportion of slag inclusions. In each case, the iron was first forged to a bar, and then the bar was rounded to give the circular section by bending first one side, then the other, and forging them down to rejoin either at the base or at the top and bottom. This is marked by S-shaped or triangular-shaped lines of slag inclusions, with large voids left where the apices of the folds failed to close completely (Figures 18a and b). The slag inclusions themselves comprise predominantly glass and coarse wüstite phases, indicative of cooling in air rather than quenching in water, which would favour a glassy slag microstructure

[Figure 18a. Cross-section of bracelet #1011 in reflected light. Folds of iron metal demarcated by bands of slag inclusions in the polished but unetched sample. The white scale bar is 1 mm.]

[Figure 18b. Central portion of bracelet #1011 in reflected light (unetched). The higher magnification shows that the slag inclusions consist of wüstite (pale grey, rounded) in glass (darker gray). The black scale bar is 500 microns.]

Examination of the bracelets after etching revealed more variation between these items. Sample #1011 consisted of two ferritic components: bands of large-grained ferrite displaying ghost phases relating to phosphorous segregation, alternating with bands of small-grained ferrite (Figure 19). The banded structure followed the same direction as the lines of slag inclusions. It is possible that these bands of ferritic and phosphoric iron are due to a deliberate manufacturing technique whereby strips of iron with different compositions have been forged together, but it is probably more likely in this instance – as the bands are not always separated by lines of slag inclusions – that the variation is due to variation of the phosphorous content within the iron blooms.

[Figure 19. Cross-section (etched) of bracelet #1011, viewed in reflected light. Two bands of phosphoric iron (lighter, complex internal microstructures) alternate with bands of small ferrite grains (darker grey). The black areas are elongated slag stringers. The black scale bar is 500 microns.]

Sample #1010 is also almost entirely composed of ferrite, with highly variable grain size (ranging between c. 40 and 400 microns) and a gradient in carbon content. There is a central band of large ferrite grains that display fine iron carbide or iron nitride particles that may have precipitated during cooling or during a subsequent thermal treatment. The grain size is much smaller towards one edge (upper left of Figure 20a). There are few slag inclusions in this area, so it is unlikely that the small grain size is due to physical restrictions in crystal growth. Instead, it might be due to variation in other elements present in the iron. ‘Ghosts’ of phosphorous segregation are visible in these smaller grains as relief at the grain boundaries (Figure 20b), though not to the same extent as in bracelet #1011. A patch of higher carbon content approximately 1000 microns by 600 microns is present on one edge of the sample, with proeutectoid Widmanstätten ferrite interspersed with pearlite colonies. A Widmanstätten ferritic plus pearlitic microstructure is indicative of rapid cooling, and its presence supports the theory that this bracelet (similarly to the other bracelets) experienced non-uniform cooling (probably in air). The carbon-rich regions in the bracelet (Figure 22) are probably due to variable carbon enrichment in the smithing hearth.

[Figure 20. Etched sample of bracelet #1010 in reflected light. 20a. Phosphorous segregation visible as 'ghosting' at ferrite grain boundaries (highlighted by red arrow). The black scale bar is 100 microns. 20b. Area of low-carbon steel (c. 0.20% C), showing proeutectoid Widmanstätten ferrite (white) interspersed with pearlite colonies (gray). The black scale bar is 200 microns.]

In the larger bracelet (#1006), the carbon content varies throughout, roughly following the bands outlined by the slag inclusions (Figure 21a). Two patches of low carbon content on opposite edges (0.15% C) grade evenly into areas of higher carbon, reaching up to 0.25% C, where irregular colonies of fine pearlite occupy the interstices between a continuous network of proeutectoid allotriomorphic and Widmanstätten ferrite. Two patches of higher carbon content – one of which is a mixed microstructure containing proeutectoid ferrite, fine pearlite, and bainite shown in Figure 21b – indicate rapid air-cooling.

[Figure 21. Cross-section of large bracelet #1006, etched, in reflected light. 21a. At low magnification, showing variation in carbon content (higher carbon content is darker and lower carbon content is brighter) and S-shaped lines of elongated slag inclusions produced by rounding of the section. 21b. Relatively high-carbon area; grains of fine pearlite and bainite are bounded by proeutectoid ferrite (white). The black shapes are glassy slag inclusions.]

