22 September 1978, Volume 201, Number 4361 SCIENCE

Complex Iron Smelting and Prehistoric Culture in Tanzania

Recent discoveries show complex technological achievement in African iron production.

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One of the primary problems in the prehistory of Africa is how iron metallurgy developed in sub-Saharan Africa. Since 1937 when Cline wrote *Mining and Metallurgy in Negro Africa* (*1*) there has been no systematic attempt to understand the technological complexities and developmental history of African iron metallurgy. Cline's study is a continent-wide ethnological survey, which prehistorians, historians of technology, and metallurgists continue to use as their main reference source. These scholars either subscribe to or passively accept the assumption that the sponge iron bloomery process, well known from European archeological contexts, also describes African iron smelting. This view persists despite the great variability known to exist in African iron smelting processes. Yet no one has tried to see whether or not the European bloomery model applies to iron smelting in Africa. This is a particular problem that we address in this article: whether or not the bloomery process as known from European archeology is similar to iron smelting technology in Africa.

Summary. Western scientists and students of history have long explained the iron bloomery process by evidence available from European archeology. Ethnographic, technological, and archeological research into the technological life of the Haya of northwestern Tanzania show that these people and their forebears 1500 to 2000 years ago practiced a highly advanced iron smelting technology based on preheating principles and, as a result, produced carbon steel. This sophisticated technology may have evolved as an adaptation to overexploited forest resources. These discoveries are significant for the history of Africa and the history of metallurgy.

It is also apparent that some authorities have overlooked important variables in African smelting furnaces, and consequently have failed to see possible explanations for the production of high-grade steel. For example, when Tylecote (*2*) looks at the evidence from Oyo, southwestern Nigeria, "reported by Bellamy in 1904" (*3*), he fails to attach importance to the production of a high-carbon (1.67 percent) steel in the induced-draught shaft furnace with tuyères (blowpipes) inserted inside the furnace. Tylecote (*2*) attaches little significance to the possibility that preheating occurred in the Oyo furnace: "At first sight it would seem that the long tuyères are designed for efficient preheating of the ingoing air, but a calculation shows that the degree of preheat would only be 10°C." We show here that these statements are based on unrealistic laboratory and theoretical models and, in fact, do little justice to the technological processes which occur in authentic furnaces, such as those operated by the Haya who live in West Lake Region of Tanzania (Fig. 1).

Our current perspective is limited to one culture, but we expect that it can be extended to other areas of the continent as we gain more archeological and ethnographic information about iron metallurgy. In Africa, there are several areas where traditional iron bloomery smelters actively practice their craft, or remember how it is practiced. Among the Haya there is an active blacksmithing tradition in which scrap iron is used, but no contemporary bloomery smelters are to be found. However, some of these smiths and other old men did smelt iron in the traditional way during their youth 50 to 60 years ago; they are still alive, able to smelt, and in many cases are eager to relive the experience once again. The knowledge held by such old men in West Lake, Tanzania, is profound in its implications for the history of iron smelting and for the prehistory of complex African civilizations. But this knowledge is threatened every day by the passage of time, by death, and by age-related infirmities occurring in this quickly shrinking group of expert smelters.

The Haya are a Bantu-speaking agricultural people who live along the western shore of Lake Victoria. The Haya live in densely populated villages while practicing some cattle herding and a banana and bean subsistence agriculture. Coffee and tea are grown as cash crops. In precolonial times, the culture area contained six small kingdoms, three of which were ruled by different branches of the Bahinda clan.

Archeological verification of oral traditions in one kingdom, Kyamutwara, shows that oral traditions accurately document the history of some ancient religious and historical sites seized by the more recent Bahinda dynasty (*4*, *5*). Archeological investigations at the Rugomora Mahe site confirmed the accuracy of traditions about iron production there and dated the iron production to 2400 to 2550 years ago. The later occupation of the site by the royal dynasty was dated

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0036-8075/78/0922-1085$01.25/0

by the carbon-14 method to 250 to 300 years ago (*4–6*), confirming dates suggested by oral, royal genealogies. Archeological analysis of this site included examination of technological materials, principally slag and fragments of tuyères.

