Iron craftsmanship in Muweis, a town of the Meroe Empire: metal production and smithing

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Ancient iron metallurgy in Sudan: overview of previous work

Sayce's famous quote (Sayce 1912, 55) regarding Meroe as being the 'Birmingham of ancient Africa', has been a subject of controversy, but should be read in the light of the state of archaeological knowledge on iron metallurgy at the very beginning of the 20th century. In Europe, ancient metallurgical remains were hardly known at the time, due to a lack of specific research and to the presence of vegetation, which very often hides them. Sayce, therefore, had no real archaeological point of comparison to gauge the importance of the metallurgical activity he had discovered. It then took more than 50 years before the first field study provided a more objective approach to the remains left in Meroe by the ancient iron smelting workshops. In the meantime, the research on ancient iron metallurgy started to develop in Great Britain with, in particular, R. F. Tylecote's works (Tylecote 1966, Wynne and Tylecote 1958). It was therefore Tylecote that P. L. Shinnie called in to study the metallurgical remains of Meroe, after an initial excavation of slag layers between 1966-1967 which were part of an east-west trench 110m long and 8m wide called the '50-metres line trench' (Shinnie and Bradley 1980, 9-10). The first metallurgical furnace in Meroe was discovered during the 1969-70 campaign. Four others were then excavated over two seasons (1973-74 and 1975-76), and some chemical analyses of slag samples were carried out. These excavations were published from the 1970s to the early 2000s (Shinnie 1970; 1985; Tylecote 1970; 1975; 1977; 1982; Shinnie and Anderson 2004; Shinnie and Kense 1982; Eigner 1996; 2000).

A new field study was undertaken in Meroe in 1992 by T. Rehren under the auspices of the University of Khartoum and the Humboldt University of Berlin. It had been planned to be multi-year, but this was never carried out. However, it led to the excavation of a quarter of the NW1 slag heap, at the bottom of which P. L. Shinnie had discovered furnaces in the 1970s and to the analysis of the chemical composition regarding major elements of nine slag and five ore samples collected from a surface survey of the slag heap (Rehren 1995; Eigner 1996; 2000; Rehren 2001, 105).

Since 2012, a research programme has been developed by UCL Qatar University on iron metallurgy in Meroe and Hamadab (Humphris 2014; Humphris and Rehren 2014; Ullrich *et al.* 2015; Carey *et al.* 2019). The first results of this ongoing research have already been published: dates of some slag heaps (Humphris and Scheibner 2017), tuyere studies (Ting and Humphris 2017) and experimental results (Humphris *et al.* 2018b). Iron mines have also been explored near Meroe (Humphris *et al.* 2018a), the fuel used in smelting workshops investigated (Humphris and Eichhorn 2019), and chemical analyses of slag and ore released (Charlton and Humphris 2019).

In parallel with research on iron metallurgy, typological studies of iron objects from the Meroitic period were undertaken, in particular by P. Lenoble and T. Rehren, but remained relatively sketchy due to the lack of a sufficient number of artefacts. The small number of iron objects discovered in Meroe led to questions about the destination of the metal produced in the smelting workshops (Abdelrahman 2011; Lenoble 2006; 2011; Lenoble and Sharif 1992; Rehren 1996).

Muweis (Figure 1), a forgotten site 50km south of Meroe with an occupation partially contemporary with this main city,[1] revealed some metallurgical activity. Pedestrian surveys indicated the presence of iron slags on the surface of a mound also made up of waste from ceramic production activities (Lenoble and Sokari 2005). The excavation of the potters' workshop was carried out in 2008, and a magnetic survey revealed strong anomalies in the western part of the mound (Baud 2008, 53-54), where slag was most abundant. In 2013 and 2014, two shallow trial excavations were carried out in the north-western part of the mound to assess the metallurgical potential of the area (Figure 2). The metallurgical material from these excavations is the main subject of the study presented here. We have included some items collected in Area 3 of the site where iron metallurgy seems to have also occurred. The study of these waste products makes it possible to characterise, in the absence of an excavation of the workshop structures, the

[1] The last results showed a continuous occupation of Muweis during the Meroitic period from the 4th century BC to the 4th century AD. The site was reused during the Medieval and modern periods.

Figure 1. Muweis' location in the Meroitic Empire (© Musée du Louvre-Mission archéologique de Mouweis- Michel Baud, Nathalie Couton-Perche).

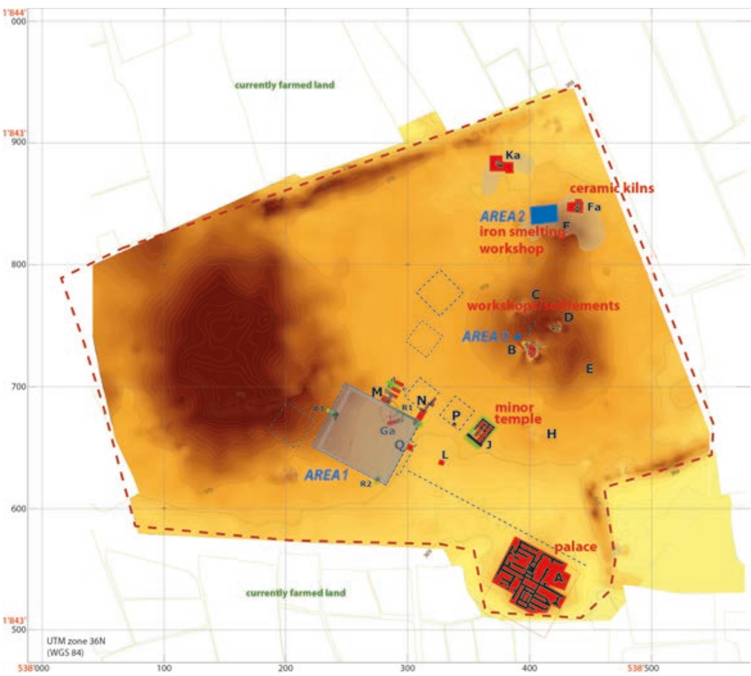

Figure 2. Layout of the Muweis site and excavated areas (© Musée du Louvre-Mission archéologique de Mouweis- Michel Baud, Marie Millet).

iron metallurgy that took place in Muweis, and to propose its first dating thanks to the presence of preserved charcoal in a certain type of slag from Area 2, and in the occupation layers of Area 3.

The slags from the Muweis smelting workshop

Excavations were carried out in 2013 and 2014 in the north-western part of the mound, which consisted of metallurgical remains and potter workshops (Area 2). The excavation trials evidenced stratigraphic units with various amounts of metallurgical waste (Figure 3). The layers generally contained slag and charcoal, but also waste from various activities (non-fired and over-fired ceramics, figurines, lithic tools, beads etc.). It is therefore likely that the excavation was located on the periphery of the metallurgical workshop itself, and that the deposits were mixed. In addition, some stratigraphic units did not contain any slag (Figure 4). This alternation of layers with differing contents was also observed by P. L. Shinnie during the excavation of 'Trench 50' at Meroe, in an area where housing and workshops followed one another over time (Shinnie and Bradley 1980, fig. 4).

All excavated metallurgical materials from Area 2 were weighed, their total mass being six tons. Given the time allocated for the study, and the fact that the slag types were the same in all the layers, they were not studied exhaustively in detail. The slags of the 2000 surface layer were only weighed. A randomly selected sample of metallurgical waste was taken from the two layers containing a large amount of slags (US 2002 and 2006) for a typological study. Then, the exhaustive study of the metallurgical material of the layers containing less slag was undertaken, but was not finished at the end of the stay. Nevertheless, 261kg of metallurgical waste was studied in detail, representing over 4% of the total weight of smelting material (Figure 5). In addition, several large slags (which have original edges with shapes) were collected, numbered, photographed and drawn; then, the furnaces' architecture deduced thanks to the shapes of these slags. Slags representative of each type were also analysed by ICP/MS to determine their chemical composition (Dieudonné-Glad and Millet, submitted).

Figure 3. View of the layers containing variable slag quantity in the trial trench cross section (© Musée du Louvre-Mission archéologique de Mouweis- Rachid El Hajaoui).

Mass of slag produced at Muweis

The 80m³ excavation supplied 6000kg of metallurgical material remains. Detailed counts and weighing show that, on average, the slag represents about 85% of the total mass of metallurgical waste (Figure 6), so the 80m³ of sediment excavated contained about 5200kg of slag, or 65kg per m³ of sediment. These results can be compared with those obtained at other metallurgical sites: in Meroe, for example, the three trial excavations carried out by J. Humphris in the slag heap of the MIS6 workshop (Humphris and Carey 2016, plate 3 and fig. 9) led to an assessment of a slag amount of one ton per m³ of sediment. In Roman Gaul, similar work has led to an amount of 750kg per m³ of sediment at Oulches (Indre, France) and 1.5t per m³ at Clérimois (Yonne, France) (Dumasy *et al.* 2010, 341). While such a comparison obviously has no historical relevance, it allows us to question the internal consistency of the data from Muweis and to propose a number of inquiries for future research. Slag density in the excavation of the Muweis mound is very low compared to that observed in the slag heaps from other smelting sites. It should be noted, however, that some stratigraphic layers excavated in Muweis did not contain any slags, probably because the trench was dug to a depth of only 400mm and was on the outskirts of the mound. The heterogeneity of deposits noticed in Muweis is comparable to that observed at Hamadab, where a trench 2x4m wide and 1m deep had slag only in its upper layer, 300-500mm thick. Unfortunately, the overall mass of the slag found in the trench was not measured and cannot therefore be compared to that of Muweis (Humphris and Rehren 2014, 185 and fig. 182).

