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Experimentation with iron reduction in Arboutchatack, central Chad

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Abstract: Metallurgical activities in Chad have interested many researchers since the colonial period. Witnesses of iron ore reduction have been modernized in the different parts of the country. Used techniques vary according to communities. No longer used due to the extinction of primary metallurgy several decades ago, these techniques are not known to them, and as a result, the types of reduction furnaces are completely ignored. Those having some knowledge of it can still experience it. Among blacksmiths in the Dababa Division, Hadjer Lamis Region, is an old reducer who, at our request, experimented with iron ore reduction in a furnace used right from his ancestors' period. Surrounded by young blacksmiths, the old reducer carried out the operational chain of iron production and transformation. While taking part in it, we had the opportunity to ask them questions about the different aspects of their steel industry. The objective of this article is to try understanding this model of the ancestral "savoir faire" (knowing how to) of the metallurgists in the community located in the central part of the country, in the Sahelian zone.

Key words: reduction, iron, technique, experimentation, Arboutchatack.

Résumé : *L'activité métallurgique au Tchad a intéressé nombre de chercheurs depuis la période coloniale. Des témoins de la réduction du minerai de fer ont été mis au jour dans les différentes parties du pays. Les techniques mises en œuvre varient selon les communautés. N'étant plus utilisées en raison de l'extinction de la métallurgie primaire il y a plusieurs dizaines d'années, ces techniques ne sont pas connues d'elles et par conséquent, les types de fourneaux de réduction sont totalement ignorés. Ceux qui en ont quelques connaissances peuvent encore l'expérimenter. Parmi les forgerons du Département de Dababa, dans la province de Hadjer Lamis, se trouve un ancien réducteur qui, à notre demande, a expérimenté la réduction du minerai de fer dans un fourneau utilisé depuis ses ancêtres. Entouré des jeunes forgerons, il a réalisé la chaîne opératoire de production et de transformation du fer. En y prenant part, nous avons eu l'occasion* *de leur poser des questions sur les différents aspects de l'activité sidérurgique. L'objectif de cet article est de chercher à comprendre ce modèle de savoir-faire ancestral des métallurgistes de la communauté située au centre du pays, dans la zone sahélienne.*

Mots clés : *réduction, fer, technique, expérimentation, Arboutchatack.*

Introduction

Researches planned by archaeologists proved the witnesses of metallurgical activities in Chad (Général Derendingueur, 1936; Jean-Paul Lebeuf and MA Detourbet, 1950; Françoise Treinen-Claustre, 1982; Tchago Bouimon, 1995; Philippe Lavachery and al, 2010; etc.). Vestiges discovered on various sites did not enable us to explain the techniques used by metallurgists, since right from the 1950's, iron production activities went through extinction, thus leading to experimentation in Fort-Lamy in 1970 by Boulala metallurgists in the Batha Region, in the central-northern part of Chad (Jean Chapelle, 1980). Another experimentation was made by a metallurgist in Deli, in the Ngambaye ethnic group, for his PhD thesis in 2009 (Clison Nangkara, 2015).

The techniques used during the experimentations in Fort-Lamy and Deli are completely different from each other. The first experimentation furnace is big and fixed, while the second one is mobile and has small dimensions. This difference shows that there are several types of furnaces, changing according to communities. It is, therefore, possible that the type in central Chad has another model.

Experimentation with iron ore reduction in another region could provide new knowledge in this area. The Dababa Division in the centre of the country has been chosen for this experiment which may clarify the techniques of metallurgists which have so far escaped the curiosity of archaeologists. To this end, we met a group of blacksmiths in Arboutchatack who agreed to reconstruct the iron production and processing chain. Under the responsibility of a metallurgist-forger, the blacksmiths carried it out on May 25, 2011.

