J World Prehist (2009) 22:415–438
DOI 10.1007/s10963-009-9030-6

ORIGINAL PAPER

Early West African Metallurgies: New Data and Old Orthodoxy

Augustin F. C. Holl

Published online: 6 November 2009

Abstract The debate on West African metallurgies cannot be properly understood without reference to the colonial template that featured Africa as the receiving partner in all crucial social, economic, and technological development. The interesting debate that took place in West Africa during the Colonial Period was more meta-theoretical than factual. These conflicting glosses, despite their lack of empirical foundations, have constrained the nature of archaeological research and oversimplified the dynamics of the many facets of technological innovation. The relative boom in archaeological research that took place from the 1960s onwards resulted in an exponential growth of factual information. Challenging evidence has emerged from Niger, Nigeria, Burkina Faso, Cameroon, Central African Republic, Gabon, Togo, and Senegal. The picture that emerges from this survey calls for more sophisticated explanations for the origins of West African metallurgies away from the single non-African source hypothesis.

Keywords Early metallurgy · West Africa · Chronology · Copper · Iron · Early forges

Introduction

> *…But my father always used to say that without counterevidence to refute a theory, science would never progress.* A theory is a battlefield in your head – *that was his pet phrase. And right now, I can't think of any evidence to counter my hypothesis.*
> Haruki Murakami, *Kafka on the Shore*. New York; Vintage Books, 2005: 204

The advent and spread of metallurgy signals the development and adoption of advanced pyrotechnology and the earliest genuine case of craft specialization. The technological innovations that played out in this case are rooted in earlier uses of fire to achieve irreversible alterations of raw materials. However, in most past societies the process of technological change was hardly goal-oriented at its very onset as the contemporary

A. F. C. Holl (✉)
943 Lennox Court, Ann Arbor, MI 48103, USA
e-mail: hollafc@gmail.com; dimichka@aol.com

mind-set tends to frame it. The past is another country. The effectiveness of technological processes and the shifting patterns of offer and demands were very likely embedded in completely different worldviews.

Innovation and technological changes generally operate on a 'trial and error' basis, sometimes called 'guided variation' (White and Hamilton, this *JWP* Special). The discovered and newly produced manufactured items were 'routinized' if distinct 'use-niches' were carved out in the social arenas. The fact that iron tools like hoes, cutlasses, and machetes are today seen as efficient agricultural equipment does not mean that the earliest metallurgists had this in mind and intended to boost agricultural output as is generally suggested (Holl 2000: 3; Van der Merwe 1980). The debate on the origins of West African metallurgies was launched in the early 1950s with a paper by Mauny (1952). Lhote's rebuttal was published the next year, triggering a new response from Mauny (Lhote 1952; Mauny 1953). This debate set the stage for what is still today an interesting scientific controversy. The issue of the debate is a simple one: how and when did metal production emerge, develop, and expand in West Africa? For Mauny, diffusion from Carthaginian North Africa was the explanation. For Lhote, the ubiquity of iron ore and the extraordinary diversity of African metal production techniques pointed to a local development.

Raw Facts

It goes without saying that Sub-Saharan Africa is one of the most under-researched continental landmasses of the world. Archaeological prospection activities in term of trial excavations sunk into the past of the continent, are few, widely scattered, and restricted in their grasp of past technological change. This said, it is worth re-stating the obvious: scientific assessments of the state of the art in any field of research are by definition provisional syntheses open to further falsification. Evidence for an early production and use of metal artifacts has been documented in a number of areas in West Africa (Figs. 1, 2). It is the case in the Akjoujt region in Mauritania, where Lambert (1975, 1983) conducted an intensive research program. She carried out surveys and excavations in the Guelb Moghrein at the copper ore mining site of the Grotte aux Chauve-souris, Lembatet-El-Kbir cemetery, and the copper smelting site of Lemdena. The small smelting furnaces recorded at Lemdena and the material from the Grotte des Chauve-souris range in date from 800 to 400 BC.

A comparable, and very likely related but in this case iron smelting tradition, dating from c. 800 to 550 BC, has been documented at Walalde, in the Middle Senegal valley (Deme 2003; Deme and McIntosh 2006). No furnace remains were found in the test pit but 47 tuyère fragments and 19 kg of slag were collected, and Killick estimated that the furnace temperature reached 1,200–1,300°C (Deme and McIntosh 2006: 336).

The Eghazzer basin in Niger has provided wide ranging evidence attesting to the mastery of copper and iron metallurgy. Grebenart (1985, 1988) has partitioned these traditions into an Early Copper I, dating from 2200 to 1500 BC, Copper II, from c. 850 to 100 BC, overlapping with an Early Iron I period. The copper exploited in the Eghazzer basin, found generally along fault lines, was sedimentary in origin. The exploitation of the Eghazzer basin copper ore did not result in the formation of long lasting mine shafts or pits which could be mapped in the landscape. Instead, the shallow (25–30 cm deep) depressions were rapidly eroded and leveled or filled up with redeposited sediments. The recorded archaeological evidence includes habitation sites, metal-smelting workshops and cemeteries.

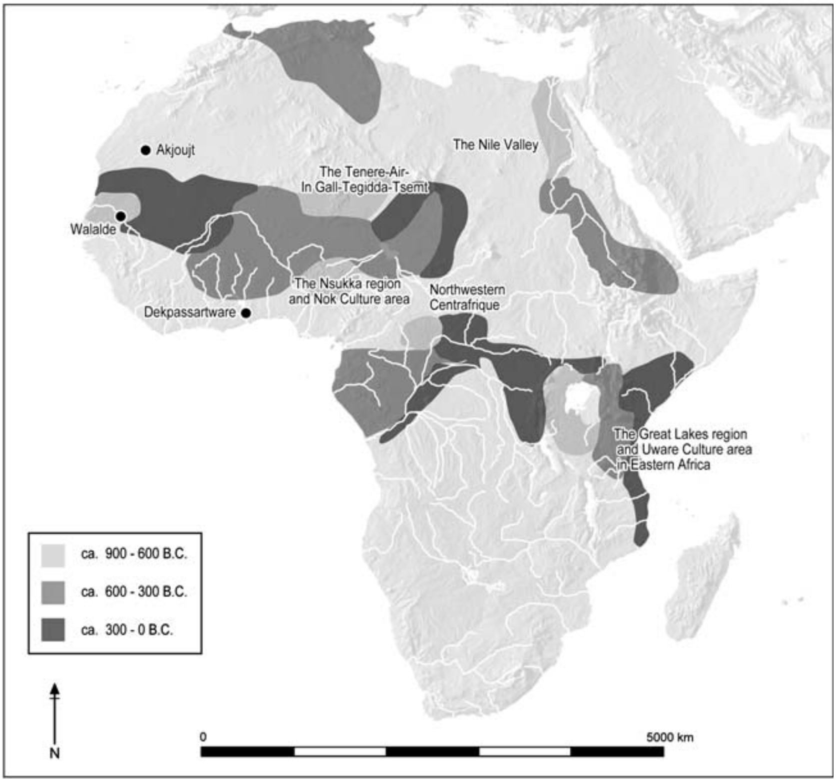

Fig. 1 Regional distribution of Early African metal producing traditions

The Termit massif further east in the Tenere was investigated in the early 1970s. A furnace base from Do Dimmi excavated in 1972 was dated to 2630 ± 120 BP and a nearby surface site with iron and copper implements dated 2925 ± 120 BP (Quechon 2002: 108). Additional research conducted in the same area at Gara Tchia Bo 48 Ouest and Est, Tchire Ouma, Tchi Guiribe, Termit Ouest 8 b and 95-b has confirmed these dates, pointing to an even earlier emergence of iron metallurgy (Table 1), with radiocarbon readings ranging from 3265 ± 100 BP to 2880 ± 120 BP (Quechon 2002: 109).

In Nigeria, first in the Nok Culture area at Taruga and Samum Dikuya, and more recently in the Nsukka region on the fringe of the equatorial rainforest, early iron smelting furnaces have been dated to around 750 BC (Okafor 1993, 2002). In the Nsukka region, the early phase of iron production is documented at Opi, Lejja, and Aku. Iron ore was smelted in natural draft furnaces measuring 0.85–1.25 m in diameter. The molten slag was drained through shallow conduits to collecting pits, where it formed huge, heavy slag blocks weighing up to 43–47 kg. The operating temperatures are estimated to have varied between 1,155 and 1,450°C (Okafor 2002: 37). This early metallurgical complex is dated to 765 cal BC to 75 cal AD. Well aware of the dispute on the reliability of radiocarbon dates when it comes to unexpectedly early metal producing features in Sub-Saharan Africa, Okafor was very rigorous in selecting adequate charcoal samples. ‘Those selected were sealed by slag and tuyère fragments on the floor of the furnace’ (Okafor 1993: 437), and run at the Oxford University MAS facility (Okafor and Phillips 1992; Table 1). The slag from these early

