The *haizeola* and the origins of the 'Catalan method' The medieval iron metallurgy culture in the Pyrenees

Haizeola a počátky „katalánské metody" Středověká metalurgie železa v Pyrenejích

Mercedes Urteaga – Xabier Alberdi – Iosu Etxezarraga – Fernando Martín Suquía – Mertxe Urkiola – Jose Luis Ugarte

Recent research shows that furnaces characteristically used in the 'Catalan method', a direct system of obtaining iron, are much older than they were thought to be. Archaeological evidence obtained in recent years indicates that the same model of furnace, although with smaller dimensions, was part of the iron-making culture of the pre-water-powered phase, when work was done by manpower. This phase has been dated to between the 9th and 14th centuries and relates to installations known as haizeolas. They have been recognized in the Basque territories of Biscay, Gipuzkoa and Alava, in a geographical area on the western edge of the Pyrenees.

Catalan process – Middle Ages – Basque country – early ironworking

Nový výzkum ukazuje, že pece používané při „katalánské metodě", přímém způsobu získávání železa, jsou mnohem starší, než se předpokládalo. Archeologické důkazy získané v posledních letech naznačují, že stejný model pece, byť menších rozměrů, byl součástí železářské výrobní tradice předcházející fázi zavádění vodní síly, kdy práce byla vykonávána silou lidskou. Tuto fázi lze datovat od 9. do 14. století, a souvisí se zařízeními známými jako haizeola. Ty byly rozpoznány na baskických územích Biscay, Gipuzkoa a Alava nacházejících se na západním okraji Pyrenejí.

katalánský proces – středověk – Baskicko – rané železářství

1. Introduction

Until the beginning of the 20th century, the Pyrenean region had its own ironmaking tradition based on the direct reduction process. It is known in literature as the 'Catalan method', 'Catalan Forge' and 'Catalan hearth' (*Tomás 1999*). This process took place in a low bloomery with a square bottom and inverted tapered-pyramid shape in which iron was obtained by the direct reduction system using hydraulic energy. In the final phase (17th–20th centuries), installations were divided into two groups: firstly, there was the Catalan forge group in the eastern zone, which was characterized by having a water-powered *trompe* to inject air into the furnace and, secondly, the Basque forge group (*ferrerías*) in the western zone, which used bellows as a forced ventilation system until their disappearance. Both types produced good quality iron ingots intended for both the European and American international market, competing with the iron produced in blast furnaces.

The same type of furnace, but in a smaller version, has been discovered in non-hydraulic establishments, mostly located in the mountains near mining areas. These are the