The blacksmiths (bassara in local terms) who carried out the reconstruction came from Idalgoz village, 5 km away from the north of Arboutchatack. Idalgoz is located close to the iron deposit, a source of raw materials for metal workers-smiths. The blacksmiths took the iron ore, processed and reduced it in the field to obtain a magnifying glass, which they themselves tranformed into finished products. In the past, other metallurgists-blacksmiths came from neighbouring localities: Batha, Kanem, Ouaddai, Guéra, Salamat and from Chari-Baguirmi. This indicates that metallurgists-blacksmiths in the region were of different origins to find themselves in this locality to practice their profession. Their prolonged stay made them natives.

The site selected for the reduction is Arboutchatack, a village in Amladoba Canton, in the Dababa Division, Hadjer Lamis Region, located in south-central Chad. Arboutchadtack was selected because of its position on a main road, the national road from N'Djamena to Mongo.

Figure 1: location of the experimentation site for iron reduction

This study aims at showing that there are iron ore reduction techniques among metallurgists in central Chad. It testifies of various architectural techniques, the method of air supply and ritual practice which accompanies this activity.

1. Methodology and materials

When we arrived in the evening of May 24, 2011 from N'Djamena to attend the iron ore reduction reconstruction, two of the oldest blacksmiths, Alradi Al-Khalil (125 years old) and Abdelrassoul Hissein (85 years old) at the head of the group of eighteen (18) blacksmiths, showed us the materials prepared to reduce the iron ore ("Kadjam", local term). These are the modeled raw materials (iron ore and charcoal), nozzles ("Farwaye") and furnace ("Siyéba"), bellows and second products but necessary for the reduction: millet balls and sand. The bellows are those of the forge. The preparation of all these materials, decided by the leading (master) reducer, was made before our arrival.

After that visit, we had interviews with the metallurgists-blacksmiths, using a questionnaire. Those interviews dealt with the acquisition of raw materials and equipments necessary for the iron ore reduction, modeling techniques for nozzles and furnaces. If all the materials were prepared before we arrived, setting up the reduction structure took place in our presence. It was at that level that the photographs were sufficiently taken.

2. Results

Our interviews with metallurgical blacksmiths and our observations of the reduction session produced results.

2.1. Preparation for iron ore reduction

The iron ore reduction workshop is located in the dry bed of Eiba (12.14198° N/ 17.56642° E), an arm of the Barh Azoum river, 1 km away from the north of Arboutchatack. Under the responsibility of that metallurgist-blacksmith (Alradi Al-Khalil), the assistants extracted ore from the old shafts that were exploited and abandoned 75 years ago. These shafts are located on the rock of

Zoo-mud and Dalgo villages. The assistants crushed the ore and made a pile of charcoal, another pile of husked millet bales ("chara" in the local language) and a third pile of sand.

Four nozzles shaped from the clay paste were exposed to the sun. The nozzles have an average length of 28 cm. Their average diameter is 12 cm. Their air duct is 10 cm in diameter.

From the truncated cone shape (Figure 3, photo 1), the kiln, also made of clay, is 80 cm high, 50 cm at the base and 20 cm at the top to which corresponds a lid measuring 34 cm in diameter. On the outer wall of the kiln, the metalworkers place 11 blisters. Its construction was made gradually: when the builder makes a round of clay paste, he lets it dry for a few hours before starting again. According to the metallurgist-reducer, this modeling took three days.

Four pairs of bellows brought back from the forges were to be used to supply the furnace with air.

2.2. Workshop choice and reduction structure creation

The leading reducer has delimited two juxtaposed areas of different dimensions. The first is 3.45 m long and 2.80 wide oriented North-South. In the center of it, he had a circular ditch dug of 53 cm in diameter and 24 cm deep (Cf. figure 2, photo 1). Four nozzles are placed at the base of this ditch. A slag evacuation channel has been built: it is 27 cm deep and 34 cm long; it is oblique.

The second area, attached to the first one at the northeast corner, is 186 cm long by 120 cm wide. These are areas where access to the public is prohibited.

Above the ditch, the metallurgist-reducer placed the mobile furnace in dried clay previously described. At 45 cm from the shaft, 4 blisters are placed. Eleven (11) prehensible poses surround the end of the shaft. A cover has a hole of 10 cm in diameter.