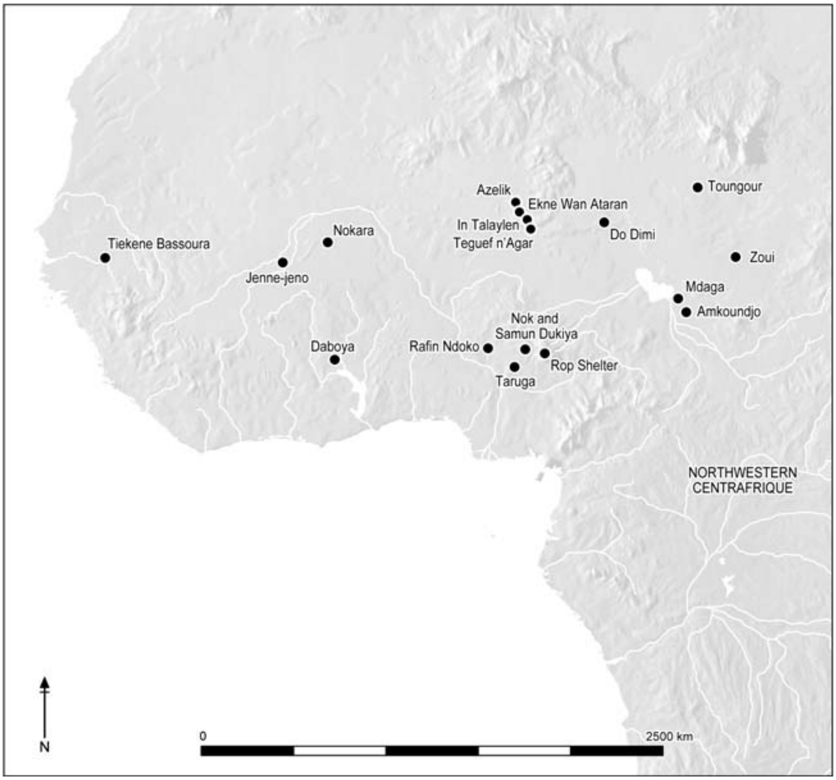

Fig. 2 Northwestern Central African early iron working sites referred to in the text

iron smelting sites consists essentially of fayalite, hercynite and wustite. The slag from Opi contains up to 22.47% of hercynite, a component with a fusion temperature as high as 1,780°C (Okafor 2002: 38).

Research conducted on both sides of the Nigeria-Cameroon border, along the northern periphery of the Mandara Mountains (MacEachern 1996), has revealed surprisingly early iron-using communities. Among many other cultural remains, iron artifacts and pieces of slag have been recorded but the trial excavations did not contain iron smelting features. Ghwa Kiva level 24 is dated to 805 cal BC (1130–390 Cal BC) (TO-4791), and Doulo Igzawa I level 6 at 760–555 cal BC (800–400 BC) (TO-4422) (Table 1). MacEachern (1996: 494) insists that ‘the iron artifacts recovered from Doulo Igzawa I and Ghwa Kiva, from the lowest levels or below, are also relatively large and in [his] opinion are unlikely to have moved significantly within the deposits’. Conservatively, it can be said that the northern periphery of the Mandara mountains was settled by iron-using communities in the first half of the first millennium BC.

Archaeological research conducted in southern Cameroon during the last three decades has completely changed our understanding of the past in that portion of Northwest-Central Africa (Essomba 1992, 2002; de Maret 2002). Many sites have brought to light evidence for the production and use of iron artifacts—Nkometou, Pan-Nsas, Pan Manguenda, Pan-Pan, Pongsolo, Obobogo, Ndindan, Ngock, Nguilmulen, Mbengue, Campo-Plage, and Okolo. Second or first millennium BC dates have come from Ndindan, Obobogo. Okolo,

Table 1 List of main radiocarbon dates mentioned in the text

Site	Date BP	CalBC/AD
Termit Massif, Niger		
Do Dimmi	2925 ± 120	1302–986 BC
	2630 ± 120	911–577 BC
Gara Tchia Bo 48 E	3260 ± 100	1666–1450 BC
Gara Tchia B 48 W	3265 ± 100	1672–1456 BC
Tchire Ouma 146	3230 ± 170	1718–1302 BC
Termit Ouest 95-b	3100 ± 100	1466–1218 BC
Termit Ouest 8-b	2880 ± 120	1254–940 BC
Tchi Gguinbe	2950 ± 100	1309–1031 BC
Nsukka Region, Nigeria		
Opi	2305 ± 90	530–246 BC
	2170 ± 80	337–115 BC
	2080 ± 90	254–6 BC
Lejja	1715 ± 35	370–266 BC
	2370 ± 40	520–410 BC
	4005 ± 40	2571–2491 BC
Mandara Mountains, Cameroon		
Ghwe Kiva Level 24	2639 ± 160	556–984 BC
Doulo Igzawa I 6	2500 ± 60	519–741 BC
Southern Cameroon		
Olinga	2820 ± 70	1096–910 BC
	2380 ± 110	700–370 BC
	1954 ± 250	272–324 AD
	1860 ± 70	75–229 AD
Gabon		
Otoumbi 2	2640 ± 120	883–691 BC
	2400 ± 50	690–432 BC
Tora-Sira- Tomo 1	2360 ± 70	761–212 BC

Source: Online Calpal: Cologne radiocarbon and paleoclimatic research

and Olinga, but the late second millennium BC dates from Olinga iron smelting furnace were rejected outright by virtually all Africanists. Essomba (2002: 137–138) re-discussed the series of radiocarbon dates from Olinga. Twelve radiocarbon dates have been run at two laboratories, Beta Incorporated at Miami, Florida, and Claude Bernard University at Lyon I, France. The Lyon series ranges from 770–210 cal BC at 1.30 m below the surface to 831 BC–AD 560 Cal BC/AD at 0.70 m. The Beta Inc series on the other hand ranges from 2820 ± 70 BP (Beta 31 414), calibrated to 1300–800 cal BC at 0.50 m below the surface to 1860 ± 70 BP (Beta 31412), calibrated to BC 334–0 Cal BC at the same depth (Table 1). The stratigraphic inconsistency of the radiocarbon readings could have been envisaged. Charcoal samples were collected throughout the excavation of the furnace fill and it is not clear what is being dated in this case (Essomba 2002: 139). The sediment filling of an abandoned furnace is the result of the inward collapse of the feature. Such a configuration cannot provide an accurate chronology of the use-life of the installation.

Early iron using communities are documented to have settled in the Gabonese rainforest during the first millennium BC. Their sites are spread all over the country, essentially along the rivers; Lope and Otoumbi in the center, Koualessis and Oyem in the north, Makokou in the northeast, Moanda in the southeast, and Mouila in the south. Otoumbi 2 furnace provided two radiocarbon dates (Table 1) that point to the middle of the first millennium cal BC for the introduction of iron metallurgy in the Gabonese rainforest (Clist 1989: 71). The excavated iron smelting sites present a number of common characteristics: furnace pits were lined with clay that turned into brick-like blocks after smelting; and reception pits for liquefied iron are absent. For Clist (1989), iron-smelting was introduced to Haut Ogooue in eastern Gabon around c. 400 cal BC: ‘it then spread from there downstream towards the coast where it was accepted ca 1900 bp by the former Neolithic people. The first secondary forest patches must have been formed at that time, after deforestation caused by charcoal production for use in iron smelting’ (Clist 1989: 90). However, the scale and intensity of early iron production in the Gabonese rainforest are not sufficiently well known to allow accurate environmental assessments. The suggestion of an early episode of deforestation linked to the production of charcoal to be used in iron-smelting operations is clearly a ‘learned guess’.

de Maret (2002) offers a summary of the chronological research on the antiquity of iron metallurgy in north central Africa, encompassing the Nok culture area in Nigeria in the north, Cameroon, Gabon, Central African Republic, and part of Rwanda. According to him, ‘iron metallurgy is present from the end of the ninth century BC’ (de Maret 2002: 125). He also mention the common attitude of some researchers of systematically rejecting radiocarbon dates that are beyond a certain threshold by claiming that the samples were contaminated by older carbon.

Recent archaeological research along the Chad–Cameroon pipeline transect has provided early first millennium BC dates for iron smelting features (Lavachery et al. forthcoming). The authors of the Chad Export Project archaeological report appear to have a hard time dealing with their own findings, findings that are in fact much less isolated than appears at first glance, and lend strong support to the research conducted by Zangato (1999, 2007) in Northwestern Central African Republic. Iron smelting furnaces dated from c. 836–782 cal BC to 513–430 cal BC were excavated at Gbabiri I and Gbavian. The sites are two kilometers apart. The former had a set of six furnaces and the latter three (Zangato 1999: 101–109). The furnace bases measure 1–1.5 m in diameter and were all associated with a relatively large bottom slag, tuyère fragments, scattered crushed slag and iron implements. These first results challenged accepted wisdom; they received at best a lukewarm reception and were in general simply ignored. Continued fieldwork has resulted not only in the confirmation of prior findings but in the discovery of still older iron processing facilities at Oboui, located at 6°03′N/15°20′E, at 1,048 m above sea level in the eastern extension of the Adamawa plateau, and dated to c. 2200–1965 BC (Zangato 2007; Saliège 2007: 135). Oboui was a small residential site of iron using communities ‘discovered’ in 1992 after torrential rains eroded most of the capping sediments (Zangato 2007: 11). It took eight field seasons of 2–9 months from 1992 to 1996 to probe some 800 m^2 of the site’s deposit. The data obtained from the excavation so far offer interesting insights into all aspects of the *chaîne opératoire* of iron production, except for the initial mining and iron ore smelting. The site was used, very likely on an intermittent basis, from 2340–2058 BC to 346–544 AD. The features of interest here include furnaces, hearths, trash pits, charcoal storage pits, and anvils, arranged in a more or less coherent forge workshop. The forge unit, the focus of Zangato’s (2007) book, measures 8 by 6 m (Fig. 3), articulated on a central furnace, surrounded by charcoal storage pits (St. 6e and 6d), a drenching pot (St. 6 g), pits (St 6f, 6i, and 6j), an anvil, a hearth (St. 6 h), bloom fragments, and finally, scattered fragments of iron artifacts. All these features are dated