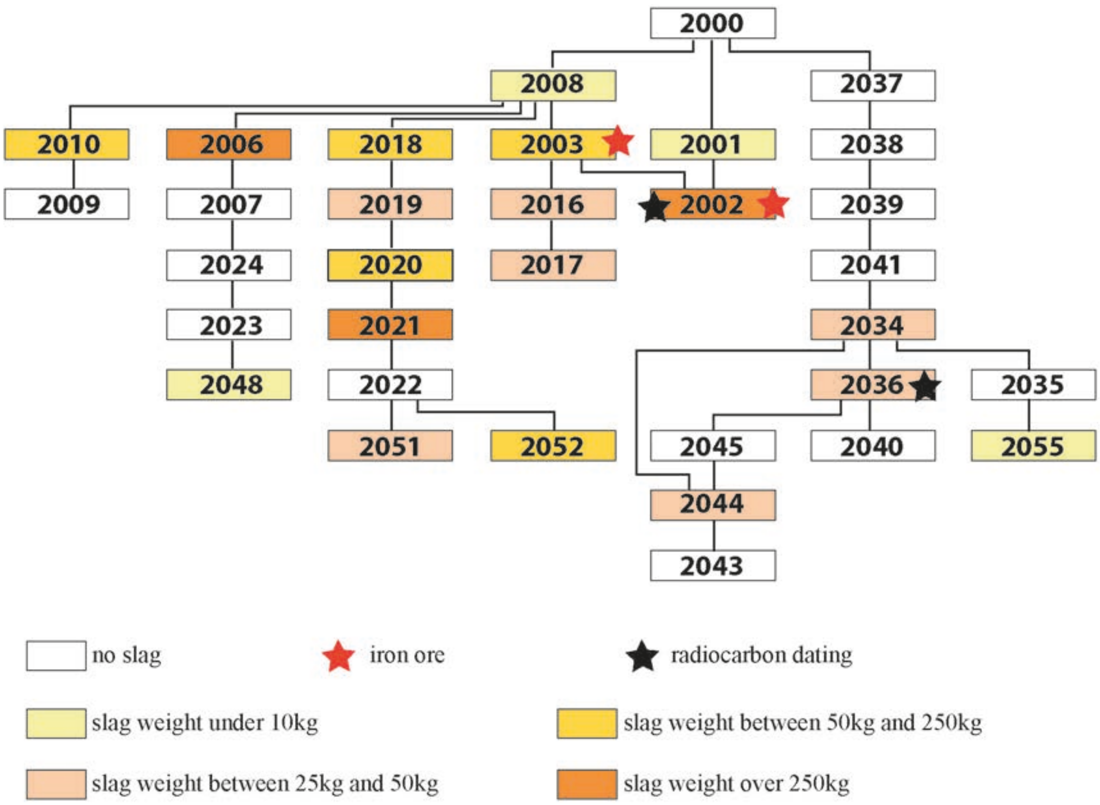

Figure 4. Harris diagram showing the stratigraphical units containing smelting slags and ore in Area 2.

archaeological layer n°	total weight of metallurgical waste (kg)	weight of waste studied in details (kg)
2000	2400	
2001	3	
2002	1802	50
2003	54	54
2006	904	40
2010	42	
2016	26	26
2017	130	
2018	112	
2019	37	37
2020	86	
2021	248	
2034	31	
2036	28	28
2044	26	26
2048	2	
2051	55	
2052	36	
2055	6	
Total	**6028**	**261**

Figure 5. Mass of metallurgical materials by stratigraphic unit in Area 2.

We hence question the representativeness of the slag density measured in the Muweis trial excavation as compared to the actual density in the entire mound. In addition, the mound results from both metallurgical activity and ceramic production, and the respective boundaries of each are not precisely known. All these elements make it impossible to propose an estimate of the overall quantity of slag produced by the Muweis workshop, as it would be very unreliable.

Typology of Muweis slags

During sorting, only fragments larger than 50mm were counted and weighed by type. All fragments smaller than 50mm were weighed all together. Their mass was then distributed among the different types of slags identified, proportionally to the type distribution of the large fragments. They represent between 6% and 45% of the total mass of slag for each layer and characterise the fragmented state of the metallurgical remains. Since the slag material is very hard, it is likely that tools were used to fracture the slag after partial cooling to make it easier to handle, considering its observed weight and size. The typological classification of metallurgical waste shows that slag represents most of the material (Figure 6). The rest is made of fragments of heated clay (furnace wall or tuyeres), often vitrified. Four main types of slags were observed. Some have shapes that allow us to establish the architectural characteristics of the furnaces in which they were formed. Slag with charcoal, solid slag and tapped slag are present in similar proportions in the waste (*c.* 30% by mass), while cord-like slag represents only *c.* 10% of the total.

The slags found by J. Humphris during the excavation of the MIS6 slag heap in Meroe is similar to those of Muweis, from a typological point of view. However, the proportion of small slag is much higher in Meroe: slags less than 30mm in size represent on average 65% of the mass of slag (Humphris and Carey 2016, table 3 and fig. 110), while in Muweis slags less than 50mm represent at most 45% of the total mass, even in the layers containing a large amount of slags: 42% in layer 2002 and 23% in layer 2006.

<u>Tapped slag</u>

The slags have the appearance of a paste-like material that flowed before solidifying gradually upon cooling (Figure 7). Their bottom side shows the imprint of the ground on which they flowed and gives the topography and the roughness of the area located just in front of the furnace. Several slag fragments flowed in a U or V-shaped channel. The width of that channel varies from 50-90 mm, with a depth of *c.* 40mm (Figure 8). The same observation is made in most workshops using this technology, as in the area of Laval (Sarreste 2011, 84) and in Normandy in France (Colliou 2013, 233) or in Bohemia (Pleiner 2000, fig. 71 n° 9).

Slags showing a vertical flow of the material, without contact with a wall, and yet with a spreading on the ground were also found (Figure 9). This is more unusual: such shape of slags is not noticed in the above cited workshops and seems specific to the Meroe area. It indicates a particular protocol used to remove liquid slag from the furnace; cf. Tylecote citing this phenomenon in Meroe: 'large masses of tap slag [...] had been formed by running downhill; some had run over a slope and others had fallen vertically' (Tylecote 1982, 32). The maximum preserved height of the vertical part of the slag is 85mm, indicating that the hole in the furnace door through which the slag flowed was more than 85mm above the ground in front of the furnace door. The shape of these slags also shows that the slopes of the ground in front of the door are diverse. Its profile ranges from the horizontal to a slope of 31°, with a series of slopes

Stratigrafic unit	Tapped slags		Cord-like slags		Solid slags		Slags with charcoal		TOTAL	
	number of fragments	weight (kg)	number of fragments	weight (kg)	number of fragments	weight (kg)	number of fragments	weight (kg)	number of slags	weight of slags (kg)
2002	637	13,15	181	2,74	49	3,3	284	9,33	1151	28,52
2003	349	13,55	89	2,15	43	15	164	14,12	645	44,82
2006	370	15,5	114	3	24	2	154	10,22	662	30,72
2016	162	4	145	2,15	37	2,55	154	4,9	498	13,6
2019	693	8,89	204	3,92	74	6,1	254	9,22	1225	28,13
2036	323	10,16	103	2,58	75	6,23	103	5,37	604	24,34
2044	139	4,25	92	1,62	28	5,6	94	5,8	353	17,27
TOTAL	**2036**	**56,35**	**747**	**15,42**	**281**	**37,48**	**923**	**49,63**	**3987**	**158,88**

Stratigrafic unit	clay with large quartz grains		clay without large quartz grains		TOTAL		Stratigrafic unit	Percentage of slags among artefacts > 5 cm in size		artefacts < 5 cm in size
	number of fragments	weight (kg)	number of fragments	weight (kg)	number of fragments	weight (kg)		number	weight	weight (kg)
2002	191	2,47	3	0,05	194	2,52	2002	85	92	20,95
2003	113	4,84	10	0,42	123	5,26	2003	84	89	3,74
2006	215	5,57	4	0,23	219	5,80	2006	75	84	8,98
2016	161	1,8	0	0	161	1,80	2016	76	88	11,57
2019	260	2,71	22	0,16	282	2,87	2019	81	91	6,86
2036	152	2,18	23	0,11	175	2,29	2036	78	91	1,71
2044	188	3,75	7	0,2	195	3,95	2044	64	81	5,47
TOTAL	**1280**	**23,32**	**69**	**1,17**	**1349**	**24,49**				**59,28**

Figure 6. Number of fragments and slag mass per stratigraphic unit in Area 2.

