Discovery of copper tuyere imprints on the site of Castel-Minier, late-13th to mid-16th century (Ariège, France)

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ABSTRACT: From the 13th to the 16th century, iron was produced at the site of Castel-Minier. The excavations since 2003 have found structures and materials that allow us to understand how past metallurgists improved a forge of rather classic design to a real iron production site, relying on a system of inter-valley exchange. This paper relates especially to the discovery of 28 slag pieces. They carry imprints of tuyeres that were embedded in ventilation holes into which bellow pipes were inserted. Traditional and 3-D plots were used to estimate their shapes and diameters.

At the end of the 13th century, the exploitation of the silver ore deposits of the Viscounty of Couserans (in the French Pyrenees, Fig 1) led to the development of an iron workshop integrated into the silver smeltery. For three centuries some iron was produced at Castel-Minier using the ore from the Rancié iron mine. This ore circulated on the basis of a system of 'trading charcoal rights for iron ore'. This workshop was isolated in the valley 4km from the village of Aulus-les-Bains. To start with, at the end of the 13th century, it owed its *raison d'être* to mining activity and takes the form of a classic smithy. When the silver mining was in full swing, in the 14th century, the metallurgists began to produce iron, at first in a shaft furnace with hand-bellows and working the bloom by hand. They adopted water power for hammering in the 15th century, and finally in the 16th century the blowing begins to use water-powered bellows and the shaft furnace turns into an open hearth. So, the current Castel-Minier excavation has revealed the whole evolution of the *mouline*, the typical steel-making device in the eastern part of Pyrenees prior to the forge à la *Catalane* (Fig 2). Confusion between the *mouline* (la *molina* in the Occitan language) and the *forge à la Catalane* is frequent. The main difference relates to how the furnace was blown: the first uses water-powered

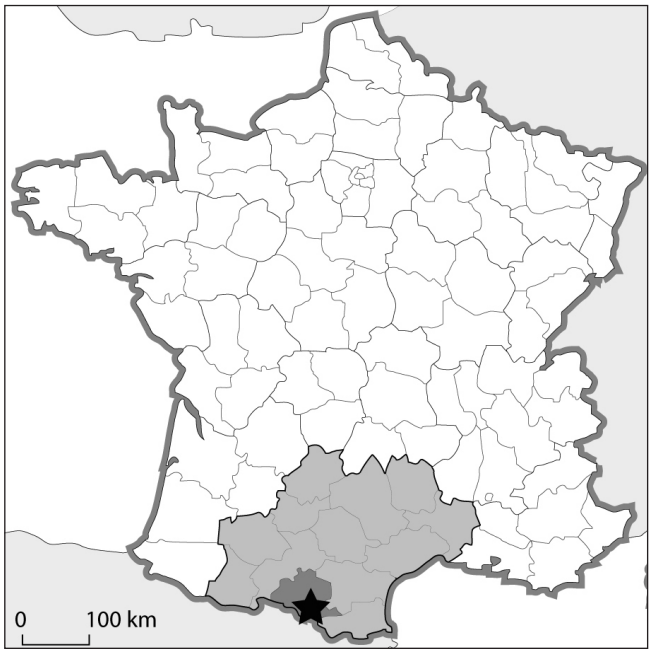

Figure 1: Location of Castel-Minier.