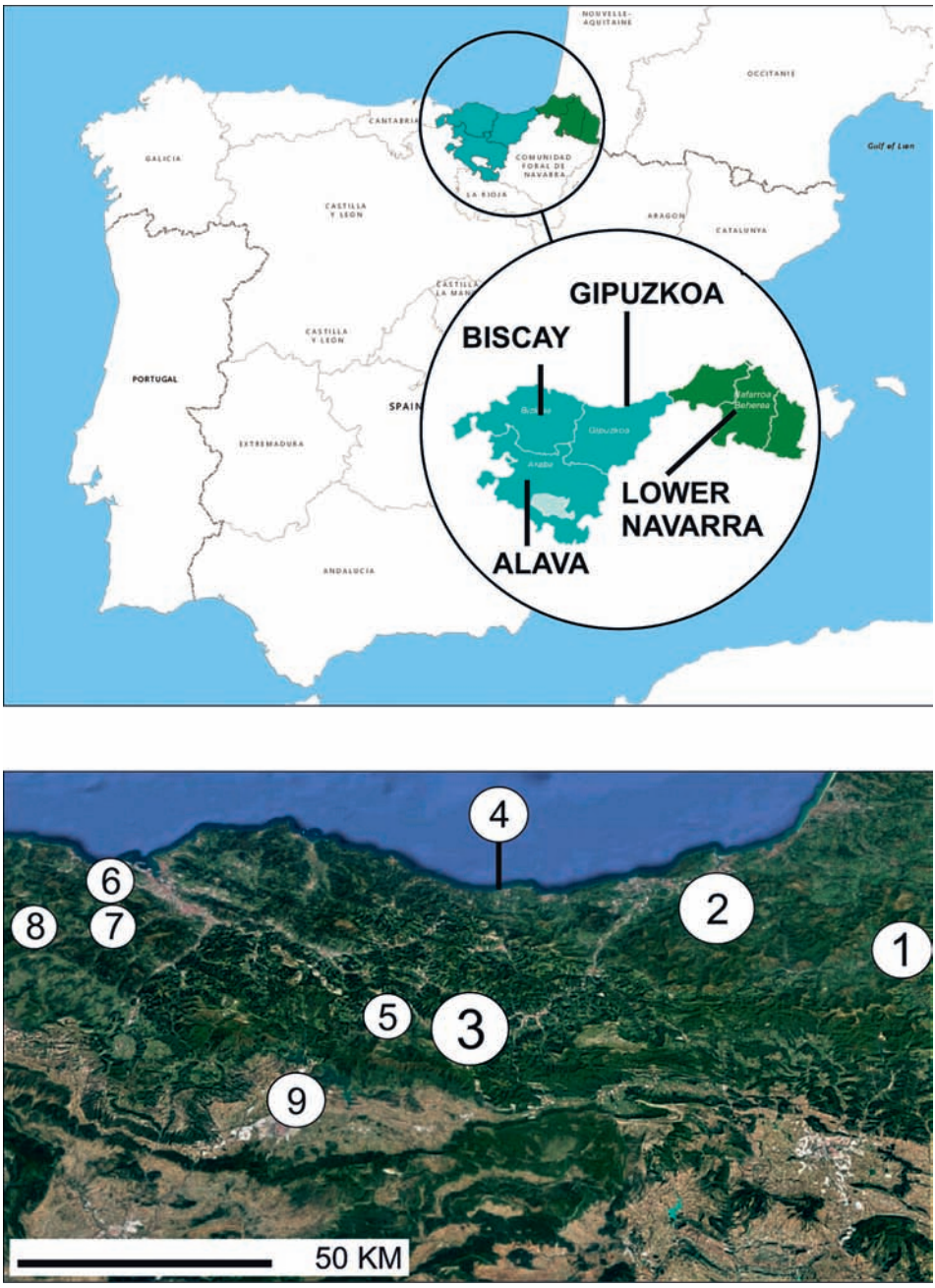


Fig. 1. Location of the area with indication of the places mentioned in the text: Drawing by M. Urteaga.
Obr. 1. Poloha oblasti s vyznačením míst uvedených v textu.
1 – Larla, 2 – Peña de Aya-Oiartzun, 3 – Legazpi-Segura, 4 – Mutriku, 5 – Arrasate/Mondragón, 6 – Muskiz-Trapagaran, 7 – Galdames, 8 – Artzentales-Sopuerta, 9 – Arrazua-Ubarrundia.

so-called *haizeolas*, the archaeological records of which date back to at least the 9th century.

The incorporation of water wheels and waterfalls must have begun in around the 11th century, although it seems to have spread and become more common place later, in the 13th century. The application of hydraulic drive power made it possible to increase the injection capacity in furnaces and the furnaces to increase in size. In this new technological context, installations came down from the mountains and were located next to rivers.

2. The name *haizeola* and pre-water-powered ironworking

In the 1950s, the engineer Manuel Laborde interviewed an elderly man in the Zerain area of Gipuzkoa who reported the use of the two Basque words *haizeola* and *gentilola*. Both terms had been used by his ancestors to refer to the old iron smelting furnaces from which abundant accumulations of slag were still extant.

Laborde (*1956*; *1979*) incorporated the term *haizeola* into the technical language of early Basque ironworking, using it to refer to the iron slag heaps found in mountain areas. From the location of the slag heaps and the characteristics of the slag itself, he also established a relationship with forges not powered by water.

These slag heaps have long been identified with manually-powered iron works. In the sixteenth century, the chronicler Esteban de Garibay (*Garibay y Zamalloa 1556*, 96) wrote that the first installations for making iron were located in the 'high areas of these same mountains' and that they were powered by hand rather than by water. He based his deduction on the fact that the slag heaps stood at a considerable distance from the river courses. Soon afterwards, Lope Martínez de Isasti (*Martínez de Isasi 1625*, 236) repeated Garibay's suggestion that the water-powered iron works were preceded by ones in which the iron was worked 'by hand' in the mountains. Villarreal de Bérriz (*Villarreal de Berriz 1736*, 43) and *Larramendi* (*1756*, 64–65) gave similar reports, as did other twentieth-century historians such as *Caro Baroja* (*1949*, 259–260) and Laborde who, as mentioned, introduced the term *haizeola*.

3. Archaeological identification of the *haizeola*: The catalogue of mountain slag heaps

Calle Iturrino (*1963*) published the first list of iron slag heaps in the Basque Country in the middle of the last century; in this chapter of precedents, mention can also be made of the group of 10 slag heaps recorded in Legazpi (*Arbide et al. 1980*). But in these cases, there was no identification of the site by means of geographical coordinates, and there was no description accompanying the location. These requirements were fulfilled for the first time in the work of *Gorrochategui* and *Yarritu* (*1984*), in which 34 slag heaps were catalogued in 6 geographical areas of Biscay.

A new episode in the evolution of the archaeological knowledge of *haizeolas* took place in 1988, with the archaeological work carried out at the Ilso Betaio slag heap in Artzentales/Sopuerta, Biscay. The program lasted until 1990 and included anthracological analyses

of carbon samples, palynological analyses and radiocarbon dating. Among the discoveries are two calcination furnaces, dust ore residue and structures with unknown functions. The slag heap dated to between 940 and 1100 AD (*Gorrochategui et al. 1995*).

After this first initiative, excavations followed at the Oiola slag heap in Trapagaran (Biscay) between 1990 and 1993 (*Aldama – Lorenzo 1991*), resulting in a corpus of reference information for learning about the metallurgical process that took place in these facilities between the 11th and 13th centuries (*Pereda García 1997*; *Larrazabal 1997*). After those dates, archaeological work became commonplace in slag heaps, also moving to other regions. In Gipuzkoa, work started in 1993 (*Urteaga 1996*; *Alberdi – Etxezarraga 2014*), in Lower Navarra in 1998 (*Beyrie 2002*) and in Alava a few years later (*Alberdi – Etxezarraga – Artetxe 2013*).

As a result of this activity, there is a catalogue of 500 slag heaps, 250 of which have been registered in Gipuzkoa, 170 in Biscay, 55 in Larla (Saint-Étienne-de-Baïgorry, Lower Navarra) and 25 in Alava. Archaeological operations have also been carried out in 52 of them, 21 in Biscay, 17 in Gipuzkoa, 13 in Lower Navarra and 1 in Alava.

It should be noted that the figure of 500 slag heaps recorded to date was certainly much more extensive. As happened in Montagne Noire (France) and in many other European regions where there was a major modern iron-steel industry, the iron slag heaps in the Basque Country were exploited industrially in the foundries of the 20th century. Moreover, it can be said that only those heaps that are difficult to access or of little importance have been preserved.

