Invention and Innovation in African Iron-smelting Technologies

David Killick

Sub-Saharan Africa is often characterized by Europeans as a region that saw no significant technological change from the adoptions of agriculture and ironworking until the European colonization of the entire continent after 1880. This article criticizes this view by exploring the distinction between invention and innovation, using African iron smelting as a case study. It argues that there is in fact much evidence for the invention of new technologies in recent African prehistory, but that very low population densities precluded innovations in mass production and transportation.

Introduction

In mid 1982 I did test excavations on archaeological sites in the Kasungu National Park, Malawi (Fig. 1), with the assistance of several Malawians hired from surrounding villages. The Falklands war was reaching its climax, and as we worked we were constantly tuning in to shortwave news broadcasts in English and in Chichewa. As former British colonial subjects, the sympathies of the Malawians were of course on the Argentine side, but they were particularly interested in the technologies mentioned in the broadcasts. What were aircraft carriers? And submarines? And Exocet missiles? Eventually a broader question was asked—why had Europeans developed these technologies, but not Africans?

Those who have read Jared Diamond's *Guns, Germs and Steel* (1997) will immediately recognize this as Yali's question. For those who have not read this book, Yali is a Papuan acquaintance of Diamond's, and it was his question about why Europeans had so much more stuff than Papuans that set Diamond (an ornithologist by trade) to researching and writing his best-selling book. I cannot claim that the question posed by my Malawian employees led to any change in my intellectual pursuits; I was already working on the comparative history of technology, and having been born and raised in Malawi, I was well aware of the larger issue that lurked unspoken behind the question. For the white settler community in Africa, the technology gap was decisive evidence that Africans were intellectually inferior to Europeans. Rural Africans are equally well aware of the technology gap, and for most of the last century African intellectuals have tried hard to counter the racist European explanation for it.

In the next section of this paper I shall briefly summarize this intellectual history. After that I will examine the view that precolonial Africans were (as the great Négritude poet Aimé Césaire ironically put it) '*ceux qui n'ont rien inventé*'.[1] I will suggest this reflects failure to distinguish between *invention* and *innovation*. There is, in fact, much evidence for past African inventiveness in technology. What really needs explaining is why so few of these inventions spread widely in Africa—in other words, why they did not become innovations like the steam engine, the canal network, or electric lighting in Europe and the Americas.

Placing Africans on the lowest rung of the ladder of technological progress

As Michael Adas shows in *Machines as the Measure of Men* (1989), sixteenth-century Portuguese records of first encounters with the peoples of sub-Saharan Africa rarely display any hint of racial or technological superiority. Portugal was then one of

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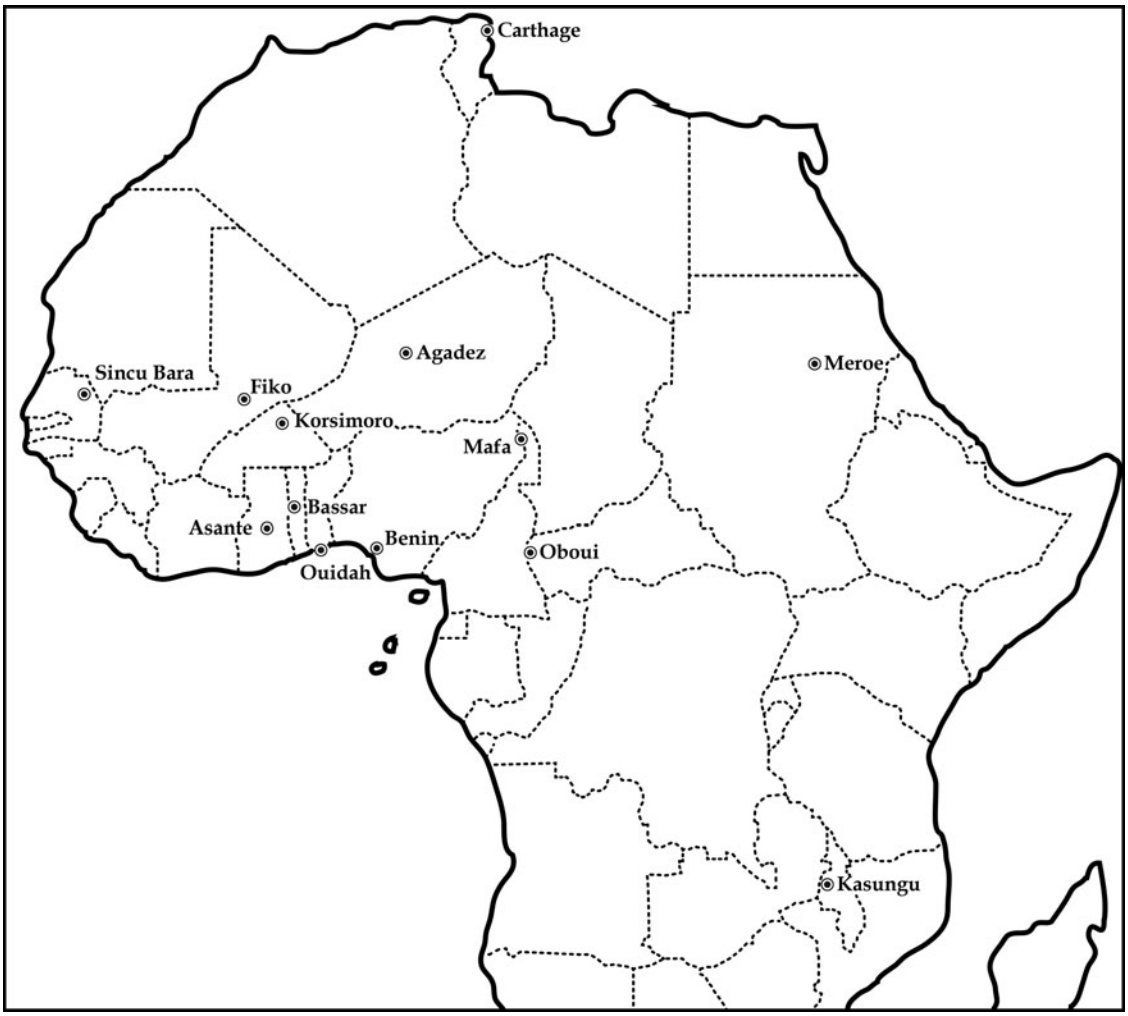


Figure 1. *Map of northern and central Africa, showing locations mentioned in the text.*

the poorest countries of Europe, and most of the Portuguese sailors would not have noticed much difference between African and Portuguese villages. The rapid Portuguese conquest of the western Indian Ocean was more a matter of dumb luck than of superior technology. The huge Chinese ships that had mapped the coasts of Arabia and Africa in the 1420s would have crushed the tiny Portuguese *naus* and *caravels* like gnats had they encountered them, but a Mongol invasion of the Ming Empire had prompted the recall of the Chinese fleet only 70 years before Portuguese ships entered the Indian Ocean (Alpers 2014; Levathes 1997). The Portuguese also had the good fortune to find Islamic ships unarmed and their ports unfortified, for the western Indian Ocean in the late fifteenth century was a highly connected Islamic free trading zone (Abu-Lughod 1989; Alpers 2014; Pearson 1998).

