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The *chaîne opératoire* of Bronze Working in Ancient Sudan: An Attempt at Reconstituting the Manufacture of Kushite Weapons

Faïza Drici

1. Introduction

Weaponry has played a significant part in ancient societies. Around this production are arrayed issues of economic exchanges, raw material supplies, technical know-how, and social and cultural prestige.¹ In ancient Sudan, weaponry takes a special place because of the geographical area concerned and because of connections with Egypt and the Mediterranean world. Within this context, high quality metallurgy flourishes, from Kerma to the post-Meroitic period, with chronological and regional specificities (*fig. 1*, overleaf).

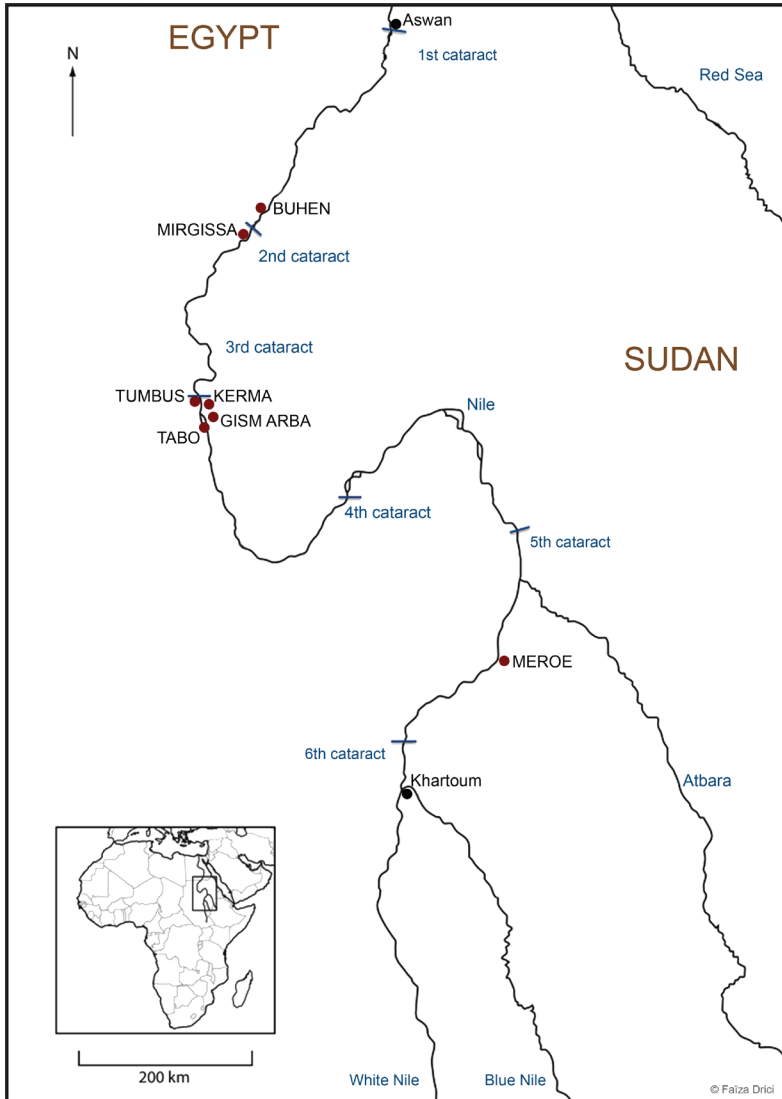
This article lays out all available sources of understanding relating to metalworking in Nubia, in particular the production of Kushite weapons: iconography, archaeological remains, and objects. These allow us to know and understand the choice of ores and their exploitation, and to reconstitute the various stages in the manufacture of weapons with the techniques and instruments required for this production.

This study does not stand alone, but joins related investigations into metallurgy, which constitutes one of the current research is-

* The writing of this article follows the lecture given at the round-table conference on “Know-How and Techniques in Ancient Sudan,” which took place at the University of Lille 3 in September 2013. Photos of weapons illustrating this article were taken by the author. I would like to thank Dr. Marsha Hill, curator at the Metropolitan Museum of Art of New York, for proofreading this article.

1 DRICI, “Combat réel et combat symbolique au Pays-de-l’arc.”

Fig. 1. Map of the Nubian sites mentioned below.



sues in the archaeology of Sudan.² Interest in metallurgy has been continuous since the discoveries of the furnaces of Kerma and Meroe.³ Recently, researchers have looked at the case of techniques and methods of production of various metal objects. Ultimately, results will enrich our knowledge about specific crafts and about pop-

2 MOHAMED FAROUQ ABDELRAHMAN, "A New Study concerning Kushite and Post-Meroitic Iron Objects," pp. 391-402; HUMPHRIS & REHREN, "Iron Production and the Kingdom of Kush," pp. 177-90.