2.3. Charging, firing and combustion

While preparing for charging, the leading reducer spreads sand at the bottom of the ditch and then pours 4 "coros" of fine millet bales into it. Checking that the quantity of bullets is sufficient, he authorizes charging of the charcoal and iron ore.

The charging of these raw materials took place in three stages. In the first step, the metallurgist-reducer ("bassir") filled the ditch by pouring 5 "coros" of charcoal into it (Cf. figure 2, photo 2). Then two men placed the furnace on the ditch by adjusting their ends (Cf. figure 2, photo 3) as do metallurgists in Maradi Region, Niger (A. Levy-Luxereau, 1983: 232). In the second stage, the metallurgist-reducer loaded the furnace by alternating coal and crushed ore, with a big difference in terms of the quantity of raw materials loaded. The "coro" served as a measuring vessel. His assistants charged under his control. They successively poured 8 "coros" of coal, 4 "coros" of crushed ore and 4 other "coros" of coal. The furnace was filled as can be seen in figure 2, photo 4 below.

Between the second and the third charge, was firing. To ignite, the leading reducer introduced an ember into the orifice of one of the nozzles and asked a blower to gently activate the bellows.

Figure 2: set-up of reduction structure and start of charging

(Source: photos C. Nangkara, 2011)

At the base of the furnace, four nozzles were placed and four pairs of bellows were attached to the nozzles as it was the case in Taruga during reconstitution (D. Grébénart, 1988: 144). The fire gradually ignited from the millet bales. He then asked the four blowers ("naffakh") to start working. Eight blowers were working at the same time, while the other eight were waiting. They replaced one another about every ten minutes because the work was painful. Thirty-four minutes later, the flame appeared at the top. Immediately, the master gearbox (leading reducer) closed the shaft with the cover to limit heat loss. The role of the cover is to regulate the combustion heat. The assistants closed the joints between the furnace and the ditch with clay paste to avoid possible heat exhausts.

Using fresh wood of Mitragina inermis (called "Angato" in local Arabic), the reducer checked the combustion to see if the batch was burning. The plastering of the cracked outer wall continued to be made by the assistants.

Unlike the first two, the third loading phase was operated gradually. This phase was carried out only with charcoal. When the reducer noticed that the batch was diminishing, he poured 4 "coros" of charcoal into the stove at the same time, and immediately closed it with the lid. Thus, he successively loaded eight “coros” four times, then three “coros” six times, that is to say 10 loads of charcoal in 2h: 35 min (from 7h: 55 min to 9h: 50). By loading the furnace in the third phase, the master gearbox went from four "coros" to three "coros" when he noticed that there was "a lot of fire".

Combustion control guided the master gearbox in his decision-making. When Aguid, a metallurgist, pushed the stick into the batch, he touched the magnifying glass which did not stick to the stick as the slag sticked to it. If the crushed and loaded ore were completely liquefied, it could be seen by this control.

After the coal stock was exhausted, the blowers continued to operate. The wind tunnel should be gradually reduced until the reduction was complete. This would allow the gangue to flow properly. The master gearbox opened an orifice and found that it was clogged. He unblocked it by removing the iron slag. He found that the coal was completely consumed and the ore liquefied. He ordered the blower to shut down and the bellows to be removed; the nozzles remained in their position.

The reduction was over. The workers waited a few minutes for the flame to subside, and then wrapped a rope around the stove (more or less in the middle) to pull it out of the sacred space where it was abandoned. The ditch remained with the glowing bottom. The workers waited for the cooling to extract the magnifying glass.