European attitudes towards Africans underwent major changes in the seventeenth century, as the trans-Atlantic slave trade boomed and Europe threw off the shackles of religion and encouraged rational inquiry. By the mid 1700s, technological innovations in agriculture, transportation, metallurgy, manufacturing and weaponry, supported by institutional innovations in banking, insurance and capital markets, had enabled European technology to surpass that of the Islamic World and China (Landes 1999). Some of these innovations, like gunpowder, the magnetic compass and blast furnaces, had in fact been invented in China, and other concepts and techniques (especially in chemistry, optics and navigation) in the Islamic world (Carlson 2005; Pacey 1990). But it was undeniably in Europe that the Industrial Revolution started.

From the eighteenth century on, Europeans sought moral justification for enslaving other peoples

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in Europe's accelerating lead over other regions in science and technology. This marked the emergence of scientific racism, which is the notion that the world's peoples should be ranked by their levels of intelligence, the evidence for which was particularly sought in their relative achievements in science and technology (Adas 1989; Gould 1981). Europeans installed themselves at the top of the ladder of technological prowess; the Chinese, Indians and some residents of the Islamic world were assigned rungs in the middle, while Africans were placed at the very bottom (Adas 1989). The purportedly low intellect of Africans provided convenient cover for the trans-Atlantic slave trade, which landed around 10.7 million African survivors of the slave trade in the Americas and the Caribbean between 1600 and 1870 (Manning 1990).

Whether they supported the slave trade or not, some of the leading figures in the history of western philosophy promoted scientific racism. David Hume wrote (1758, 125, n.):

> I am apt to suspect the Negroes to be naturally inferior to the Whites. There scarcely ever was a civilized nation of that complexion, nor even any individual, eminent either in action or speculation. No ingenious manufactures amongst them, no arts, no sciences. ... [In] our colonies, there are Negro slaves dispersed all over Europe, of whom none ever discovered the symptoms of ingenuity; though low people, without education, will start up amongst us, and distinguish themselves in every profession. In Jamaica, indeed, they talk of one Negro as a man of parts and learning; but it is likely he is admired for slender accomplishments, like a parrot who speaks a few words plainly.

Hume's words were parroted much later by Georg Hegel, who dismissed the very possibility of African history thus (Hegel 1840, 116): 'They have no arts, no sciences—as we see them now, so have they always been ... '.[2]

There are many similar passages in the works of other nineteenth-century European intellectuals—for examples, see Gould (1981) and Bernal (1987). Hegel wrote this in the 1820s, when most European nations other than Portugal had abolished (or were abolishing) slavery and European characterizations of Africans south of the Sahara were being slightly reframed. Africans were gradually recast as unfortunate child-like subjects who needed protection from the (largely Islamic) remnants of the slave trade, and who should be charitably exposed to the benefits of Christianity, western technology and western education. Christian missions were therefore sent to many parts of sub-Saharan Africa before the colonial annexation of the continent, which was formally divided among the European powers at the Berlin Conference of 1884/85 (Iliffe 2007).

Reactions from African intellectuals

European colonists founded primary and secondary schools in sub-Saharan Africa. Initially these were all associated with missions, but later the colonial administrations also established schools. Only a small proportion of colonial subjects were able to enter secondary education and very few indeed of these went on to tertiary education (Iliffe 2007). There they discovered what Europeans had written about them. Unlike the other European colonial powers, France took the view that at least some of its colonial subjects would become full French citizens, and the task of making them so was referred to as '*la mission civilisatrice*'. Thus a number of promising students from France's African and Caribbean colonies were sponsored for university education in France. In the 1920s a small group of African and Caribbean writers resident around Paris discovered the works of Langston Hughes, and other writers of the Harlem Renaissance, on racism and black pride. By the mid 1930s some African writers were well respected in progressive French literary circles, and by 1935 three of them—Léopold Senghor (later the first President of Sénégal), Aimé Césaire (from Martinique) and Léon Damas (from Guyana)—had founded the *Négritude* movement. This asserted that persons of African descent should be proud of their heritage, and even that they were superior to white-skinned peoples in matters of self-expression. (Think here of jazz, which was taking France by storm in the 1930s.) Jean-Paul Sartre was a prominent supporter of the movement, and in 1948 called it an 'anti-racist racism' (Sartre 1976, 59).

For the purposes of this essay, the most striking feature of *Négritude* was that its proponents readily conceded that people of European descent were inherently superior to those of African descent in mathematical, scientific and technological ability. Senghor expressed this most pithily—'*L'émotion est nègre, comme la raison est hellène*' (Senghor 1964, 288—originally published in 1939). This did not sit well with the very few Africans who were studying the sciences. The most vocal of these was Senghor's fellow countryman Cheikh Anta Diop. He earned a diploma in chemistry in 1950, but then switched directions, registering for the doctoral thesis 'Who were the ancient Egyptians?' with Marcel Griaule in 1951. He finished this in 1954, but his conclusion that 'Ancient Egypt was a Negro civilization' (Diop 1974, xiv) was so controversial that he was unable to form a committee to examine it. (It was, however, published in

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1954 as *Nations Nègres et Culture*.) Undeterred, he registered for another doctoral dissertation on comparison of cultural trajectories in Europe and sub-Saharan Africa from antiquity to the medieval era, while simultaneously studying nuclear physics with the Nobel Prize-winning physicist Frédéric Joliot-Curie. He was awarded his doctorate in history in 1960 and returned to Dakar to establish the first radiocarbon laboratory in sub-Saharan Africa. He continued to publish and promote his ideas on the African origins of Egyptian civilization until his death in 1986, and the leading university in Sénégal is named for him.

Diop's arguments have found favour with Afrocentrists in the USA (e.g. Asante 1988), and his thesis that Egyptian civilization came out of sub-Saharan Africa influenced Martin Bernal, whose *Black Athena* (Bernal 1987; 1991) argued that Greek civilization developed out of a fusion of Egyptian and Phoenician concepts—thus completing a revisionist historical trajectory that traces the origins of western civilization to sub-Saharan Africa! Criticism of these arguments (e.g. Lefkowitz 1997) just convinces their proponents that white scholars will do anything to supress evidence of past African achievments.

Diop's arguments for sub-Saharan roots of Egyptian civilization have not been taken seriously by most African and Africanist archaeologists,[3] but his contention that the past achievements of sub-Saharan Africa have been systematically ignored in Europe and the Americas is widely shared. Diop's views certainly did spur a search for precolonial African inventions in technology. Much of this search has focussed on purported African inventions in the field of iron metallurgy, and especially on the idea that iron metallurgy was first invented, or independently invented, in sub-Saharan Africa.

Was iron metallurgy invented in Africa?

Some African historians and archaeologists have tried to fight back against the view that Africans are '*ceux qui n'ont rien inventé*' by claiming that iron smelting was first invented in Africa (e.g. Bocoum 2002; C.A. Diop 1973; L.-M. Diop 1968; Zangato & Holl 2010), or was at least independently invented there (e.g. Cline 1937; Trigger 1969; Vansina 1995). Iron-working in sub-Saharan Africa could not even be dated until radiocarbon dating became widely available in the early 1960s, by which time there had already been 80 years of speculation about origin(s) (Alpern 2005). Raymond Mauny, the most prominent French colonial archaeologist in West Africa after the second World War, argued that the Phoenicans brought iron-working to North Africa between 900 and 800 BC, and that it spread from here into West Africa some centuries later (Mauny 1952). Although hard evidence of eighth/ninth-century Phoenican iron smelting in the western Mediteranean did not emerge until the late 1980s, almost all textbooks of African and world archaeology since the 1960s have dutifully reproduced Mauny's view (e.g. Scarre 2009). But there is still no archaeological evidence whatever for transmission of iron technology across the Sahara (Alpern 2005).