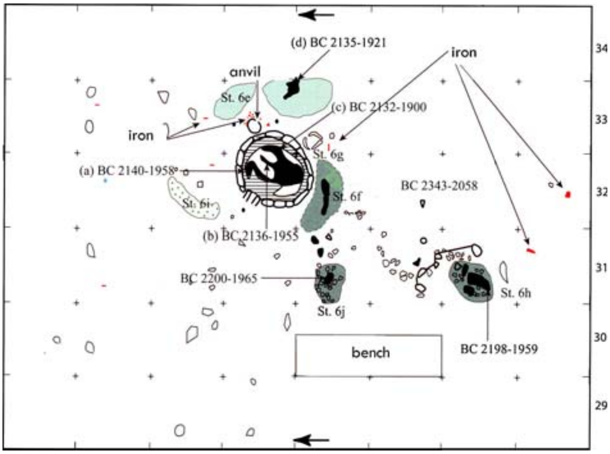

Fig. 3 The forge area from Oboui, Central African Republic (adapted from Zangato 2007: 50)

from 2343–2058 BC to 2135–1921 BC, indicating that they were clearly in use at the same time. The recorded early artifacts range from needles to blades, with undetermined iron fragments. The analysis of slag samples attests to high-performing smelting installations with very small amount of lost iron. The dendritic pattern of ferrite crystallization points to high furnace temperatures that may have reached 1,536°C (Fluzin 2007b: 60). And the main technique of artifact manufacture appears to have been hot-hammering combined with quenching (Fluzin 2007a: 72). The Oboui blacksmith workshop was very likely built under a shelter, and the collapse of all these features may have enhanced the preservation of the site's archaeological record.

The site of Gbabiri 1 is located five kilometers north of Oboui, at 1,080 m above sea level. It measures some 8 ha with two trial excavations, 200 and 300 m^2 in size, sunk in the south and east of the site (Zangato 2007: 67). The uncovered forge is dated from 902–794 BC to 895–773 BC. In this case too there is a forge furnace, a quenching pot, a charcoal storage pit, slag pieces, clay smoking pipes and a number of iron artifacts (Zangato 2007: 69). A sample of 141 iron artifacts was collected during the research project. Weaponry is largely predominant, accounting for 11 out of 18 functional categories (Zangato 2007: 118). These include knives (and fragments), spears (and fragments), arrow heads (and fragments), harpoons (and fragments), and axes (and fragments). Needles were probably used in craft activities, and rings point to personal adornment. Oboui and Gbabiri were blacksmiths' workshops. In both cases, the initial smelting of iron ore took place in a different locality that has not yet been found. The iron-working traditions of northern Central Africa, also found around Djohong in Adamawa, Cameroon, but better researched in Northwestern Central African Republic, emerged at the very end of the third/very beginning of the second millennium BC. At this stage there are no documented copper or bronze making traditions in the area, suggesting the possibility of direct shift from Late Stone Age to iron smelting technology.

Recent research conducted at Dekpassanware in north central Togo has revealed the existence of early iron smelting sites that took the principal investigator totally by surprise (de Barros 2003, 2006). The tested site measures some 30 ha in size, with 1.80–2.10 m thick cultural deposit consisting of slag concentrations, laterite zone, a burial pit, as well as burnt wattle and daub pieces. The pre-Iron Age deposit, dated to 800–400 BC, underlay the site's occupation sequence which is also capped by a later Iron Age deposit dated to AD 1300–1600. The intermediate deposit contains Early Iron Age remains made of slag, iron ore, and tuyères. It points to iron smelting activities that took place from 400 BC to AD 100, 'or 1,000 years older than expected' (de Barros 2003: 75).

An early iron-smelting site was found and excavated at Tora-Sira-Tomo 1 (TST-1) in the Mouhoun Bend in northwestern Burkina Faso (Holl and Kote 2000). It is part of a large cluster of 17 mounds, and measures approximately 50 m in diameter. It includes a meter thick deposit of iron-smelting waste made of slag, tuyères, and furnace wall fragments, with a series of clay containers in an upside-down position (Fig. 4). These pots, probably used by the iron-smelting crews, were arranged in clusters spread all over the eastern half of the site. The base of a relatively large iron-smelting furnace was found at 0.45 m below the surface in the central part of the site (Fig. 5). A line of red bricks found along the trench section suggests that the uncovered furnace may have measured at least 3 m and maybe 4 m in height. A fire-hardened surface was exposed on the eastern side of the furnace, the mouth of which was oriented northeast. The remaining part of the furnace measures 1.80 m in diameter (Fig. 5). Its wall, 0.20 m thick, built with superimposed irregularly shaped clay lumps in two layers, an inner and an outer one, was preserved up to a height of 0.25 m. A group of broken and complete tuyères was exposed on the north flank of the furnace; a set of three clay vessels was exposed on the fire-hardened surface on the east flank.

Fig. 4 View of the eastern half of the iron smelting site of TST 1, with series of vessels in upside down position

Fig. 5 View of the top level of TST-1 furnace

Slag, fragments of bricks, and broken tuyères filled the interior part of the furnace. This deposit was accumulated on top of a tuyère level at 0.60 m below the surface, above a relatively thin bottom slag. These eight relatively well preserved tuyères converge to the center of the furnace within the middle of a mass of burnt clay, bricks, and slag, capped with a whitish (5–10 cm thick) circular chalky deposit (Fig. 6). The preserved segments of the eight tuyères are more or less organized into pairs. They measure 30–40 cm in length and 10 cm in diameter at the proximal end, and 5–6 cm at the distal one. The more or less balanced arrangement of the tuyères, coupled with the eastern orientation of the furnace mouth, suggest that this installation was a natural draft one.

The circular white chalky deposit at the center of the furnace is presumably made of the remains of the fluxing material used in the smelting process (Fig. 7). It is not yet known if

Fig. 6 View of the eight tuyère arrangement

Fig. 7 TST 1 furnace: the bottom slag below the tuyère level

Fig. 8 View of the bottom of the furnace below the bottom slag with two series of tuyères

this was an intentional addition to the furnace, or the result of the kind of wood used as fuel. In any case, fluxing material optimizes fuel use by lowering the temperature at which the iron ore starts to melt (Schmidt 1996). Surprisingly, the bottom slag is relatively small in size, and the structure of the furnace finally appears much more complex and interesting than thought. The rest of the furnace was still to be found 1.20 m below ground, some 0.60 m below the level of horizontally laid tuyères. An underground chamber, tronconically shaped (i.e. a truncated cone), was dug in the natural brown-gray silty clay layer. It measures 0.60 m in diameter at bottom, with the base and wall lined with a mixture of crushed laterite gravel and clay. Fourteen vertical but slightly tilted tuyères arranged into two distinct sets were found in this part of the furnace installation (Fig. 8). The western set has six tuyères, and the eastern one eight, with the central space filled with termite nest material. The later material is hard enough but porous, allowing for the efficient transfer of heat from the operating furnace. The tuyères found at the bottom of the furnace had no direct connection with the combustion chamber. The six specimens from the western set measure 26–14 cm in length and 10–13 cm in maximum diameter. The eight from the eastern set were longer on average, 26–40 cm, with a narrow diameter range of 11–12 cm. Further work on these tuyères has shown that they had not been used in any smelting process, and were filled with sediment that was easily removed. This suggests that the local iron-smelters had developed a streamlined system of operating the furnace, designed to generate a reliable and constant supply of ready-to-use blow-pipes, an important economy of scale. A new supply of dry tuyères was set to be fired below the combustion chamber, taking advantage of the high temperature generated by the furnace during the iron ore smelting process. Once the process is completed, the furnace is left to cool, the bloom is collected and the new load of fired tuyères is recovered to run the next shift.

The furnace structure uncovered at TST-1 is a relatively sophisticated piece of craft engineering. There is no known case in African literature on metallurgy, in either archaeology or ethnography (Bisson et al 2000; Bocoum 2002; Coulibaly 2006; Herbert 1993; Kiethega 2006). The pyrotechnological performance of the whole installation has yet to be assessed in detail. The furnace was a natural draft one, operating without bellows on the natural strength and persistence of the dry season northeastern wind (the Harmattan). That is likely to be why the furnace mouth is oriented northeastwards.

However, the greatest surprise of the excavation of the TST-1 smelting site was the radiocarbon date obtained from a large charcoal sample collected on the fire-hardened surface at less than one meter from the furnace mouth. The reading shows the smelting site to date to 501–386 cal BC (1-Sigma) or 761–212 cal BC (2-Sigma; ISGS 4349 = 2360 ± 70 BP; Holl and Kote 2000). The technical expertise involved in the conception, construction, and operation of TST-1 furnace is astounding.

Bena, at 12°04′05″N/4°11′02″W, in the Bwamu in Western Burkina Faso, is the other early iron-smelting site discovered to date in that country. It is comprised of semi-subterranean natural draft furnaces and dated to c. 360–220 BC (Kiethega 2006; Coulibaly 2006). TST-1 and Bena are both located in the Mouhoun River catchment basin. This area of Burkina Faso seems to have witnessed an early emergence of iron metallurgy between c.700 and 300 BC.

Assessing the Evidence

Despite significant improvement in research protocols and an increased output of challenging results, the archaeology of African metallurgies is still in a remarkable state of flux (Alpern 2005). The data presented above point to the existence of metallurgical traditions as old as the late third/early second millennium BC. They are at variance with the idea of the diffusion of iron technology to sub-Saharan Africa in the mid-first millennium BC (Deme and McIntosh 2006; McIntosh 1994; Killick 2001, 2004; Killick et al. 1988; Mitchell 2005).