3 ARKELL, "Iron in the Meroitic Ages," pp. 213-14; ARKELL, "The Iron Age in the Sudan," pp. 451-52; SHINNIE & KENSE, "Meroitic Iron Working," pp. 17-28; SHINNIE, "Iron Working at Meroe," pp. 28-35; REHREN, "Meroe, Iron and Africa," pp. 102-9.

ulation groups – the artisans – who put their expertise at the service of changing needs over the centuries.

	Egypt	Nubia
2500 BCE	Old Kingdom	Pre-Kerma
		Early Kerma
2000 BCE		
	Middle Kingdom	Middle Kerma
1500 BCE		Classic Kerma
		New Kingdom
1000 BCE		
		Kushite Dynasty
500 BCE		
	Late Periods	Napata
0		Meroe
500 CE		
		Post-Meroitic

2. Nubian metallurgy

2.1 Metallurgical Issues

First, the uneven distribution of the raw material creates disparities between regions. This feature raises questions about the correlations between basis of wealth and craft area. Second, the raw material requires processing before being used. These operations require specific techniques to extract the metal from the ore. The “metallurgy of preparation” is followed by the “metallurgy of transformation,” in which the objects are manufactured.⁴ Here we note

4 SCHEEL, *Egyptian Metalworking and Tools*, pp. 21–33.

an important fact for research: even if it is a single *chaîne opératoire*, the techniques used at these stages are different, as the locales can be as well. When talking about “workshops,” it is essential to ask about the specific situation under consideration: near an extraction site, or in a manufacturing location. Third, the particularity of metallurgy, compared to other crafts, lies in one of its properties: the option to melt down the metal, and thus to recycle it, complicating the patterns of production and distribution of the objects. A producer that needs to import the raw material may try to economize, supplementing the supply by reusing scrap. Nevertheless, metallurgy offers points of similarity to other crafts. Thus, the sources of study have much in common, since the majority of the work is based on manufacturing remains. The production of weapons made from copper alloy requires knowledge and know-how. We need to characterize the materials and processes, as well as the organization of the workshop, through the excavation of workshops providing access to scrap, such as crucibles or furnaces remains.⁵ Finally, a last trait shared with other crafts can be noted, insofar as metallurgy, like ceramics or lithic artifacts, benefits from sophisticated means of investigation associated with laboratory work.

2.2 Sources

Firstly, knowledge of Nile Valley metalworking has long relied exclusively on the study of smelting scenes from Egyptian tombs. Such a study can assess the techniques, the tools used by bronze-workers, and their evolution. However, this approach has limitations. On the one hand, the paintings and reliefs depicting copper work are uneven in number among the different periods: in the Old and New Kingdoms, examples are numerous and allow analysis and comparisons, while Middle Kingdom representations are very basic and only include the melting scenes. On the other hand, it is sometimes difficult to distinguish copper work from the working of other metals such as gold, silver, or electrum, when the inscriptions do not specify. Nevertheless, many of the techniques used, especially melting and hammering, could be similar to those associated with copper working, while devices employed like furnaces, crucibles and ventilation methods could be likewise. Finally, we cannot reconstruct the *chaîne opératoire* simply from the tombs; in all the scenes that represent copper-working, none shows the reduction of ore. The only steps illustrated are weighing the ore, melting the metal, casting and hammering. New Kingdom scenes represent a further stage in workshop operations: finishing work, namely polishing and decoration. In sum, the scenes depicted concern mainly metallurgy

5 OGDEN, “Copper and Copper Alloys,” p. 155.

of transformation, performed in the workshop, and not extractive metallurgy.⁶

Secondly, tools and instruments used for copper-working also contribute to elaborating a standard *chaîne opératoire*, to defining manufacturing methods, and to creating a classification of technical features according to functional criteria. However, further field-work is essential in order to locate other remains, to determine the nature of the furnaces, and to specify the raw materials used. The contribution of a new material requires a specific organization of production, from the raw material supply to the distribution of the finished product. A distinction must be made between ore extraction workshops, located close to the mines in order to reduce the volume of the product and thus make it more easily transportable, and bronze-working furnaces for the production of manufactured objects. All the structures (buildings, furnaces, fireplace pits), but also scrap and failures (crucibles fragments, abandoned drafts), despite their lesser value, are crucial references to craft activities.⁷ The main shaping steps are divided into different operations with corresponding specific remains: mold and crucible for smeltery, hammer for hammering, and chisel for decorations.⁸

Thirdly, the finished objects, here weapons, preserve marks that testify to various stages of the *chaîne opératoire*, and support the results of the previously discussed sources of evidence. There are constraints to technical evaluations; in the absence of laboratory analysis of weapons, identification of raw materials and working techniques rely on simple observation. The material concerned is rarely the object of analysis that could confirm a particular method of work, or the particular percentages of copper and tin used in the preparation of alloys. This is a serious shortcoming; a study of metallurgy that is not supported by laboratory analysis cannot specifically characterize the techniques used by the Kushite bronze-workers.