The other route suggested by those who favour an external origin for Africa iron working is from Egypt up the Nile to Meroe, and from there to the rest of sub-Saharan Africa. This speculation can be traced back at least as far as 1912, and has been a staple of textbooks ever since, in spite of cogent criticism by Cline (1937, 124) and Trigger (1969). We still do not know when iron smelting began at Meroe. Although there are an estimated 5000–10,000 tons of iron-smelting slag at Meroe itself (Rehren 2001) and large amounts at other Meroitic sites in the vicinity of Khartoum (J. Humphris pers. comm., 2014) almost all of this is tap slag produced by bloomery furnaces of Roman design (Tylecote 1982) and thus likely dating after the Roman conquest of Egypt in 31 BC. There is as yet only slight evidence of iron working at Meroe in the first millennium BC. A radiocarbon date of 2464 ± 73 BP for a wall near metallurgical slag 'should be used with caution' (Shinnie & Kense 1982, 24) and a date of 2230 ± 120 BP is from a pit intrusive into a layer with small bowl furnace linings (for smelting or for forging?). The older date calibrates to 800–400 cal BC. By now there are several dozen radiocarbon dates on iron-smelting sites from West and Central Africa that fall in the same interval, and some that are much older (Alpern 2005; Bocoum 2004; Clist 2012; Zangato & Holl 2010). Nor is there any evidence at present for introduction of iron-working from the Arabian Peninsula through present Ethiopia or Eritrea (Killick 2014b).

The weakness of the evidence for external origins has emboldened those who claim that iron metallurgy was invented, or invented independently, in sub-Saharan Africa. Yet major doubts have also been expressed about claims for African origins of this technology. Killick (2004) and Alpern (2005) reviewed claims published before 2004 and found the evidence to be inconclusive in every instance. Almost all of the doubts relate to the contexts and the calibration of radiocarbon dates. In some cases there is a wide spread of radiocarbon dates for what appears to have been an archaeological event of short duration. (Proponents of independent invention invariably favour the oldest ones). In most of these publications there is no stratigraphic section, or other explicit evidence of the exact context of the dated samples. Many

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authors have based their conclusions on uncalibrated radiocarbon dates—a major problem, given that many of these dates fall in the 'black hole' in radiocarbon dating between 800 and 400 cal BC. In arid parts of the Sahel deflation of archaeological sites by wind is a problem. One much-publicized claim for independent invention of iron in Niger is based upon radiocarbon dating of organic temper in pottery that was found together with iron objects on deflated surfaces (Bocoum 2004; Paris *et al.* 1992). Around Agadez deflation has brought ancient charred tree stumps to the surface, and there is good reason to suspect that this old charcoal was used by later metallurgists (Killick *et al.* 1988).

The most startling—and superficially the strongest—claim for an African invention of iron working comes from the site of Oboui in the Central African Republic, where an undoubted iron forge has seven consistent radiocarbon dates around 2000 cal BC (Zangato 2007; Zangato & Holl 2010). If these are accepted, Oboui is the earliest known iron-working facility anywhere in the world. But if this site is really 4000 years old, why are the iron objects so well preserved, given that they came from an open site in the tropics? Clist (2012) argues that the site is massively disturbed and that the charcoal samples were dug up from a lower stratigraphic level.

What interests me here is not whether iron metallurgy diffused into, or was invented within, sub-Saharan Africa, but why this is the most contentious issue in later African archaeology. As Alpern (2005, 89) has noted, 'doubt that sub-Saharans invented iron smelting has at times almost been equated with racism', and he followed this comment with a selection of published remarks that illustrate exactly his point (2004, 89–93). Why should this topic be so controversial?

An answer to this question appears on the back cover of a widely distributed book on the origins of iron metallurgy in Africa, sponsored and published by UNESCO in both French and English. The French edition (Bocoum 2002) proclaims that '*l'industrie du fer est un marqueur lourd de la civilisation*'; in the English version (Bocoum 2004) this is rendered as 'the iron industry is a benchmark of civilization'. Here, then, is Africa's riposte to the view that Africans were '*ceux qui n'ont rien inventé*': modern industrial civilization could not exist without iron metallurgy, and iron metallurgy was invented in Africa! This also explains the angry denunciations aimed at those sceptics whose position is simply that 'archaeology has usually demanded extraordinary proof of extraordinary claims' (McIntosh 2005, 78). Since many of the potential problems are with the context and interpretation of radiocarbon dates, I suggested long ago that fired furnace ceramics should be dated instead by luminescence dating (Killick 1987). This suggestion has been largely ignored.

These arguments over African iron metallurgy echo arguments about the writing about African history at large. The Norwegian historian Finn Fuglestad identified a problem in African historical studies that he calls 'the Trevor-Roper trap' (Fuglestad 1992). This is named for the Oxford historian Hugh Trevor-Roper (1914–2003), who famously dismissed precolonial African history as 'the unrewarding gyrations of barbarous tribes in picturesque but irrelevant corners of the globe' (Trevor-Roper 1965, 9). Fuglestad detected in subsequent African historical studies 'an enduring defensive attitude bordering on an inferiority complex' (Fuglestad 1992, 309). He charged African historians with being overly reactive, with trying too hard to show that Africa did indeed have civilizations and 'sophisticated' technologies. But this is a game played with loaded dice, for the rules for what counts as a civilization, or even 'sophisticated', have all been set by European historians like Trevor-Roper. The great irony of Afrocentrism—from Diop to Bernal to the UNESCO volumes on African iron metallurgy—is that Afrocentrists have been so willing to accept Eurocentric definitions of historical significance.

The two decades since Fuglestad's critique have seen the steady growth of the World History movement, which aims to transcend regional (and especially Eurocentric) biases in writing history. World historians explicitly avoid the triumphalist narratives of Eurocentric (and Sinocentric) history, preferring to focus on connections and processes across wide areas (e.g. Alpers 2014). In the remainder of this paper, I shall attempt to bring a World History sensibility to an examination of technological change in precolonial Africa.

Technological change in African iron smelting

The major problem confronting historians of technology in sub-Saharan Africa is the scarcity of written records. Few regions had literacy before European colonization, and in those that did (parts of the Sahel, the middle Nile valley, Ethiopia, the Swahili coast of East Africa) the surviving documents are almost entirely concerned with religion and trade (e.g. Horton & Middleton 2000; Levtzion & Hopkins 1981). The only written accounts of African technology are those made by Europeans within the last 400 years, but few Europeans were much interested in this topic and fewer still (mostly missionaries) acquired sufficient fluency in African languages to make any detailed inquiries.

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These historical documents are complemented by recent ethnoarchaeology, which can potentially provide much more detail, but there have been only a handful of long-term ethnoarchaeological field projects in sub-Saharan Africa (David & Kramer 2001). Beyond this there is archaeology, which can obviously only record evidence of technologies that leave durable residues.