In all the bracelet samples there is no grain deformation apparent; the bracelets were evidently deliberately annealed and air-cooled after shaping to their final forms.

Tool

An iron knife blade (Figure 22) was excavated from Unit 36 of BAS-252, at a depth of 88 cm, sandwiched in between two EIA dates (Beta-169562 and -173472) of 382-40 cal. BC and 371 cal. BC-53 cal. AD (Table 2) It comprised of a heavily rusted triangular blade, just under 90 mm long, with a maximum width of 23 mm, and with a mass of c. 15 g. The surviving thickness ranged from 1.95 mm at the tip to 3.34 mm at the wide end. A longitudinal section 23 mm long was cut from the tip back along the mid-line of the object and mounted to expose a cross-section of the blade at the mid-line (Figure 23). This is a comparatively well-preserved item given the inferred age of this artefact (c. 400 cal. BC – c. cal. 50 AD), and it is surprising that it still contains any iron at all given its thin profile.

[Figure 22. EIA iron knife blade from BAS-252 (after P. de Barros).]

[Figure 23. Sketch of EIA iron knife blade from BAS-252, indicating location of sample (L. Frame and P. de Barros).]

There is a moderate amount of slag in stringers parallel to the length of the sample. Individual slag inclusions are elongated from extensive hot forging above the glass transition temperature, with aspect ratios mostly between 5:1 and 10:1. Wüstite tends to be the dominant crystalline phase in the larger inclusions, with small slag inclusions composed only of glass (Figure 24a). Etching revealed a low-carbon microstructure of ferrite and pearlite; the average carbon content over the entire section is estimated at less than 0.05% C. The highest carbon content is in a small patch just behind the tip (the tip itself has been lost to corrosion), which consists of allotriomorphic ferrite, secondary Widmanstätten ferrite, fine pearlite and bainite (Figure 24b) - the carbon content of this areas is estimated to be 0.4% C. The carbon content gradually diminishes lengthways along the sample until c. 4 mm from the pointed end where only ferrite is present (Figure 24c). The ferrite-only microstructure persists along the length of the section until 1.5 mm from the other end of the mounted section, when the carbon content starts to rise again. The ferritic microstructure is fine-grained and contains tiny precipitates of iron carbide or iron nitride similar to (though more abundant than) those observed in bracelet #1010 (Figure 24d). The increased carbon content near the working edge of the knife would have ensured higher hardenability and slightly increased hardness through solid-solution strengthening to maintain a sharp cutting edge. The Vickers Hardness (HV) of this slightly carburised zone ranged between 140 and 179 HV over three readings. The lower-carbon core of the knife ensured increased toughness to prevent cracking and brittle failure of the knife during use (103-113 HV). It is difficult to determine from the limited evidence whether such a carbon gradient was intentional during fabrication, but the effects of the carbon-gradient would likely have been noticeable to the knife's user.

[Figure 24. Sample of knife blade sample, in reflected light. 24a. Slag inclusions at high magnification, unetched. The larger inclusions consist of wüstite globules (light grey) in glass (dark grey). The black scale bar is 50 microns. 24b. Higher carbon region near the tip of the sample (etched). Bainite and pearlite colonies are surrounded by jagged rims of secondary Widmanstätten ferrite (white) growing from allotriomorphs. This microstructure is typical of a normalised (air-cooled) medium carbon steel. 24c. Very low carbon region at low magnification, etched. This area consists entirely of fine ferrite grains (light) and lenticular slag stringers (dark). Etching is uneven, so not all ferrite grain boundaries are fully revealed. 24d. Area of low carbon iron at high magnification, etched. This region consists of ferrite grains with small amounts of pearlite at grain boundaries. Inside the ferrite grains are small black rods of iron carbide or iron nitride precipitates. The black spheroids at the bottom of the frame are tiny glassy slag inclusions. Width of field is 22 microns.]

The presence of precipitates in the ferrite may have formed during air-cooling or a low-temperature heat treatment after cooling. The precise thermal processing recipe (time and temperature) cannot be determined from observation of the optical micrograph alone. Because intermetallic compounds precipitate in steel at different rates depending on temperature and composition, further characterisation of these carbides using scanning electron microscopy (SEM), energy dispersive spectrometry (EDS), and x-ray diffraction (XRD) may allow a more detailed conclusion regarding heat treatment times and temperatures for this artefact.