Figure 3: furnace, blower and combustion

Reduction furnace 4 blowers in operation Burning furnace
(Source: Photos C. Nangkara)

2.4. Magnifying glass extraction, processing and forging

At the end of the reduction, the produced magnifying glass was still hot. Located at the bottom of the crucible, the glass was covered with iron slag. If it did not cool down, the slag did not easily separate from it. For this reason, the reducer left the stove and the magnifying glass glowing for a day to cool down. It was the next morning that he returned with some of his helpers to remove the iron magnifying glass. Extracting the glass required four people who tied two ropes in the middle of the stove, leaving four ends for them to grab. By pulling on the cord, the metalworkers wisely moved the furnace to leave it outside the sacred areas. The crucible was thus released. The next day, when everything cooled down, the metallurgist returned with his helpers. They destroyed the crucible in order to extract the iron magnifying glass (Figure 4, photo 1).

Still containing impurities, the glass was given by the master gearbox to one of the assistants who were blacksmiths. When extracting the glass from the bottom of the crucible, it broke into two pieces which were then crushed on a large lump of iron ore with a forging hammer. It weighs 5.450 kg (see figure 4, photo 1).

The two fragments were put in a container (figure 4, photo 2). The forge workshop being created right next to the reduction workshop for the occasion, the blacksmiths put them in the forge hearth (Figure 4 photo 3) to breathe there. After heating them to white, the impurities detached from the good iron which was extracted with a pair of tongs. The blacksmith gave them a few light taps to clear them from the rest of the charcoal debris and some remaining slag. The obtained good iron was used to make a sickle. The blacksmith put a wooden handle in the socket (Figure 4, photo 4).

Figure 4: iron magnifying glass, its processing, forging and finished product (sickle)

(Photos C. Nangkara, 2011)

(Source: photos C. Nangkara, 2011)

When you put the crushed magnifying glass in the hearth of the forge, the waste comes out and you get iron. From time to time, it is necessary to stir the iron and lift it slightly to separate it from the slags which descend or remain in the hearth of the forge. The sparks fly, a sign that the magnifying glass must be removed from the fireplace. The blacksmith removed the magnifying glass and placed it on the anvil to give light blows of the hammer. The pieces of the magnifying glass sticked together more, forming a single larger piece, quite free of impurities. The blacksmith could already make a tool out of it. For the case of this experiment, he made a sickle (Figure 4, photo 4).

2.5. Ritual practices

Ritual practice involves the sacrifice of an animal in a sacred space by one of the team members who observes seclusion for sanctification. One of the workers slaughtered a sheep before the furnace ignited. Anyone could immolate, since he was appointed by the master gearbox. The aim is not only to enjoy blessing and protection of the ancestors in order to avoid accidents during the reduction but also reach a good result. An animal was slaughtered within the demarcated sacred perimeter and its blood was poured into the crucible before placing the furnace there. A part of the meat was grilled and eaten, while the other was given to a woman to prepare a meal for the workers.

Access to the demarcated area is prohibited to anyone who is not a member of the metallurgist-blacksmith team. According to their leading reducer, if a non-blacksmith enters the prohibited area, their reduction will not give the expected result: either the combustion does not take place properly, or the workers experience a burn-like accident, or the slag will not separate from the iron magnifying glass. All the workers went into seclusion for three days before starting the activity. They alone were allowed to set their foots in the sacred area.

3. Discussion

The furnace ("Siyéba") of Arboutchatack metallurgists is made of adobe with medium dimensions. By its architecture and dimensions, a stove mentioned in Burkina Faso is comparable to it: slightly frustoconical in shape, it measures 80 cm high and 54 cm in diameter inside the chimney (E. Coulibaly, 2006: 107). Unlike "Siyeba", the Burkina furnace has six openings at its base, two of which are large and four secondary intended to receive nozzles serving as air ducts during reduction operations. The number of openings in this furnace is greater than those of "Siyeba". In addition, unlike its multiple use and fixed nature, the Arboutchatack stove is mobile.