Having made this assessment, the available records show concentrations in specific areas, such as the 124 slag heaps around Legazpi (*Ugarte – Urteaga 2014*), the 55 in Larla in Saint-Étienne-de-Baïgorry (*Beyrie 2008*), the 54 in Galdames (*Franco Pérez 2008*) and the 45 in Peñas de Aya (*Alberdi – Etxezarraga – Artetxe 2013*). This distribution is related to the existence of significant iron ore deposits.

4. Archaeological work and the chronology of *haizeolas*

Table 1 shows dated slag heap data and their chronology. Of the 45 registered sites, 44 of them are slag heaps, but one (Bagoeta) is a rural settlement. The dated sites are 8.5 % of the total. A significant portion of them have chronologies from the Second Iron Age, the Roman Era and the Late Antiquity; they represent 3.2 % of the total and the 35 % of the dated slag heaps; there are also very complete records of the furnaces from that period in the case of Larla (*Beyrie 2014*).

In the other 26 dated slag heaps, chronologies fall between the 9th and 14th centuries, with a higher concentration in the 11th and 13th centuries (16 examples).

The Larla furnaces belong to a type that has been well-known for centuries that frame the change of era; semi-excavated in the natural terrain, with a narrow and elongated plant divided into two distinct parts: the entrance and the reduction chamber, which is closed with a chimney. According to the archaeological experimentation campaigns, they worked with a natural draught (*Beyrie 2014*).

Although the term *haizeola* is used to identify the furnaces that have produced the accumulations of iron slag that are located in mountain areas, following the historiographic

Name		A=Alava; B= Biskai; G=Gipuzkoa; L.N.=Lower Navarra Reference	III	II	I	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
Zepamendi	A	*Alberdi – Etxezarraga – Artetxe 2015*																	
Bagoeta	A	*Azkarate – Solaun 2014*																	
Oiola 2 (Loiola)	B	*Cepeda – Unzueta 2015*																	
Akalarra	B	*Franco Pérez 2014*																	
Arteta	B	*Franco Pérez 2011*																	
Artobilla 2	B	*Franco Pérez 2011*																	
Lekubarri	B	*Franco Pérez 2014*																	
Biriguera	B	*Franco Pérez 2008*																	
Crucero	B	*Franco Pérez 2008*																	
Gongeda 1	B	*Franco Pérez 2008*																	
Los Campillos	B	*Franco Pérez 2007*																	
Salbartondo 2	B	*Franco Pérez 2007*																	
Ilso Betaio	B	*Gorrochategui et al. 1995*																	
Arrastaleku	B	*Franco Pérez 2014*																	
Peña Helada 1	B	*Franco Pérez – Etxezarraga – Alberdi 2015*																	
Saukutza 3	B	*Franco Pérez 2011*																	
Peñas Negras	B	*Franco Pérez et al. 2014*																	
Callejaverde II	B	*Franco Pérez et al. 2014*																	
Callejaverde I	B	*Franco Pérez et al. 2014*																	
Oiola 4	B	*Pereda García 1997*																	
Peña Helada 2	B	*Franco Pérez – Etxezarraga – Alberdi 2015*																	
Erdokazabaleta 3	G	*Ugarte – Urteaga 2014*																	
Basaundi 2	G	*Ugarte – Urteaga 2014*																	
Teniola 1	G	*Franco Pérez – Etxezarraga – Alberdi 2015*																	
Erdokazabaleta 5	G	*Ugarte – Urteaga 2014*																	
Otañu 3	G	*Ugarte – Urteaga 2014*																	
Aizaleku 5	G	*Ugarte – Urteaga 2014*																	
Galarraga	G	*Franco Pérez – Etxezarraga – Alberdi 2015*																	
Zabarain 7	G	*Ugarte – Urteaga 2014*																	
Aizpee 5	G	*Ugarte – Urteaga 2014*																	
Teniola 4	G	*Ugarte – Urteaga 2014*																	
Larrosain	G	*Ugarte – Urteaga 2014*																	
Erlaitz 1	G	*Ugarte – Urteaga 2014*																	
Harotzainekoborda	L. N.	*Beyrie 2014*																	
Oheta	L. N.	*Beyrie 2014*																	
Larla 1	L. N.	*Beyrie 2014*																	
Larla 2	L. N.	*Beyrie 2014*																	
Larla 3	L. N.	*Beyrie 2014*																	
Larla 4	L. N.	*Beyrie 2014*																	
Larla 5	L. N.	*Beyrie 2014*																	
Larla 6	L. N.	*Beyrie 2014*																	
Larla 7	L. N.	*Beyrie 2014*																	
Larla 8	L. N.	*Beyrie 2014*																	
Larla 9	L. N.	*Beyrie 2014*																	
Larla 10	L. N.	*Beyrie 2014*																	
Larla 11	L. N.	*Beyrie 2014*																	

Tab. 1. The chronology of the slag heaps.
Tab. 1. Chronologie struskových hald.

tradition and the results that are analyzed, our work has reduced the field of application of that name to square, low and open furnaces which chronology extends between the 9th and 14th centuries in our era.

One contemporary text explicitly refers to installations in which iron was made without the use of water power – in other words, *haizeola*. The document dates from 1335 and forms part of a bylaw whereby the local council of Segura required ironworkers in their jurisdiction to sell their iron and purchase their supplies through the town. The preamble makes particular mention of the different types of iron works in the area and differentiates between *masuqueras*, those which used water-driven hammers, *mazo de agua*, and those which used 'omes'. The first two refer to water-powered installations, whereas those powered by 'omes' (a Spanish medieval term meaning *men*), as their name suggests, were the hand-operated installations (*Urteaga 1996*). It also shows that they co-existed with water-powered works and that the latter were sufficiently developed. In the fifteenth century, the increased production capacity of the newly expanded water-powered works forced the more primitive ones out of business.