Science and speculation are not antinomic. They are in fact intimately related. Hypotheses are speculative statements devised to be tested. A reassessment of the state of research (Bocoum 2002, 2006; Bisson et al. 2000) shows that iron metallurgy is older in the continent than on its periphery. Evidence for copper metallurgy dated from c. 2200 to 700 BC is documented in the Eghazzer basin in Niger and the Bir Moghrein in north-central Mauritania. The exploitation of copper ore, its smelting in low bowl furnaces, and the production of artifacts ranging from items of personal adornment to weaponry were practiced in West Africa as early as the end of the third millennium BC (c. 2200 BC) (Bisson et al 2000; Bocoum 2002, 2006; Holl 2004). Iron metallurgy is also attested in archaeological contexts dated to the very beginning of the second millennium BC, in the Air-Termit in Niger, and the Bouar region in northwest Central African Republic (Zangato 1999, 2007). The recorded iron-working traditions from northwestern Central African Republic, Northern Adamawa in Cameroon, Walalde in the Middle Senegal Valley, Dekpassanware in Togo, and in the equatorial forest of Southern Cameroon and Gabon are not preceded by any copper or bronze metallurgy tradition. There is a near simultaneity in the emergence of iron technology in at least four distinct areas: the In Gall Teggida-n-Tesemt in Niger, the Nsukka area in Nigeria, the Middle Senegal Valley, and Northern Mandara (Deme and McIntosh 2006; Grebenart 1985, 1988; MacEachern 1996; Okafor 1993, 2002). Egypt and the Lower Nile valley are a special case certainly influenced by the developments in the Near East. From approximately 1000/900 BC to 100 BC, the practice of iron metallurgy spread to large stretches of the continent, from the Central Sahara to most of West Africa, as far south as Dekpassanware in Togo, where a surprisingly early iron smelting site dated to 400 BC was discovered recently (Bocoum 2002, 2006; de Barros 2006), along the Nile Valley in the Northeast, in Carthaginian North Africa, and within and along the north edge of the equatorial rainforest. The series of recent finds (Pringle 2009) have not affected the conviction that metallurgy was imported to and spread throughout Africa (Childs and Herbert 2005; Childs and Killick 1993; Killick et al. 1988; Killick 2001, 2004; Mitchell 2005) by Carthaginians, Egyptians, or still unknown protagonists in the middle of the first millennium BC. Two competing hypotheses were used to explain the advent of iron metallurgy in Africa. The Meroe hypothesis was enhanced by the impressive evidence of iron metallurgy found around that Nubian town located in the Nile Valley. It was nicknamed the 'Birmingham of Africa', and considered to have been a crucial staging point of iron metallurgy, from where it spread to the rest of the continent. This scenario was falsified by Trigger (1969) and Shinnie (1985). Van der Merwe (1980), on the other hand, offers the most wide ranging characterization of the alternative, 'Carthaginian Origins' thesis. According to him,

> 'They [the Carthaginians] must obviously have had iron and the knowledge to produce steel, since their roots in the Eastern Mediterranean were practically in the heartland of iron-working of the time. No direct evidence for metal working has been found in Phoenician sites of the North African coast, but many references to iron and copper smelters occur on the stelae. Metal production probably took place elsewhere in the interior, the coastal towns having been sited for reasons other than a metal industry. Iron-working in this region is likely to have been of a utilitarian nature, with emphasis on the tools of war. The Phoenicians traded extensively with the Berbers, who in turn bartered with the Neolithic peoples south of the desert. To the existing trade of salt for West African gold and slaves the Berbers probably added Phoenician goods, including iron' (Van der Merwe 1980: 477).

This conjectural history conflates material and events spanning more than 1,000 years (Holl 2000: 8). The stelae alluded to is from Dougga and dates to the second century BC. Recent intensive archaeological works allow for a better grasp of the history of Carthage (Aubet 2001). The city, founded in the eighth century BC, reached 55 ha in extent in the seventh century. As detailed in Holl (2004), it was built at 1.7 m above sea level, directly on the beach sand, with streets, squares, gardens, and large isolated houses made of sun-dried bricks. 'The archaeological evidence suggests that the earliest colony of the eighth to the seventh centuries BC was surrounded by a kind of "industrial belt" outside the walls, consisting of workshops and metalworkers' furnaces…, installations devoted to working the murex to obtain dye, and to potters kilns' (Aubet 2001: 219). The earliest evidence for Carthaginian iron-working thus dates from the eighth to seventh centuries BC, synchronous with or later than in some parts of sub-Saharan Africa. The core of the issue seems to revolve around the evolutionary model used to make sense of the archaeological record at hand. Proponents of the mid-1st millennium BC date for the introduction of iron metallurgy in sub-Saharan Africa rely explicitly on technological gradualism, with their emphasis on the necessity of prior familiarity with advanced pyrotechnology. Punctuated equilibrium models on the other hand, make more sense of a sudden, unforeseen, and unpredictable burst of creativity that may have resulted in multiple independent discoveries of metallurgical techniques. Data at variance with the artificial 'standard 500 BC baseline' tend to be ignored (Childs and Herbert 2005; Herbert 1993; Killick 2001, 2004; Mitchell 2005; Schmidt 1996, 1997).

A Critique

Scientific data tend to answer some questions and generate new ones. For scientific inquiry to work, researchers have to share some commonalities on the standards required for new discoveries to be accepted as valid. The earliest objection to an early presence of metallurgy in sub-Saharan Africa, formulated by Mauny (1953), was for a long time articulated by citing the lack of prior pyrotechnological skills. Further research has shown this position to be incorrect. Copper metallurgies have been documented in the Akjoujt region of Mauretania and In-Gall Teggida-n-Tesemt (Eghazzer basin) in Niger. The objection then shifted to the unreliability of radiocarbon dates older than 500 BC, for two distinct but related reasons: on the one hand, it is ascertained that erratic fluctuations of atmospheric carbon during part of the first millennium BC produces a flat calibration curve between 800 and 400 BC, making it impossible to assign a precise time range to the appearance of iron metallurgy (McIntosh and McIntosh 1988). On the other hand, it is assumed that dates older than 500 BC are systematically contaminated, or plagued by the problem of the 'old wood' effect. Some researchers emphasize the uncertainty of the link between the dated sample and the cultural remains contained in the deposit to be dated (Deme and McIntosh 2006: 341, Killick et al. 1988). Metal production features are not 'Pompei-like' installations. As with all other archaeological features, they are exposed to taphonomic and other post-depositional disturbances, from their initial construction to their discovery by archaeologists. It is therefore not surprising that some installations, like the furnaces of Oliga in southern Cameroon (Essomba 2002) and Koussane in Mali (Dupuy et al. 2001–2002), have provided problematic suites of radiocarbon dates. These are serious objections, but they are not unsolvable. Relying on a handful of problematic radiocarbon dates to trump an important historical and socio-economic issue would be poor science. Referring to the findings from Niger and their surprisingly early dates for copper and iron metallurgies, Killick et al. 1988 wrote:

> ' the only positive evidence for metallurgy in this region … is a single radiocarbon date of 1710 ± 110 BC (Gif 5176) for a copper working furnace… We suggest that this radiocarbon date be viewed with great caution until it can be corroborated by another method such as thermoluminescence dating of the fired lining of the furnace…Until these are available, the evidence for metallurgy in Niger prior to 1000 BC remains in doubt'.

The position is reasonable, and fair enough if the objecting researchers are ready to change their minds and accept new information that confirms the unexpected antiquity of copper and iron metallurgies. But, unfortunately, the researchers criticized did not think that thermoluminescence dating techniques were an appropriate response to the chronological problems they were trying to solve. With the objection of Killick et al. (1988) in mind, Paris, Person, Saliège and Quechon (Quechon et al. 1992) devised a radiocarbon dating project for the Termit area that aimed at minimizing the discrepancy between the material dated and the context being dated (Quechon 2002, Person and Quechon 2002). Samples to be dated were taken from the organic temper found in potsherds, and from charcoal found in smelting features and other archaeological features in habitation sites (Quechon 2002: 108). The concordance between the radiocarbon readings obtained from the two sources provides strong and convincing data. Despite this carefully crafted research protocol, these new results do not seem to have significantly influenced positions (e.g. Killick 2001, 2004). According to Deme and McIntosh (2006: 341), 'archaeometallurgists have argued that no clear evidentiary mandate for any position on origins currently exists; much more evidence on smelting technology in different areas needs to be collected before arguments for technology transfer vs. independent invention can be evaluated'. This is fair enough, but it is not clear precisely who among the West Africanist archaeometallurgists is alluded to. Benoit et al. (2004), Okafor (1993, 2002), Bocoum (2000, 2002, 2006), Coulibaly (2006), Fluzin (2002), and others do not share the position. Finally, the suggestion that '…only three sites in West Africa—Taruga and Opi in Nigeria and Walalde in

Senegal—have produced a combination of evidence that includes first millennium cal BC ^{14}C dates in undoubted, stratigraphically sealed association with metallurgical remains, published metallurgical analysis of slag and other residues, and descriptions or reconstructions of furnace type and technology' (Deme and McIntosh 2006: 341) is incorrect. Lambert (1975: 19–22; Tables I, III, and IV) has published analyses of sediment, copper ore and slag from Lemdena and the Grottte des Chauves-Souris in the Akjoujt region. Grebenart (1985: 331–346) has published metallographic analyses of copper and iron objects done by Bourhis of the CNRS *Laboratoire de Métallographie* of the University of Rennes in Brittany and France-Lanord of the *Centre de Recherches de l'histoire de la siderurgie* at Nancy. These analyses are complemented by a series of high magnification metallographic photographs. Discussions simply focused on archaeometry and radiocarbon dating of early West African metallurgy completely misses the point. What is required is a generative model encompassing the production and the social demand sides of metallurgy. Direct dating of iron artifacts being developed at the Lawrence Livermore National laboratory at Berkeley by Cook et al. (2003) may in future be able to solve any chronological