3. *Chaîne opératoire*

Iconography, archaeological remains, and artifacts are the sources that allow us to know and understand the selection and the exploitation of ores, the reconstitution of the various steps necessary for the manufacture of weapons, and the techniques and instruments required for this production. Craft production is part of a series of

6 GARENNE-MAROT, "Le travail du cuivre dans l'Égypte pharaonique d'après les peintures et bas-reliefs," pp. 85-100; BEDNARSKI, "Use of Metals," pp. 109-27.

7 FEUERBACH & MERKEL, "Considerations for the Field Treatment of Archaeometallurgical Remains," p. 212, chart 1.

8 SCHEEL, *Egyptian Metalworking and Tools*, pp. 21-46.

steps that make up a *chaîne opératoire*, a succession of all the working operations required to move from a raw material to one or more completed products. All these steps require perfect knowledge of techniques and specific choices according to the treated material, here copper and its alloys.⁹ The concept of *chaîne opératoire* thus serves as a tool to put in order the different techniques. Sequences can therefore be identified even if the work is carried on outside the site or if the products are missing. The ideal would be to have remains that testify to each step of the process, but the reality is different: it is by combining the different sources that we can obtain indications, even if sometimes isolated, illustrating the manufacture of Kushite bronze weapons:

ore mining → oxydoreduction → weighing → alloy production →
 shaping → annealing → finishing touches → weapon use → repairs
 → abandonment → recycling → weapon discovery

3.1 From the ore to the metal

The “metallurgy of preparation” means the operations that extract the metal from the ore, that is the phases of preparation and reduction of this ore. To carry a bronze weapon, it is necessary to procure copper metal or alloys. Metal compounds of such alloys, which circulate in the metallic state in Egypt and Nubia, are copper, tin, zinc, and lead. They can also be used unmixed, namely unalloyed.¹⁰

Ore mining and ore processing. Extracting metals from their ores is the step that immediately follows the mining work. Metallurgical processing can take place at the site of the mine, or in specific workshops. In Egypt, several mining sites are known in Sinai and the Eastern Desert.¹¹ In addition, many of the ores were imported directly from the island of Cyprus.¹² Copper oxide beds were also reported in the quarries of Tumbus, located 25 km north of Kerma.¹³ Finally, one kilometer from the fortress of Buhen, the extraction of copper was considered: some copper ore fragments, with malachite

9 OGDEN, “Copper and Copper Alloys,” pp. 151–61.

10 GARENNE-MAROT, “Le cuivre en Égypte,” pp. 97–102.

11 In Egypt, Serabit el-Khadim and Ayn Sukhna revealed complete mining sites. See CHARTIER-RAYMOND, GRATIEN, TRAUNECKER & VINÇON, “Les sites miniers pharaoniques du Sud-Sinai,” pp. 31–77; CASTEL & POUIT, “Anciennes mines métalliques dans la partie Nord du désert oriental d’Égypte,” pp. 101–12; TALLET, “Six campagnes archéologiques sur le site d’Ayn Soukhna, golfe de Suez,” pp. 10–31; ABD EL-RAZIQ, CASTEL & TALLET, “Ayn Soukhna et la mer Rouge,” pp. 3–6.

12 HELCK & OTTO, “Kupfer,” col. 881–82; GARENNE-MAROT, “Le cuivre en Égypte,” pp. 104–5; CHARTIER-RAYMOND, GRATIEN, TRAUNECKER & VINÇON, “Les sites miniers pharaoniques du Sud-Sinai,” p. 65.

13 REISNER, *Excavations at Kerma IV–V*, p. 16, pp. 176–78; BONNET, “Un atelier de bronziers à Kerma,” p. 19.

and a high proportion of gold, were found nearby the gold mines of the site.¹⁴

The preparation consists in concentrating the ore in order to produce a substance in which the copper content is high enough to move to the reduction step. In veins, the ore is linked most often to the rock that contains it, and named gangue. There are three successive steps for enrichment of the ore. We begin with crushing, using anvils and stone hammers. The goal is to obtain grains of the same size, so that during the cleaning, the relative density separation is easily accomplished. Crushing to achieve a finer grind may follow, and finally washing. The ore concentrate, along with the ore that did not need to be treated because of its purity, is now capable of undergoing the appropriate heat treatments.

Oxydoreduction. Copper is usually found in oxidized form. In order to extract the metal from the ore, it must be reduced, so that the copper atoms are transformed to metallic copper. Both the nature of the ore and know-how determine the choice of the furnace and the reduction process. The reduction of copper ores takes place in low furnaces. The chemical reaction requires very specific heat conditions.¹⁵ The fuel commonly used to achieve these temperatures, namely charcoal, was also an ideal reducing agent to attract oxygen from ores and isolate the metal. Charcoal could come from acacias, which are highly flammable and generate little ash.¹⁶ The actual heating of the ore in the furnace consists of sprinkling the ore in the upper part of the furnace, alternating with charcoal layers. Combustion is provided by natural or artificial ventilation.¹⁷ During this oxidation, the iron is separated from the copper by the action of heat and carbon oxide. At the end of the operation, the air supply is removed. The slag remains on the surface, while the cupreous matte flows at the bottom of the furnace. The resulting copper is heated in a crucible to be liquefied. The preheated crucible is placed in the center of the embers and covered with charcoal. Air is blown onto the crucible and fans the embers until the copper melting point, 1084°C, is reached.¹⁸ The copper is then poured into molds to obtain ingots, easily transportable for exchange.¹⁹

14 EL SAYED EL GAYAR & JONES, "A Possible Source of Copper Ore Fragments Found at the Old Kingdom Town of Buhen," pp. 31-40.