5. Introduction to the archaeological identity of the *haizeola*

The sites

With the exception of Torre in Astigarribia, all the other slag heaps are located in mountain areas close to iron ore deposits. Although they were situated near mining areas, they did not form part of them; they were built in the immediate vicinity. In addition, they all share two other features: an adjoining river or stream, and clay soil. The reason they were not located next to the iron mines may have been because of the need for a supply of water or also for other reasons. Indeed, a water source is a feature of practically 100 % of the slag heaps catalogued. These tend to consist of springs or streams with a weak flow, but they would have been enough to meet the requirements of a small group of people and basic industrial activity. Another constant is the clay soil on which the installations are built. Such sites may have been preferred because they made it easier to dig the base of the furnaces and build the foundations of the wooden structures or because they provided the clay required for building the walls of the furnaces and other auxiliary items.

It is also worth bearing in mind that larger quantities of charcoal than iron ore were required for the process. The exact ratio of iron ore to charcoal used in the *haizeola* is not known, but in the water-powered works the volume is estimated at around 3 to 5 (*Urteaga 2000*, 258). As we shall see, water-powered works and *haizeola* appear to share the same ironworking tradition and the loads of charcoal required would have been much greater than those of ore. This would have made it more important to build them near woodland than close to deposits of iron ore (albeit they could not be too far from the mines).

The installations identified in Astigarribia constitute an exception, in that according to analyses, the ore used there did not come from the immediate environs (*Pérez Centeno 2009*). This difference may have something to do with the monastery to which it appears to have been attached and the existence of a sea and river port at the site.

Finally, we should also note that the sandstone used in the construction of the furnaces and auxiliary structures was also available in the sites chosen.

Characteristics of the installations

Based on the information we have gleaned to date, the works appear to have consisted of small sheds situated on small plots of levelled ground, dug out of gently-sloping land (*Fernández Carvajal 2009*). The furnaces occupied a central and important position and were accompanied by small roasting structures in the immediate area; the ore and charcoal were stored beside the furnace. The most complete information comes from Basaundi 2 (Legazpi). In this case it has been seen that there is a basic building next to the furnace where the charcoal was stored and auxiliary operations were carried out. The furnace is located outside this building, but protected by a roof supported by wooden poles.

The ore

The samples analysed (*Simon 2014*, 87) coincide in indicating that the ore was quite pure, comprising hematite iron ore (Fe_2O_3) with remains of siliceous gangue (SiO_2). This is quite a pure iron oxide which is easy to reduce. The samples recovered are of ore that has been treated previously to remove impurities. The resulting concentrate was roasted on site and broken up to be put in the furnace.

The charcoal

A lot of research work still needs to be conducted in this area, since each slag heap contains a large quantity of charcoal which needs to be identified and quantified. To date, 4 different sites analysis has been performed (*tab. 2*): Torre (Astigarribia, Mutriku), Oiola IV (Trapagaran), Ilso Betaio (Arcentales) and Bagoeta (Arrazua-Ubarrundia). This last site does not correspond to the mountain location of the iron slag heap or *haizeola*; it was found during an archaeological excavation in a medieval rural settlement, but has the same type of furnace and the same chronology (*Azkarate – Solaun 2014*).

From these data an extreme variety in the origin of charcoal is deduced; in the case of Torre can be established three groups: oak charcoal accounts for 35 % of the whole, followed by apple, 29 %. Of the remainder, the most abundant species is beech, which comprises 15 % of the total. Bagoeta is in the opposite side; in this case a single species has been used for charcoal: oak. Ilso Betaio provides the beech domain with almost 90 % of the total, and in the last case, Oiola IV, the oak is the most important species, exceeding 50 % of the sample.

The arragoas or roasting structures

The ore was roasted in elongated oval structures, with two low parallel walls about 1 m apart, as can be seen at the slag heap of Basaundi 2 (*Ugarte – Urteaga 2014,* 60). This type of "*arragoa*" has also been identified in the slag heap of Oiola IV in Trapagaran, Bizkaia (*Pereda García 1997*) and at Peñas Negras (*Franco et al. 2014*, 201). The shape of those constructions may vary from site to site though, since a circular plant roasting structure has recently been found at Peña Helada (Galdames, Biscay) (*Franco Pérez – Etxezarraga – Alberdi 2015*). However, at the moment, oval arrangement seems to be the average feature.

Species	Common name	Percentage
Torre 1 (Astigarribia, Gipuzkoa). *Pérez Centeno* (*2007*).		
Quercus subg. *Quercus*	Oak	35%
Rosaceae Pomoideae	Apple	29%
Fagus sylvatica	Beech	15%
Rhamnus alaternus / *Phillyrea*	Thorn	6%
Taxus baccata	Yew	11%
Corylus avellana	Common hazel	4%
Oiola IV (Trapagaran, Biscay). *Zapata* (*1997*)		
Quercus subg. *Quercus*	Oak	55.8%
Fagus sylvatica	Beech	12.5%
Corylus avellana	Common hazel	7%
Rosaceae Pomoideae	Apple	3.2%
Frangula alnus	Alder buckthorn	5.5%
Others		15%
Ilso Betaio (Arcentales. Biskay). *Zapata* (*1993*)		
Fagus sylvatica	Beech	89.6%
Quercus subg. *Quercus*	Oak	6.18%
Ilex aquifolium	Holly	2%
Bagoeta (Arrazua-Ubarrundia, Álava). *Azkarate – Solaun* (*2014*)		
Quercus subg. *Quercus*	Oak	100%

Tab. 2. Documented wood species used for charcoal.
Tab. 2. Dokumentované druhy dřeva používané pro výrobu dřevěného uhlí.