Table 2 Radiocarbon dates from a sample of iron artifacts from the Mouhoum Bend, Burkina Faso, in context

ISGS NO	SAMPLE	C-14 AGE (RCYBP)	C-13 (VS PDB)	Cal BC/AD (1 sigma)	Cal BC/AD (2 sigma)
Kerebe Sira Tomo (KST)					
KST-4					
1-4340	KST-4 (0-20)	710 ± 70	−25.1	1262–1382 AD	1195–1401 AD
2-4343	KST-4 (40)	550 ± 70	−26.2	1313–1435 AD	1292–1453 AD
3-4320	KST-4 (50)	660 ± 70	−24.6	1282–1396 AD	1244–1418 AD
4-LLNL	*KST-4 (40-60)*	*1830 ± 50*	–	*123–235 AD*	*67–291 AD*[a]
5-4341	KST-4 (60)	720 ± 70	−26.8	1259–1379 AD	1191–1399 AD
6-4344	KST-4 (75-80)	790 ± 70	−25.2	1191–1284 AD	1042–1379 AD
7-4345	KST-4 (100)	720 ± 70	−24.7	1259–1379 AD	1191–1399 AD
Tora Sira Tomo (TST)					
TST 3					
8-3927	TST-3 East (20-40)	460 ± 70	−22.5	1412–1477 AD	1326—1631 AD
9-3931	TST-3 East (80-100)	780 ± 70	−26.4	1211–1287 AD	1059—1382 AD
10-3928	TST-3 East (120-140)	710 ± 70	−25.8	1262–1382 AD	1195—1401 AD
11-4586	TST-3 West (20-40)	790 ± 70	−24.8	1191–1284 AD	1042—1379 AD
12-LLNL	*TST-3 West (20-40)*	*740 ± 40*	–	*1212–1300 AD*	*1220—1380 AD*[b]
13-4587	TST-3 West (40-60)	740 ± 70	−24.6	1223–1298 AD	1163—1393 AD
14-4588	TST-3 West (60-80)	880 ± 70	−25.5	1037–1241 AD	1018—1281 AD
15-4585	TST-3 West (100)	960 ± 70	−25.4	1003–1162 AD	904—1222 AD
16-4590	TST-3 West (120)	980 ± 70	−24.9	997–1158 AD	899—1216 AD
TST 12					
17-4596	TST-12 (40)	720 ± 70	−25.7	1259–1379 AD	1191—1399 AD
18-LLNL	*TST-12 (40-60)*	*570 ± 30*	–	*1280–1400 AD*	*1300—1430 AD*[c]

LLNL Lawrence Livermore National Laboratory

Radiocarbon dates from iron objects processed by Dr. Andrea C. Cook at Lawrence Livermore National Laboratory, UC Berkeley: [a] From an iron ring; [b] From a small iron spear; [c] From a large iron spear discrepancy between metal by-products and archaeological contexts: the carbon contained in an iron artifact is dated directly through a complex experimental protocol allowing for a more accurate assessment of the chronological congruence between the artifact and the stratigraphic context. Cook and co-workers obtained iron artifact samples from different parts of the world. Three such artifacts from the current author's research at Tora Sira Tomo and Kerebe Sira Tomo in Burkina Faso were used in the experiment. Two of the pieces support the results obtained from charcoal samples collected in the deposit (Table 2). One provided a radiocarbon date older than the deposit but still within the time frame of the occupation of the site, suggesting that this artifact may have been 'scavenged' from older deposits.

Technological Innovation: A Model

The invention or adoption of new technologies is best considered as linked to what may be termed 'craft specialization'. There is an important and substantial difference between invention and innovation. 'The term invention is reserved for genuinely original acts of discovery, occurring under circumstances that are largely outside of and immune from economic processes. Innovations, on the other hand…involve the combination, modification, and application of themes drawn from an existing pool of knowledge' (Adams 1996: 19). Technological innovation can thus be conducted on a trial-and-error basis, and independently in different socio-cultural contexts. Three options can be considered here. In the first, the adoption of an innovation may be delayed for various lengths of time and different reasons. In the second, the known innovation can be rejected, ignored or discarded. And in the third, the new technology can be mastered quickly and adopted widely after a short period of trial and error. The social and economic value of an innovation is often unpredictable even within modern advanced technological societies (Adams 1996; Latour 1993). A technological innovation can be termed neutral if it does not modify the overall format of a social system. It can also trigger unexpected and radical transformations if its adoption results in genuine change of the actual society, a change that may be positive (positive feedback) or negative (negative feedback) (Holl 1997).

The analysis of the emergence of craft specialization among African late prehistoric societies has to be implemented within a wider research framework—a framework that may include, to mention but a few major variables, changing relations between social systems, environment, subsistence, and socio-economic organization. Technological systems of whatever kind are always embedded in social systems. The advent of a new technology may create a new and unsuspected social demand, satisfy a pre-existing one, or even collapse if the new offer is not supported by sustained demand. In other words, any novelty has to be meaningful for any society. As Lemonnier puts it (1993: 17):

> 'techniques appear quite arbitrary from the standpoint of their physical adequation to specific effects on matter. And one crucial aspect of this arbitrariness seems to be that it finds its own logic in the production of what is called (for want of a better term) "meaning". By classifying and interpreting what constitute their social and material environment, and notably the relations they carry on with other individuals and groups, people confer meaning on the world they live in . . . men put meaning into the very production of techniques as well as make meaning out of existing technical elements'

Metal products are embedded in wide-ranging social tactics and strategies of identification and distinction encompassing functional imperatives (Bourdieu 1979; Holl 2000). Consequently, to the normal archaeological question of 'how?' one will have to add the question 'why?'. In contrast to the usual taxonomic approaches, the model of metallurgical production outlined in this paper focuses on relations between diverse components of the archaeological record. It does not aim to provide a universally valid classification of one class of the material record. It is assumed that the investigation of patterned variability in the archaeological record is the most accurate research strategy to understand innovation. In fact, technological innovation is but one facet of cultural selection that operates from variation. Those which fit and are congruent with actual social values are selected and transmitted from one generation to the next. Some of the variations, if not the majority, are neutral, with a last category of innovations, deemed negative, which may have been rejected.

As far as metallurgy is concerned, in all cases of pristine development, metal production was geared toward the manufacture of small-size items and 'sumptuary' goods: items of personal adornment, weapons, scepters, crowns, etc. (Levy and Holl 1988; Welsby 1998; Zangato 2007). Utilitarian goods, in the sense of tools used in productive activities, are almost nonexistent during the initial stages. They appear to result from later development, when the technology was 'generalized' (Trigger 1993). The invention of metal production technology is thus better considered as an unpredictable and contingent product of historical circumstances, not straightforwardly as an adaptive technical response to a pre-existing production problem. The consequences of metallurgy on productive, and 'destructive' activities, thus appear as desirable or undesirable side effects, as is well known in contemporary debates on advanced technologies (Adams 1996; Latour 1993; Lemonnier 1992, 1993).

Metal production can be framed as a technological system with diverse components in permanent and patterned interaction (Holl 2000). The eco-system or the physical environment offers raw materials, that is, metal ores, clay, fuel, while climate generates a specific scheduling and timing of metal production activities. Through diverse societal arrangements, for instance, affinity, alliance, friendship, kinship, antagonism, competition, domestic groups, and identity, distinct forms of social division of labor may develop and shape the organization of labor, provide a sustained social demand for the manufactured products, and support a distribution network and varying patterns of consumption. The potential stock of technological knowledge can be materialized by a range of manual skills, *know-how*, and possibilities of innovation. The point of emphasis here is that, near a bifurcation point (that is, the threshold of a radical change), the consequences of an innovation are fundamentally unpredictable for actual individuals (Prigogine and Stengers 1984). And this is still clearly the case in contemporary high-technology research and development (Adams 1996; Latour 1993) if one considers a few emblematic technological breakthroughs like X-rays, laser, and computers. Every technique has five related components: (1) matter; (2) energy; (3) objects; (4) gestures; and finally, (5) specific knowledge (information), and technologies can safely be regarded as social productions (Lemonnier 1992).

Theoretically, systems of production and consumption of metal artifacts can be partitioned into seven main activity sequences with their corollary sets of behaviors and material fingerprints: (1) the procurement of raw materials in alluvial and/or geological contexts; (2) the processes of metal ore smelting in especially built furnaces; (3) the processing of the metal bloom and the manufacture of a range of implements in forges and blacksmiths' workshops; (4) the distribution of manufactured items; (5) the consumption or use; (6) the storage, discard and/or loss; and finally, (7) the recycling of the precious material. Each of these steps may produce identifiable archaeological remains amenable to systematic investigation. In terms of labor mobilization and time budgeting, the above-mentioned activity sequences, inserted within an operational chain of metal production, are generally integrated into the fabric of the whole social system. Whatever the society, the ordering of activity sequences arranged according to the different states of the matter being processed, and structured around a few strategic nodes, cannot be altered without serious damage to the whole production (Lemonnier 1992, 1993). According to actual worldviews and patterns of social division of labor, metal producers are or are not granted specific social statuses (Bisson et al. 2000; Echard 1983; Herbert 1993; Okafor 1993; Schmidt 1996, 1997; Vansina 1990). In addition, the timing of metal production may vary from full to part-time activities.