Discussion: iron production technologies in EIA Bassar

Although the above analyses have taken place on a limited sample size, the analysis of slag samples from EIA sites in the Bassar region have provided a first glimpse into the production technologies in operation at this time. The analyses have stimulated several questions about the procurement of raw materials for the local iron production industry, including fuel and ore, and the organisation and operation of these production technologies.

Organisation of production

With the caveat that this was a sample of only two sites, it is still possible to hypothesise that in the EIA there was distinct separation of production activity areas. One relatively small EIA site (BAS-273) demonstrated evidence for smelting activity, with no evidence for smithing other than a small *likumanjool* used for pulverising small bits of bloom and/or bloom-slag mix as part of the iron refining process and/or added to courtyards and house walls to harden them as noted earlier. Smithing, however, was undertaken at a very large, contemporaneous EIA site 7 km to the west (BAS-252), where there was only limited evidence for concurrent smelting activity. Two additional, probably contemporaneous, EIA metallurgical sites were recorded in 1982 (as indicated by broken tuyères on the surface and the presence of Bright Mica Ware) a few kilometres west of BAS-252 (BAS-257 and possibly BAS-306), but these sites have not yet been studied (de Barros 1985: 383). As well as the apparent tendency for EIA smelting and smithing sites to be at different locations, there is also a relatively distinct separation between the residential and production areas within EIA smelting and smithing sites. . At BAS-273, there is a distinct residential zone north of the ironworking areas to the south, whereas at BAS-252 the six iron working zones are either directly adjacent to residential areas (Zones 1,2, 4 and 5) or separated at some distance (Zones 3 and 6), with little evidence that smithing was conducted inside or integrated into residential areas. During the LIA, de Barros et al. (in prep) show that both ethnographic and archaeological data from smithing sites in the Bitchabe region (Figure 1) do show such integration. As discussed earlier, LIA smelting sites are almost always located well away from residential areas.

Of note at BAS-252 is the change in technological focus from smithing in the EIA to smelting in the LIA after a long period of abandonment between radiocarbon dates of 211 cal. BC to 132 cal. AD (Table 1, Beta 173470), 1219-1284 cal. AD (Beta 385466; Robion-Brunner 2018: 16). No evidence of smithing activity was found in the LIA deposits, which is perhaps not surprising given the archaeological documentation of LIA spatial separation of smelting and smithing villages from at least as early as the 16th century due to regional specialization (de Barros 1985; 1986: 154-55). It may be that BAS-252, given its large size and its location with expansive views of the Bassar region, served as a central market place for smithing goods during the EIA. Whether this indicates an important degree of central control of production cannot be determined at this time and is beyond the scope of this paper.

BAS-273, the only well-documented EIA smelting site in this region, is just 1.1 km from the nearest ore deposit (*Bidjilib*, Figure 1). Previous studies have shown that during the LIA 57% of smelting sites with 77% of the regional slag volume are within 2 km of the nearest ore source; and at 4 km the figures increase to 85% and 97%, respectively (de Barros 1986: 157). Given the small scale of iron production during the EIA it is likely that carrying iron ore long distances for smelting was generally avoided. Finally, while EIA ironworking sites show little separation between ironworking and residential areas, the separation between smelting and residential areas became quite distinct during the LIA. However, how do we explain that at BAS-252 slag mound group A is only about 100 metres from the LIA habitation area?

Avoiding habitation areas may have served to reduce: 1) the risk of fire; 2) violations of taboos against sexual intercourse and the presence of fertile or menstruating women; 3) chances of witchcraft and other evil influences; or, 4) espionage regarding smelting secrets. However, several other factors also may have affected smelting site location during the LIA, including distance to ores, to water, to suitable clays for furnace and tuyère making, as well as charcoal availability and avoidance of good farming lands (de Barros 2000: 188-90). In this light, there is a good source of furnace clay exposed in a small drainage (not shown) that traverses the area of the slag mound groups A and B (Figure 2b), which may have encouraged smelters to build closer to their settlement than they might otherwise do. Thus, when choosing a smelting site location, a certain balancing act was likely to be in play.