As part of our study of the ancient technology, we attempted to discover the flow temperatures of slag which had been formed in Early Iron Age furnaces. Test results showed a temperature of 1350° to 1400°C. On the basis of European archeological evidence, this is within the highest temperature limits obtained during most experiments performed in bloomeries. In addition, the physical properties of the tuyère fragments suggested that they had come from inside the furnace. From these archeological data we developed the hypothesis that preheating of the air blast had been a prominent feature of African Early Iron Age smelting. We reasoned that higher combustion temperatures achieved by this preheating would have formed slag at temperatures similar to or higher than those indicated by our heat tests on prehistoric slag. Preheating would permit the attainment of much higher furnace temperatures and better fuel economy than was obtainable in cold blast European bloomeries.

This hypothesis was subsequently tested by experiment, which showed that 20th-century metallurgists and anthropologists, given sufficient money, instrumentation, and effort, could preheat air and make some iron in a reconstructed furnace. But we felt that observations in Africa of traditional iron smelters were necessary in order to obtain reliable and authentic results. We knew from previous research, especially from interviews with old men who had smelted, that the Haya had placed their tuyères or blast pipes inside their furnaces, thereby creating a situation which would have led to a hot air blast. As Tylecote observes (*2*), enormous gains were made in 19th-century blast furnaces with low degrees of preheat (100°C) brought about by "inefficient [rough] pipe stoves." Although Cline (*1*) mentions several furnace types with tuyères inside furnaces as part of his broad ethnological consideration of iron metallurgy, these examples, along with Oyo, have never been recognized as possible preheating. We presumed that, if a similar technological phenomenon occurred during prehistoric times in West Lake, then there was an excellent possibility that an efficient and complex technology prevailed there during the Early Iron Age.

The implications of our studies suggested that ethnographic research on iron smelting and iron forging, including quantitative technological observations, was critical to testing the hypothesis as well as to understanding the "bloomery" process itself and its associated cultural behaviors. Before we formed our preheating hypothesis, we had assumed—like Maddin, Muhly, and Wheeler (*7*)—that "the highest temperature that could be reached in a primitive smelt appears to have been about 1,200 degrees." That assumption is accompanied by the idea that "smelting iron ore at that temperature yields not a puddle of metal but a spongy mass mixed with iron oxide and iron silicate." These were apparently valid assumptions until our research among the Haya demonstrated at least two unique and important characteristics in this advanced iron technology.

The first demonstrated example of preheating in an African smelting furnace is the Haya process. As oral information had indicated, the Haya do place tuyères inside their furnaces (Fig. 2). The furnace is what we call a shaft-bowl type, with a forced-air draught. A cone-shaped shaft 140 centimeters high (Fig. 3) and constructed with old, refractory slag and mud made from the earth of a termite mound is built over a bowl 50 to 60 centimeters deep and lined with termite mud (Fig. 4). Swamp grass is burned in the bowl until the bowl is filled with the charred swamp reeds. The charred reeds provide a charcoal bed of filamentary alkaline-coated carbon fiber that is readily wetted and infiltrated by the molten iron slag. Eight drum bellows covered with goatskins are used to force air into tuyères, 50 to 60 centimeters in length, which are inserted inside the furnace. The combustion zone just beyond the tuyère develops very high temperatures.

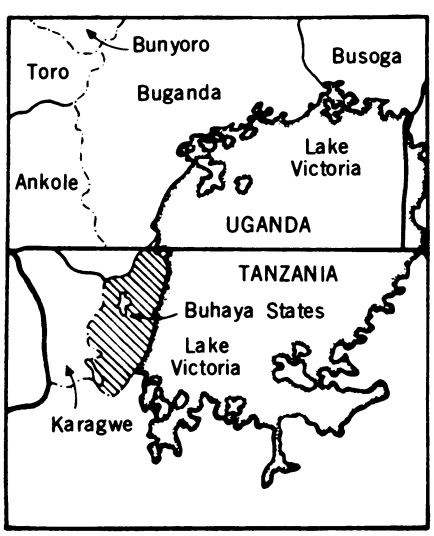

Fig. 1 (left). The traditional kingdoms of the interlacustrine region. Fig. 2 (right). Smelters and assistants place tuyères inside the furnace to variable depths. Tuyères inserted inside the furnace cause preheating of the air blast and result in high temperatures in the combustion zone. The eight tuyères are placed between large blocks of refractory slag, which are used as the foundation for the furnace chimney.