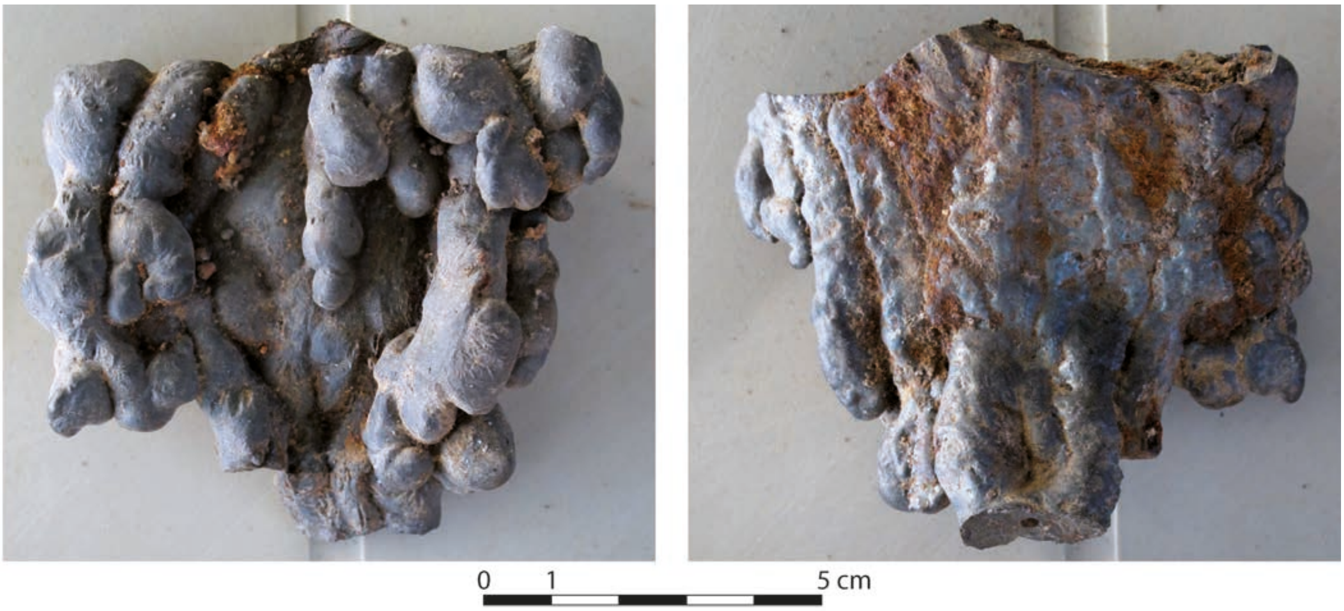

Figure 7. View of the upper and lower faces of a tapped slag (MWSS1C2.01) (cl. N. Dieudonné-Glad, HeRMA, Université de Poitiers).

between 20° and 23° and another between 27° and 31° (Figure 10). This variability suggests that the configuration outside the furnaces was modified regularly as part of their maintenance. In Meroe, the slope of the ground at the front of the door of Furnaces 2 and 3 was shown in cross-section by Shinnie and Anderson (2004, folding pl. Vb). Their angle is respectively 24° and 36° with respect to the horizontal, thus around the same size as that defined by the tapped slag of Muweis.

Solid slags

Solid slags differ from tapped slags by their external aspect, while the material they are made of is the same (Dieudonné-Glad and Millet forthcoming). They have no flow marks and are very compact. Their break, of bluish grey colour, is homogeneous with very few cavities, even of small size (Figure 11). Despite their hardness, they are always incomplete. Their break was caused by a very violent impact after cooling.[2] On a portion of their surface, grey-fired sandy clay containing large grains of quartz, which corresponds to the inner lining of the furnaces, can be seen. This part of the surface is often curved, sometimes describing a fragment of a sphere (Figure 12). In addition, these slags also have a flat surface, either smooth or with fairly large 'bubbles' (Figure 13). As these slags have been liquid, the flat surface observed corresponds to the horizontal plane, which permits us to locate them in the furnace: they

[2] As experienced in the laboratory when such slags were smashed to retrieve a sample for chemical analysis.

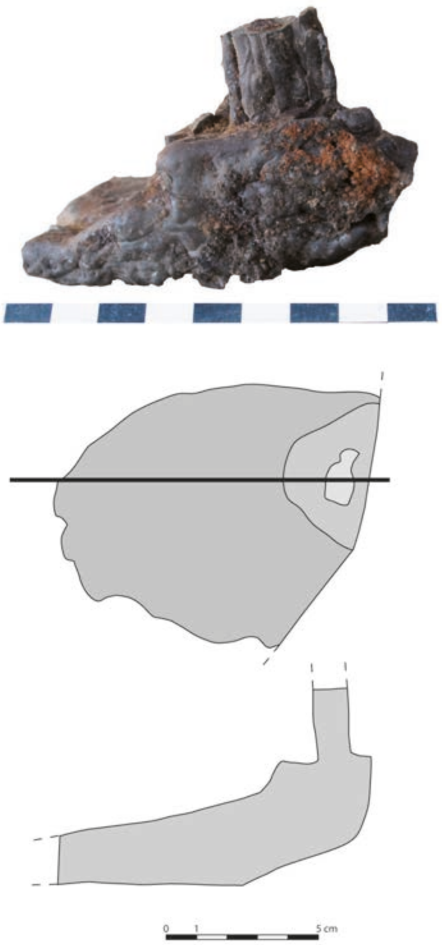

Figure 8. Cross section of the channels in which the slag flowed (MWS2002.28; MWS2006.10; MWS2002.24) (cl. N. Dieudonné-Glad, HeRMA, Université de Poitiers).

Figure 9. Slag made of a vertical flow of material spread on the floor of the workshop (MWS2002.25) (cl. N. Dieudonné-Glad, HeRMA, université de Poitiers).

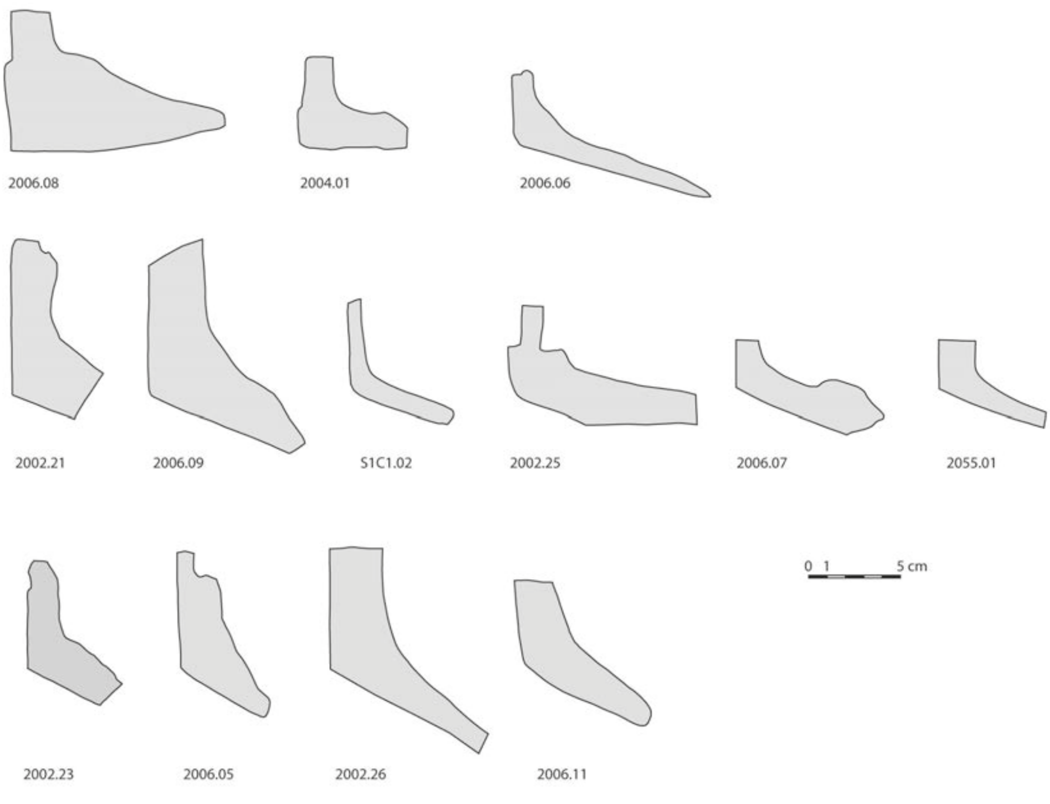

Figure 10. Cross section of a slag formed after a vertical flow of the viscous material in Area 2.

accumulate at its bottom, and the construction material of the furnace is embedded in the curved surface of the slag. These slags are 70-80mm thick. They were broken during the cleaning of the furnace after each smelting in order to clean up its bottom before the next use.

Slag with charcoal

These slags contain charcoal or show the imprint of charcoal. They are sometimes rusty, indicating the likely presence of small amounts of metal that have turned into hydroxides and oxides during the landfill of the slag. These slags are located in the furnace above the solid slags, and under the mass of iron in formation, from which they flow. The charcoal imprint is usually very clearly visible and in some cases, charcoal itself has been preserved in the slag (Figure 14). Sixteen slags were selected for analysis (Figure 15). Charcoal (n=20) and imprints (n=38) are angular, square or triangular in cross-section, with a volume of 3 cm^3 in average. Charcoal fragments were extracted and split along the three diagnostic planes (transversal, longitudinal-tangential and longitudinal-radial) for anatomy identifications using an incident light microscope. The majority of charcoal (n=14) corresponds to Nile acacia (*Acacia* type *nilotica* (L.) Willd. Ex Delile, syn. *Vachellia nilotica*; L. P.J.H. Hurter & Mabb.), which is the only species among *Acacia* genus growing in North Africa showing clear vasicentric axial parenchyma (Figure 16, Neumann *et al.* 2001, 287, 300-301). Three fragments have predominantly axial parenchyma aliform-confluent and are allocated to a general category *Acacia* sp. Two fragments are too vitrified to be identified. No bark has been found. Because of the absence of anthraco-typology study on acacia trees so far, we are not able to precisely estimate the wood diameter. However, all *Acacia* type *nilotica* and *Acacia* sp. fragments have parallel rays, indicating the use of large branches or trunks rather than small branches. We are also unable to know if the fragments come from the central part of the stem or trunk (heartwood) or from the periphery (sapwood).