So far there is only one branch of indigenous African technology for which there is a substantial amount of data.[4] Many European travellers in sub-Saharan Africa over the last 300 years saw Africans smelting iron, and a few dozen wrote brief descriptions of it, some with illustrations. These were brought together and discussed by Walter Cline in his invaluable *Mining and Metallurgy in Negro Africa* (Cline 1937). There are also a few dozen more detailed ethnographic and ethnoarchaeological studies of iron smelting, some historical film clips and a small number of supporting laboratory analyses of ores, slags and iron objects. Lastly, there are a few archaeological studies that include detailed archaeometallurgical analysis, and these extend the record of African iron working back into the first millennium BC. Unfortunately, progress in the study of African iron smelting is slow because of the shortage of trained archaeometallurgists and the scarcity of funding for radiometric dating and for chemical and metallurgical analysis. (European and American funding agencies give generously to the study of human evolution in Africa, but are much less inclined to support research on later African prehistory.)

All African iron-smelting processes recorded to date are variants of the bloomery process. Bloomery smelting is a batch process, in which the air blast must be stopped periodically to remove the solid mass, or masses, of metal. These are called blooms. The waste product (slag) may be tapped from the furnaces as a liquid, or may solidify within it. Bloomery furnaces are fundamentally different from blast furnaces, from which both liquid metal and liquid slag are periodically discharged by opening tap holes in the side of the furnaces. Blast furnace processes are continuous operations—the furnaces may run without interruption for weeks or months, and thus offer great gains in thermal efficiency over bloomery processes. Blast furnaces were invented in China by at least the fifth century BC, and spread from there (replacing bloomeries) to the Islamic world and possibly as far west as Scandinavia; they may have been independently developed from bloomeries in present Germany in the thirteenth century AD (Wagner 2008). They were not used in sub-Saharan Africa until European colonization.

The earliest securely dated iron-smelting furnaces in sub-Saharan Africa (*c.* 400–200 BC) were shaft

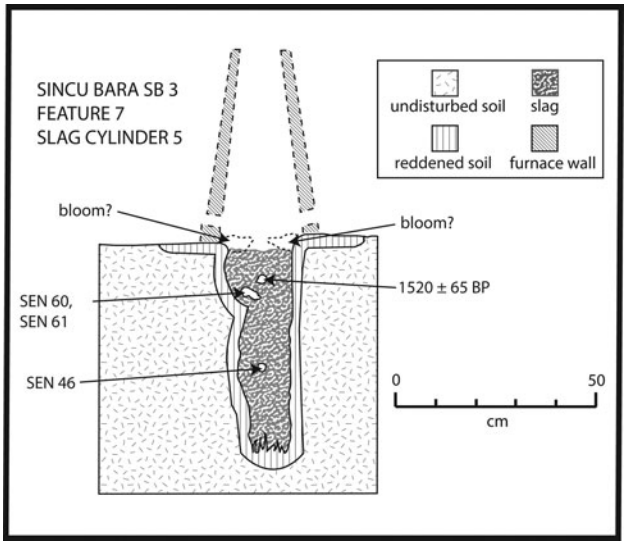


Figure 2. *One of several dozen slag pits excavated at Sincu Bara, Senegal (McIntosh & Bocoum 2000). This furnace type is thought to have had a portable shaft, indicated here by dashed lines. The arrows show the locations where samples were taken for microstructural and radiocarbon analyses. (From Killick in press. Illustration: L. Perry.)*

furnaces with multiple bellows and internal diameters ranging from about 0.8 to 1.2 m. Contemporary European Iron Age (La Tène) furnaces mostly had internal diameters of 0.35 to 0.65 m and a single set of bellows (Pleiner 2000), so it seems probable that these African furnaces produced more iron per smelt than contemporary European techniques. From this relatively uniform early smelting technology, African metallurgists developed an astonishing variety of furnaces, both smaller and larger. These range in size from the tiny slag-pit furnace shown from Senegal (Fig. 2) dated between 400 and 600 cal AD (Killick in press) to the 6.5 m natural draft furnaces used in some parts of West Africa in the early twentieth century (Martinelli 2004). Natural draft furnaces were also widely used, and perhaps independently developed, in South East Africa (Fig. 3). Most natural draft furnaces were permanent installations, relined and reused over decades (e.g. Huysecom & Agustoni 1997), but in some regions smelters used a portable shaft, light enough to be moved from one furnace base to another to produce the natural draft (e.g. Echard 1965; 1968) (Fig. 2). Some smelting furnaces used no shaft at all—the large standing army of the Zulu king Shaka in the early nineteenth century was entirely equipped with iron from small bowl furnaces (Maggs 1992). The most radical African furnace design to Western eyes is

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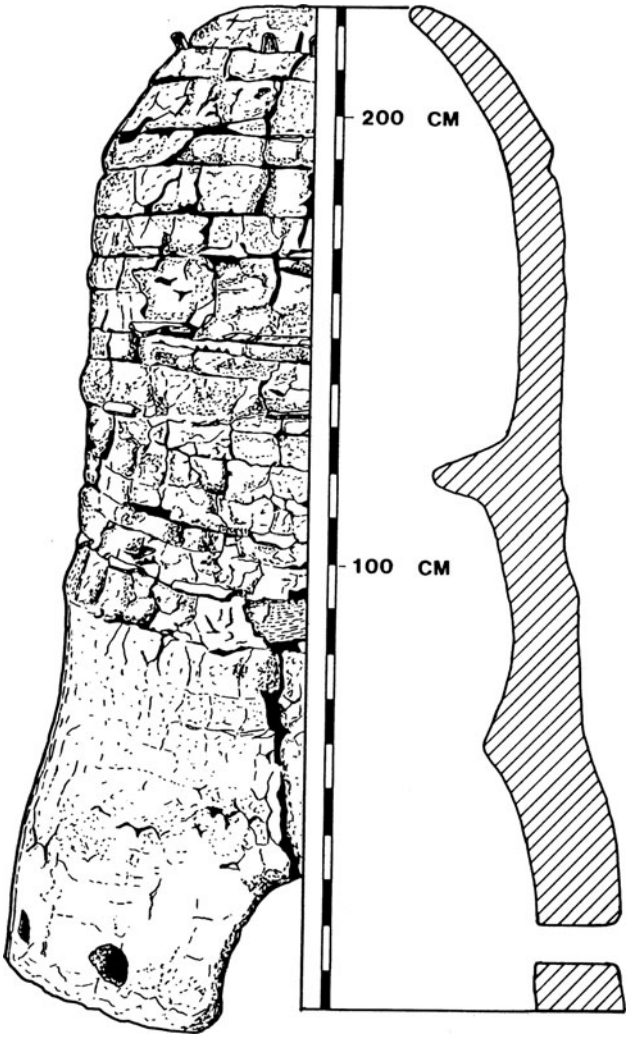


Figure 3. *Half-elevation/half section of a natural draft smelting furnace from the Kasungu National Park, Malawi. (Illustration: D. Killick.)*