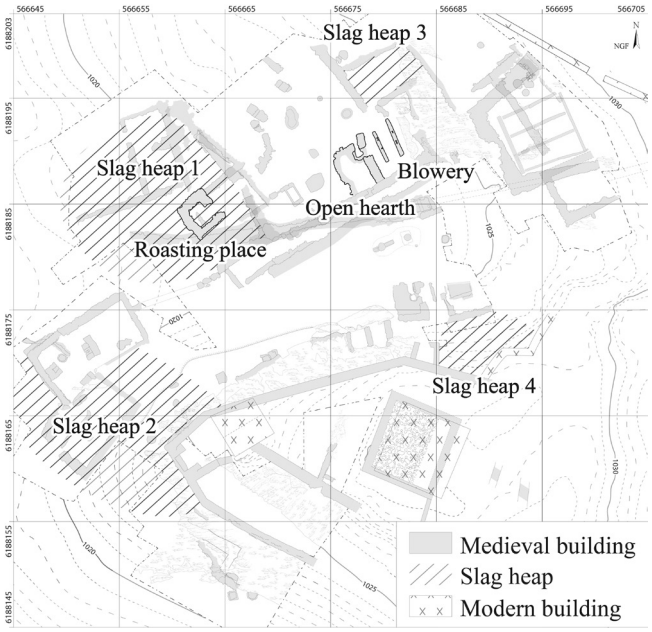

Figure 2: Plan of Castel-Minier. The grid squares are 10m.

bellows, the second a waterfall to create an air flow (sometimes known as a trompe).

For more than three centuries iron was produced on the site. At first it was for a local use but production evolved and finally it was all for export. More than 160kg of iron, a total of 3400 objects, were excavated and also 320 tons of slag, some of which included slag imprints. As well as the negative impressions of furnace walls and bottoms, 28 slag pieces have caught our attention (Table 1, Fig 3). These carry the imprints of tuyeres and valves embedded in ventilation holes into which bellows pipes were inserted (Fig 4). They were mainly discovered in three slag heaps (18) while seven come from structures which belong to the latest levels of occupation – roasting place (1), blowery (2) and open-hearth (4) – and three from desertion levels. The imprints from the slag heaps span all periods of iron smelting at Castel-Minier, from end of the 13th to the 16th century, whereas pieces found in structures come from the last period of activity.

Table 1: The slag lumps from Castel-Minier with tuyere imprints.

Area	Slag heap 2					Slag heap 1					
Date (century)	13-14th	14-15th			16th	2nd half 14th		1st half 16th			
No	1	2	3	4	5	6	7	8	9	10	11
Group	A	**B**/C				**B**/C				B/**C**	A
Diameter I (mm)	100	70	80	100	90	60	80	110	70	90	65
Diameter II (mm)		40				40					
Length R (mm)		6			2	3					3
Angle L°		25	30			25				25	8
Angle l°											

Area	Roasting	Open hearth				Blowery	
Date (century)	1st half 16th	2nd half 16th				2nd half 16th	
No	12	13	14	15	16	17	18
Group		A	**B**/C			A	
Diameter I (mm)	110	80	60	110	110	70	80
Diameter II (mm)		60	50			55	
Length R (mm)	3	15	5			15	
Angle L°	25	8	22.5			8	
Angle l°		16				14	

Area	Slag heap 3							Desertion		
Date (century)	1st half 16th		2nd half 16th							
No	19	20	21	22	23	24	25	26	27	28
Group			B/**C**	B/**C**	B/**C**			**B**/C		
Diameter I (mm)	100	60	95	95	90	70	120	85	110	90
Diameter II (mm)								45		40
Length R (mm)						1.5		4		10
Angle L°			25	25	25	22.5		25		
Angle l°										

Notes: Group A (cylinder) has average gradient (L) of 8°, Group B (cone) has average gradient (L) of 25°, Group C (cone) has average gradient of 25°. Less complete pieces could not be assigned to any of these groups