The furnaces

The furnaces are of square sloped type (*figs. 2* and *3*). They are low and open, with air forced in by handed bellows. The best information comes from the 11th–13th century *haizeola* of Callejaverde 1, Callejaverde 2 (Muskiz, Biskay), Peñas Negras (Ortuella, Biscay), Peña Helada (Galdames, Biskay), Anporreta (Arrasate-Mondragón, Gipuzkoa), Olazar 3 (Oiartzun, Gipuzkoa) and Basaundi 2 (Legazpi, Gipuzkoa). In the three last examples only the lower part of furnaces remains, but they are similar in their characteristics to those seen in the well-preserved furnaces of the other sites. In all cases the area on which the furnace was constructed can be seen to have been carefully prepared to repel damp.

The walls are around one metre thick and were built out of medium-sized sandstone blocks, held together with clay. The base of the furnace was dug into the ground. Viewed from above, it is rectangular with rounded angles. Its size is around 35 cm long by 30 cm wide and beneath this level a tank with the shape of a bowl was dug deeper. The tank was separated from the base with a levelled slag layer.

The base is smaller than the frame at the top, where reaches 70 × 60 cm, and slopes slightly backwards. The nozzle (*tuyère*) was placed halfway up the back wall through which the air from the wall bellows entered the furnace. The upper section overhangs the *tuyère*, narrowing the upper opening of the furnace. The *tuyère* leaded through the wall on a horizontal slab. The opposite wall stands at an angle of 45º and finishes in a prepared stone

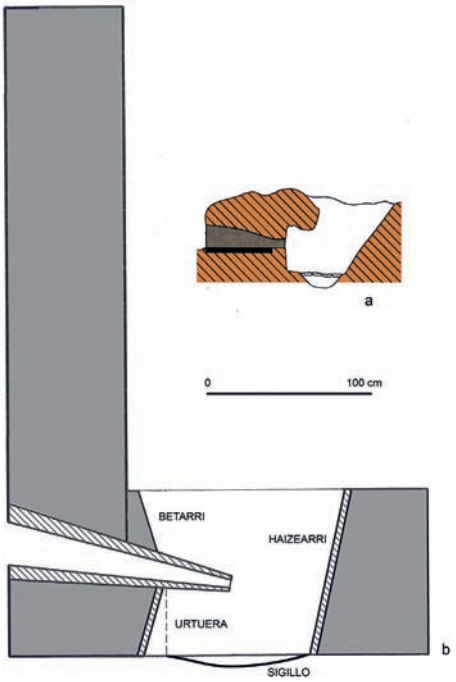


Fig. 2. a – the haizeola furnace; b – the water-powered ironworks furnace. Drawing by M. Urteaga & J. Maroto.
Obr. 2. a – pec *haizeola*; b – pec železárny s vodním pohonem.

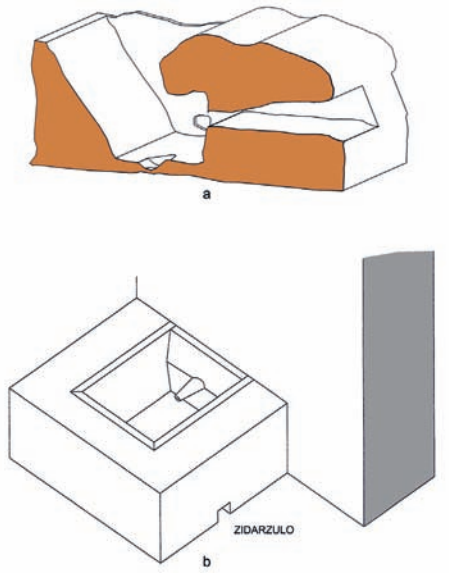


Fig. 3. a – the haizeola furnace; b – the water-powered ironworks furnace. Drawing by M. Urteaga & J. Maroto.
Obr. 3. a – pec *haizeola*; b – pec železárny s vodním pohonem.

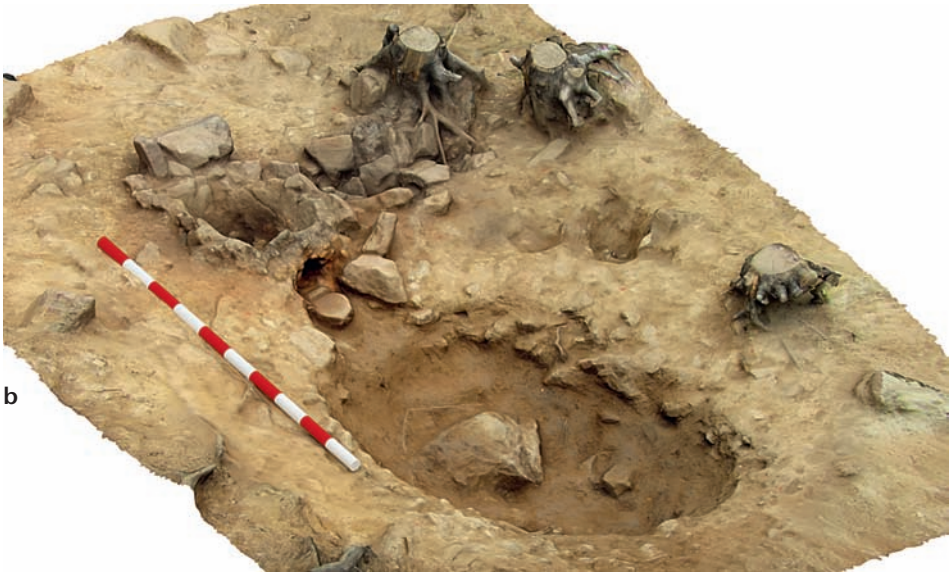
with the same angle. One of the other two walls has a gap at the base level of the furnace for removing slag.