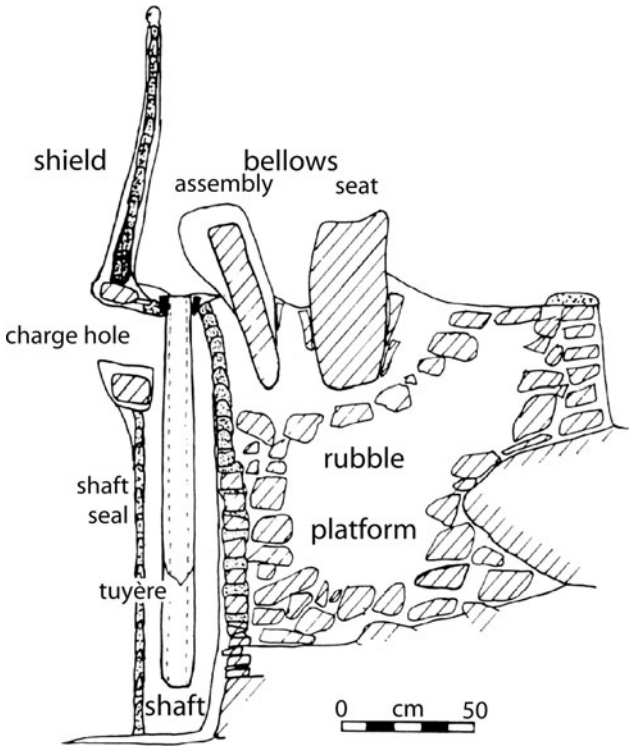


Figure 4. *Section through a Mafa iron smelting furnace in the Mandara Mountains, Cameroon, showing the length of the vertical tuyère at the beginning and end of the smelting process. The temporary shaft seal was removed at the end of each batch to rake out the furnace content and to remove the used tuyère. (Drawing: Nicholas David, from David et al. 1989. Reproduced by permission of Cambridge University Press.)*

undoubtedly the Mafa furnace (Fig. 4) from the Mandara mountains of north Cameroon (David *et al.* 1989). In this design the single ceramic tuyère was extraordinarily long (1.7 m) and was mounted vertically rather than horizontally, as in all other known bloomery furnaces. The bellows were blown from above, and the hot exhaust gases exited from a hole on the side. This furnace produced cast iron, steel and wrought iron simultaneously, but all solidified within the furnace. These products were hand-sorted from each other and the cast iron pellets decarburized to steel in shallow crucibles.

Literally dozens of variants of the bloomery process have been recorded in sub-Saharan Africa (Cline 1937). This variety is striking when compared to the relatively limited number of variants of the bloomery process recorded in Europe, where there are many more archaeometallurgists than in Africa (Pleiner 2000). Why were there so many variants in Africa? Part of the answer to this question is certainly that this reflects reflect functional adaptations of the bloomery process to local conditions, which are of course much more variable in Africa than in Europe. For example, the Mafa live in an arid mountain environment with very few trees. Their unique process was designed to process almost pure iron oxide ore and thus wasted little charcoal on making slag from gangue (impurities) in the ore. It was therefore very fuel-efficient (David *et al.* 1989). At the opposite end of the scale were African natural draft furnaces, which had prodigious appetites for charcoal (Killick 1991; Serneels *et al*. 1997). The rate of charcoal consumption in these furnaces was very slow, with smelts typically taking 20–48 hours to complete (rather than 3–6 hours in bellows-blown furnaces) so they necessarily lost much heat to radiation. But the geographical distribution of

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natural-draft furnaces corresponds exactly to the areas of infertile, dry, deciduous savanna woodlands in Africa, in which trees were plentiful but population densities were low. Natural draft furnaces were expensive in terms of fuel, but were very economical in terms of labour. The long smelting times also promoted even diffusion of carbon into the iron, producing high-quality steel blooms instead of the less homogeneous and generally lower-carbon blooms of the smaller forced-draft furnaces (Killick 1991; Martinelli 2004; Serneels *et al.* 1997).

African ironworkers adapted bloomery furnaces to an extraordinary range of iron ores, some of which cannot be used by modern blast furnaces. In both northern South Africa (Killick & Miller 2014) and in the Pare mountains of northern Tanzania (Louise Iles pers. comm., 2013) magnetite-ilmenite ores containing up to 25 per cent TiO_2 (by mass) were smelted. The upper limit for TiO_2 in iron ore for modern blast furnaces is only 2 per cent by mass (McGannon 1971). High-titanium iron ores can be smelted in bloomery furnaces because these operate at lower temperatures and have less-reducing furnace atmospheres than blast furnaces. In the blast furnace titanium oxide is partially reduced and makes the slag viscous and hard to drain, but in bloomery furnaces it is not reduced and combines with iron and silicon oxide to make a fluid slag (Killick & Miller 2014). Blast furnace operators also avoid ores containing more than a few tenths of a percent of phosphorus or arsenic, because when these elements are dissolved in the molten iron, they segregate to grain boundaries on crystallization, making the solid iron brittle on impact. In the bloomery furnace iron is usually reduced in the solid state, so phosphorus and arsenic do not concentrate at grain boundaries. In fact, both elements have positive effects in bloomery iron, hardening it and making it more resistant to corrosion. Abdu and Gordon (2004) show that, from about 300 BC, Meroitic ironworkers in Nubia forged together plates of arsenical and phosphoric iron with plates of mild carbon steel. These composite ingots were then twisted, forged and etched with acid to create decorative swirls of lighter and darker metal. (The layers containing arsenic and phosphorus are resistant to acid etching and appear lighter).

I have chosen these few examples to make the point that African ironworkers invented many novel iron-smelting processes (for many other examples, see Cline 1937). Some of these have not yet been noted anywhere else in the world. I could have chosen non-metallurgical examples to make my point, such as the many truly ingenious variants of swidden agriculture described in the *miombo* woodlands of present Zambia (Allan 1965). So why do many Europeans—and a good many Africans too—think that Africans were less inventive than other peoples? I suggest that this is because both are confusing invention with innovation.

Invention *vs* innovation

Although these terms are used interchangeably by the public, journalists and many archaeologists, they are quite distinct concepts for historians of technology, economic historians and business historians. I use these terms as they are usually defined in these fields of study:

1. An invention is the initial appearance of a idea or process, whether truly novel, or a distinct modification of an existing idea or process;
2. An innovation is an invention that is widely adopted.

With modern complex technologies, the transition from invention to innovation usually requires organizational skills to assemble the resources (engineering talent, finance, manufacturing, marketing) to create what the historian Thomas Hughes (1989) calls 'technological systems'. Hughes gives Thomas Edison's creation of the urban electrical system as an example of a technological system. Many more recent examples are discussed by Rogers (2003) and Arthur (2009), but technological systems are certainly not confined to industrial capitalism. Law (1987) shows that the Portuguese maritime exploration of the coast of Africa in the late fifteenth century was a technological system, put together by the Infante Dom Henrique (1394–1460), known in English as Prince Henry the Navigator. He combined a number of prior innovations with some new inventions, creating a technological system of shipbuilding, navigation and mapmaking that allowed Portuguese ships to sail down the coast of West Africa and to find their way home again—something that had never been done before. Further back in time, it is useful to think of the first regular smelting of metals as a technological system. Smelting copper from ore required bringing together prior innovations (charcoal fuel, ceramic containers, annealing of native copper) with new inventions (tubular blowpipes, ceramic blowpipe tips, carved stone or clay moulds) and deploying all of these in a novel *chaîne opératoire* (mining, smelting, remelting, casting, forging/annealing) (Killick 2014a).

I suggest that, when Europeans accused Africans of lacking the capacity for technological invention, they were failing to distinguish between invention and innovation. Most of the innovations to which European colonists were accustomed, such as paved

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Table 1. *Estimated 2014 population size and annual rates of increase from the Population Reference Bureau's 2014 World Population Data Sheet*
http://www.prb.org/publications/datasheets/2014/2014-world-population-data-sheet.aspx Land areas are from Wikipedia; population density calculations by the author.