15 BONNET, "Les fouilles archéologiques de Kerma (Soudan). Rapport préliminaire sur les campagnes de 1980-1981 et 1981-1982," pp. 34-38.

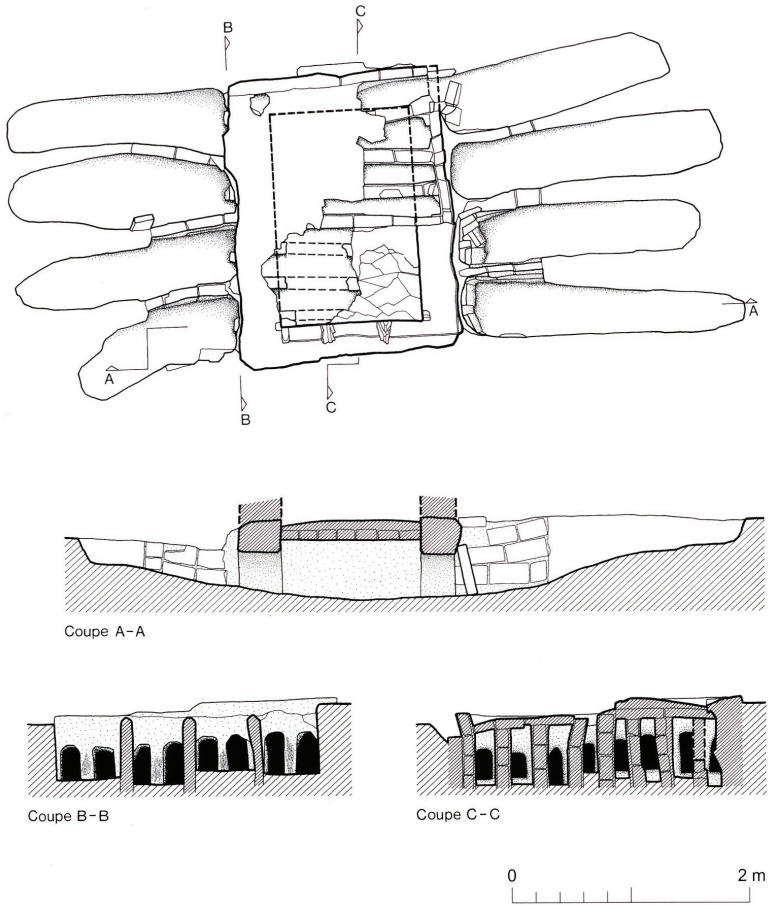
16 SCHEEL, *Egyptian Metalworking and Tools*, p. 27; CHARTIER-RAYMOND, GRATIEN, TRAUNECKER & VINÇON, "Les sites miniers pharaoniques du Sud-Sinai," pp. 64-65; ABD EL-RAZIQ, CASTEL, TALLET & FLUZIN, *Les ateliers métallurgiques du Moyen Empire*, p. 151.

17 BEDNARSKI, "Use of Metals," pl. 6A-B.

18 OGDEN, "Copper and Copper Alloys," p. 153; ABD EL-RAZIQ, CASTEL, TALLET & FLUZIN, *Les ateliers métallurgiques du Moyen Empire*, pp. 151-52.

19 OGDEN, "Copper and Copper Alloys," p. 156.

Fig. 2. Bronze-worker furnace from Kerma.



We have some examples in the field. First, at Kerma, inside the *deffufa*, the remains of a bronze-maker's workshop dating from the Middle Kerma were found: "un atelier dont la production était essentielle aux questions de défense, comme l'indique le nombre élevé de couteaux et de dagues en bronze recueillis sur le site."²⁰ The remains constitute a rectangular furnace, consisting of eight parallel channels intended for hearth (fig. 2).²¹ The fuel was put into the furnace by eight coupled gates at the bottom of four ramps. The metal analysis from the crucible and the furnace showed an alloy of copper and tin.²² At the Egyptian fortress of Buhen, several metalworking remains were discovered: furnaces, crucibles with a hole

²⁰ BONNET, "Un atelier de bronziers à Kerma," p. 21.

²¹ BONNET, *Le temple principal de la ville de Kerma et son quartier religieux*, p. 37, fig. 28.

²² The laboratory of the Geneva Museum of Art and History has identified and analyzed the metal remains on fragments of crucibles found in the furnace structure. See BONNET, "Un atelier de bronziers à Kerma," p. 22.