"Siyeba's" air supply mode is a forced draft with eight bellows operating at the same time. In other regions, the forced draft is sometimes provided by two bellows when it comes to a mobile column furnace (clay) or pottery (C. Nangkara, 2015: 342). The reinforcement of the blower in the forced draft system at Arboutchatack shows that the heat in this furnace must be very strong. But some metallurgists also use several pairs of bellows as it is the case in the Buta Region, Burundi, where they start two pairs of bellows in two nozzles (G. Celis, 1991: 31). In reduction workshops in central and eastern Africa, the number of nozzles and bellows increases (8 or more nozzles for 16 or more bellows) when it is not built in the form of a column but a simple hearth (G. Celis , 1991: 74 and 75). In large stoves, sometimes three meters high in the case of Booanga at the Kougsabla site, in the Bam Region, Burkina Faso, the air supply is provided by natural induction (SN Birba, 2012: 181)

Arboutchatack metallurgists have three species of trees from which they produce coal for reduction; they are: Entada abyssinica ("Arad" in local Arabic); Anogeisus leocarpus (or “Sahaba”); Prosopis africana (or "Guirli"). Metalworkers' trees vary by region and metalworker. In Burkina Faso, the studies carried out by Jean-Baptiste Kiethega made it possible to retain the following six species used by blacksmiths: Butyrospermum paradoxum, Burkea africana, Prosopis africana, Terminalia (avicennoïdes and macroptera), Combretum (camprocarpum and glutinosum) and Khaya senegalensis. Among all these trees, those commonly used by metallurgists are Burkea africana and Prosopis africana (J.B. Kiethega, 2009: 250). They produced the best coals in the country. The lack of anthracological study does not make it possible to identify the trees producing charcoal for the most remote periods (4th BC - 17th century AD) among Bwamu metallurgists. However, oral tradition reports that the best species requested by these craftsmen are, because of their calorific value, and by order of importance, Prosopis africana, Terminalia macroptera, Afrormosia laxiflora (E. Coulibaly, 2006: 267).

In southern Chad, Logone Occidental Region, metallurgists have chosen the following two species for the calorific value of their charcoal observed by experience: Prosopis africana and Anogeissus leiocarpus (C. Nangkara, 2015: 322). Metallurgists in Maradi, Niger, for their part, prefer Prosopis africana, Acacia Nilotica and Terminalia avicinnoïdes (A. Levy-Luxereau, 1983:

231). Generally, these two species of trees are sought later by steelworkers in Africa, including Chad. We cannot exclude other variants that appear on the list out of necessity, for example in the event of non-existence due to climatic phenomena or the exhaustion of a desired species. This is how those in Arboutchatack, placed at the gateway to the desert, added another variant, Entada abyssinica, a thorn tree adapted to Sahelian or desert areas.

In Arboutchatack, the loading follows a technique in accordance with the reduction structure architecture. A metallurgist filled the crucible with only charcoal, then placed the mobile furnace in it before adding ore alternated with charcoal until it was filled. Finally, since the batch consumed, he poured charcoal into the stove while checking the combustion. The end of this third phase corresponded to the complete liquefaction of the loaded ore and signaled by the leading reducer. This loading method is found among metallurgists in the Bulkiemdé Province in Burkina Faso from the point of view of alternative horizontal charging (T. Kienon-Kaboré, 2003: 90). It differs from this when we know that it is made in stages and that in the second furnace, the charging is successful within only the first action.

The difference is not just in the loading mode, but also in the ore / charcoal ratio. The Arboutchatack reducer put 62 "coros" of charcoal for 4 "coros" of iron ore. In Bulkiemdé, metallurgists put ten to eleven baskets of fuel for seven baskets of ore, whereas in Yatenga, metallurgists load in large furnaces 60 baskets of coal for 50 baskets of ore or 15 baskets of coal for 10 baskets of ore (T. Kienon-Kaboré, 2003: 91). Saye metallurgists in Kaya, Burkina Faso, during an experiment in 2008, loaded 102 baskets of charcoal against 20 baskets of iron ore in the *Boanga* furnace (C. NANGKARA, 2008: 37). It can be seen that the measurements are varied, but in all cases, the amount of coal always exceeds that of iron ore. The purpose of the metallurgists is to reach reduction.