A Trial and Error Approach

Evidence of metal production includes a broad range of data. They range from ore procurement and processing installations, smelting and forging apparatus, discarded by-products, to manufactured artifacts. Each of the components may have a different historical trajectory. A longitudinal analysis of a sample of processing features reveals the technical solutions ancient metallurgists have devised to deal with problems at hand. The research carried out in Niger (Bernus and Gouletquer 1976; Bernus and Echard 1992; Grebenart 1983, 1985, 1988) provides a reliable data base with hundreds of smelting furnaces investigated, 100 at Afunfun, 175 in the southeast and 185 at Ikawaten in the northwest (Holl 1997, 2004).

In copper-producing sites, furnaces, often arranged into distinct clusters, are built according to different standards. Early copper furnaces, dated to 4000–3000 BP, are extremely diverse in shape, size, and internal organization. It is not an exaggeration to say that each is virtually unique. They can nonetheless be organized into four loose groups (Fig. 9). The first group with two variants consists of small pseudo-cylindrical-shaped furnaces with a flat or curved base, comprising one tuyère entrance at the bottom. The second group is comprised of larger furnace installations, measuring 2 m in diameter on average, with many enigmatic conduits and pockets (Fig. 9); a number of these features (Fig. 9: 3), misidentified as furnaces, were very likely the remains of tree stumps which burnt in sedimentary copper deposits, triggering the smelting of copper ore. The third group is composed of complex furnace shapes, combining a sub-cylindrical part with an adjoined rectilinear extension (Fig. 9). And finally, the fourth group appears to be characterized by the combination of two cylindrical furnaces (Fig. 9).

Copper II furnaces dating from c. 3000 to 1000 BP, are much less diverse and all cylindrical in shape. They can be divided into four variants according to the angles of walls and characteristics of their bases (Fig. 10). Two variants present inward-tilted walls, one with a small depression at the bottom that may have been used for some kind of ‘protective medicine’: one or more substances intended to protect the furnace from the ‘evil eye’ are buried at the bottom of the furnace, in a medicine pot or a specially made depression to protect the smelting process from malicious interference (Herbert 1993; Schmidt 1997). The remaining two variants have straight and parallel walls, one specimen having an outlying platform.

Iron-smelting furnaces that date from c. 2600 BP present a standard cylindrical shape with straight and parallel or inward tilted wall, and in most of the cases, a smaller central

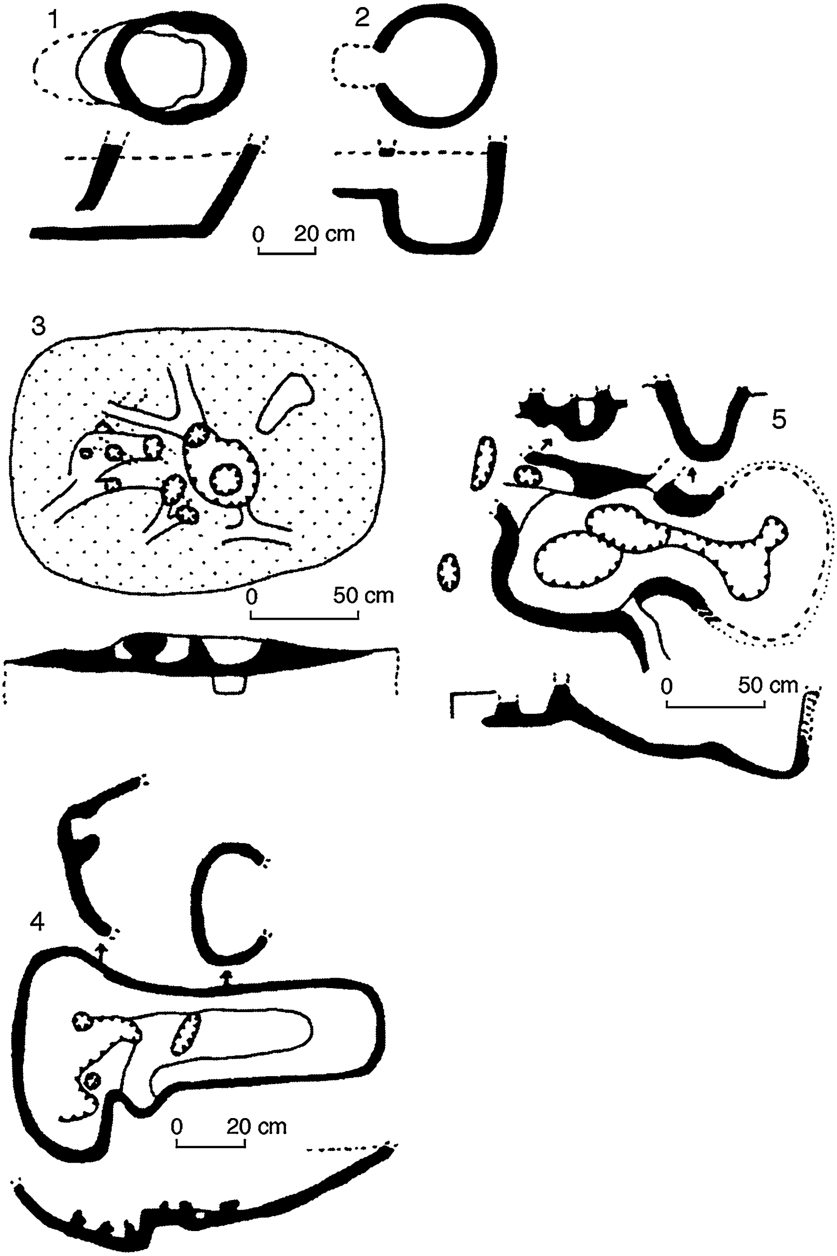

Fig. 9 Early Copper I furnaces

depression. As can be inferred from the record at hand, the association of iron smelting with ‘protective medicine’ is well consolidated and relatively ‘popular’.

The diversity of furnaces from the pioneer phase of copper production is intriguing. The variations may have been geared to adjust to unknown characteristics of the copper ore

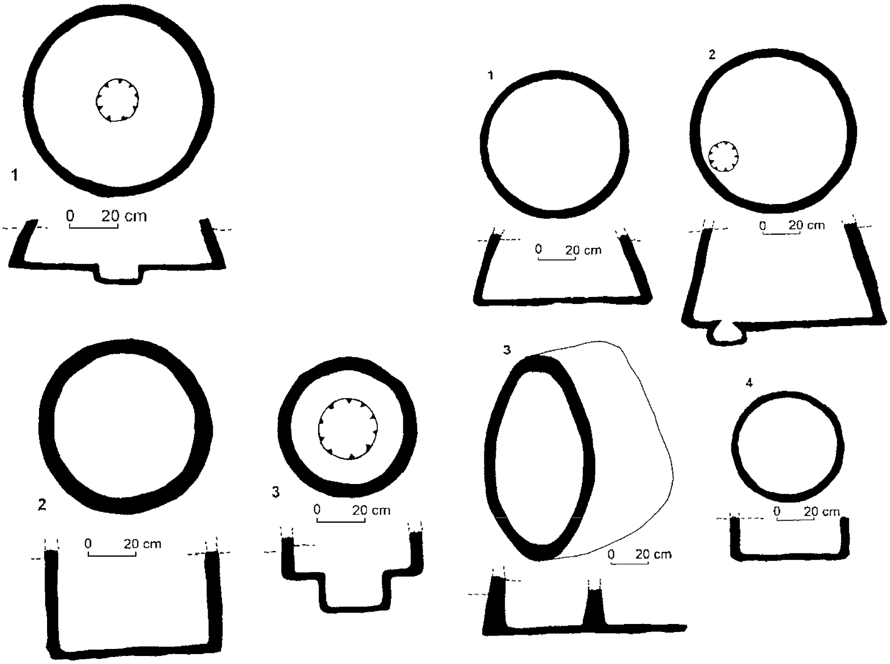

Fig. 10 Sample of Copper II and early iron smelting furnaces from the Eghazzer Basin, Niger

being processed. Read from the perspective of technological innovation, the diversity of furnace shapes from this early phase of metal production highlights a process of trial and error. Each individual copper producer may have 'tested' different technical devices helping to cope with the nature and quantity of the processed copper ore and fuel. It is far from certain that all the smelting episodes represented in the archaeological record were successful in producing an adequate quantity of good quality metal. In fact, the amount of recorded slag suggests a small-scale, episodic, if infrequent production. After a relatively long trial and error phase, adequate technical solutions were found, selected, transmitted from one generation of smelters to the next, and applied to copper as well as iron production. Formal training of apprentices may have been instrumental in the development of the metallurgical traditions of the Eghazzer basin in Niger. The long-term trend in furnace shape documented above, with a rather long period of trial and error, is not congruent with a wholesale technological package brought in from elsewhere.

Consumption and Use of Metals

Despite assumptions, the earliest metal artifacts were not tools used to boost land clearing and agricultural productivity. Such a development occurred much later, when the production process was 'routinized' and access to metal more 'democratic'. Elements of personal adornment and weapons were, for a very long time, the most common artifacts made of metal, whether copper or iron (Bisson et al. 2000; Holl 2004). These artifacts were used and displayed in the social arena as strategies for social distinction. The spread and development of metallurgical traditions generated different evolutionary trajectories. Metal producers, smelters and blacksmiths played different, sometimes conflicting, roles in their respective societies. In the Eghazzer Basin and the Termit Massif in Niger, as well as the Bir Moghrein region of Mauretania, the practice of metallurgy for the manufacture of copper and iron artifacts took place within a general context of the emergence of pastoral elites all over the Sahara (MacDonald 1998). It is these elites, scattered all over the Sahara/ Sahel, that generated the social demand that sustained the production, distribution and use of metal objects.