In this instance, the spatial organisation of iron production activity at BAS-252 and BAS-273 is broadly consistent with the model built from ethnohistoric sources of the 19th and 20th centuries, that sees highly ritualised smelting activity kept isolated and secret, whereas less-ritualised smithing activity was public (Herbert 1993: 115). At this point, it might be relevant to consider the features associated with the EIA smelting remains at BAS-273, which suggest unexplained stylistic or symbolic behaviour. This includes the unusual grooved tuyère decoration, and a tuyère that had been buried vertically. Is this potentially symbolic behaviour associated with early iron production in general, or the application of a bellows technology specifically? These questions cannot at this point be fully addressed.

Furnace design

A key question is whether the EIA furnaces of the Bassar region were bellows-driven, or were natural draft furnaces comparable to those of the LIA. Given that the furnace height and the placement and number of the tuyères of the excavated furnaces are unknown, it is not possible to be certain. However, given the absence of multiple fused tuyères at the EIA BAS-273 site, and the conical shape of the tuyères at that site, it is likely that the EIA furnaces were bellows-driven. This supports wider evidence from sub-Saharan Africa, as natural draft furnaces have not been documented in Africa prior to 700 AD (Serneels et al. 2013). The microstructural analyses of the slag samples from BAS-273 confirmed that the EIA furnace that they derived from was not a slag-tapping furnace. This contrasts with the slag-tapping technology of the LIA furnaces studied to date in the region (de Barros 1986).

The furnaces from BAS-273 can be compared with three broadly-contemporaneous EIA furnaces from across West Africa (Deme and McIntosh 2006; Clist 2012; Fagg Rackham et al. 2017; Okafor 2004). The characteristics of the furnaces at Taruga, Opi and Walalde, as well as at BAS-273, are summarised in Table 6. All are dated by radiocarbon to the first millennium BC. The LIA furnace from BAS-252 dates from the late 13th to the end of the 14th centuries AD (Beta-169561, Table 1). The EIA furnace dimensions vary considerably in base diameter and slag pit depth, but all are probably forced draft (bellows-driven) furnaces. Only the Opi EIA furnace and the Bassar LIA natural draft furnace were slag tapping, but they used different techniques; at Opi it was a slag pit linked to the furnace via channels, whereas in Bassar the furnace was periodically opened to allow slag to flow into a shallow surface slag pit outside of the furnace.

[insert Table 6 here]
[Table 6: Important characteristics of four EIA furnaces, compared with Bassar LIA furnace.]

All four of the EIA furnaces in Table 6 are likely to be forced draft furnaces. The BAS-273 furnace is most like that at Taruga in that both are non-slag tapping furnaces with slag pits. In addition, while the internal diameter of Taruga furnaces ranges from 40-100 cm, the furnace at BAS-273 does fall within Taruga's higher range at an estimated at 96-104 cm. There are also some similarities between Walalde and BAS-273 in that both are non-slag tapping and both appear to be associated with probable agro-pastoralist populations (Deme and McIntosh 2006: 344-345; de Barros 2013: 18-19). Our analyses thus confirm that – in agreement with broader regional changes in technological practice – Bassar smelting technology shifted from an EIA forced-draft, pit-furnace method (BAS-273), to a later slag-tapping approach in the LIA that was likely natural draft (BAS-252).

Raw material exploitation

The EIA slags from the BAS-273 furnace indicate the use of ores rich in iron oxide and very low in alumina, reflected in the absence of hercynite ($FeAl_2O_4$) from the slag microstructure. This inference is supported by the analyses of the two hematite ore samples. It is likely that the source of this ore is the little ore mountain called Bidjilib situated south of BAS-273 (Figure 1). In fact, it is likely that Bidjilib ores were used during both the EIA and the LIA (Serneels, email communication, 12 February 2009; de Barros 2013), as it is the closest iron ore deposit to both BAS-273 (one kilometre to the north) and BAS-252 (seven kilometres to the west).

However, the LIA slag was heavily dominated by wüstite (c. 85 area% FeO), compared to the much lower iron oxide content of the EIA slags. This poses an interesting question for future research: were lower grade ores used during the EIA, and only later – as larger and hotter natural draft furnaces were developed – were higher-grade hematite ores that form liquid slags at higher temperatures used? Or to put it another way, was there less selectivity for higher grade ores during the EIA as opposed to the LIA? A more thorough documentation of the technology in operation – obtained through the study of a greater number of samples – is needed to address these questions.