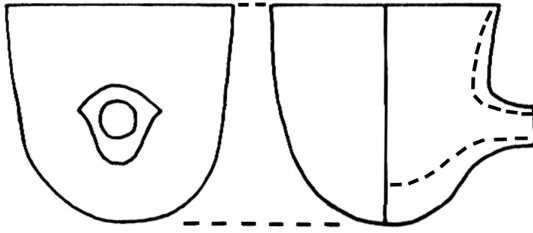


Fig. 3. Crucible from Buhen.

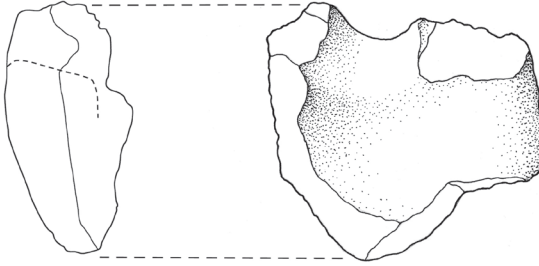


Fig. 4. Crucible fragment from Gism Arba.

for the metal flow (fig. 3),²³ and *tuyères*.²⁴ At Gism Arba, inside a classic Kerma dwelling, the discovery of a crucible also points to such work (fig. 4),²⁵ although looted graves did not produce a significant quantity of copper metal objects.

Alloy production. Most elements are soluble in copper, and can constitute alloys with it. Despite its remarkable properties, copper has insufficient mechanical strength properties, hence the use of copper alloys, especially in the manufacture of weapons. In addition, variation of the alloy ratio creates changes in the color of the object. Thus, copper is combined with a large number of metals to provide alloys, such as bronze consisting essentially of copper and tin.²⁶ Tin increases hardness and resonance, but makes the metal brittle and less malleable. Therefore, the proportions of the two metals are dependent on the intended use of the weapon, functional or ceremonial.

3.2 From the metal to the weapon

If metallurgy is generally implemented in the vicinity of the metal deposits (copper in this case), processing is preferably performed near the consumers. Making objects of copper alloy does not require

23 EMERY, SMITH & MILLARD, *The Fortress of Buhen*, fig. 741, pl. 43; WILLIAMS, "Industrial Metallurgy in Egypt and Sudan," pp. 201-6.

24 *Tuyères* are ceramic conduits placed at the base of the furnace for the supply of oxygen. See EMERY, SMITH & MILLARD, *The Fortress of Buhen*, fig. 760, pl. 56.

25 Fragment found by Brigitte Gratien inside a dwelling. I thank her for allowing me to study and draw it.

26 HELCK & OTTO, "Bronze," col. 870-71; GARENNE-MAROT, "Le cuivre en Égypte," pp. 107-8.

Fig. 5 (l). Tomb of Kaemrehu, Saqqara, tomb 79, wall D, register 4.



Fig. 6 (r). Tomb of Rekhmire, Qurna, tomb 100, south side, east wall, register 3.

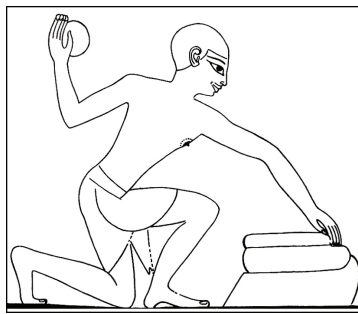
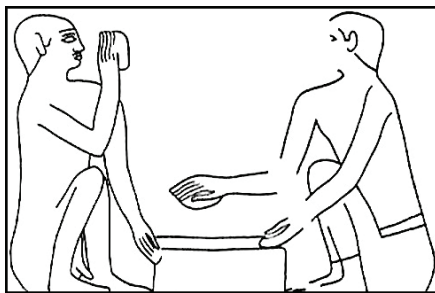


Fig. 7. Tomb of Pepiankh, Meir, tomb 2, room A, west wall, register 2.



complex architectural installations. However, through all the Kushite kingdoms, we know little about specific structures of this craft. Here, we must remember that we are talking about secondary metallurgy, that is, the stages from the shaping to the recycling of the object, including its use.

Shaping and annealing. The shaping stage is linked to a particular property of the metal, elasticity. Indeed, copper is a ductile metal; it can be worked and welded to itself by hammering. The technique of hammering consists in hitting the surface of the piece with a series of percussions in order to reduce or to extend its thickness and to homogenize the metal. Hammering also hardens some parts of the product and makes it more resistant. Large plastic deformations are carried out by hammering and provide plastic capacity to the metal, always associated with annealing to avoid the breaking point.²⁷

The continuity of hammering techniques is depicted in Egyptian tombs. For these operations, the same tools are used throughout the Pharaonic period: a small round or hemispherical stone and an anvil. The latter is made from a single block of stone in the Old Kingdom, as illustrated in the graves of Kaemrehu (fig. 5)²⁸ and Pepiankh

²⁷ OGDEN, "Copper and Copper Alloys," p. 157.

²⁸ MOGENSEN, *Le mastaba égyptien de la Glyptothèque Ny Carlsberg*, p. 42, fig. 41; WRESZINSKI, *Atlas zur Altaegyptischen Kulturgeschichte*, pl. 404.