The high-temperature products of combustion divide, part passing up through the furnace shaft and part back-flowing along the tuyère; this heats the tuyère and the blast air passing through it. Eventually, external tuyère surfaces are wet with slag and dissolve in it at about 1250° to 1300°C. This means the external temperature of the tuyère clay is in excess of 1250°C. Slag penetrated approximately one-third through the tuyère wall.

The air temperatures inside the tuyère were measured by passing a ceramic-insulated thermocouple down the tuyère. Figure 5 shows typical curves at different times and tuyère lengths. The rapid rise in the last 10 centimeters probably represents significant radiation heating of the thermocouple; however, the preheating temperature of the air is clearly in the range of 600°C or more. The preheating efficiency of the tuyère (as reflected in the combustion temperature) is related to its length (Fig. 5). As the tuyère shrinks in size, the temperature in the combustion zone decreases. Combustion zone temperatures were found to vary, but in many cases were above the melting point of a Pt-PtRh (10 percent rhodium) thermocouple, which melts at 1820°C. The Zelechovise I type furnace (Northern Moravia, 8th century A.D.) tested by Pleiner (*8*) in Czechoslovakia during 1964 reached a maximum temperature of 1450°C in its small underground shaft. During tests of an experimental 2nd-century Roman shaft furnace, Tylecote *et al.* (*9*) recorded a combustion zone temperature as high as 1600°C. We feel confident that the high combustion zone temperature in the Haya furnace is caused by preheating of the air blast. The high temperatures achieved through preheating are critical to the Haya process. Given the other unique characteristic of the process—the crystalline formation of the bloom discussed below—the attainment of high temperatures means that iron will be produced more efficiently.

The other remarkable characteristic that makes this process of great interest to science and history is that, in the Haya process, the bloom does not form by the sintering of fine solid particles. Throughout Europe and in many areas of the world, the bloomery process is known as one in which reduction takes place in a CO atmosphere while the bloom forms by sintering of fine solid particles in an iron sponge and by liquation of a fluid slag. But in the Haya smelting furnace of West Lake, iron is precipitated as large crystals growing in a fayalite-wüstite slag; the molten slag undergoes a carbon boil in much the

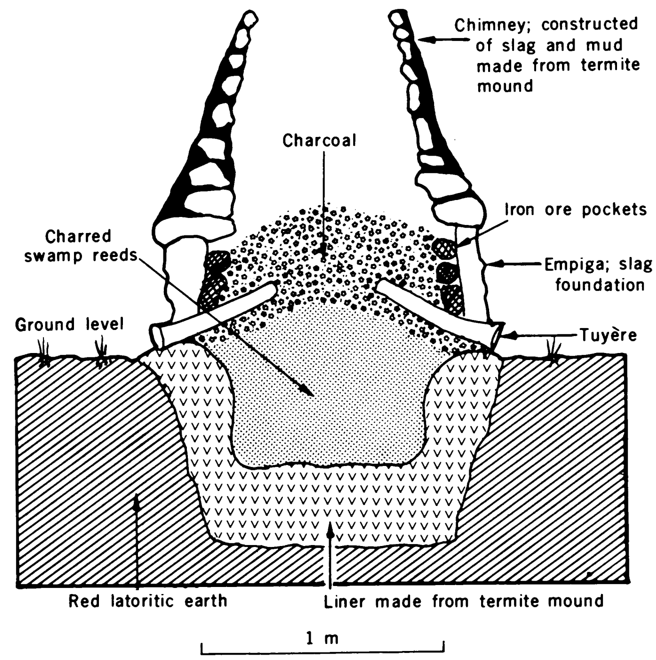

Fig. 3. An idealized profile of a Haya iron smelting furnace; this view is before the mixed iron ore and charcoal charge has been added. Note that the tuyères are inside the furnace and therefore are conduits that preheat the air passing through them. Iron ore pockets are added inside the foundation blocks to roast iron ore for the next smelt.