The charcoal study led in other areas of Muweis (domestic and artisanal contexts, study in progress) shows the presence of Nile acacia along with other species, such as jujube tree (*Ziziphus* sp.) and desert palm (*Balanites aegyptiaca* (L.) Delile). These first results concur with observations made in Meroe and Hamadab where archaeologists concluded that iron producers selected Nile acacia charcoal for use during iron production for over 1000 years (Humphris and Eichhorn 2019). Nile acacia is a fast-growing tree commonly found in Sudan along the Nile and in habitats with high groundwater table. Its very dense wood with a high calorific value, makes it useful for iron production (Carsan *et al.* 2012; Fagg and Stewart 1994; Fagg and Mugedo 2005)

Cord-like slag

These slags, present in small quantities, have a pasty, cord-like appearance. They solidified during their vertical stretching. They differ from tapped slags by several features: they are less massive, have no imprint of a surface over which they would have flowed and are broken only at their upper end (Figure 17). They are therefore not fragments of slag that have flowed vertically outside the furnace, unlike tapped slag. In addition, their cross-section is often very small and charcoal imprints are present on some of them (Figure 18). We therefore consider that these slags dripped inside the furnace at the end of the smelting, in a space left partly empty by the removal of most of the liquid slag contained in the furnace.

The typology we have established in Muweis is relatively similar to that of Meroe. Muweis' 'slags with charcoal' correspond to Category 1 of the Meroe slags ('light porous furnace slag'), while 'solid slags' correspond to Category 2 ('large, heavy furnace slag') based on J. Humphris's typology (Humphris and Carey 2016, 135). However, two categories of tapped slags have been distinguished in Meroe: 'fragmented tapped slags' and 'large tapped slags', but this distinction corresponds more to the way in which waste was treated by craftsmen after cooling than to the way the smelt itself was operated. On the other hand, the existence of 'cord-like slags' are not mentioned in Meroe. Given their small quantity in Muweis and the high fragmentation rate of the Meroe slag, they may not have been identified. In Muweis, as in Meroe, the proportions between the different types of slag are relatively variable from one layer to another (Figure 19). In Meroe, these proportions change depending on the location of the excavated areas in the same slag heap (Humphris and Carey 2016, fig. 10). As all four types of slag are found in each layer in Muweis, it is likely that they were produced together during each smelt.

Muweis slags, like Meroe slags, are characteristic of the use of a technique consisting in removing part of the slag

Figure 11. View of the break of a solid slag (MWS2002.05) (cl. N. Dieudonné-Glad, HeRMA, Université de Poitiers).

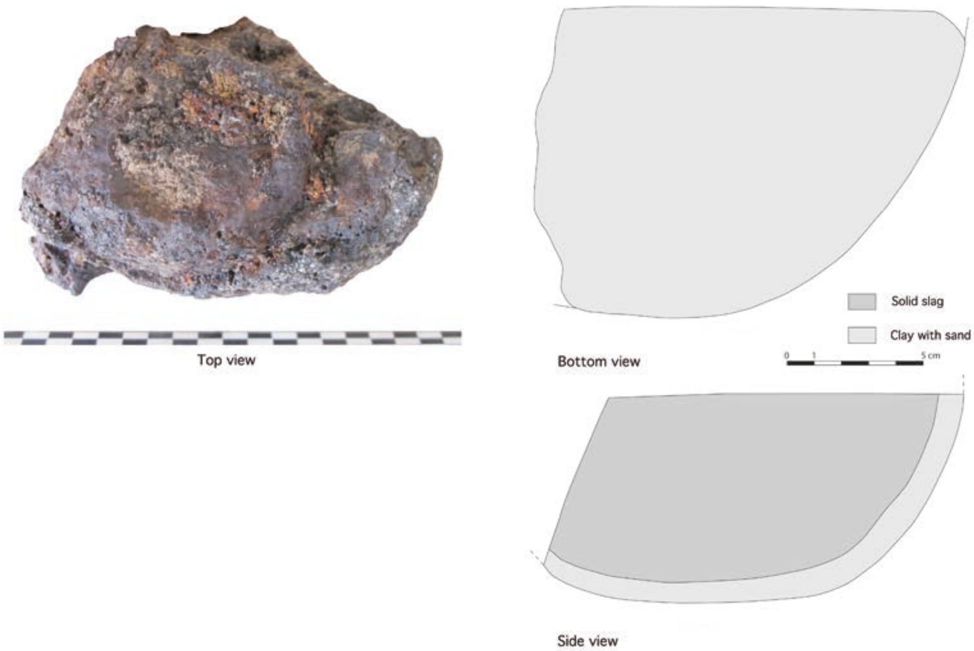

Figure 12. Solid slag MWS2002.27 (cl. N. Dieudonné-Glad, HeRMA, Université de Poitiers).

Figure 13. Solid slag with spherical voids on the upper surface (MWS2006.04); (cl. N. Dieudonné-Glad, HeRMA, Université de Poitiers).

Figure 14. Slag MWS14-2000-S1C3.02 with charcoal prints and embedded charcoals (© Musée du Louvre-Mission archéologique de Mouweis-Hélène David-Cuny).

ID slag	Type	Length (mm)	Width (mm)	Thickness (mm)	Taxa	Evaluation of growth-ring curvature
MWS14_2000_ Bot1	Imprint	45	12	10		
	Imprint	40	22	7		
	Imprint	30	17	5		
MWS14_2000_ S1A1_Bot1	Charcoal	20	15	15	*Acacia* type *nilotica*	LARGE
	Imprint	17	13	12		
	Charcoal	9	9	9	*Acacia* type *nilotica*	LARGE
	Imprint	20	12	12		
	Imprint	12	10	6		
	Charcoal	11	14	10		
	Imprint	24	13	12		
	Imprint	20	12	10		
MWS14_2000_ S1C1_Bot1	Imprint	19	17	15		
	Imprint	11	9	8		
	Imprint	12	8	6		
	Imprint	30	12	15		
	Charcoal	20	10	10	*Acacia* type *nilotica*	LARGE
	Charcoal	50	10	7	*Acacia* type *nilotica*	LARGE
	Charcoal				*Acacia* type *nilotica*	LARGE
MWS14_2000_ S1C3_Bot1	Imprint	19	15	8		
	Imprint	13	12	13		
	Imprint	17	8	6		
	Imprint	30	18	15		
	Charcoal	20	18	10	*Acacia* type *nilotica*	LARGE
	Imprint	15	12	8		
MWS14_2000_ S1C3_Bot2	Charcoal	25	10	8	*Acacia* type *nilotica*	LARGE
	Charcoal	15	8	6	*Acacia* sp.	LARGE
	Charcoal	23	18	17	*Acacia* type *nilotica*	LARGE
MWS14_2000_ S1C3_Bot3	Charcoal	15	11	20	*Acacia* type *nilotica*	LARGE
MWS14_2002_ Bot14	Imprint	22	13	6		
	Imprint	12	9	7		
	Imprint	18	14	10		
MWS14_2002_ Bot14bis	Charcoal	28	29	12	*Acacia* type *nilotica*	LARGE
	Imprint	20	14	12		
	Imprint	20	13	15		

Figure 15. Analysis of slags containing charcoal or charcoal imprints.

ID slag	Type	Length (mm)	Width (mm)	Thickness (mm)	Taxa	Evaluation of growth-ring curvature
MWS14_2002_Bot15	Imprint	13	7	5		
MWS14_2002_Bot16	Imprint	35	12	15		
	Imprint	28	12	15		
	Imprint	30	25	30		
	Charcoal	15	10	7	*Acacia* type *nilotica*	LARGE
	Charcoal	20	12	10	*Acacia* type *nilotica*	LARGE
	Imprint	22	7	7		
	Charcoal	26	13	10	*Acacia* sp.	LARGE
	Imprint	16	10	10		
MWS14_2002_Bot17	Imprint	18	12	8		
	Imprint	20	20	25		
	Charcoal	20	17	20	*Acacia* type *nilotica*	LARGE
MWS14_2002_Bot18	Imprint	20	18	17		
MWS14_2002_Bot19	Imprint	10	10	15		
MWS14_2002_Bot20	Imprint	30	17	15		
MWS14_2003_Bot2	Charcoal	23	15	15	Indeterminate	
	Imprint	15	8	10		
	Imprint	15	10	8		
	Imprint	20	7	7		
	Charcoal	21	12	8	Indeterminate	
	Imprint	23	8	12		
MWS14_2036_Bot1_1	Charcoal	27	15	10	*Acacia* type *nilotica*	LARGE
	Charcoal	20	12	8	*Acacia* sp.	LARGE
	Imprint	17	6	8		

Figure 15 continued. Analysis of slags containing charcoal or charcoal imprints.

in liquid form from the furnace during the smelt. As solid slags and cord-like slags solidified inside the furnace, the question of how the end of the smelting operation was managed is raised: was the mass of iron produced extracted hot from the furnace, or after its partial cooling? In any case, it seems that the lower part of the furnace, where the massive and cord-like slags are present was cold enough for these slags — which were initially liquid — to solidify.

The tuyeres

About half of the tuyeres of Muweis were found in Area 2 Trial Excavation 1, a rectangular trench located in the southern part of the excavated area, in the surface layer that yielded only a few slags, all small in size. The rest was scattered in layers containing a lot of slag fragments. This distribution suggests the possibility of a differentiated deposit of waste on the periphery of the workshop depending on its nature, whether slag or tuyeres. This hypothesis will have to be tested during subsequent excavations.