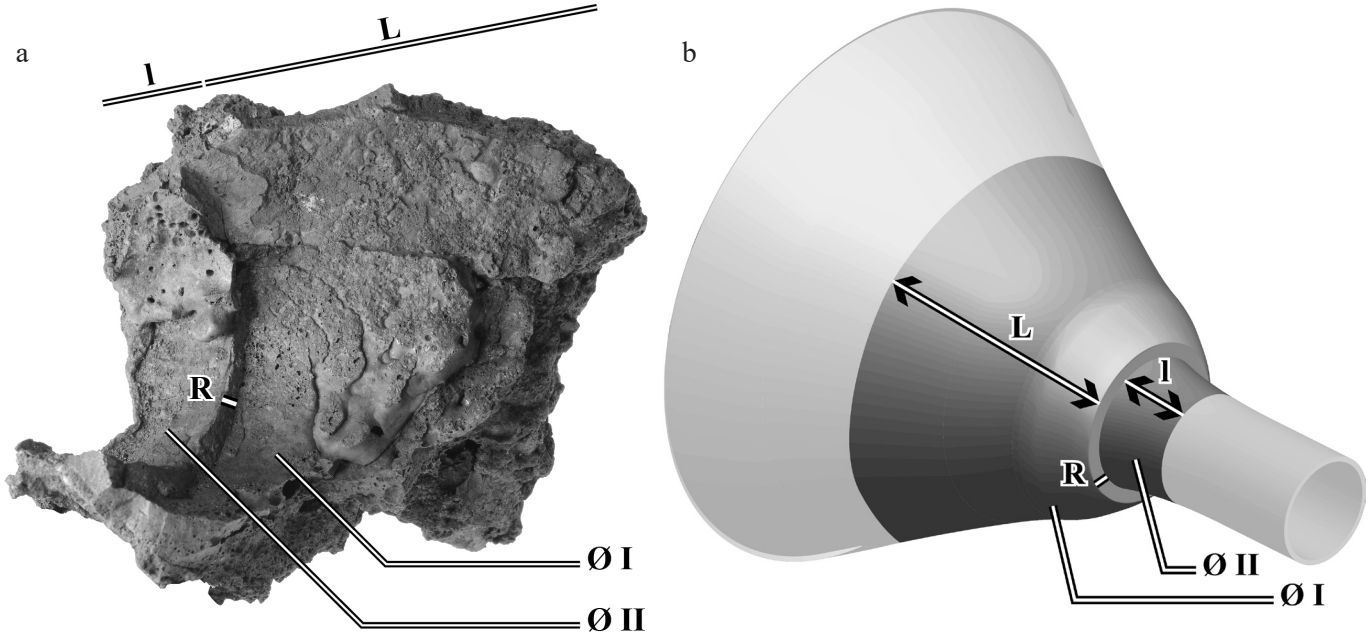

Figure 3: a) Piece of slag with a tuyere and valve imprint. Type B/C (CM08_2026_10314/1); b) Isometric view of the shape of the group B/C tuyere. The annotations show where the dimensions given in Table 1 were measured.

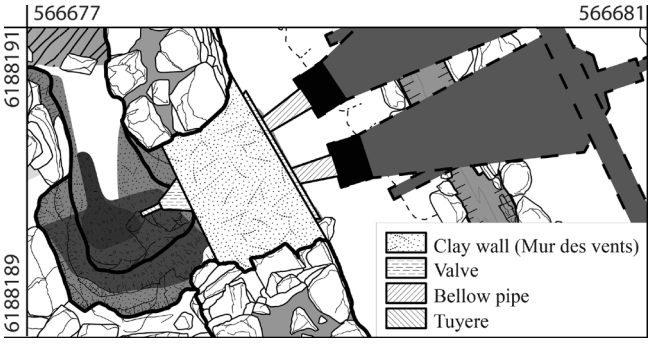

Figure 4: Plan of part of the blowery and the open hearth with the position of the devices embedded in the mur des vents added. Image width 4m.

The observation of these slags and the presence of metallic traces revealed the use of rolled unalloyed copper sheets with an average thickness of 6mm. Traditional and 3-D plots were used to estimate forms and diameters of tuyeres and valves. Digital photogrammetry, an image-based 3-D modelling technique, produced drawings and 3-D models. The qRansacSD plugin, developed by the Computer Graphics Group of the University of Bonn (Schnabel *et al* 2007) and available in CloudCompare software, was used for point clouds shape detection. This automatic algorithm, based on random sampling, is able to detect five basic shapes in unorganized point clouds:

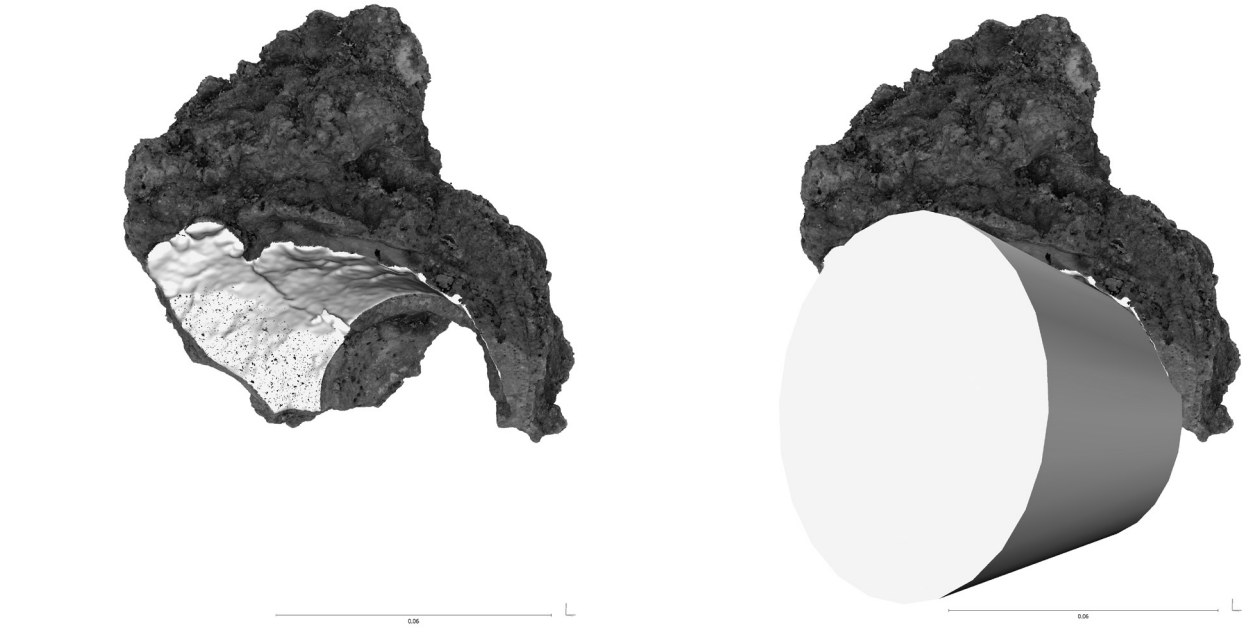

Figure 5: The qRansacSD plugin applied to the photo model of a type B/C slag imprint (CM08_2026_10314/1). Scale bar 60mm.

planes, spheres, cylinders, cones and tori; in this case the shapes were cones and cylinders (Fig 5).

Three morphological groups were identified within the tuyere imprints on the slag lumps. The first (group A) has a pseudo cylindrical facies. The following two groups (B and C), with conical forms, were associated: **B**/C for the mouth and B/**C** for the body (cf Table 1). Some of them belong to the nozzle mouth (group B), while the others were positioned on its body (group C) (Fig 6).

In Book 9 of Agricola's *De Re Metallica*, published in 1556 (Hoover and Hoover 1950), a device similar to the group B-C tuyeres is mentioned. However, the archaeological imprints reveal the existence of a cylindrical tuyere inserted into the first one. If they were built with the same material, the internal diameters of these pieces should be in the range 30-50mm. Surface irregularities of some of the slag pieces reveal the occasional use of lining for sealing.

Study of this corpus shows the use of metallic tuyeres before the arrival of water-powered blowing. The morphology of these slags does not demonstrate any real standardization. Most importantly, the size of the tuyere mouth does not change with the transition from manual to water-powered blowing. The unmodified dimensions show that the reduction capacity of the furnace increases because of the additional bellows pressure from water power. However, this increased capacity would tend to produce cast iron, so the shaft furnace had to be modified to become an open hearth.