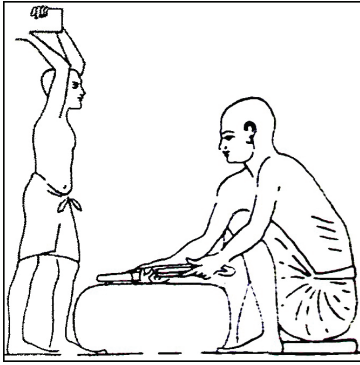


Fig. 8 (l). Tomb of Petosiris, Hermopolis, pronaos, section 1, north wall, lower register.



Fig. 9 (r). Tomb of Puyemre, Theban Necropolis, tomb 39, south side, east wall, register 5.

(fig. 7).²⁹ The anvil seems to be made of two parts in the New Kingdom: a wooden block, supporting a mass of stone, as in the tomb of Rekhmire (fig. 6).³⁰ Hammering stones seem to differ again in the Late Period: the tomb of Petosiris presents a scene in which a worker beats a sheet of metal placed upon an anvil while another worker holds the metal with a long pliers (fig. 8).³¹ An example of this type of pliers was found at Buhen. Continuous hammering hardens the metal: to restore flexibility so that work can go on without the risk of cracking, the metal has to be annealed.

Copper alloys are a complex synthetic material, that is to say, they require thermo-chemical treatment, but also that the treatment may be reversible. The practice of annealing consists of heating the metal, but below its melting point.³² This technique is depicted in the tomb of Puyemre (fig. 9).³³ Annealing affects the internal structure of the metal, allowing the metal to recover its elasticity and ability to be worked. In all cases, these techniques require significant know-how: to hammer a weapon, the bronze-worker has to know the technical properties of the copper alloy. In the case of the practice of annealing, he must be able to manage the temperature, based on evaluation of the color of the metal. In the end, however, despite the large number of scenes depicting the shaping of metal objects, they are too simplified and do not lead to a clear understanding of the process.

29 BLACKMAN & APTED, *The Rock Tombs of Meir*, pl. 16.

30 WRESZINSKI, *Atlas zur Altaegyptischen Kulturgeschichte*, pl. 318; DAVIES, *The tomb of Rekh-mi-re at Thebes II*, pl. 55.

31 LEFEBVRE, *Le tombeau de Pétoisiris III*, pl. 7.

32 GARENNE-MAROT, "Le travail du cuivre dans l'Égypte pharaonique d'après les peintures et bas-reliefs," pp. 97–98.

33 DAVIES, *The tomb of Puyemre at Thebes I*, pl. 23; WRESZINSKI, *Atlas zur Altaegyptischen Kulturgeschichte*, pl. 153.

Fig. 10. (clockwise, starting left). Kerma, sword, E.07391 (Brussels, Cinquantenaire Museum), L. 45 cm.



Fig. 11. Meroe, quiver, 24.963.1 (Boston, Museum of Fine Arts), L. 42 cm.



Fig. 12. Kerma, spearhead, SNM 2082 (Khartoum, Sudan National Museum), L. 75 cm.



Fig. 13. Mirgissa, rivet, SNM 14076 (Khartoum, Sudan National Museum), L. 2 cm.

Fig. 14. Kerma, dagger, 027453 (Geneva, Museum of Art and History), L. 17.3 cm.



Finishing touches and use of the weapon. The completion stage includes several activities: polishing, decoration, and assembly. Polishing is done after each production step of the *chaîne opératoire*, including after annealing. The final polishing is to shine the weapon's blade, as illustrated by the bronze sword discovered at Kerma (fig. 10).³⁴ In order to do this, a very fine-grained material was used, such as sand or very fine abrasives.

When polishing was finished, decoration could be applied. Plastic deformation comprises repoussé (a technique for producing high relief decoration) and chasing (displacement of metal to produce linear decoration).³⁵ Decoration can also include surface treatment, for example gilding. Blades of daggers and swords illustrate finishing work on the cutting edge such as polishing. The only example of a bronze quiver was found in the western cemetery of Meroe (fig. 11).³⁶ It measures forty centimeters, is cylindrical in shape, and has a chain for transport and three bells. It is decorated with bands of incised lines running around its circumference, but also on the lid and the bottom. Arrowheads and spearheads also display geometric designs, as on an example from Kerma, which is decorated by hatching and two incised bands that encircle the shaft (fig. 12).³⁷

Finally, the last step, mechanical assembly, included cold operation by riveting (fixing parts together by means of a separate insert) or setting (adjustment of two parts in such a way as to lock them together). Rivets assembled many weapons.³⁸ These are small pins, formed by a cylindrical rod (fig. 13). The ends were then hammered so as to serve as an assembly device, and secondarily so as to fit inconspicuously in the decorative scheme (fig. 14).³⁹ In addition, handles can take various forms, including animal (fig. 15, overleaf).⁴⁰