All tuyeres in Muweis are cylindrical in shape and the diameter of their bore varies between 15 and 32mm. This significant variation is due to the fact that the pipes are not entirely cylindrical and are not always fully

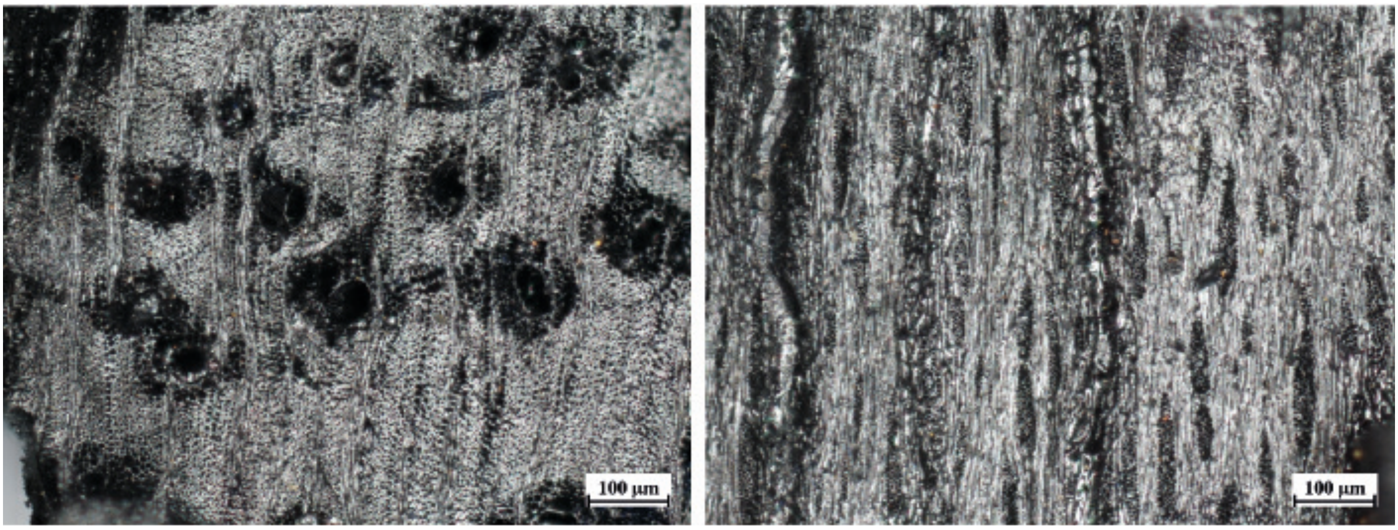

Figure 16. Microscope images of wood anatomical *Acacia* type *nilotica*, transverse section with vasicentric axial parenchyma (left) and longitudinal transversal section (right).

Figure 17. Cord-like slag with only one broken end (MWS2002.13); (cl. N. Dieudonné-Glad, HeRMA, Université de Poitiers).

Figure 18. Cord-like slag with charcoal imprints (MWS2002.08); (cl. N. Dieudonné-Glad, HeRMA, Université de Poitiers).

preserved. The bore is quite often off-centre and the thickness of the tuyere wall is therefore not regular. There are two main ways of making tuyeres: either by wrapping a clay plate around a cylindrical core, a stick, for example, which is removed after joining together the two ends of the plate, or by drilling a clay mass. The first process probably allows the manufacture of tuyeres with a more regular wall thickness and a better centred hole than the second, which could be the one used at Muweis, based on our observations. However, it is possible that some deformations occurred during the use of the tuyere, due to the high temperature of the furnace, inducing the irregularities observed.

None of the tuyeres are complete. The best preserved example has a length of 180mm, indicating that the total length was greater than this dimension. These measurements are compatible with those of a cylindrical slag (MWS2002-22) 60mm long and 27-30mm in diameter discovered in stratigraphic layer 2002. This slag probably solidified inside a tuyere. Tylecote observed this phenomenon (Tylecote 1982, 30): 'many [...] tuyeres were filled with slag for as much as 10 cm.' When the tuyeres were clogged in this way, it was probably necessary to change them during smelting in order to continue the operation. Some tuyeres from Muweis are vitrified at one end over a length of *c.* 50mm. The tuyeres therefore protruded inside the furnace over this length. The fabric that makes up the tuyeres is a fine Nile silt fabric without any apparent temper, unlike the walls of the furnaces, which contain large quartz grains.

The excavations carried out in Meroe and Hamadab have provided a large corpus of tuyeres (Ting and Humphris 2017) that we can compare with the Muweis one. Two different shapes were observed at these sites: tuyeres with

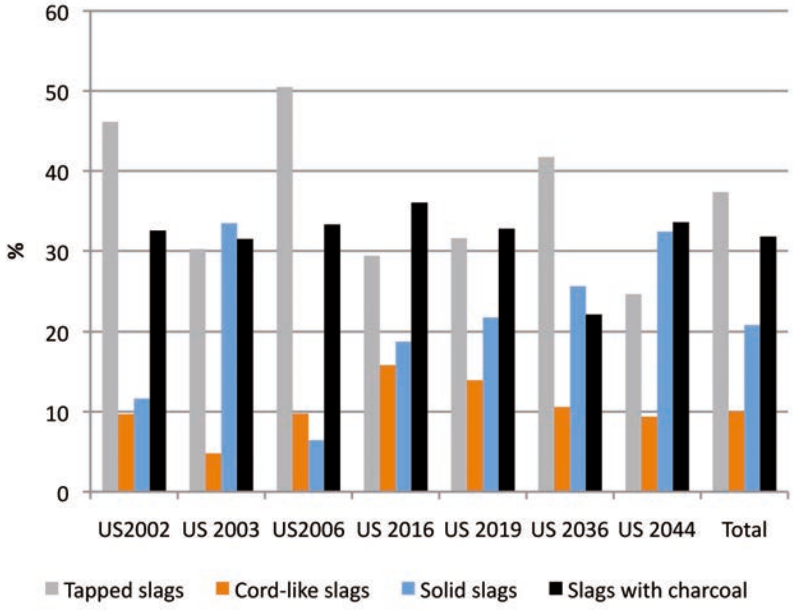

Figure 19. Mass of the different types of slags, taking into account debris less than 50mm in size in Area 2 (US = stratigraphic unit).

cylindrical outer sections and others with square sections. The second type is present in the MIS4 and MIS6 workshops of Meroe and in Hamadab. In the last two workshops, they were found alongside cylindrical tuyeres. Among the cylindrical tuyeres Ting and Humphris identified thin-walled and thick-walled tuyeres, and a set of tuyeres of medium-thickness wall (Ting and Humphris 2017, table 3). The Muweis tuyeres fall under the medium walled, cylindrical category from Hamadab and the MIS6 workshop in Meroe (Figure 20). However, it should be noted that the wall thickness of the so-called thick-walled tuyeres varies considerably, whereas this variability is very low for thin-walled ones. In addition, there is some overlap between the size ranges of the thick-walled and the tuyeres of medium-thickness wall in Meroe, Hamadab and Muweis. The features of these categories have therefore probably to be clarified.

The inner diameter of the Muweis tuyeres is rather smaller than that of the MIS6 workshops' tuyeres in Meroe and in Hamadab, but is commensurate with that of the MIS4 and MIS1/2 workshops' tuyeres in Meroe (Figure 21). The inner diameter of the tuyere has an impact on the air flow rate entering the furnace, but it is not certain that the differences in diameters observed are significant from a technical standpoint. Finally, as to their external dimensions, the thin-walled tuyeres of the MIS1/2 workshops in Meroe stand clearly apart from the others. This is due to a combination of two factors: their inner diameter is slightly smaller than that of other types of tuyeres, and their wall is thinner.

Hypothesis regarding the location of the Muweis smelting furnaces

In the case of metallurgical furnaces producing tapped slag, such as those at Muweis, as metallurgical waste is magnetic, the peak of magnetic anomaly indicates the location of the thickest area of the slag deposit rather than the furnaces themselves (Dumasy, Dieudonné-Glad and Laüt 2010). In Sudan, magnetic survey results were evaluated on the Meroe MIS6 metallurgical mound (Humphris and Carey 2016, Fig. 3a, Trench 1), and workshop structures were discovered in the trench located south of the area of highest magnetic susceptibility, i.e., on the south face of the slag heap. This is also the case in Hamadab (Ullrich *et al.* 2015). The shape and location of the magnetic anomalies in the slag mound of Muweis are almost identical to those in the Meroe MIS6 slag heap (Figure 22). In addition, the excavation conducted by Shinnie in 1969 that led to the discovery of the other furnaces known in Meroe was also located 'on the south side of this mound' called 'NW1' by Tylecote (Shinnie and Anderson 2004, 74; Tylecote 1970, fig. 1).

The regularity in the layout of metallurgical workshops from Meroe and Hamadab (Eigner 1996, abb.2; Humphris *et al.* 2018b fig. 3; Humphris 2015) — i.e. roughly east-west oriented furnaces, steps in the middle of the long side of the built space, deposition of slags to the north of the workshop — hints at a common know-how within the same culture and can be compared to the rather stereotypical organization of the towns themselves with, in particular, the axis of the religious complexes perpendicular to the Nile.

A large excavation is essential to discover possible successive metallurgical structures. At Muweis, a rectangular excavation area measuring 20mx10m, immediately south of the peak of the magnetic anomaly (Figure 22), would allow us to determine whether the smelting workshops in other towns of the Meroe Empire have the same topographical and architectural characteristics as those of the capital itself. It would also characterise more precisely the activities taking place in Muweis, in particular the refining and metal smithing activities, which seem to have been present in the MIS6 workshop of Meroe (Humphris *et al.* 2018b, 4).