Acknowledgements

Figures 2 and 4 are based on a survey by F Téreygeol, J Heckes et al, field drawings by O Vingoltc et al and computer graphics by J-C Méaudre. The plugin RansacSD used to detect shapes is available from CloudCompare software: http://www.danielgm.net/cc/, Especially: https://www.cloudcompare.org/doc/wiki/index.php?title=RANSAC_Shape_Detection_(plugin)

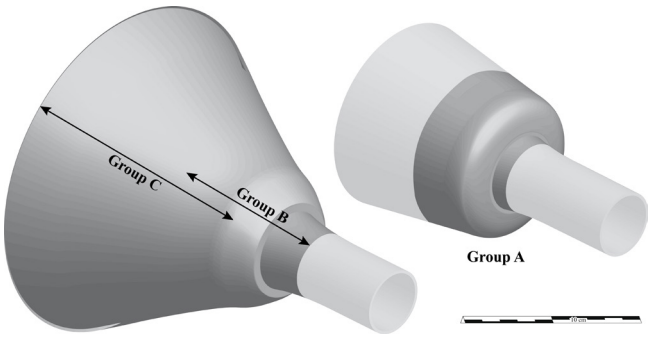

Figure 6: Isometric view of the shape of both groups of tuyeres (group B-C on the left, group A on the right). Scale bar 100mm.

References

Hoover H C and Hoover L H (trans) 1950, *Georgius Agricola's De re metallica* (New York).

Schnabel R, Wahl R and Klein R 2007, 'Efficient RANSAC for Point-Cloud Shape Detection', *Computer Graphics Forum* 26(2), 214-226. Available at http://cg.cs.uni-bonn.de/en/publications/paper-details/schnabel-2007-efficient/

Verna C 2001, *Le temps des moulines, Fer, technique et société dans les Pyrénées centrales (XIIIe-XIVe siècles)* (Paris).

Background to excavations at Castle-Minier

Flament J, Mercier F, Dubois C, Téreygeol F 2019, 'Mining archaeology and micro-Raman analysis associated to ESEM-EDX: toward chrono-spatial definition of ores consumption in a Pyrenean medieval workshop (14th-16th c.)', *Archaeometry* 66(1), 99-116.

Flament J, Sarah G, Téreygeol F 2017, 'Litharge cakes from Castel-Minier (Ariège, France): Understanding strategies of the cupellation in a multi metals workshop from the 14th century', in I Montero-Ruiz and A Perea (eds), *Archaeometallurgy in Europe IV* (Madrid: Bibliotheca Praehistorica Hispana 33), 269-281.

Flament J, Téreygeol F 2019, 'De la mine au creuset : l'essai de la chalcopyrite au flux noir', in G Verly, F Rademakers and F Téreygeol (eds), *Studies in experimental archaeometallurgy: methodological approaches from non-ferrous metallurgies* (Montagnac: Monographies Instrumentum 60), 57-66.

Florsch N, Llubes M and Téreygeol F 2012, 'Induced polarization 3-D tomography of archaeological direct reduction slag heap', *Near Surface Geophysics* 10(6), 567-574.

Florsch N, Llubes M, Téreygeol F and Roblet P 2011, 'Quantification of slag heap volumes by using induced polarization. Application to Castel-Minier site', *Journal of Archaeological Science* 38, 438-451.

Géraud M, Flament J, Hunt A, Sarah G, Foy E and Téreygeol F in press, 'Les céramiques métallurgiques de Castel-Minier (Ariège, France) XIII^{e}-XV^{e} s.', *ArchéoSciences* 43.

Leroy S, Cohen S, Verna C, Bertrand L, Gratuze B, Téreygeol F, Fluzin P and Dillmann P 2012, 'Depiction of the medieval iron market in Ariège (France). Multidisciplinary analytical approach and first development of multivariate analyse', *Journal of Archaeological Science* 39, 1080-1093.

Tereygeol F, Arles A, Foy E, Florsch N and Llubes M 2010, 'Dosages par pXRF d'ateliers médiévaux de production des métaux non-ferreux : les exemples de Castel-Minier et d'Agnesserre (Aulus-les-bains, 09)', *ArchéoSciences* 34, 253-267.

Téreygeol F and Gauthier J 2013, 'Le godet d'une pile du XIV^{e} s. à Castel-Minier', *Bulletin Instrumentum* 38, 44-46.

Téreygeol F and Heckes J 2012, 'El vent de les manxes i el poder del mall : les eines hidrauliques de la «mouline» del jaciment arqueologic Castel-Minier (XVI^{e} s., França)', in *Boscos de Ferro, Actes de 1es primeres jornades de recerca i desenvolupament de la vall ferrera* (Alins), 51-63.

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