In most of central and southern Africa, from the Democratic Republic of Congo to South Africa, metal producers belonged to the ruling stratum and social elite. Depending on areas and time periods, they were themselves rulers or had control over access to kingship. In general however, they were free, if important members of their respective societies, providing much needed services and tools. In north and northeastern Africa, in today's Sudan, Ethiopia, Egypt, Libya, and Maghreb, metallurgists were very likely to belong to specialized guilds of craftsmen in these strongly ranked and/or stratified societies. The situation was much more diverse in West Africa. There, they ranged all along the spectrum from a despised caste-like group at one end to a tight association with rulership at the other. In all the Sahelian countries, from Senegal in the west to Sudan in the east, metalworkers belonged to endogamous caste-like groups. They were feared and despised and, at the same time, performed a broad range of services as healers, negotiators, speakers, circumcisers, and grave-digger/undertakers. In the southern part of the subcontinent, as suggested by the position of the god of iron, Ogun, in the Yoruba pantheon, metal producers were, for most of the time, free members of the society and sometimes part of the elite. There are some indications that the radical change in the social status of metalworkers took shape in the first half of the second millennium AD in West Africa (Bocoum 2000, 2006; Tamari 1995). The founding dynasty of Takrur, the Jaa-Ogo, was of iron-producer extraction. The exclusive control of the craft, and its concomitant esoteric knowledge, was the core reason for their accession to kingship. Takrur was invaded and conquered by a Soninke army from the neighboring kingdom in Ghana in the eleventh century AD. The ruling Jaa-Ogo dynasty was removed from power (Bocoum 2000: 204–207). The relative and paradoxical marginalization of iron-workers was a by-product of the Islamization process.

Conclusion

Empirical evidence pertaining to ancient West African metallurgies strongly supports an early development of metallurgical systems for the production of copper and iron artifacts. The extreme variability of early copper furnaces from Niger is a serious impediment to typological classification. Such diversity takes on a totally different meaning, and is better explained by a long period of low production intensity that was part of a long trial and error sequence. Once the techniques were mastered, a system of transmission of knowledge based on apprenticeship was developed. Such a system can explain the overall similarities of the smelting furnaces from the later part of the Niger copper producing period and ensuing early to later iron metallurgy. The earliest metal artifacts were confined to two major categories, weaponry and personal adornment. These early metal objects were more likely items of social distinction, geared to support or enhance individuals' prestige and status. The manufacture of tools for production purposes was a much later development. African metallurgies did not emerge from the explicit imperative of boosting the production of food. The origins of West African metallurgies cannot be subsumed under a simple 'Carthaginian origins' hypothesis. The recent discovery from Oboui in Central Africa and Lejja in the Nsukka region, Nigeria, point to the late 3rd or early 2nd millennium BC for the emergence of iron metallurgy along the northern margins of the equatorial forest (Bocoum 2002, 2006; Bisson et al. 2000; Zangato 2007; Eze-Uzomaka 2008, 2009). There is still a lot of work to be done and alternative dating techniques like thermoluminescence have to be tested on most of the sites referred to in this paper. However, radiocarbon dating is affordable for most of the small-budget research projects conducted in West Africa (Pringle 2009); thermoluminescence dating and other sophisticated laboratory techniques are not only too expensive but difficult to access for most African archaeologists. The *chaîne opératoire* of metal artifact production that may vary from area to area can be an excellent indicator of regional craft traditions, and as such deserves to be much more systematically investigated. Structural metallographic studies, which shed light on the technical characteristics of metal artifacts, are crucial in the understanding of the intentions and motivations of the producers and users of metal objects.

Acknowledgments The fieldwork conducted in the Mouhoun Bend in Burkina Faso from 1997 to 2000 was funded by the Centre national de la recherche scientifique (CNRS) France, National Geographic Society Research Grant #6378–98, and the University of California Start-up funds. The illustrations were cleaned and improved by Kay Clahassey of the Museum of Anthropology at the University of Michigan.

References

Adams, R. Mc C. (1996). *Paths of fire: An anthropologist's inquiry into western technology*. Princeton: Princeton University Press.

Alpern, S. (2005). Did they or didn't they invent it? Iron in Sub-Saharan Africa. *History in Africa, 32*, 41–94.

Arnold, D. E. (1985). *Ceramic theory and cultural process*. Cambridge: Cambridge University Press.

Aubet, M. E. (2001). *The Phoenicians and the West: Politics, colonies, and trade*. Cambridge: Cambridge University Press.

de Barros, P. (2003). Recent early Iron Age research in Bassar, Togo. *Nyame Akuma, 59*, 76–78.

de Barros, P. (2006). The surprising early Iron Age site of Dekpassanware (Togo). *Paper presented at the Society of Africanist Archaeologists, Calgary*, 22–26 June 2006.

Benoit, P., Coulibaly, E., & Fluzin, P. (2004). Le laboratoire, lieu de coopération. In A. Bazzana & H. Bocoum (Eds.), *Du nord au sud du Sahara: Cinquante ans d'archéologie française en Afrique de l'Ouest et au Maghreb* (pp. 325–330). Paris: Editions Sepia.

Bernus, S., & Echard, N. (1992). *La Region d'In-Gall-Teggida-n-Tesemt (Niger) V: Les Populations actuelles*. Niamey: Etudes Nigeriennes No 52.

Bernus, S., & Gouletquer, P. L. (1976). Du cuivre au sel: Recherches ethnoarchéologiques sur la région d'Azelik (Campagnes 1973–1975). *Journal des Africanistes, 46*(1–2), 7–68.

Bisson, M. S., Childs, S. T., de Barros, P., & Holl, A. F. C. (2000). *Ancient African metallurgy: The sociocultural context*. Walnut Creek: AltaMira Press.

Bocoum, H. (2000). *L'Âge du fer au Sénégal: Histoire et archéologie*. Dakar/Nouakchott: IFAN/CRIAA.

Bocoum, H. (2006). *Histoire technique et sociale de la métallurgie du fer dans la vallée moyenne du Sénégal*. Doctorat d'Etat thesis. University Cheikh Anta Diop, Dakar.

Bocoum, H. (ed.). (2002). *Aux origines de la métallurgie du fer en Afrique: Une ancienneté méconnue*. Paris: Editions de l' UNESCO.

Bourdieu, P. (1979). *La distinction: Critique sociale du jugement*. Paris: Editions de Minuit.

Childs, S. T., & Herbert, E. W. (2005). Metallurgy and its consequences. In A. B. Stahl (Ed.), *African archaeology: A critical introduction* (pp. 276–300). Oxford: Blackwell Publishing.

Childs, S. T., & Killick, D. (1993). Indigenous African metallurgy: Nature and culture. *Annual Review of Anthropology, 22*, 317–337.

Clist, B. (1989). Archaeology in Gabon 1986–1988. *The African Archaeological Review, 7*, 59–96.

Cook, A. C., Southon, J. R., & Wadsworth, J. (2003). Using radiocarbon dating to establish the age of iron-based artifacts. http://www.tms.org/pubs/journals/JOM/0205/Cook-0305.html.

Coulibaly, E. (2006). *Savoir et savoir-faire des anciens métallurgistes d'Afrique*. Paris: Karthala.

Deme, A. (2003). *Archaeological investigations of settlement and emerging complexity in the Middle Senegal Valley*. Unpublished Ph.D. Thesis, Rice University, Houston.

Deme, A., & McIntosh, S. K. (2006). Excavations at Walalde: New light on the settlement of the Middle Senegal Valley by iron using peoples. *Journal of African Archaeology, 4*(2), 317–347.

Dupuy, C., Fluzin, P., Ploquin, A., Durand, A., & Rolando, C. (2001–2002). Nouvelles données sur l'âge ancien des métaux au Mali. *Sahara 13*, 61–90.

Echard, N. (Ed.). (1983). *Métallurgies africaines: Nouvelles contributions*. Paris: Mémoire de la Société des Africanistes.

Essomba, J. M. (1993). *Le fer dans le passé des sociétés du sud Cameroun*. Paris: L'Harmattan.

Essomba, J. M. (2002). Bilan de l'archéologie de l'âge du fer au Cameroun méridional. In H. Bocoum (Ed.), *Aux origines de la métallurgie du fer en Afrique* (pp. 133–146). Paris: Editions de l'UNESCO.

Eze-Uzomaka, P. (2008). New dates for iron smelting in Lejja, Nigeria. Paper read at the biannual conference of the Society of Africanist Archaeologists, September 2008, J.W. Goethe Universitat, Frankfurt, Germany.

Eze-Uzomaka, P. (2009). Iron and its influence on the prehistoric site of Lejja. Paper read at the world of iron conference, February 16–20, 2009, University College London, United Kingdom.

Fluzin, P. (2002). La chaîne opératoire en sidérurgie: Matériaux archéologiques et procédés. Apport des études métallographiques. In H. Bocoum (Ed.), *Aux origines de la métallurgie du fer en Afrique* (pp. 59–92). Paris: Editions de l'UNESCO.

Fluzin, P. (2007a). Les analyses métallographiques. In E. Zangato (Ed.), *Les ateliers d'Oboui: Premières communautés métallurgistes dans le nord-ouest du Centrafrique* (pp. 72–77). Paris: Recherches sur les Civilisations.