Region	2014 population (millions)	Land area (million km^2)	Population density (per km^2)	Annual rate of increase (%)
Sub-Saharan Africa	920	24.2	38.0	2.6
Europe	741	10.2	72.8	0.0
China	1364	9.6	142.1	0.5
India	1296	3.3	393.9	1.5

roads, bridges, canals, watermills, blast furnaces, steam engines, railroads, machine guns, etc., were not found in sub-Saharan Africa, and from the perspective of the global history of technology, it is certainly true that there were fewer major technological innovations in sub-Saharan Africa than in the Islamic world, India, China or Europe. So the question is not why Africans were incapable of *invention*—there is plenty of evidence for African inventiveness. The real question is why relatively few major technological *innovations* can be seen in the later prehistory and precolonial history of sub-Saharan Africa.

At this point, I can only suggest only the outline of an explanation. My own understanding of the world literature on the history of technology is that rates of technological innovation over the last 8000 years have been strongly correlated with three factors. The most important of these is population density. Dense populations must be fed, clothed, housed and supplied with tools, and thus high population density promotes the spread of innovations in agriculture and in craft technologies. The second factor, contingent upon the first, is the presence of large towns and cities. Urban populations must have everything brought to them, which promotes innovations in transportation and in the scale of production, which drives innovations in machinery, factories and alternative sources of power. The third factor is literacy, which promotes the diffusion of ideas and the rapid spread of innovations.

Estimates of population density in 2014 for sub-Saharan Africa, China India and Europe are shown in Table 1. Note that sub-Saharan Africa still has much lower population density than Europe, China or India—in spite of the fact that the population of sub-Saharan Africa has nearly quadrupled since 1950 (Tabutin & Schoumaker 2004), while the rate of population increase in China and Europe dropped markedly in the same interval. The fact that Africa's population has grown so rapidly since 1950 is attributable to both technological and social factors. On the one hand, imported innovations in water supply, sanitation and medicine have dramatically reduced mortality. On the other hand, the lack of social security insurance in most African countries promotes high fertility—the more children one has, the more likely it is that one will be adequately supported in old age.

What was the population of sub-Saharan Africa in 1700, slightly before the start of the Industrial Revolution in Europe? Demographers can only make informed guesses by projecting backwards. J.-N. Biraben offers 97 million and D. Cordell 71 million (both cited in Tabutin & Schoumaker 2004, table 3). Both Biraben and Cordell suggest that the population of sub-Sahara grew little, if at all, between 1700 and 1900, while the population of the rest of the world at least doubled and possibly tripled (Tabutin & Schoumaker 2004, 464; see also Manning 1990). The major factor in the inferred stagnation of African population during this period was the external slave trade—both the European trans-Atlantic trade and the Islamic slave trade by land and sea to North Africa, the Near East and India. The number of African slaves shipped from Africa by Europeans is well documented—the Trans-Atlantic Slave Trade Database lists 12,521,336 embarked and 10,702,656 delivered between 1501 and 1866 (www.slavevoyages.org, accessed 15 December 2014). This does not include those brought by undocumented voyages, or those who died in Africa from slave raiding, or in captivity. The Islamic slave trade is not well documented, and there are disagreements about its size among economic historians. Austen (1987) argued that it removed at least as many persons from sub-Saharan Africa as the Trans-Atlantic trade, though over a longer span of time (650–1900), while Manning (1990) proposed a figure of 6 million for the period 1400–1900. Manning (1990, 171) suggested that by 1850 the population of sub-Saharan Africa was likely only half of what it might have been without the cumulative effect of both the European and the Islamic slave trades. The long-term effects of the slave trades are still with us; the economic historian Nathan Nunn has shown that those areas of Africa from which

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the largest number of slaves were exported across the Atlantic still had significantly worse average Gross Domestic Products in 2000 than those that were barely affected by the trans-Atlantic slave trade (Nunn 2008).

If we assume that the population of sub-Saharan Africa was 97 million in 1700, this equates to a population density of only four persons per square kilometre. With such low population densities, it made no sense to invest in roads or bridges—pack animals, ferries and even human porters were better suited for transportation of goods, depending on the terrain. Compared to Europe and China, Africa has a notable scarcity of navigable waterways. The lack of large urban populations also ruled out investments in mass production of food, tools or clothing. Thus most production was for local consumption and only items that had high value-to-mass ratios were transported over long distances. These were mostly metals, fancy textiles (from the Islamic world and India), glass beads (ditto), ivory and stimulants (kola nuts and—after European contact—tobacco).

African population was not evenly dispersed: both archaeological and historical research show instead a pattern of pockets of population with large, more or less empty, spaces in between—the 'internal African frontier', in the famous phrase of Igor Kopytoff (1987). This pattern of settlement explains sub-Saharan Africa's striking cultural diversity—some 2000 languages, a vast range of artistic styles, kinship and residence rules, political systems and ritual practices. I suggest that it also explains why so many local variants of the bloomery process were developed in Africa.

Yet at least one invention did become a widespread technological innovation within sub-Saharan Africa. This was the large natural draft iron-smelting furnace. These were particularly common in the West African Sudanic woodland zone from Senegal to Nigeria and in the *miombo* woodlands of Tanzania, Zambia, Malawi and Mozambique (Cline 1937; Killick 1991). Whether these were invented independently in these two zones is as yet unknown. I suggest that they spread widely, in spite of their wasteful use of charcoal, because they required less labour in pumping bellows than forced-draft bloomeries. Both of these zones of savanna woodland soils have very infertile soils, so swidden (slash-and-burn) agriculture was dominant. Trees were felled and burned to produce ash for fertilizer, but new plots had to be burned every five to seven years as soil fertility declined and weeds proliferated (Allan 1965). I suggest that the labour requirements for swidden agriculture conflicted with those for iron smelting, and that this conflict favoured the spread of the natural draft furnace.

In West Africa several specialist centres of iron production using natural draft furnaces emerged from the early second millennium AD. In the Dogon region of Mali, one sub-region (Fiko) has about 300,000 cubic metres of slag produced by this technique (Robion-Bruner 2010). The Bassar region in Togo has more than 82,000 cubic metres (de Barros 1985) and the Korsimoro district in Burkina Faso has *c.* 60,000 tons (Serneels *et al.* 2014). The development of further specialist centres of iron production after 1650 was in part a consequence of the gun-iron-slave cycle in West Africa (for which see Manning 1990). Demand for iron increased to defend populations against slave raiders, but also for making the shackles and chains that bound columns of slaves to each other as they were marched to the coast or across the Sahara. The slave-exporting states that emerged in the West African forest zone after 1500 (Asante, Ouidah, Benin) were all major importers of iron.

Conclusion

Attitudes towards Africa have changed in some quarters. The *Journal of African History* celebrated its 50th year in 2010, and recent African inventiveness in the fields of music and the arts is now widely acknowledged. Yet Hegel's image of a stagnant pre-colonial Africa—a subcontinent without history—is still invoked by some European politicians and business journalists. One recent example is the notorious speech delivered by Nicholas Sarkozy, then President of France, at Cheikh Anta Diop University in Senegal in July 2007.[5] And although I regard *The Economist* as essential reading, I thoroughly dislike its practice of praising modern African contributions to the arts on the one hand while dismissing African history on the other.