The furnace of the *haizeola* was about two-thirds of the size of that used in the water-powered works. Whereas the furnace of the water-powered forge was a metre in height, that of the *haizeola* was 60 cm and the other parts were more or less to the same scale (*fig. 2* and *3*).

However, some geographical differences are observed in this described model. The four furnaces found at Biscay were built excavated in the ground (see *fig. 3*). Two of its walls are the terrain slopes, while the wall of the *tuyère* and the remaining wall were built with stones and clay in a massive way (*Franco Pérez – Gener Moret 2017*). In the furnaces from Gipuzkoa only the base was excavated in the ground. The rest were built out of medium-sized sandstone blocks, held together with clay. The walls are around one meter thick. In Basaundi 2, for example, the perimeter ring on which the walls are erected has been excavated to a depth of around 30 cm; this would have facilitated drainage and ensured that the base of the furnace was protected from seepage (*fig. 4*).

There is extensive documentation for the terms used for the different parts of the furnace in water-powered works. In the 18th century Metallurgy Manual from the Royal Society of Friends of the Basque Country (*Urteaga 2000,* 260), the wall with the *tuyère* was called in

a



b

Fig. 4. a – Callejaverde 1 Site; b – Callejaverde 2 Site. Photo by Ondare Babesa S. L.
Obr. 4. a – lokalita Callejaverde 1; b – lokalita Callejaverde 2.

Basque language the *betarri* (unknown meaning) in the upper part and *urtuera* (unknown meaning) in the lower one. The opposite wall was the *haizearri* (translated: the wind stone). Out of the two other walls, the one with the hole for slag tapping was the *zidarzulo* (translated: the slag hole). The hole was in the lower part of the furnace at the same height as the plate of the *sigillo* (from Latin *sigillum*? – to seal?).

Archaeological experiments at the 18th century rebuilt Agorregi hydraulic ironworks (Aia, Gipuzkoa) conducted by Peter Crew (*Crew – Crew 2002*) shows that this arrangement creates a circular draught inside the furnace, allowing temperatures of 1300 °C close to the mouth of the *tuyère* (*Fluzin – Herbach – Dillmann 2002*). It is in that area that the bloom or *agoa*, created by reduction of the iron ore in contact with the charcoal, is formed.

Analysis of the slag from the *haizeola* furnaces also shows evidence of these temperatures. Solidified fayalite has been found, indicating a temperature of 1205 °C, as well as leucite, suggesting that the temperature in the furnace was 50–100 °C higher (*Simon 2014*, 96).

Iron production in the haizeola

To judge from the type of furnace and associated structures identified and the remains of ore and slag analysed, the *haizeola* obtained iron in much the same way as the water-powered iron works, although output was smaller and they were hand-operated. Good quality and easily reducible ore was used, iron oxides (hematites), that were roasted and broken up on site before being placed in the furnace. As in the water-powered works, the charge would have been carefully studied, since the result of the reducing operation depended to a great extent on how this was done. Because the furnace was open, the process could be controlled quite easily and any necessary changes made. The furnaces used forced injection, in other words, the air was injected from the rear using hand-operated bellows. This allowed temperatures of up to 1300 °C, enough to obtain sponge iron through direct reduction and to tap the liquid slag, helped by reduction of the wüstite. Work in the *haizeola* concluded when the *agoa* (bloom) was produced. The refined blooms must have been prepared in separate premises, since none of the characteristic waste material of forging operations has been found on the slag heaps.

If we focus on water-powered iron production, we find that in Pyrenean regions, particularly Catalonia, Ariège and the Basque Country, iron continued to be produced in low and open square furnaces until the twentieth century, despite the fact that elsewhere in Europe, indirect smelting in blast furnaces had been commonplace since the end of the Middle Ages. These installations were gradually abandoned as a result of the introduction of the blast furnaces, accompanied by mechanisation of the processes and industrial levels of output. With the closure of the last such installations in the Pyrenees in the twentieth century, direct reduction finally came to an end. Technological change also led to the disappearance of the bloomeries which, with variations, used the same open, square sloped model described above throughout the Pyrenees.

Thanks to the evidence obtained from the *haizeola* it is possible to trace the basic design of that type of furnace back to the pre-hydraulic period, establishing its origins at least as early as the tenth century or even earlier in the Basque provinces of Bizkaia, Gipuzkoa

and Alava. In short, this type of furnace appears to correspond to a different tradition to those used in the pre-Roman and Roman periods. We do not know with any certainty when it was introduced and how much further back it dates than the earliest available records. What we do know is that once adopted, it was retained long after the *haizeola* themselves had disappeared. The design continued to be used in the furnaces of water-powered ironworks until, with the coming of the Industrial Revolution, they closed due to competition from blast furnaces.

There is an increasing body of information on the transition from the *haizeola* to water-powered ironworks. As we have seen, it shows that the *haizeola* and the water-powered ones share a common culture, reflected in the model of furnace. This model formed part of the medieval ironworking culture of the Pyrenean area, between the Atlantic and the Mediterranean, from the High Middle Ages.