Fluzin, P. (2007b). Les analyses métallographiques. In E. Zangato (Ed.), *Les ateliers d'Oboui: Premières communautés métallurgistes dans le nord-ouest du Centrafrique* (pp. 60–67). Paris: Recherches sur les Civilisations.

Grebenart, D. (1983). Les métallurgies du cuivre et du fer autour d'Agades (Niger) des origines au début de la période médiévale: Vues générales. In N. Echard (Ed.), *Métallurgies africaines: Nouvelles contributions* (pp. 109–125). Paris: Mémoire de la Société des Africanistes.

Grebenart, D. (1985). *La région d'In-Gall – Tegidda-n-Tesemt (Niger), II: Le néolithique final et les débuts de la métallurgie*. Etudes nigériennes 49, Niamey.

Grebenart, D. (1988). *Les premiers métallurgistes en Afrique occidentale*. Paris: Editions Errance.

Herbert, E. W. (1993). *Iron, gender, and power: Rituals of transformation in African societies*. Bloomington/Indianapolis: Indiana University Press.

Holl, A. F. C. (1997). Metallurgy, iron technology and African late holocene societies. In R. Klein-Arendt (Ed.), *Traditionelles Eisenhandwerk in Afrika* (pp. 13–54). Koln: Heinrich Barth Institut.

Holl, A. F. C. (2000). Metal and precolonial African society. In J. O. Vogel (Ed.), *Ancient African metallurgy* (pp. 1–83). Walnut Creek: Altamira Press.

Holl, A. F. C. (2004). *Holocene Saharans: An anthropological perspective*. New York/London: Continuum.

Holl, A. F. C., & Kote, L. (2000). Settlement patterns, food production, and craft specialization in the Mouhoun Bend (NW Burkina Faso: Preliminary results of the MOBAP 1997–1999 field seasons. *West African Journal of Archaeology, 30*(1), 69–108.

Kiethega, J. B. (2006). *La métallurgie lourde du fer au Burkina Faso. Une technologie à l'époque précoloniale*. Paris: Karthala.

Killick, D. (2001). Science, speculation and the origins of extractive metallurgy. In D. R. Brothwell & A. M. Pollard (Eds.), *Handbook of archaeological sciences* (pp. 479–488). London: Wiley.

Killick, D. (2004). Review essay: What do we know about African iron working? *Journal of African Archaeology, 2*(1), 97–112.

Killick, D., van der Merwe, N. J., Gordon, R. B., & Grebenart, D. (1988). Reassessment of the evidence for early metallurgy in Niger, West Africa. *Journal of Archaeological Science, 15*, 367–394.

Lambert, N. (1975). Mines et métallurgie antiques dans la région d'Akjoujt. *Annales de l'Institut Mauritanien de la Recherche Scientifique, 1*, 6–24.

Lambert, N. (1983). Nouvelle contribution a l'étude du chalcolithique mauritanien. In N. Echard (Ed.), *Métallurgies africaines: Nouvelles contributions* (pp. 63–87). Paris: Mémoires de la Société des Africanistes.

Latour, B. (1993). Ethnography of a 'high-tech' case: About Aramis. In P. Lemonnier (Ed.), *Technical choices* (pp. 372–398). London: Routledge.

Lavachery, P., MacEachern, S., & Gouem Gouem, D. (forthcoming). The Chad export project: Archaeological report. *Journal of African Archaeology Monograph Series*.

Lemonnier, P. (1992). *Elements for an anthropology of technology*. Ann Arbor: University of Michigan Museum of Anthropology.

Lemonnier, P. (1993). Introduction. In P. Lemonnier (Ed.), *Technical choices* (pp. 1–35). London: Routledge.

Levy, T. E., & Holl, A. (1988). Les premières chefferies de Paléstine. *La Recherche, 203*, 1166–1174.

Lhote, H. (1952). La connaissance du fer en Afrique occidentale. *Encyclopedie Mensuelle d'Outre-Mer*, 269–272.

MacDonald, K. C. (1998). Before the Empire of Ghana: Pastoralism and the origins of cultural complexity in the Sahel. In G. Connah (Ed.), *Transformations in Africa: Essays on Africa's later past* (pp. 71–103). London: Leicester University Press.

MacEachern, S. (1996). Iron Age beginnings north of the Mandara mountains, Cameroon and Nigeria. In G. Pwiti & R. Soper (Eds.), *Aspects of African archaeology* (pp. 489–496). Harare: University of Zimbabwe Publications.

de Maret, P. (2002). L'Afrique centrale: Le 'savoir-fer'. In H. Bocoum (Ed.), *Aux origines de la métallurgie du fer en Afrique* (pp. 123–132). Paris: Editions UNESCO.

Mauny, R. (1952) Essai sur l'histoire des métaux en Afrique occidentale. *Bulletin de l'IFAN, 14*(2), 545–595.

Mauny, R. (1953). *Autour de l'introduction du fer en Afrique occidentale*. Encyclopédie Mensuelle d'Outre-Mer, pp. 109–110.

McIntosh, S. K., & McIntosh, R. J. (1988). From stone to metal: New perspectives on the later prehistory of West Africa. *Journal of World Prehistory, 2*(1), 89–133.

Mitchell, P. (2005). *African connections: Archaeological perspectives on Africa and the wider world*. Lanham: AltaMira Press.

Okafor, E. (1993). New evidence on early iron-smelting in Southeastern Nigeria. In T. Shaw, P. Sinclair, B. Andah, & A. Okpoko (Eds.), *The archaeology of Africa: Food, metals, and towns* (pp. 432–448). London: Routledge.

Okafor, E. E. (2002). La réduction du fer dans les Bas-Fourneaux—Une industrie vieille de 2500 ans au Nigeria. In H. Bocoum (Ed.), *Aux origines de la métallurgie du fer en Afrique* (pp. 35–48). Paris: Editions UNESCO.

Okafor, E. E., & Phillips, P. (1992). New ^{14}C ages from Nsukka, Nigeria and the origins of African Metallurgy. *Antiquity, 66*, 686–688.

Person, A., & Quechon, G. (2002). Données chronométriques et chronologiques de la métallurgie a Termit—Matériaux graphiques pour l'étude des âges anciens du fer. In H. Bocoum (Ed.), *Aux origines de la métallurgie du fer en Afrique* (pp. 115–122). Paris: Editions UNESCO.

Prigogine, I., & Stengers, E. (1984). *Order out of chaos*. New York: Bantam Books.

Pringle, H. (2009). Seeking Africa's first iron men. *Science, 323*, 200–202.

Quechon, G. (2002). Les datations de la métallurgie du fer a Termit (Niger): Leur fiabilité, leur signification. In H. Bocoum (Ed.), *Aux origines de la métallurgie du fer en Afrique* (pp. 105–114). Paris: Editions UNESCO.

Quechon, G., Paris, F., Saliège, J.-F., & Person, A. (1992). Les débuts de la métallurgie au Niger septentrional. *Journal des Africanistes, 62*, 55–68.

Saliège, J.-F. (2007). Apport de la chronologie ^{14}C, la méthode et ses limites. In E. Zangato (Ed.), *Les ateliers d'Oboui: Premières communautés métallurgistes dans le nord-ouest du Centrafrique* (pp. 131–135). Paris: Recherches sur les Civilisations.

Schmidt, P. R. (Ed.). (1996). *The culture and technology of African iron production*. Gainesville: University Presses of Florida.

Schmidt, P. R. (1997). *Iron technology in East Africa: Symbolism, science, and archaeology*. Bloomington: Indiana University Press.

Schmidt, P. R. (2006). *Historical archaeology in Africa: Representation, social memory, and oral traditions*. Lanham: AltaMira Press.

Shinnie, P. L. (1985). Iron working at Meroe. In R. Haaland & P. L. Shinnie (Eds.), *African iron working: Ancient and traditional* (pp. 28–35). Oslo: Norwegian University Press.

Tainter, J. A. (1988). *The collapse of complex societies*. Cambridge: Cambridge University Press.

Tamari, T. (1995). Linguistic evidence for the history of West African 'castes'. In D. C. Conrad & B. E. Frank (Eds.), *Status and identity in West Africa: Nyamakalaw of Mande* (pp. 61–85). Bloomington: Indiana University Press.

Trigger, B. G. (1969). The myth of Meroe and the African Iron Age. *African Historical Studies, 2*, 23–50.

Van Der Merwe, N. J. (1980). The advent of iron in Africa. In T. A. Wertime & J. D. Muhly (Eds.), *The coming of the age of iron* (pp. 463–506). New Haven: Yale University Press.

Vansina, J. (1990). *Paths in the rainforests: Toward a history of political tradition in equatorial Africa*. Madison: University of Wisconsin Press.

Welsby, D. A. (1998). *Soba II: Renewed excavations within the metropolis of the Kingdom of Alwa in Central Sudan. British Institute in Eastern Africa Memoir 15*. London: British Museum Press.

Welsby, D. A., & Daniels, C. M. (1991). *Soba: Archaeological research at a medieval capital on the Blue Nile. Memoir 12*. London: British Institute in Eastern Africa.

Zangato, E. (1999). *Sociétés préhistoriques et mégalithes dans le nord-ouest de la République centrafricaine [BAR International Series 768]*. Oxford: BAR.

Zangato, E. (2007). *Les ateliers d'Oboui: Premières communautés métallurgistes dans le nord-ouest du Centrafrique*. Paris: Editions Recherches sur les Civilizations.