I have argued that the frequent characterization of Africans as uninventive reflects the failure of European observers over the past three centuries to distinguish between invention and innovation. In conclusion I want to broaden the discussion by commenting on the recent return of interest in innovation in anthropology and archaeology. Given that the archaeological record is largely the record of human inventions and innovations, it is puzzling that archaeologists have contributed so little to the theoretical literature on these topics. The important volume edited by van der Leeuw and Torrence (1989) failed to ignite much new research over the following two decades, but there are now signs of renewed interest (e.g. O'Brien & Shennan 2010; Schiffer 2011). What concerns me particularly

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about most recent recent literature is that it is wholly focused on the adoption/diffusion of innovations—invention is rarely mentioned. One possible reason for this is that most archaeologists may think it impossible to detect invention in the archaeological record. I grant that it is highly unlikely that credible evidence for inventions can be found in deep time (inventions of fire, blade technologies, etc.) and also that most evidence of inventions in perishable materials has not been preserved. But those of us who work with the durable inorganic residues of past pyrotechnologies—ceramics, glass or metals—frequently find evidence of inventions that did not become innovations. These can potentially provide information on the social conditions that favoured invention, and the demographic and social conditions under which inventions did, or did not, become innovations. These surely ought to be among the major reasons for studying prehistoric technologies.

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Notes

1. This line comes from Césaire's epic poem *Cahier d'un Retour au Pays Natal*, published in 1939, translated as *Return to My Native Land* (Césaire 1969).
2. The title of Eric Wolf's *Europe and the People Without History* points to this passage (Wolf 1982).
3. Following standard usage in my field, I define African archaeologists as citizens of African nations. Africanist archaeologists are those, like myself, who work on African prehistory and history, but who are not citizens of African nations.
4. For a short review of other aspects of indigenous African technology, see Killick (2005).
5. Sarkozy's speech can be found on the internet, along with outraged responses by several prominent African intellectuals. For a short summary of this controversy, see http://uk.reuters.com/article/2007/09/05/uk-africa-sarkozy-idUKL0513034620070905 (accessed 4 Jan 2014).

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References

Abdu, B. & R.B. Gordon, 2004. Iron artifacts from the land of Kush. *Journal of Archaeological Science* 31, 979–98.
Abu-Lughod, J., 1989. *Before European Hegemony: The World System, AD 1250–1350*. New York (NY): Oxford University Press.
Adas, M., 1989. *Machines as the Measure of Men: Science, Technology and Ideologies of Western Dominance*. Ithaca (NY): Cornell University Press.
Allan, W., 1965. *The African Husbandman*. New York (NY): Barnes & Noble.
Alpern, S.B., 2005. Did they or didn't they invent it? Iron in sub-Saharan Africa. *History in Africa* 32, 41–94.
Alpers, E.A., 2014. *The Indian Ocean in World History*. Oxford: Oxford University Press.
Arthur, W.B., 2009. *The Nature of Technology: What It Is, and How It Evolves*. New York (NY): Free Press.
Asante, M.K., 1988. *Afrocentricity* (3rd revised edition). Trenton (NJ): Africa World Press.
Austen, R., 1987. *African Economic History*. London: James Currey.
Bernal, M., 1987. *Black Athena: the Afroasiatic Roots of Classical Civilization*. Rutgers (NJ): Rutgers University Press.
Bernal, M., 1991. *Black Athena: the Archaeological and Documentary Evidence*. Rutgers (NJ): Rutgers University Press.
Bocoum, H. (ed.), 2002. *Aux Origines de la Métallurgie du Fer en Afrique: Une Ancienneté Méconnue. Afrique de l'Ouest et Afrique Centrale*. Paris: Éditions UNESCO.
Bocoum, H. (ed.), 2004. *The Origins of Iron Metallurgy in Africa. New Light on its Antiquity: West and Central Africa*. Paris: UNESCO.
Carlson, B. (ed.), 2005. *Technology in World History* (7 volumes). New York (NY): Oxford University Press.
Césaire, A., 1969. *Return to My Native Land* (trans. John Berger & Anna Bostock). Harmondsworth: Penguin.
Cline, W.W., 1937. *Mining and Metallurgy in Negro Africa*. (General Series in Anthropology 5.) Menasha (WI): George Banta.
Clist, B., 2012. Vers une réduction des préjugés et la fonte des antagonismes: un bilan de l'expansion de la métallurgie du fer en Afrique sud-Saharienne. *Journal of African Archaeology* 10, 71–84.
David, N., R.B. Heimann, D.J. Killick & M. Wayman, 1989. Between bloomery and blast furnace: Mafa iron-smelting technology in North Cameroon. *The African Archaeological Review* 7, 185–210.
David, N. & C. Kramer, 2001. *Ethnoarchaeology in Action*. Cambridge: Cambridge University Press.

https://doi.org/10.1017/S0959774314001176 Published online by Cambridge University Press

de Barros, P., 1985. Bassar: a quantified, chronologically controlled, regional approach to a traditional iron production centre in West Africa. *Africa* 56, 148–74.

Diamond, J., 1997. *Guns, Germs and Steel: The Fate of Human Societies*. New York (NY): W.W. Norton.

Diop, C.A., 1973. La métallurgie du fer sous l'ancien Empire égyptien. *Bulletin de l'Institut Fondemental d'Afrique Noir, Série B*, 35(3), 532–47.

Diop, C.A., 1974. *The African Origin of Civilization: Myth or Reality?* (trans. M. Cook). Chicago (IL): Lawrence Hill Books.

Diop, L.-M., 1968. Métallurgie traditionelle et âge du fer en Afrique Noire. *Bulletin de l'Institut Fondemental d'Afrique Noir, Série B*, 30(1), 10–38.

Echard, N., 1965. Note sur les forgerons de l'Ader (Pays Hausa, République du Niger). *Journal de la Société des Africanistes* 35(2), 353–72.

Echard, N., 1968. *Noces de feu* (16 mm film). Paris: Musée de l'Homme.

Fuglestad, F., 1992. The Trevor-Roper trap, or the imperialism of history. An essay. *History in Africa* 19, 309–26.

Gould, S.J., 1981. *The Mismeasure of Man*. New York (NY): Norton.

Hegel, G.W.F., 1840. *Vorlesungen über die Philosophie der Weltgeschichte* (2nd edition, trans. J. Sibree (1857) as *Lectures on the Philosophy of History*.) Kitchener (ON): Batoche.

Horton, M. & J. Middleton, 2000. *The Swahili: the Social Landscape of a Merchantile Society*. Oxford: Blackwell.

Hughes, T.P., 1989. *American Genesis: A Century of Invention and Technological Enthusiasm, 1870–1970*. New York (NY): Viking Press.

Hume, D., 1758. *Essays and Treatises on Several Subjects*. London: A. Millar.

Huysecom, E. & B. Agustoni, 1997. *Inagina, the Last House of Iron* (film on DVD). Geneva: University of Geneva, Department of Anthropology.

Iliffe, J., 2007. *Africans: The History of a Continent* (2nd edition). Cambridge: Cambridge University Press.

Killick, D.J., 1987. On the dating of African metallurgical sites. *Nyame Akuma* 28, 29–30.

Killick, D.J., 1991. A little known extractive process: iron smelting in natural-draft furnaces. *JOM (Journal of the Minerals, Metals and Materials Society)* 43(4), 62–4.

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

Killick, D.J., 2005. Sub-Saharan Africa, in *Technology in World History*, ed. W.B. Carlson. New York (NY): Oxford University Press, vol. 4, 8–35.

Killick, D.J., 2014a. From ores to metals, in *Archaeometallurgy in Global Perspective: Methods and Syntheses*, eds. B. Roberts & C. Thornton. New York (NY): Springer, 11–46.