Fig. 4. A melt under way in Nyunge village in the Bukoba area of West Lake Region in Tanzania. Eight double-drum bellows are operated for up to 8 hours in a process that yields a carbon-steel bloom in crystalline form.

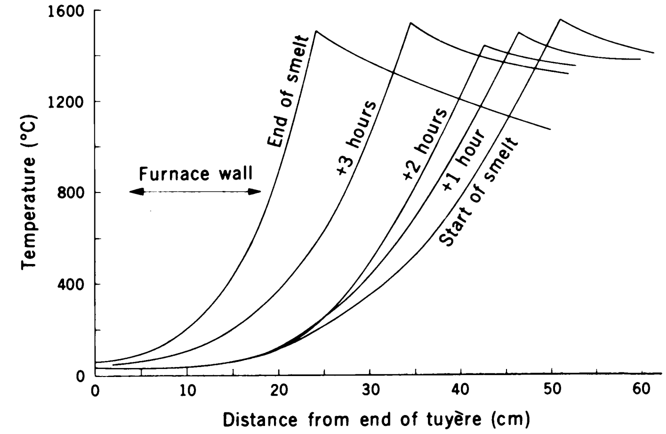

Fig. 5. Temperature profiles along a tuyère and into the blast zone. As smelting progresses, the tuyères burn off, the preheating length decreases, and furnace temperatures drop.

same way that an open hearth furnace has a carbon boil. The carbon boil is caused by an intimate and large contact area with solid carbon (the charred swamp reeds) throughout the molten slag mass. The critical variables in the process appear to be roasting of the iron ore, the use of charred swamp reeds in the furnace bowl, and high temperatures.

"Roasting" of the ore is an important initial step, for then carbon is introduced into the ore. The ore is "roasted" in a reducing atmosphere in a pit with wet wood and limited O_2 access. This reduces the ore, with the ore providing the O_2 for combustion

$$2Fe_3O_4 + 8CO \rightarrow 6Fe + 8CO_2$$

After roasting the ore cools off in a CO_2 atmosphere and is reoxidized with carbon deposited

$$6Fe + 3CO_2 \rightarrow 6FeO + 3C$$

This and the use of charred swamp grass is important: when the iron ore melts above the tuyères, it forms a fayalite-wüstite slag with carbon inclusions from the roasting; it then infiltrates and interacts with the fibrous, carbonaceous interface provided by the burned swamp grass. This, in turn, provides an extremely high carbon-slag contact area. The solid carbon reacts with the slag to form CO bubbles that coalesce and rise to the slag surface, forming large bubbles, 5 centimeters in diameter. As the carbon boil removes oxygen from the slag, the slag becomes supersaturated with iron; iron crystals then precipitate and grow. As the liquid slag changes its composition and loses wüstite (FeO), it becomes increasingly refractory and its melting point rises. Thus, a high temperature allows further and more efficient precipitation of iron crystals.

Metallographic examination of these iron precipitates shows a planar growth interface (Fig. 6a). Here we see the massive iron, white area, growing into the fayalite-wüstite slag, gray area. The growing interface seems always to be pure (carbon-free) iron. The crystal perfection is very good with large straight Neüman bands and large well-formed crystals, as illustrated in the micrographs of a traditional bloom (Fig. 6, b and c). As the iron grows, some slag and carbon are entrapped. The entrapped carbon then locally carburizes the iron surrounding it, producing a highly variable local carbon content (Fig. 6d). If this local carburization were to continue beyond 2.4 percent carbon, then it would result in the formation of cast iron droplets. But this level of carburization is not typical in the Haya process. Our analyses show that the bloom obtained from six smelts in West Lake during 1976 have a carbon content ranging from pure iron to eutectic and hypereutectic microcompositions. Further sampling and testing will determine whether the eutectic compositions predominate.

The assemblage of Early Iron Age artifacts is not complex, being limited to two braceletlike objects from both the Rugomora Mahe and KM2 sites, and one possible knife blade fragment from each site.