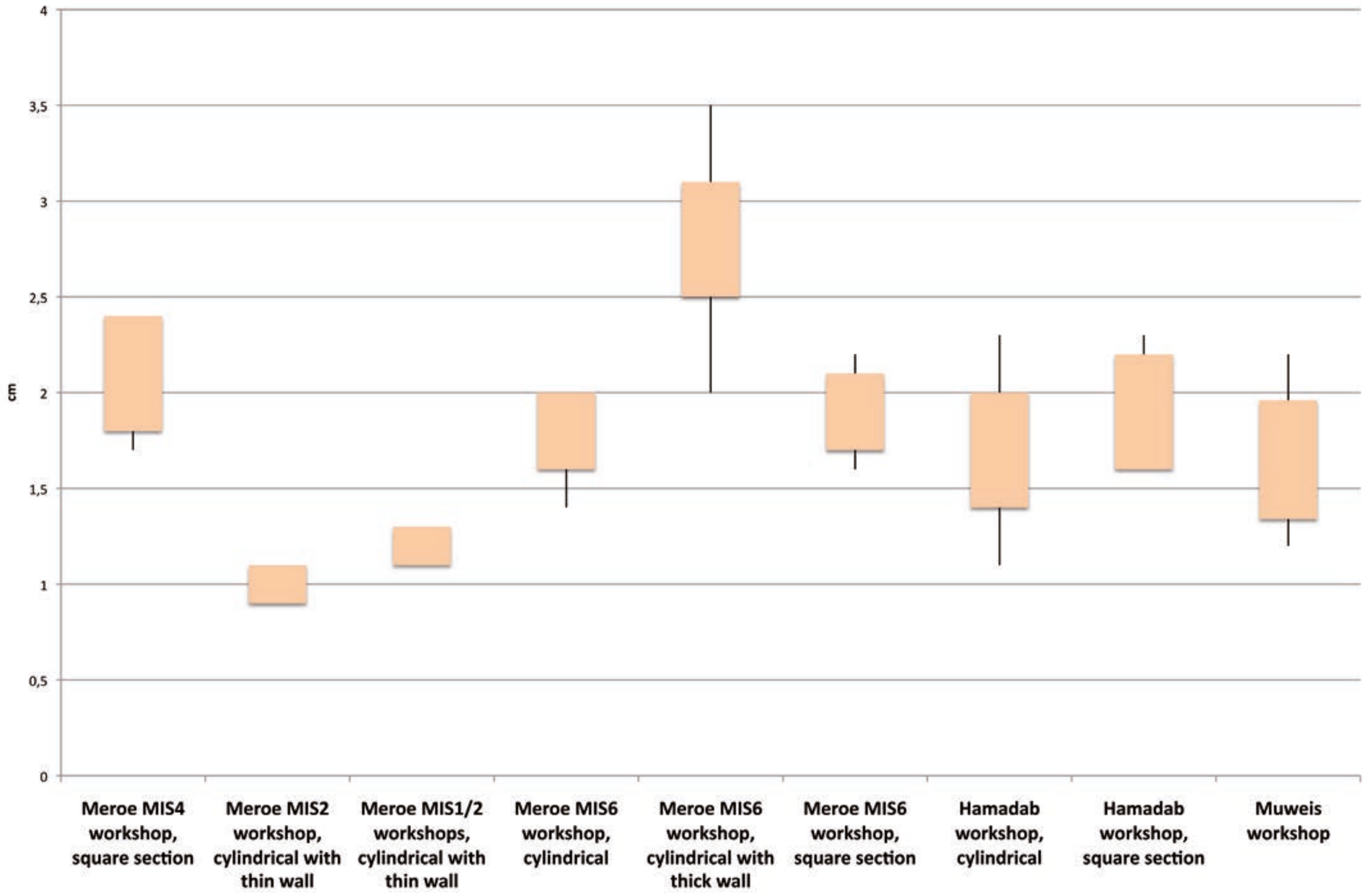

Figure 20. Thickness of the walls of the Muweis tuyeres compared to those of Meroe and Hamadab after Ting and Humphris 2017, table 3 (maximum, mean + standard deviation, mean - standard deviation, minimum).

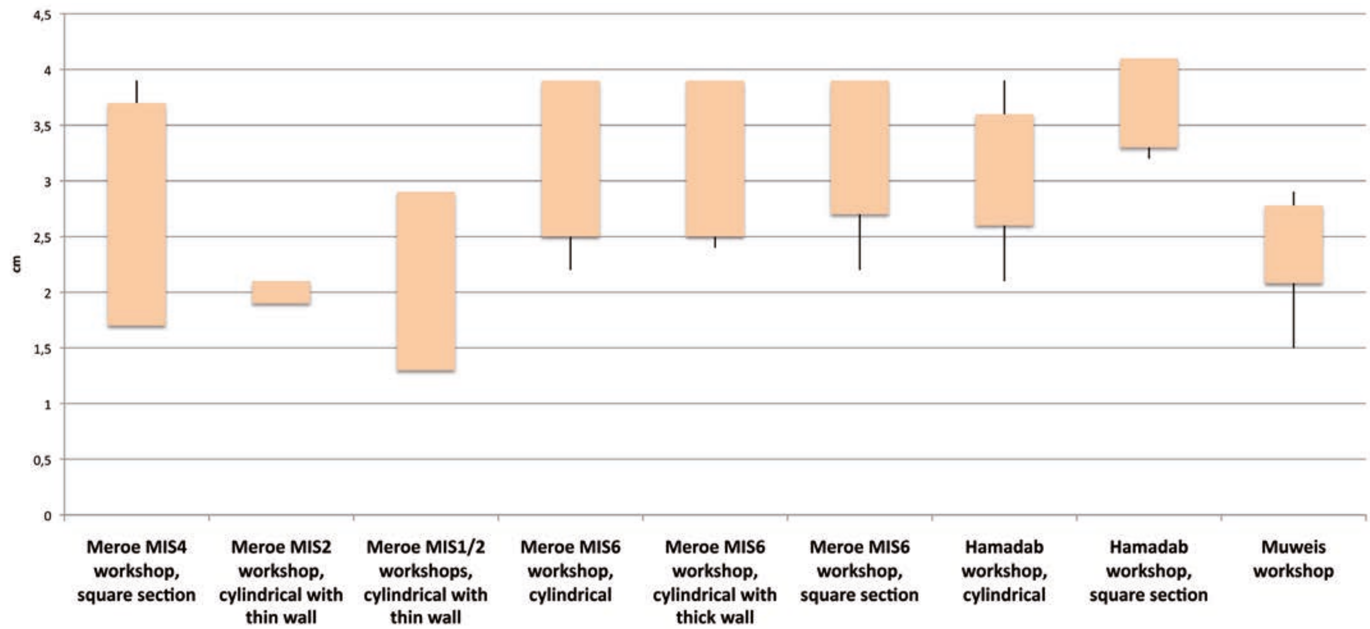

Figure 21. Diameter of the Muweis tuyere pipe compared to that of Meroe and Hamadab after Ting and Humphris 2017, table 3 (maximum, mean + standard deviation, mean-standard deviation, minimum).

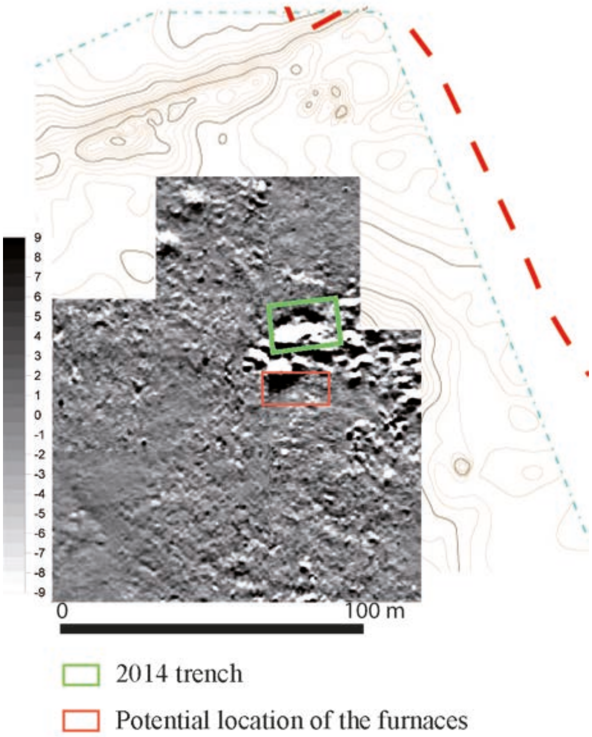

Figure 22. Hypothesis of the smelting furnaces location at Muweis in Area 2 (© Musée du Louvre-Mission archéologique de Mouweis- Yves Bière).

Smelting furnaces

The Muweis furnaces have not yet been found, but the similarity we have established between the different types and shapes of slags and tuyeres found at Muweis and Meroe suggests that the furnaces at the two sites were similar. As stated above, several furnaces were discovered in Meroe between 1970 and 1976. There are inconsistencies in the reports on the excavations of these furnaces, in particular in the numbering of the one discovered last (sometimes called Furnace 5, but at other times Furnace 6). Whatever these uncertainties, they are all of the same model. The best preserved is the furnace called F5 or F6. From the descriptions and rare illustrations published, in particular Kense's layout (Kense 1983, fig. 1), Furnaces 2 and 3 section (Shinnie and Anderson 2004, folding pl. Vb) and Furnace 5/6 drawing (Shinnie and Kense 1982, fig. 1), we can get a precise idea of their architecture up to the tuyere level.

The workshops are usually made up of two furnaces facing each other inserted inside the short side of a rectangular mud brick structure. Their inner diameter is *c.* 0.7m and the preserved part of their wall is slightly inclined inward. No doors have been preserved *in situ*, but the cross-section of Meroe Furnaces 2 and 3 show an arrangement at its location that creates a counter slope towards the inside of the furnace (Shinnie and Anderson 2004, pl. Vb). This counter-slope prohibits a part of the slag from flowing outside of the furnace and may explain the presence of the solid slags identified in the Muweis corpus. The very good state of preservation of Meroe Furnace 5 with one tuyere in place, the preserved location of five others and the presence of three of the six bellow pots provides a lot of information. As the ventilation of the furnace is 'forced ventilation' (with bellows) a fairly abundant workforce during smelting was required: three blowers per furnace, one or two people to ensure the filling of the furnace with raw materials and one or two other people to control the formation and the flow of the slag (Figure 23); but we cannot know whether the two furnaces of each workshop were operating at the same time or in alternation.