Killick, D.J., 2014b. Cairo to Cape: the spread of metallurgy through eastern and southern Africa, in *Archaeometallurgy in Global Perspective: Methods and Syntheses*, eds. B. Roberts & C. Thornton. New York (NY): Springer, 507–28.

Killick, D.J., in press. Iron smelting technology in the Middle Senegal Valley, ca. 550 BCE–1500 CE, in *The Search for Takrur: Archaeological Excavations and Reconnaissance along the Middle Senegal River Valley*, eds. R.J. McIntosh, S.K. McIntosh & H. Bocoum. New Haven (CT): Yale University Press.

Killick, D.J & D.M. Miller, 2014. Smelting of magnetite and magnetite-ilmenite ores in the northern Lowveld, South Africa, ca. 1000 CE–ca.1880 CE. *Journal of Archaeological Science* 43, 230–55.

Killick, D.J., N.J. van der Merwe, R.B. Gordon & D. Grébénart, 1988. Reassessment of the evidence for early metallurgy in Niger, West Africa. *Journal of Archaeological Science* 15, 367–94.

Kopytoff, I., 1987. *The African Frontier: The Reproduction of Traditional African Societies*. Bloomington (IN): Indiana University Press.

Landes, D.S., 1999. *The Wealth and Poverty of Nations*. New York (NY): W.W. Norton.

Law, J., 1987. On the social explanation of technical change: the case of the Portuguese maritime expansion. *Technology and Culture* 28, 227–52.

Lefkowitz, M., 1997. *Not Out of Africa: How Afrocentrism Became an Excuse to Teach Myth as History*. New York (NY): Basic Books.

Levathes, L., 1997. *When China Ruled the Seas: The Treasure Fleet of the Dragon Throne 1405–1433*. Oxford: Oxford University Press.

Levtzion, N. & J.F.P. Hopkins, 1981. *Corpus of Early Arabic Sources for West African History*. Cambridge: Cambridge University Press.

Maggs, T., 1992. 'My father's hammer never ceased its song day and night': the Zulu ferrous metalworking industry. *Southern African Humanities* 4, 65–87.

Manning, P., 1990. *Slavery and African Life*. Cambridge: Cambridge University Press.

Mauny, R., 1952. Essai sur l'histoire de métaux en Afrique occidentale. *Bulletin de l'Institut Français de l'Afrique Noir* 14(2), 545–95.

Martinelli, B., 2004. On the threshold of intensive metallurgy: the choice of slow combustion in the Niger River Bend (Burkina Faso and Mali), in *The Origins of Iron Metallurgy in Africa: New Light on its Antiquity*, ed. H. Bocoum. Paris: UNESCO, 165–88.

McGannon, H.E. (ed.), 1971. *The Making, Shaping and Treatment of Steel* (9th edition). Pittsburgh (PA): United States Steel Corporation.

McIntosh, S.K., 2005. Archaeology and the reconstruction of the African past, in *Writing African History*, ed. J. Philips. Rochester (NY): University of Rochester Press, 51–85.

McIntosh, S.K. & H. Bocoum, 2000. New perspectives on Sincu Bara, a first millennium site in the Senegal Valley. *African Archaeological Review* 17, 1–44.

Nunn, N., 2008. The long-term effects of Africa's slave trades. *The Quarterly Journal of Economics*, February 2008, 139–76.

https://doi.org/10.1017/S0959774314001176 Published online by Cambridge University Press

O'Brien, M.J. & S.J. Shennan, (eds.), 2010. *Innovation in Cultural Systems: Contributions from Evolutionary Anthropology*. Cambridge (MA): MIT Press.

Pacey, A., 1990. *Technology in World Civilization*. Cambridge (MA): MIT Press.

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

Pearson, M.N., 1998. *Port Cities and Intruders: The Swahili Coast, India and Portugal in the Early Modern Era*. Baltimore (MD): Johns Hopkins Press.

Pleiner, R., 2000. *Iron in Archaeology: the European Bloomery Smelters*. Prague: Archeologický Ústav Av.

Rehren, Th., 2001. Meroe, iron and Africa. *Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V. (MittSAG)* 12, 102–9.

Robion-Bruner, C., 2010. *Forgerons et Sidérurgie en Pays Dogon, Vers une histoire de la Production du Fer sur le Plateau de Bandiagara (Mali) durant les Empires Précoloniaux*. (Journal of African Archaeology Monograph Series 3). Frankfurt: Africa Magna Verlag.

Rogers, E.M., 2003. *Diffusion of Innovations* (5th edition). New York (NY): Free Press.

Sartre, J.-P., 1976. *Black Orpheus* (trans. S.W. Allen.) Paris: Présence Africaine.

Scarre, C. (ed.), 2009. *The Human Past* (2nd edition). London: Thames & Hudson.

Schiffer, M.B., 2011. *Studying Technological Change: A Behavioral Approach*. Salt Lake City (UT): University of Utah Press.

Senghor, L.S., 1964. *Liberté, vol. 1. Négritude et Humanisme*. Paris: Seuil.

Serneels, V., E. Huysecom & P. Fluzin, 1997. Inagina—iron, slags and eutectoid steel, in *Early Ironworking in Europe*, eds. P. Crew & S. Crew. (Plas Tan y Bwlch Occasional Paper 3). Blaenau Ffestiniog: Snowdonia National Park Study Centre, 104–10.

Serneels, V., F. Donaldini, H. Kiénon-Kaboré, *et al.*, 2014. Origine et développement de la métallurgie du fer au Burkina Faso et en Côte d'Ivoire. Premiers résultats sur le site sidérugique de Korsimoro (Sanmatenga, Burkina Faso). *Schweizerisch-Liechtensteinische Stiftung für Archäologische Forschungen im Ausland (SLSA)*, Annual Report 2013, 65–112.

Shinnie, P.L. & F.J. Kense, 1982. Meroitic iron working, in *Meroitic Studies: Proceedings of the Third International Meroitic Conference, Toronto 1977*, eds. N.B. Millet & A.L. Kelley. Berlin: Akademie-Verlag, 17–28.

Tabutin, D. & B. Schoumaker, 2004. The demography of sub-Saharan Africa from the 1950s to the 2000s. A survey of changes and a statistical assessment. *Population* 59(3–4), 457–566.

Trevor-Roper, H., 1965. *The Rise of Christian Europe*. New York (NY): Harcourt Brace.

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

Tylecote, R.F., 1982. Metal working at Meroe, Sudan, in *Meroitic Studies: Proceedings of the Third International Meroitic Conference, Toronto 1977*, eds. N.B. Millet, A.L. Kelley. Berlin: Akademie-Verlag, 29–42.

van der Leeuw, S. & R. Torrence (eds.), 1989. *What's New? A Closer Look at the Process of Innovation*. London: Unwin Hyman.

Vansina, J., 1995. Historians, are archaeologists your siblings? *History in Africa* 22, 369–408.

Wagner, D.B., 2008. *Science and Civilization in China. Volume 5: Chemistry and Chemical Technology, Part 11: Ferrous Metallurgy*. Cambridge: Cambridge University Press.

Wolf, E., 1982. *Europe and the People Without History*. Berkeley (CA): University of California Press.

Zangato, E., 2007. *Les Ateliers d'Oboui: Premières Communautés Métallurgistes dans le nord-est du Centrafrique*. Paris: Éditions Récherche sur les Civilisations (ERC).

Zangato, E. & A.F.C. Holl, 2010. On the iron front: new evidence from Central Africa. *Journal of African Archaeology* 8, 7–23.

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