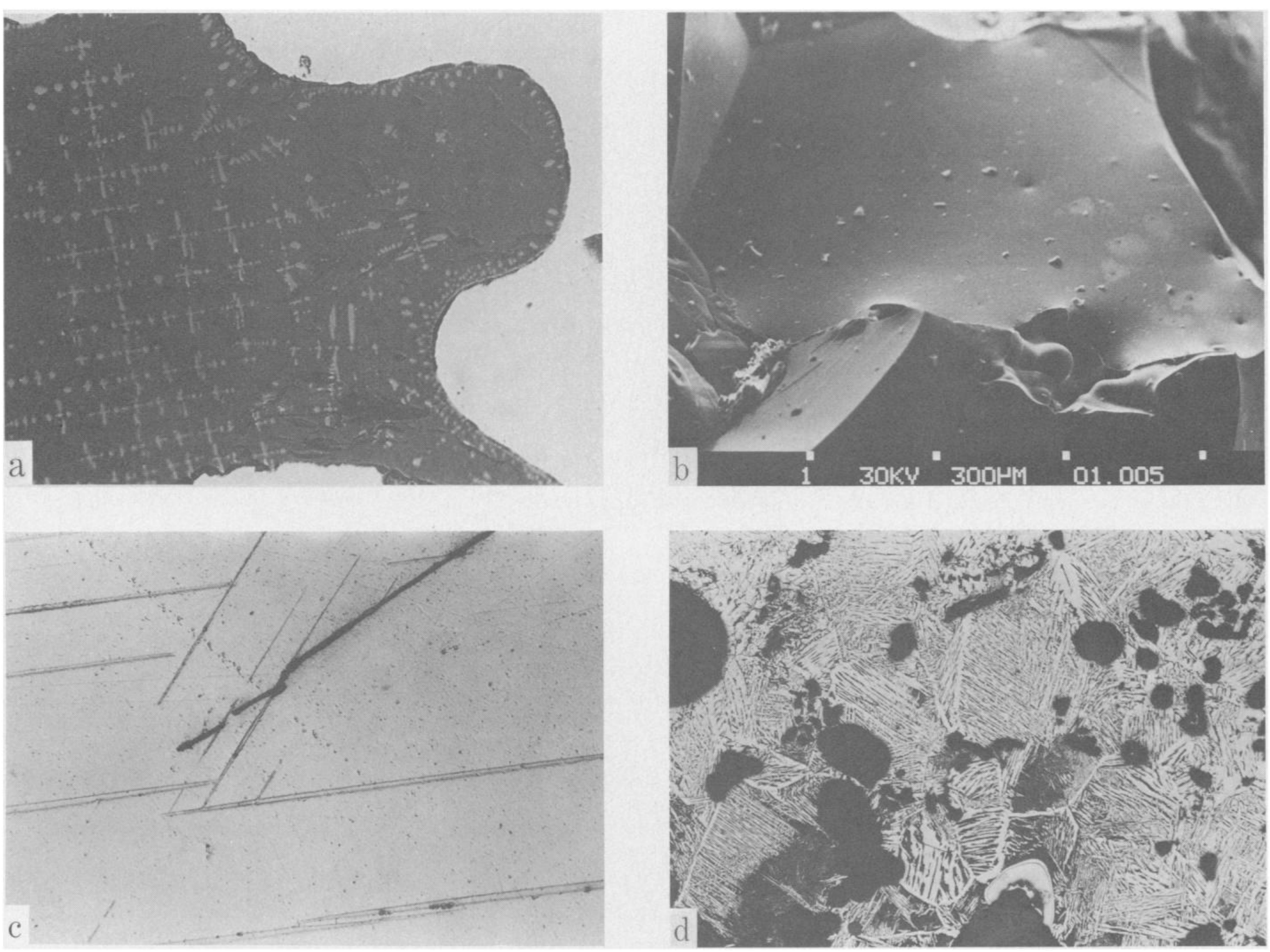

Fig. 6. (a) Bloom from 1976 smelt, showing growth interface between iron (white) and slag (gray) (unetched, ×20). (b) Scanning electron micrograph view of intercrystalline fracture in traditional bloom. (c) Photomicrograph of same bloom illustrated in (b), showing long undistorted Neüman bands (2 percent Nital, ×18). (d) Etched micrograph of bloom from 1976 smelt, showing wide local range of carbon content (×18).