Differences in manufacturing techniques can be observed that appear to align with two different types of weapons, functional or non-functional. Those with a functional purpose are hardened both by hammering and by being alloyed with tin. Certain others were cast, shaped by hammering, annealed, and then left in this state without undergoing a final hammering.⁴¹ This would seem to indi-

34 BRUWIER, *Pharaons noirs*, p. 120, fig. 10.

35 SCHEEL, *Egyptian Metalworking and Tools*, p. 46; BEDNARSKI, "Use of Metals," p. 115.

36 The discoloration of seventy-three arrowheads placed in this metal quiver suggests that they may have been soaked in poison. See DUNHAM, *The Royal Cemeteries of Kush V*, pp. 204–6, fig. 147–49; KENDALL, *Kush*, p. 50–52 (<http://www.mfa.org/collections/object/quiver-145858>).

37 DUNHAM, *Excavations at Kerma VI*, p. 37, fig. 66 (28).

38 VERCOUTTER, "A Dagger from Kerma," p. 266.

39 BONNET, "Les fouilles archéologiques de Kerma (Soudan). Rapport préliminaire sur les campagnes de 1982–1983 et 1983–1984," p. 16, fig. 15; BONNET, *Kerma*, p. 51, fig. 41 and p. 183, fig. 146; CHAIX, "Omni-présence du cuir à Kerma (Soudan) au III^e millénaire av. J.-C.," p. 37, fig. 6; CHAPPAZ, *Kerma et archéologie nubienne*, p. 42, fig. 13.

40 REISNER, *Excavations at Kerma IV–V*, p. 199, fig. 189 (5), fig. 2, pl. 50 (6); HONEGGER, *Aux origines des pharaons noirs*, p. 74.

41 YOUNG, "Archaeometric Analysis of Copper Swords from Kerma (Nubia)," p. 481.

Fig. 15. Kerma, knife, SNM 1060 (Khartoum, Sudan National Museum), L. 24 cm.



Fig. 16. Meroe, arrowheads, SNM 2465 (Khartoum, Sudan National Museum), L. 3 cm.



cate that these weapons were not manufactured for use as such but rather had a decorative intention, a conclusion supported by the fact of their discovery in a funerary context: for example, ceremonial weapons (fig. 16).⁴²

Repairs, abandonment, and recycling. The concept of *chaîne opératoire* includes all activities from the acquisition of ores to the realization of the finished product, but also the phases of use and abandonment of the object, which bring about alterations of morphology and structure like wear or corrosion. In most cases voluntary abandonment, such as in funerary deposits, is in question. The weapon can be repaired either during manufacture or during its term of use. Repair techniques generally consist of adding a piece to the object, which follows methods similar to those used during assembly of several parts of a single object.

The *chaîne opératoire* of copper alloys is finally complete with the integration of an essential notion in the study of metallurgy: recycling. The cupreous metal is a complex synthetic material, which offers the advantage of being recyclable. Recycling may occur at various stages. On one hand, it allows reintegration of objects that could not be brought to completion, such as casting failures, in the *chaîne opératoire*. This explains why the workshops sites are so poorly documented. On the other hand, the physicochemical properties of the

42 The majority of bronze arrowheads discovered in the tombs are too thin and too fragile to have any real use. See DUNHAM, *The Royal cemeteries of Kush V*, p. 206, fig. 149 (d).

metal permit used objects to be melted down to produce new ones. Finally, the ability of the metal to be recycled is an important characteristic, particularly in the case of areas without ores or in which the supply is temporarily insufficient.

4. Weapons and archaeometallurgy

4.1 *Observations and analysis*

The remains of copper craft, such as crucibles or scorias, provide much information about metalworking. But it is the finished objects that constitute the majority of the remains and that allow us to understand certain manufacturing techniques. By observing the number of pieces that form the weapon and the constituent material of each part, we understand the manufacturing processes. Laboratory work is unfortunately not sufficiently used, cost being the main deterrent. But before resorting to sophisticated and expensive methods, simple observations can be made. Indeed, observing the weapon with the naked eye or binocular microscope can identify heavily corroded areas and working defects. Such features relate to links in the *chaîne opératoire* that traces the manufacture and the life of the weapon. However, while weapons are a source for the study of metal craft, they provide only a partial view because of their nature and their place in the *chaîne opératoire*. Because they are finished products, these weapons present few signs that actually reflect their manufacture. Quite the opposite; the artisan did his best to erase all traces related to processes of casting or hammering. In the most favorable situation, the reverse or the interior, that is, the parts that were not meant to be seen, can retain manufacturing marks. By analyzing these marks, we can get an idea of some shaping processes, especially those related to plastic deformation, decorations or repair. These observations are often not sufficient to convincingly conclude the nature of the techniques used, hence the interest in archaeometallurgy.⁴³

Metallurgy can be understood by studying the internal structure of metals and alloys. From the weapon itself we can reconstruct the artisanal know-how. The metal retains information that indicates the thermo-mechanical activity the object has undergone: hammering, casting, annealing. Observations by naked eye and microscope, combined with analysis of alloy composition, identify the manufacturing processes and evaluate artisanal knowledge. Leaving aside the question of the origin of ores, we can determine the composition

43 In the 1970–80s, R.F. Tylecote was the first to use archaeometallurgy for the study of ancient civilizations. See TYLECOTE, "Metal working at Meroe, Sudan," pp. 29–49; PICHOT, FLUZIN, VALLOGGIA & WUTTMANN, "Les chaînes opératoires métallurgiques en Égypte à l'époque gréco-romaine : premiers résultats archéométriques et archéologiques," pp. 217–37.