We are grateful to José Ángel Fernández Carvajal (Ondare Babesa Sl) *for providing us the images of figure 4; Josu Maroto for his help in the preparation of the figures and to Javier Sánchez in the configuration of the dynamic tables. Special thanks to Peter Crew for having reviewed the first text and for his suggestions.*

References

Alberdi, X. – Etxezarraga, J. 2014: Proyecto de investigación de las ferrerías de monte o haizeolak en Gipuzkoa y Álava. Avance de resultados. Kobie Anejos 13, 181–192.

Alberdi, X. – Etxezarraga, J. – Artetxe, O. 2013: Prospección arqueológica sistemática para la localización y catalogación de ferrerías de monte en los territorios de Gipuzkoa y Álava. Arkeoikuska 12, 345–347.

Alberdi, X. – Etxezarraga, J. – Artetxe, O. 2015: Prospección arqueológica sistemática para la localización y catalogación de ferrerías de monte en los territorios de Gipuzkoa y Álava. Arkeoikuska 14, 411–413.

Aldama, J. P. – Lorenzo, F. A. 1991: Sondeo arqueometalurgico en Loiola (Trapagaran): contribución al estudio de las ferrerías de monte por el método arqueológico. Zonas, fases y primeros resultados. Kobie Paleoantropología 19, 209–211.

Arbide, I. – Azpiazu, J. A. – Gordoa, I. – Salmerón, M. – Urcelay, J. M. – Zubizarreta, A. 1980: Ferrerías en Legazpi. San Sebastián: Caja de Ahorros Provincial de Guipúzcoa.

Azkarate, A. – Solaun, J. L. 2014: De ferro de Alava. Metalurgia altomedieval en la Llanada alavesa (siglos VII–XI D.C.). Kobie Serie Anejo 13, 161–180.

Beyrie, A. 2002: La métallurgie antique du fer sur le massif de Larla (commune de Saint-Martin d'Arrossa). In: J.-B. Orpustan ed., « Urzaiz » La vallée d'Ossès en Basse-Navarre : Orzaizeko ibarra, Saint-Etienne-de-Baigorry: Editions Izpegi, 287–294.

Beyrie, A. 2008: L'exploitation du fer dans le Sud-ouest de la Gaule. L'exemple du site de Larla (Pyrénées-Atlantiques – 64). Archéopages 22, 32–33.

Beyrie, A. 2014: Aux origines de la siderurgie tarbelle. Kobie Serie Anejo 13, 125–138.

Calle Iturrino, E. 1960: Las ferrerías vascas. Bilbao: Artes Gráficas de la Santa Casa de Misericordia.

Caro Baroja, J. 1949: Los Vascos, Etnología. San Sebastián: Biblioteca Vascongada de los Amigos del País.

Cepeda, J. J. – Unzueta, M. 2015: Ferrería romana de Loiola. Arkeoikuska 14, 249–251.

Crew, P – Crew, S. 2002: Experimental iron working at Agorregi, 1994–1999. In: M. Urteaga ed., La ferrería y los molinos de Agorregi. Arqueología experimental, Donostia – San Sebastián: Diputación Foral de Gipuzkoa, 43–91.

Fernández Carvajal, J. A. 2009: Ferrería de monte de Callejaverde. Arkeoikuska 2008, 300–302.

Fluzin, Ph. – Herbach, R. – Dillmann, Ph. 2002: Etudes métallurgiques et thermodynamiques. In: M. Urteaga ed., La ferrería y los molinos de Agorregi. Arqueología experimental, Donostia – San Sebastián: Diputación Foral de Gipuzkoa, 123–160.

Franco, J. – Fernández Carvajal, J. A.– Alberdi, X. – Etxezarraga, I. 2014: Ferrerías de monte Callejaverde y Peñas Negras. Nueva tipología de horno plenomedieval y metodologías aplicadas a su estudio. Kobie Anejos 13, 193–206.

Franco Pérez, J. 2007: Ferrerías de monte en los macizos de montaña de Mello, Serantes, Sollube, Bizkargi y Lemoatxa. Arkeoikuska 06, 154–158.

Franco Pérez, J. 2008: Ferrerías de monte en los macizos de Ganekogorta, Beraskola y Oiz (Alonsotegi, Bilbao). Arkeoikuska 7, 309–313.

Franco Pérez, J. 2011: Ferrerías de monte en los macizos de montaña de Gorbeia, Itxina, Saibi, Eskuagatx--Ugatza, Altun, Legarmendi, Mandoia, Mendigisa, Odoriaga, Arrola y Valle de Orduña. Arkeoikuska 10, 318–321.

Franco Pérez, J. 2014: Haizeolak en Bizkaia: una investigación de largo recorrido sobre la Arqueología de la producción del hierro. Kobie Serie Anejo 13, 21–38.

Franco Pérez, J.– Alberdi, X. – Etxezarraga, I. 2014: Ferrería de monte de Peñas Negras II Campaña. Arkeoikuska 13, 245–247.

Franco Pérez, J.– Etxezarraga, I. – Alberdi, X. 2015: Los orígenes de la tecnología del hierro en el País Vasco: ferrerías de monte o haizeolak. Kobie Serie Paleoantropología 34, 267–282.

Franco Pérez, J. – Gener Moret, M. 2017: Early ironwork in Biscay: Survey, excavation, experimentation and materials characterization. An integral studyof the mountainside ironworks (ferrerías de monte or "haizeolak"). Materials and Manufacturing Processes 32, 876–884.

Garibay y Zamalloa, E. 1556–1666: Los quarenta libros del compendio historial de las chronicas y universal historia de todos los reynos de España. Barcelona: Sebastian de Cormellas 1628.