Often the iron is severely oxidized, and therefore we await better archeological evidence for the cultural and technological aspects of prehistoric iron implements.

We find in traditional Africa an Iron Age technological process that was exceedingly complex and, in historical and relative terms, also advanced. There are indications from cultures near the Haya that similar types of furnaces were used in Uganda (*2*). Ethnographic data, although incomplete, indicate that many other neighboring cultures practiced an entirely different kind of technology. However, we suggest that this level of complexity was not limited to East Africa. The probable use of preheating in Yoruba furnaces (*3*) and the high carbon steel produced in them suggests that this and other African smelting technologies may have technological characteristics that are highly advanced and technologically sophisticated according to contemporary historical and scientific values. The insertion of multiple tuyères in large (4-meter-high) shaft-type furnaces such as those among the Wafipa people of southwestern Tanzania (*10, 11*) also suggests preheating and the possible production of steel by a process different from that observed in West Lake.

Our ethnographic study of recent smelting has also provided material evidence that the technological process revealed in 1977 archeological discoveries in the West Lake region has remained unchanged during the last 1500 to 2000 years. Archeological excavations at the KM2 site, an Early Iron Age industrial locale near the Lake Victoria shore (1°28′30″S, 31°44′45″E), have yielded excellent data which demonstrate that similar furnace form and preheating were employed during the Early Iron Age. Furthermore, archeological surveys tentatively show that Early Iron Age peoples lived in large villages where they practiced iron production. It has been suggested (*4*) that large settlements may be linked to localized high population densities caused by an industry "which demanded significant manpower." Our recent observations of the diversity of skills required for preparation of materials, operation of the furnace, and processing of the iron bloom show an organized, highly cooperative labor force. We suggest that the recently observed exploitative behavior is a reasonable, general model for the Early Iron Age. This does not mean that we believe the two are the same, but that the demands of the prehistoric industry were very similar to those of the recent past. It is abundantly clear that the industry is labor intensive, particularly during the direct production phase, during which a minimum of one dozen craftsmen are engaged in the cooperative enterprise. It is also possible that an economically complex and technologically advanced culture with high population densities may be linked to the evolution of politically centralized states in West Lake Region and in neighboring areas such as Rwanda.

Further archeological research is required to discover why such a complex technology grew up along the western shore of Lake Victoria. One possible hypothesis is that the heavy exploitation of forests (for charcoal and for agricultural purposes) may have triggered the development of an efficient, fuel-economizing technology. The widespread distribution of Early Iron Age industrial sites in West Lake, the manner of charcoal production and its 10 to 1 weight ratio of wood to charcoal, and the need for 500 pounds of charcoal, all suggest that, if smelting was widely practiced in prehistoric times, then the impact of the technological system must have been severe. The decline of productivity may be linked to an overexploited forest resource base; the evolution of the fuel-efficient preheated furnace may be an adaptation by the local smelters to that depleted resource.

Preliminary information on prehistoric vegetation obtained through study of prehistoric pollen indicate possible widespread forest clearance during prehistoric times. The enormous drop in productivity since the first colonial government in 1840 is attributed by the smelters to the availability of cheap, imported iron tools and spring steel and to the greater economic rewards of coffee farming.

One of the more profound implications of the West Lake discoveries is that we are now able to say that a technologically superior iron-smelting process developed in Africa more than 1500 years ago. This knowledge will help to change scholarly and popular ideas that technological sophistication developed in Europe but not in Africa. In that respect the ramifications are significant for the history of Africa and her people.

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12. We thank the United Republic of Tanzania, especially the University of Dar es Salaam and the Department of Antiquities for permission to conduct research in West Lake Region. A feasibility study of field research was assisted by a grant (P.S.) from the Wenner Gren Foundation for Anthropological Research. Field research and analyses were supported by NSF grant BSN 75-19611.