Fig. 17. Kerma, sword, 13.4016 (Boston, Museum of Fine Arts), L. 52 cm.



of the alloys. The various major component elements provide information about the conditions of preparation. In the manufacture of weapons, it is clear that a copper-tin alloy is preferred over unalloyed copper. Harder and more easily melted than copper, bronze is an alloy of superior quality, and it can be worked with a hammer, melted, and beaten. It has, moreover, excellent resistance to corrosion. The proportion of tin added depends on the type of weapon that the artisans wish to produce. For example, a weapon manufactured for hunting or war has to strike without breaking and therefore needs to be low in tin to resist accumulated blows. However, a ceremonial weapon, which has to support only minimal use, is made from a metal with tin in large proportion; tin addition in excessive quantities results in a greater fragility of the object.⁴⁴ The use of tin also determines the color of the bronze: color changes to yellow (fig. 17).⁴⁵

4.2 Examples of laboratory studies

Few compositional analyses of Kushite weapons have been performed. Among the rare examples, two swords, found by G.A. Reisner at Kerma with the Harvard Expedition to the Sudan (1913–1916), were the subjects of archaeometric analysis, which offers information about craft technologies and practices.⁴⁶ The microstructure and the chemical composition of these swords indicate a very hard metal that underwent cold working but no final annealing. The weapons are unalloyed copper, implying a ceremonial or decorative use. The Brussels Royal Institute for Cultural Heritage analyzed another sword from Kerma housed in the Museum of Khartoum.⁴⁷ The metal of the blade is an alloy of copper and tin (free from zinc), with a homogeneous structure revealing hammer-hardening and annealing techniques. The blade was, therefore,

44 BONNET, *Le temple principal de la ville de Kerma et son quartier religieux*, p. 38.

45 REISNER, *Excavations at Kerma IV-V*, fig. 1, pl. 50 (<http://www.mfa.org/collections/object/bronze-dagger-with-wood-and-ivory-handle-141509>).

46 YOUNG, "Archaeometric Analysis of Copper Swords from Kerma (Nubia)," pp. 475–90.

47 SNM 1228. See VERCOUTTER, "A Dagger from Kerma," pp. 265–67, pl. 35–37.

not molded but hammered and reheated. The rivets are made of unalloyed copper, they were cast and cold worked; analysis characterized their structure as dendritic. The use of alloys is attested for other categories of objects, including statuary. Laboratory tests are still rarely performed, but we do have some data. Analyses on the statue of a Meroitic king found in the temple of Tabo on the island of Argo revealed a copper-tin-lead alloy, plated with gold leaf and cast by the lost-wax process.⁴⁸ The use of alloys, in particular the use of bronze, has been demonstrated from Kerma to the Meroitic kingdom, despite the greater use of iron during the latter period.⁴⁹ Deposition of daggers in graves appears to have been quite common in the Kerma period as evidenced by the discoveries of blades, pommels, rivets, and traces of green color on bones owing to oxidation of contiguous metal.⁵⁰ These objects raised the question of actual or symbolic use; they seem so fragile for any use other than liturgical.

5. Conclusion

The Kushite craftspeople attained a remarkable degree of skill in the manufacture of bronze weapons. This expertise testifies that several particular foundry techniques were in employ, that plastic deformation was in use, and finally that the alloys were not random choices. Study of iconography and archaeological remains needs to be supported by direct technical analysis of objects, according to established laboratory procedures. Based on objects such as weapons, archaeometallurgy can reconstruct the working methods and skills of artisans. In addition, the study of bronze weapons illustrates certain steps of the *chaîne opératoire* revealed by other sources, particularly shaping and finishing work. Lastly, archaeometallurgy is a discipline that is not confined only to egyptology, but on the contrary widens the scope of study to other geographical areas, bringing new discoveries in terms of weaponry and ancient metallurgy.

48 SNM 24705. See MAYSTRE, *Tabo I*; BAUD, "La statue d'un roi archer," pp. 180–81.

49 LENOBLE, "L'arsenal de Méroé et le monopole royal du fer dans l'Empire méroïtique," pp. 209–17; BAUD, "La métallurgie méroïtique," pp. 130–33; DRICI, "L'armement méroïtique," pp. 67–70.

50 REISNER, *Excavations at Kerma IV–V*, pp. 187–94; HAFSAAS-TSAKOS, "Edges of Bronze and Expressions of Masculinity," pp. 84–89.

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