The successful iron ore reduction depends on several technical actions. The use of sand by Arboutachatck metallurgists is a rare occurrence in their steel industry. Before loading, the reducer took the precaution of putting sand at the bottom of the crucible to prevent the magnifying glass from settling directly on the ground and sticking to it. This would create difficulty in dissociating them and increase the impurities. Metallurgists in the southern part of Chad did not mention this technique. A similar technique was rather used by Bulkiemdé metallurgists who, instead of using sand, put potash at the bottom of the crucible to prevent "the magnifying glass from being welded to the ground" (T. Kienon-Kaboré , 2003: 90). The deposit of these materials aims at reducing the impurities that cause trouble to blacksmiths and leads to another phase of work which is treatment of the magnifying glass.

For most of these craftsmen, raw material acquition and techniques for their use are not the only conditions for successful reduction. It is necessary to associate with it, the ritual aspect to which metallurgists attach great importance. Indeed, according to metallurgists, their ancestors are the ones intervening for metallurgical activities to be successful. This is the reason why, before undertaking any metallurgical activity, the reducer or the blacksmith sanctifies himself, retires into seclusion, complies with prohibitions or makes sacrifices. In Arboutchatack, before lighting fire, the leading reducer has a sheep slaughtered, pours its blood into the crucible which is to receive the iron magnifying glass. At the Yelwani foundry in Niger, the reducer sacrifices a goat to the spirits to implore them (G. Celis, 1991: 63). Its blood is spilled in the reduction workshop. Some African reducers proceed in a different way. In Burundi, "a hen is sacrificed on an altar in the fetish hut to favorably prepare the spirits for the melting" (G. Celis, 1991: 650). The difference here is at the altar and not in the reduction workshop.

When some metalworkers sacrifice animals, others donate birds. But, whether animals or birds are sacrificed, it is their blood that is important, and provided it is not human blood. All these ritual practices are for the same goal: having support from senior people, divinity, God or spirits of the ancestors. The example of

Yoruba founders and blacksmiths in Nigeria is illustrative. "They had to be morally right because Ogun, their tutelary (guardian) god, was credited with a fiery temper and was believed to be capable of instantly punishing those who strayed from the right path" (IA Akinjogbin, 2002: 56). The ironworker daring to work without making a sacrifice would experience an accident or fail in his business.

Conclusion

Iron metallurgy was an activity practiced by craftsmen in the Dababa Division. They came in the pre-colonial times, about four centuries ago, to live near the iron deposit. Metallurgists-blacksmiths, or iron craftsmen, had acquired their "savoir-faire" from their villages of origin before migrating to the current area where they had become natives after living for several centuries.

They knew how to model a clay furnace. This work took them two to three days. Being mobile, the furnace was mounted above a shallow crucible. It was loaded in alternating layers of charcoal and ore, but the charcoal quantity greatly exceeded that of iron ore. The charcoal was supplied with air by a forced draft system where four nozzles received four pairs of bellows started up by four blowers. The reduction lasted about two and a half hours.

At the end of the reduction, the furnace was moved with the help of a rope, but the ditch was completely destroyed to make it possible to salvage the magnifying glass which was processed in a forge by the metallurgists themselves, as they were both metallurgists and blacksmiths. The magnifying glass, this spongy metal, was purified and then transformed into a finished product.

This "savoir-faire" (know-how) experienced its extinction towards the end of the colonial period and the beginning of the Chadian independence (C. Nangkara, 2015: 454). The metallurgists and blacksmiths in the colonial period have become blacksmiths nowadays. Their conversion to this blacksmith trade resulted from the fact that they abandoned the reduction activities and abundant salvaged irons. If one day these few former metallurgists die, maybe of old age, they will go away with their iron ore reduction techniques, eluding their offspring.

If three experiments (at Fort-Lamy in 1970, at Deli in 2009 and at Arboutchatack in 2011) make it possible to distinguish three types of reduction stove, we can estimate that there are other types of stove in Chad. This process is to be explored for future research.

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