INTRODUCTION

When archaeologists have the opportunity to conduct laboratory analyses on the remains of metallurgical activities (Figure 1), they usually reach for samples of ore, slag and metal. Few researchers, however, fully recognize the potential interpretive value of the ceramic artifacts at their sites, unless forced to do so by sheer quantity. Tuyeres, furnace-wall materials, pit liners, bellow pots, crucibles and molds, as well as specialized and domestic pottery vessels, can all play important roles in metallurgical operations.

Systematic analysis of ceramic evidence not only corroborates technical reconstructions based on ores and slags, but it provides other information useful to understanding ancient technology and culture. For instance, a full reconstruction of a smelting process should not ignore the physical and chemical contributions of tuyeres placed in the furnace, as well as the furnace walls and pit liners. The kind of clay used and the method of crucible and mold formation certainly affect the microstructure and chemistry of the metals they hold. Economic and sociopolitical dynamics of ancient cultures can also be considered by examining evidence of resource specialization, the constraints on clay selection (e.g., controlled access to materials) and the interaction between metal workers and other craft groups.

IRON SMELTING IN ANCIENT TANZANIA

Permanent villages lined the shores of Lake Victoria in northwestern Tanzania (Figure 2) during the Early Iron Age (c. 300 B.C.–A.D. 800), just as they do today. Farmers, fishermen and hunters occupied the villages and, among them, some were skilled ironworkers and potters. Population growth during the Early Iron Age, 1 continuous occupation of the area for over two millennia and the rise of the Haya states 4 in recent centuries is testimony to the inhabitants' ability to exploit resources and adapt to changing environmental (i.e., deforestation and soil degradation) and cultural constraints.

The success of the local economies was supported by an active and widespread iron smelting and smithing technology that supplied vital tools such as axes, adzes, hoes, knives and spears. The ironworkers smelted a self-fluxing ore rich in limonite and goethite in induced-draft, non-slag-tapping shaft furnaces.

The temperatures achieved in these furnaces exceeded 1,600°C based on field reconstructions of the traditional techniques. Materials analysis of the slags and tuyeres indicates that temperatures certainly reached 1,500°C in some areas of the prehistoric furnaces.

The skilled craftsmen, probably part-time specialists, were cognizant of the physical properties and qualities of the raw materials they used. Clay, like ore and charcoal fuel, was a critical resource because its performance could significantly affect the outcome of a smelt. This is well demonstrated, in an unusual way, by the smelting technique of the Mafa in northern Cameroon who used a single tuyere made of nonrefractory clay. The Mafa wanted the tuyere to progressively melt during the smelt to provide a source of flux to the high-grade magnetite ore used. The Early Iron Age peoples of northwestern Tanzania, in contrast, sought highly refractory clay for their tuyeres and used other clays for building the furnaces.

A full evaluation of the constraints on and the successes of most metallurgical techniques should consider the associated ceramics. This involves investigating the kinds of clay available in a region, their distribution and accessibility, how they performed at different functions, and the consistency with which a specific clay was selected for a particular role. It is also important to consider the needs and practices of the principal competitors for clay—the potters.

CERAMIC AND CLAY ANALYSIS

The many questions related to clay resource selection and function were examined using an interactive strategy that employed two avenues of study. First, local clays that are currently used in the Kagera region by Haya craftsmen were collected and tested in the laboratory. The second stage of analysis fo-
Figure 1 (left). A pair of clay furnaces at Chisamba, Zambia, surrounded by scattered debris of tuyeres and slag.

Figure 2. An Iron Age blacksmith and tuyere clay selected, shows the author how to select high-grade tuyere clay based on its plasticity, lack of inclusions and color.

Figure 3. Taa Norbert, a blacksmith and former iron smelter, shows the author how to select high-grade tuyere clay based on its plasticity, showing a representative sample of tuyeres, bricks, pit lining and domestic Age sites. Binocular and petrographic microscopy (i.e., grain identifications and grain size analysis) and physical tests (i.e., Munsell color, hardness, apparent absorption and apparent porosity) were conducted. Chemical analysis on the clay fraction and some inclusions in each thin section was performed by electron probe microanalysis. Findings were compared to the results from the fired test squares.

Finally, to understand the reactions of the tuyere tips during smelting and their relationships to slag and bloom formation, reflected light microscopy was performed on some slagged and vitrified tuyere tips. Slags from the same furnaces, including highly metallic ones that may have formed at the periphery of the reduction zone near the tuyere tips, were examined in the same manner. Clues of interaction between the ceramics, slags and metal, such as phases not found in other slag samples, were sought.

CLAY AS A CRITICAL RESOURCE

The ancient ironworkers used clays to build the furnace superstructure out of brick-like segments, to line the furnace pit and to make tuyeres that articulated with hand-pumped bellows (Figure 4). Laboratory and experimental evidence indicate that they consistently chose certain clay types for specific ceramic functions. Several criteria were probably used in this selection process, including the physical characteristics of plasticity, thermal expansion and refractory quality. The bulk amount of clay necessary for certain tasks must have been evaluated in terms of available labor and transport.

A large amount of clay was required to build the air-tight furnace walls, estimated to be about 1 m tall, and to line the 1 m diameter pits. During a smelt, the furnace brick interiors and the pit liners were primarily subjected to a reducing atmosphere and temperatures that varied between 600–1,200 °C. The variation depended on the insulation provided by the charcoal fuel and the fluctuating size of the reduction zone. The brick exteriors, in contrast, were always oxidized and heated to low temperatures (<200 °C).

Clays appropriate for the functional needs of the furnace bricks and liners had to be: plastic and sufficiently workable to be formed into rectangular brick shapes or a thick (1–2 cm) lining without excessive crumbling or cracking during drying and smelting; porous enough to endure differential thermal expansion and shock; and refractory enough to withstand total collapse from melting or bloating from excessive heat.

The comparative evidence between the ancient artifacts and local clays in the Kagera region demonstrate that the ironworkers never left their hillside smelting sites to find the quantities of clays appropriate for furnace construction. In fact, it is likely that termite mounds commonly found around the sites were exploited as convenient, above-ground sources of material. All the sites were situated on iron-rich soils that contained enough clay to be sufficiently workable and plastic for brick making and for lining the furnace pits. The clayey soils also included abundant quartz sand that provided the porosity necessary to control drying shrinkage and thermal expansion. Additionally, however, these soils contained iron oxide impurities which acted as a flux to lessen their refractory quality in a reducing atmosphere. The limitations on the suitability of the hillside soils caused by the impurities could be and were easily mitigated by making thick bricks and liners. Even if the inner layer of the bricks and liner succumbed to terrible heat, the furnace was built with sufficient structural support for a smelt to continue.

The conditions under which the tuyeres had to function were more extreme, and their ability to perform successfully was very critical to the formation of an iron bloom. They channeled a flow of air to the furnace center which served to maintain charcoal combustion as well as to elevate and then maintain...