Gorrochategui, J. – Yarritu, M. J. 1984: Prospecciones arqueológicas en Vizcaya durante 1983. Del Eneolítico a la Edad Media: asentamiento al aire libre, necrópolis y ferrerías de monte. Cuadernos de Sección Prehistoria y Arqueología 2, 171–219.

Gorrochategui, J. – Yarritu, M. J. – Martín, I. – Zapata, L. – Iriarte, M. J. 1995: Paleometalurgia del hierro en Bizkaia. Las ferrerías de monte altomedievales. In: E. Tomás i Morera ed., La farga catalana en el marc de l'arqueologia siderúrgica, Andorra la Vella: Govern d'Andorra, Ministeri d'Afers Socials i Cultura, 229–241.

Laborde, M. 1956: Datos sobre los orígenes de la minería e industria del hierro en Guipúzcoa, Homenaje a D. Joaquín Mendizabal Gortázar, San Sebastián: Ciencias Naturales Aranzadi, 225–236.

Laborde, M. 1979: Ferrones. In: J. M. de Barandiarán dir., Euskaldunak: la etnia vasca, San Sebastián: Etor, 297–360.

Larramendi, M. 1756: Corografía o Descripción general de la muy noble y muy leal provincia de Guipúzcoa. In: J. I. Tellechea Idígoras ed., San Sebastián: Sociedad Guipuzcoana de Ediciones y Publicaciones 1969.

Larrazabal, J. 1997: Análisis de muestras siderometalúrgicas procedentes de los yacimientos Oiola II y Oiola IV (Trapagarán-Bizkaia). Kobie Paleoantropología 24, 95–105.

Martínez de Isasi, L. 1625: Compendio historial de Guipuzcoa. San Sebastián: Ignacio Ramón Baroja Ed. 1850. Bilbao: La Gran Enciclopedia Vasca (facsímil ed.) 1972.

Pereda García, I. 1997: Aportación al conocimiento de la metalurgia del hierro en los siglos XI–XIII en Bizkaia: el yacimiento de Oiola IV (Trapagaran, Bizkaia). Kobie Paleoantropología 24, 69–93.

Pérez Centeno, J. M. 2007: Memoria arqueológica Iª campaña de Prospección arqueológica en la cuenca del río Deba (Mutriku-Mendaro). Unpublished report, Provincial Council of Gipuzkoa. Archives and Heritage Services Archive.

Pérez Centeno, J. M. 2009: Valle del Deba (Mutriku, Deba) II y III Campaña de prospección. Arkeoikuska 2008, 432.

Simon, J. 2014: Análisis metalográficos y caracterización de materiales. In: J. L. Ugarte – M. Urteaga, Arqueología del hierro medieval. Los escoriales del distrito de Legazpi (Gipuzkoa). Boletín Arkeolan 17, 85–97.

Tomás, E. 1999: The Catalan process for the direct production of malleable iron and its spread to Europe and the Americas. Contributions to Science 1/2, 225–232.

Ugarte, J. L. – Urteaga, M. 2014: Arqueología del hierro medieval. Los escoriales del distrito de Legazpi (Gipuzkoa). Boletín Arkeolan 17, 1–85 and 103–350.

Urteaga, M. 1996: Siderurgia medieval en Gipuzkoa. Haizeolas, ferrerías masuqueras y ferrerías mazonas. In: I Jornadas sobre minería y tecnología en la Edad Media peninsular, León: Fundación Hullera Vasco-Leonesa, 543–558.

Urteaga, *M. 2000*: El Tratado de Metalurgia de las Comisiones Segundas de la Real Sociedad Bascongada de Amigos del País, 1765–1773. Donostia – San Sebastián: Diputación Foral de Gipuzkoa.
Villarreal de Berriz, *P. M. 1736*: Maquinas hidráulicas de molinos y herrerías y gobierno de los arboles y montes de Vizcaya. Madrid: Sociedad Guipuzcoana de Ediciones y Publicaciones de la Real Sociedad Vascongada de los Amigos del País (facsímil ed.) 1973.
Zapata, *L. 1993*: Haizeoletarako egur erabilpena Bizkaian. Ikuska 1993/2, 55–58.
Zapata, *L. 1997*: El uso del combustible de la ferrería medieval de Oiola IV: implicaciones ecológicas y etnobotánicas. Kobie Paleoantropología 24, 107–115.

MERCEDES URTEAGA, Provincial Council of Gipuzkoa, Archives and Heritage Services, Culture Department. Urdaneta street 9, E-20006 Donostia-San Sebastián, Basque Country; murteaga@gipuzkoa.eus
XABIER ALBERDI, Mining Museum in the Basque Country, Bº Campodiego, S/N, E-48500 Gallarta (Abanto-Zierbena) Bizkaia; x.a.lonbide@gmail.com
JOSU ETXEZARRAGA, Mining Museum in the Basque Country, Bº Campodiego, S/N,. E-48500 Gallarta (Abanto-Zierbena) Bizkaia; iosu.eo@gmail.com
FERNANDO MARTÍN SUQUÍA, Burdinola Society, Bº Telleriarte Auz, S/N, E-20230 Legazpi (Gipuzkoa) fernando.sukia@sidenor.com
MERTXE URKIOLA, Burdinola Society, Bº Telleriarte Auz, S/N, E-20230 Legazpi (Gipuzkoa) murkiola@gmail.com
JOSE LUIS UGARTE, Burdinola Society, Bº Telleriarte Auz, S/N, E-20230 Legazpi (Gipuzkoa) jl-ugarte@euskadi.eus