The presence of a rectangular depression lined with mud bricks is recurrent in the Meroe workshops and appears both on the layouts and photos (Shinnie and Anderson 2004, fig. 52). Its first identification as a water tank (Shinnie and Anderson 2004, 76; Tylecote 1982, 36) has now been ruled out. As no traces of charcoal or ore have been reported in this depression, the possibility of a storage of raw materials seems also to be excluded. Its use as a receiver for slag flows could also be considered as a hypothesis, but the shape of the slag shows that it solidifies very quickly after contact with the ground. It could therefore not flow over the distance between the furnace and the rectangular pit. However, slag has to be broken and removed as soon as it is solidified to make way for another flow, but it remains very hot and is therefore difficult to handle. The hypothesis that this depression was used for the temporary storage of slags while waiting for them to cool down and be evacuated from the workshop seems therefore plausible. In this case, it is possible to suggest a location of the stocks of raw materials (ore and charcoal) outside the workshop. Craftsmen would access it by the staircase, which is the only way out (Figure 23). It is also by the stairs that the slag would be evacuated once cooled down to be dumped a little farther away, hence gradually forming the slag heap marking the presence of the smelting workshop. This hypothesis could be tested by carrying out an extended excavation in search for possible raw material storage areas on the ground near the staircase leading to the workspace.

The location of the tuyeres and their tilt determine the hottest area in the furnace (at the intersection of the six incoming air flows), where the metal is formed. It is located *c.* 600mm above the bottom of the furnace. In Muweis, the presence of cylindrical slag of the same diameter as that of the tuyere's inner diameter and Tylecote's observation of solidified slags *in situ* in tuyeres, show that liquid slag occupied the bottom of the furnace almost at the tuyere level during operation: 'Some of the tuyeres found *in situ* in the furnaces were filled with slags. Considering their high level this seems surprising but indicates that the slag came up to this level during the operation' (Tylecote 1977, 168). Poor monitoring of the furnace could have led to an overflow of slag, which could have clogged the tuyeres and forced craftsmen to remove and replace them.

The presence of vertically flowing slags in the Muweis corpus shows that the furnace door had one or more superimposed holes drilled through it, at a height from the ground at the front of the furnace that was at least 85mm. It can therefore be assumed that the furnace was emptied in several stages, first through the high hole or holes, then through the base of the door (Figure 24). Some of the slag remained inside the furnace, at its bottom, due to the counter-slope of the ground. As they cooled, they adhered to the lower part of the furnace wall. They make up the solid slag in our corpus. Slags with charcoal were found above the solid slags, as traces of them have been identified on the upper side of some solid Muweis slags. Cord-like slags solidified as they flowed from the periphery of the iron mass into the voids left by the evacuation of the main stream of slag at the end of the process. After furnace cooling, the solid slag was broken and taken away to allow for the next round of smelting.

Even if the ironmaking process is broadly known from ancient excavations, the corpus of furnaces remains very small and does not allow us, for example, to perceive a change in their shape or dimensions over time. The excavation of other workshops is also necessary to better understand their organisation: research work has so far focused mainly on the furnaces themselves and the first real stratigraphic excavation was only carried out in 2014 (Humphris 2015). These future excavations should not be limited to the enclosed part of the workshop, since the bellows stick out of the wall. A stratigraphic excavation over a larger area would make it possible to take into account the surroundings of the building, where supplementary activities related to metal production will have probably taken place (e.g., ore preparation, metal smithing), even if hammering waste seems to have been identified inside the enclosed area of a workshop during the 2014 excavation in Meroe (Humphris 2015).

Figure 23. 3D model of a smelting workshop in operation, based on the assumption that both furnaces are used at the same time and that the raw materials, ore and charcoal, are stored outside the enclosed part of the workshop, while the tapped slags are put in the rectangular depression in the middle of the workshop. After the layout and cross section of the furnaces published by Shinnie (Shinnie and Kense 1982, fig. 1, Shinnie and Anderson 2004, pl. Vb; 3D view: Etienne Chabrol, HeRMA, Université de Poitiers).

Figure 24. 3D model of a furnace interior during slag removal, based on the cross sections of the furnaces published by Shinnie (Shinnie and Kense 1982, fig.1, Shinnie and Anderson 2004, pl. Vb; 3D view: Etienne Chabrol, HeRMA, Université de Poitiers).

The smithing activity in Muweis

Smithing activity is indicated in Muweis by the discovery of hammer-scales in the sediment of two excavated areas, more than a hundred metres apart. The first (Area 2) is the smelting slag heap where their presence was expected. This confirms that the smelting workshops were linked to workshops where the hammering of the crude iron bloom was carried out. But these hammer-scales have not been found *in situ* and the forge workshop (earth, anvil) remains to be located. Is it embedded in the smelting area as in the MIS6 workshop in Meroe or established next to it?

Spheroidal slags were discovered in the stratigraphic layers 2000 and 2001. They usually correspond to slag trapped in raw metal, expelled at the start of metal bloom hammering. They attest to the practice of primary smithing of the metal produced in Muweis. Their metallographic study confirms this hypothesis (Dieudonné-Glad and Millet submitted). However, the presence of numerous flat hammer-scales indicates that the work performed was probably more thorough than a mere cleaning and compaction of the iron mass. As these scales form on an already flattened metal surface, they can be related to the shaping of 'semi-finished products' such as bars, or even to the manufacture of objects.

Another area where smithing is documented is found in a settlement area (Area 3). The excavation revealed the presence of a series of reddish-black floors alternating with charcoal layers containing hammer-scales. The Harris matrix shows at least four levels where smithing activity has occurred[3] (Figure 25) in the excavated building. The same types of hammer-scales as in the smelting area are found in this zone.

It was not possible to quantify the different types of hammer-scales found in the sediment samples and to compare their proportions in the different excavated areas, which may have shown a possible specialisation of the smithies in Areas 2 and 3. Indeed, the samples were first sieved for archaeobotanical study with a 2mm sieve on one side during the excavation, and with a 1mm and 0.5mm sieve column on other side by the archaeobotanical team. Only the hammer-scales present in 1 and 0.5mm screen refusals were retained, so hammer-scales greater than 2mm could not be studied. As the corpus of hammer-scales is incomplete, quantitative data would not have been reliable.

Nevertheless, for the first time on a Meroitic site, the study of sieve refusals in Area 3 has revealed the presence of smithing activity in the town, outside the area linked to the smelting of iron. This observation raises the question of the status of iron in Muweis: was manufacture intended for 'export' trade or for local use? If both, what was the magnitude of local consumption?

Dating of the metallurgical activity

In Muweis, the archaeological layers in which the slags were discovered also contain domestic waste and may have been subject to reshaping. The dating of the metallurgical activity was thus not carried out from isolated 'free' charcoal fragments in the sediment, as it is not certain that they are contemporary with the production of the slag. On the other hand, as a type of Muweis slag contains charcoal fragments, charcoal pieces from these slags were collected for dating. Two slags from two different stratigraphic layers of the metallurgical mound provided two acacia charcoal

[3] The presence of hammer-scales in floors or occupation layers is a very reliable clue for locating smithing workshops even if the remains of smithing earth are missing (Dieudonné-Glad *et al.* 2002).

samples each, and a charcoal sample was extracted for C^{14} dating from a third slag.

Nile acacia lives generally *c.* 60 years and its maximum longevity is estimated to be less than 100 years (February *et al.* 2006). The 'old wood' effect is thus limited but cannot be ruled out. The five calibrated C^{14} dating intervals[4] include the 2nd and the 4th century AD (Figure 26). Thus, while smelting at Muweis operated over an unknown duration, it was at least ongoing at a date between the middle of the 2nd century and the end of the 4th century AD. This dating range is similar to that of the MIS6 workshop in Meroe and overlaps partially with the dating range of the metallurgical sites in Hamadab. A real synchronicity of these workshop operations however remains hypothetical (Humphris and Scheibner 2017).

Successive smithies of Area 3 have also been radiocarbon dated using charcoal and seeds contained in the sediment from the workshops layers (Figure 25). The date range obtained is compatible with the hypothesis that smelting and separate smithing in an urban context were contemporaneous. If so, it would be a strong indication of local manufacture of finished objects from the metal produced in Muweis (Millet 2013, 88, fig. 7).

Muweis and its metallurgy during the Meroitic period

The idea that the Meroitic Empire had a centralised political structure with power based on military force and, therefore, needed to control the production of iron to produce weapons, has been widely developed. It implicitly rests on the presence of iron smelting workshops in a very limited number of archaeological sites (Haaland 1985, 70).

In light of recent research showing the existence of iron smelting workshops in Hamadab, el-Hassa (Rondot 2006) and Muweis, settlements linked to the central authority of Meroe, it would seem that the premises of this reasoning, the centralisation of production in the city of Meroe, can be called into question.[5] The idea of the control of iron production, essentially for military purposes, by the authorities in Meroe is, therefore, far from being completely established, at least for the end of the Meroitic period. A new analysis, without *a priori* arguments, of the archaeological data is therefore necessary. It should be based on a better knowledge of the sites where smelting is attested, through the increase of the corpus of excavated workshops and a systematisation of their dating. Radiocarbon dating of charcoal embedded in slags or in archaeological levels *in situ* in furnaces is the only truly reliable method for dating smelting activity in mixed, domestic and craft locations. Based on current data, metallurgical activity seems to begin in Meroe between the beginning of the 8th and the end of the 6th century BC, whereas it has only been detected in Muweis and Hamadab from the 2nd or 4th century AD (Humphris and Scheibner 2017, fig. 4 and table 1b). However, the oldest levels have not been reached in the Muweis slag heap (the oldest dating occupation of Muweis is 4th-3rd centuries BC), and research on Hamadab is still in its early stages. A better understanding of the economic organization of the Meroitic Empire would require a comprehensive study of wood-fuelled crafts, particularly iron metallurgy and ceramic, the latter being already identified in Meroe, Muweis and Musawwarat es-Sufra. Iron metal itself, from the Meroitic period, remains very poorly known and the 'know-how' of blacksmiths, which can be deduced from the metallographic study of raw metal or objects, is still almost entirely to be discovered. Considerable work remains to be done to better understand how Meroitic metal was made and worked. This requires greater attention to be given to metal masses without defined shape, particularly when discovered in metallurgical contexts, and to look for preserved metal that can provide information on the activity of local blacksmiths.