Furthermore, the EIA slags contain small amounts of potassium-rich oxides, present as the cotectic of either kalsilite or leucite with wüstite. The source of the potassium would likely be wood ash from charcoal combustion. This contrasts with the lack of a kalsilite/leucite matrix present in the LIA tapped slag from BAS-252. One possible interpretation of this is that the LIA draft furnace was more fuel efficient (using a higher ore:fuel ratio) than at BAS-273, with a correspondingly lower proportion of fuel ash becoming incorporated into the slag. Another possibility is that different wood was used to make charcoal with a lower ash content. However, it is also notable that the LIA natural draft furnace slag's melting temperature would be about 100˚C higher (1400˚C) than at the BAS-273 furnace because of its particularly high $FeO:SiO_2$ ratio, as estimated from the slag microstructure, and this may have had a corresponding impact on fuel consumption. A more detailed investigation of the chemistry of a greater, representative sample of the slag from these sites would have to be undertaken to explore this avenue further.

The presence of phosphoric iron in two of the artefacts (bracelets #1011 and #1010) is of interest. Ores with a notable (though still relatively low) phosphorous content are generally found in the east of Bassar, including the ore outcrops of Bidjilib, Liba and Wawa (Figure 1), which have phosphorous contents ranging between 0.1 to 0.85 wt% P_2O_5 (Lawson 1972). More recent analyses by Robion-Brunner et al. (in prep.) have found the ores at Wawa to contain 0.12 wt% P_2O_5, and the ores at Bidjilib 0.18 wt%. In the west of Bassar, the ores have a very low phosphorous content, less than 0.1 wt% P_2O_5 at Tchogma and Bitchabe (Robion-Brunner et al. in prep.), and between 0.01-0.06 wt% P_2O_5 at Bandjeli (Lawson 1972). The presence of phosphorous in the iron objects from BAS-252 supports the hypothesis that they derive from ores from eastern Bassar. Phosphorous is considered unfavorable in modern metallurgy as it can result in unevenly distributed carbon and lead to brittle steel. However, phosphorous hardens ferrite and thus can produce positive effects in very low-carbon steel (McDonnell 1989; Iles 2014: 439-440).

Smithing technology

The availability of EIA iron objects presented a valuable opportunity to examine the material outputs of the Bassar EIA iron production technologies. The EIA iron artefacts from BAS-252 show quite dramatic variation in carbon content within individual items: the knife blade contained higher carbon steel in select regions, while the larger bracelet (#1006) displayed greater areas of higher-carbon (seemingly unnecessary for its function). The other bracelets are also dissimilar: one with a negligible carbon content (#1010), while the other shows bands of phosphoric iron (#1011).

The slag inclusions present in the EIA iron objects are mostly consistent with the EIA slag samples that were examined. All the artefacts appear to have been subjected to air-cooling after heating above the Ac_3 temperature. Any variation in the microstructures appear to be more closely related to the variations in composition (specifically the carbon and phosphorus content) than variations in heat treatments. Of particular note in terms of functionality related to observed microstructures is the knife blade. The higher carbon content at the blade tip would provide higher strength and the lower carbon core would provide increased toughness. The intentionality on the part of the craftsperson is difficult to determine from the examination of a single knife, but it is likely that the benefits of these microstructural features would eventually be recognised as the knife was used and replicated by the iron smiths.

Concluding thoughts

This research has identified an EIA non-slag-tapping furnace technology, powered by bellows, that seems to have encompassed some extent of symbolic behaviour. This is expressed through the decoration of some tuyères, and in the burial of an upright tuyère within a pit at the smelting site. Analysis of the iron objects suggests that these smelts produced variable blooms, with variable carbon contents – an expected outcome of bellows-powered bloomery iron technology.

Together, the archaeological and archaeometallurgical datasets have been able to provide detailed information about the *chaîne opératoire* of early iron production in Bassar, Togo. The discovery of EIA smelting and smithing sites in close proximity to one another, along with the availability of EIA iron artefacts, has provided a rare opportunity to build a comprehensive reconstruction of iron production technology. The availability of iron objects is especially unusual considering the antiquity of the iron objects; it is remarkable that they have survived in the archaeological record with sufficient iron remaining for meaningful analysis.

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