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[4] Using Chronomodel software (chronomodel.com, CNRS, France).

[5] The scattering of small slagheaps at Meroe during the later period is more representative of a local iron production pattern than of a regional production organization (Carey *et al.* 2019, 447-448).

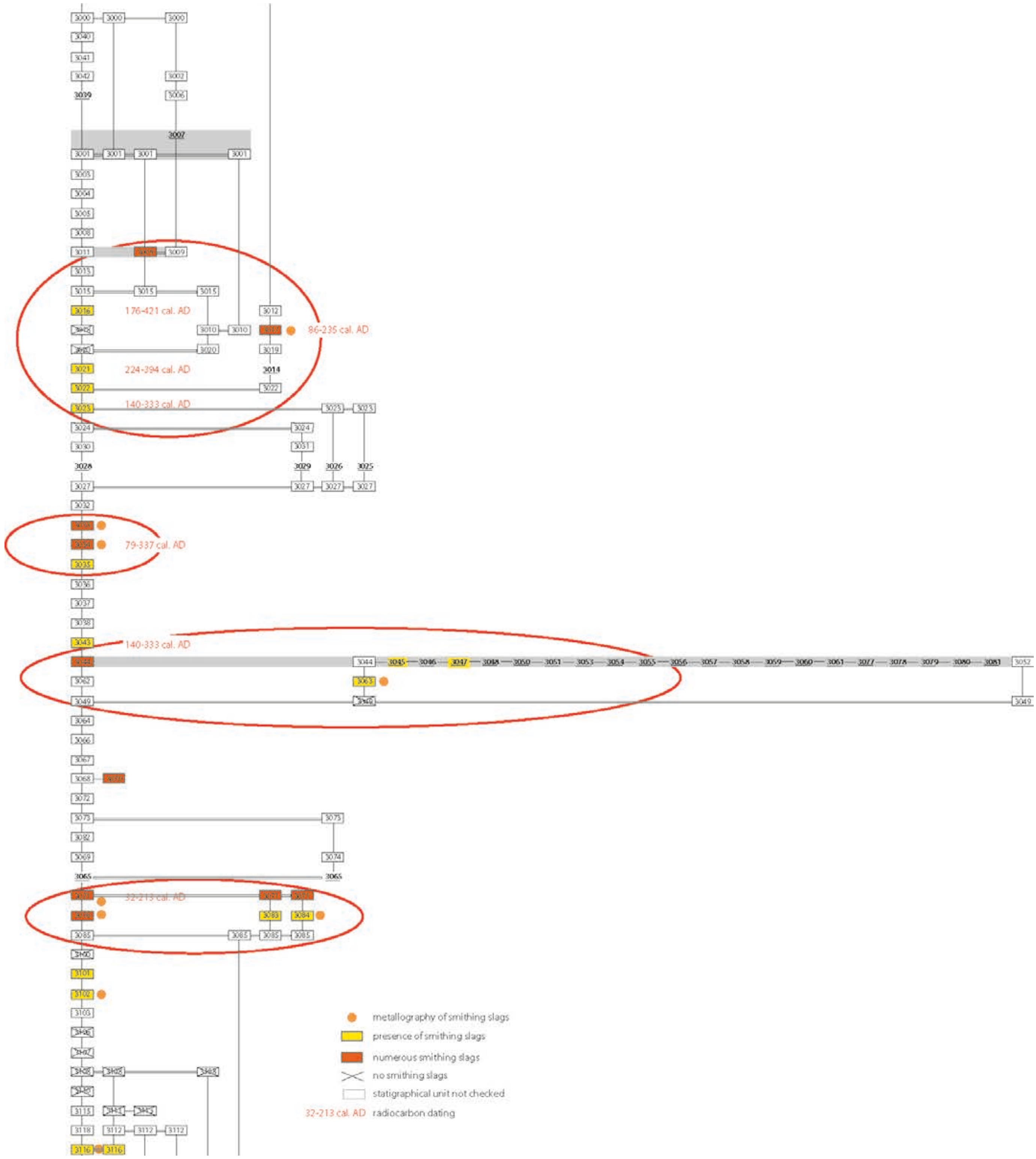

Figure 25. Stratigraphic diagram of area 3 with levels containing hammer scales (with Desachy 2015)

(Calibrated dating: 95% probability range. Unit 3016, UBA-30480, Age 14C:1722+/_48 years BP; unit 3021, UBA-30481, Age 14C: 1738+/_36 years BP; unit 3023, ECHo1831, Age 14C: 1780+/_25 years BP; unit 3034, UBA-30482, Age 14C: 1753+/_39 years BP; unit 3043, ECHo1832, Age 14C:1780+/_25 years BP; unit 3044, UBA-30483, Age 14C:1834+/_38 years BP; unit 3071, UBA-30485, Age 14C:1917+/_39 years BP).

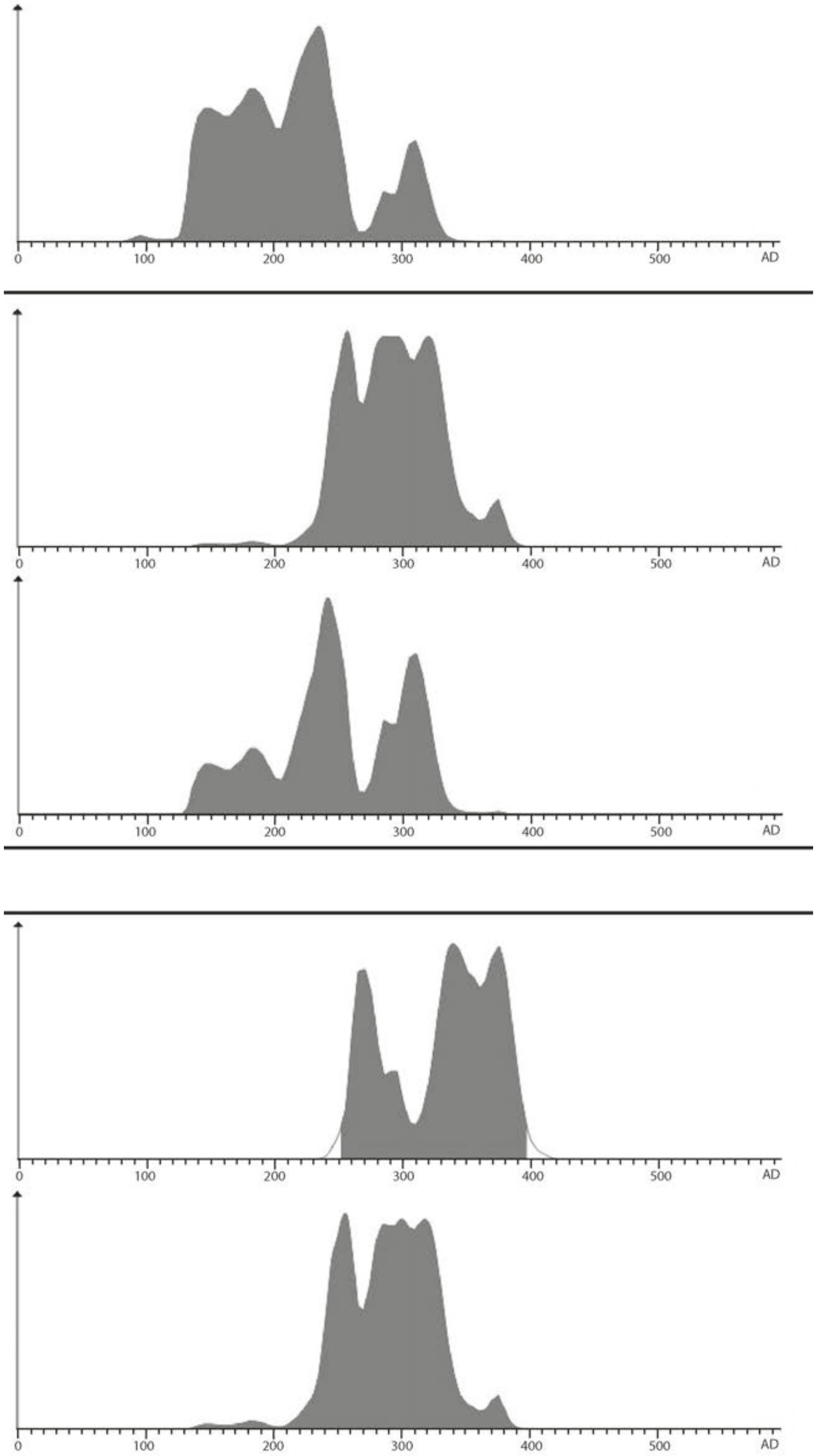

Figure 26. Calibrated radiocarbon dating (95% probability range) of strategraphic laters of metallurgical material from mound.
Top: dating of 1 charcoal from 2036 statigraphic unit slag (UBA-30478, Age C14: 1803 +/- 29 years BP).
Middle: dating of 2 charcoals from 2002 stratigraphic unit slag (ECHo1827, Age C14: 1750 +/- 25 years BP, ECHo1828, Age C14: 1785 +/- 25 years BP).
Below: dating of 2 charcoals from 2036 stratigraphic unit slag (ECHo1829, Age C14: 1710 +/- 25 years BP, ECHo1830, Age C14: 1755 +/- 25 years BP.

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