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THE BASQUE BLOOMERY FURNACE "HORNO VASCO": NEW FINDINGS OF A LARGE IRON SMELTING FURNACE AND HISTORICAL PERSPECTIVE

El "Horno Vasco" de reducción directa: nuevos hallazgos de hornos de reducción de mineral de hierro de gran tamaño y perspectiva histórica

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RESUMEN

El "Horno Vasco" es un nuevo tipo de horno que ha sido investigado y recientemente descrito por los autores. Varios cientos de estos hornos de reducción de mineral de hierro, de gran tamaño, han sido identificados en el País Vasco. A pesar de la falta de referencias históricas para conocer la edad de los mismos, se sugiere una época medieval. Algunos de estos hornos fueron posteriormente reutilizados como hornos para fabricar cal. En este trabajo se plantea la importancia histórica de la producción y comercio del hierro vasco en la Edad Media y las fuentes para la obtención de la materia prima. Se describen y discuten este tipo de hornos con dimensiones de 3 a 4 m de diámetro y hasta 6 m de altura, que funcionaron sin ayuda de la energía hidráulica. También se ha caracterizado la composición química y mineralógica de las escorias. Por último, se plantean algunas consideraciones de como pudo funcionar el horno.

PALABRAS CLAVE: País Vasco, hierro, "Horno Vasco", horno de reducción directa, horno de cal, Edad Media.

ABSTRACT

The 'Basque furnace' is a new type of furnace technology that has been recently described and investigated by the authors. Several hundred of these large iron smelting furnaces have been identified in the Basque Country. In spite of the lack of historical references to ascertain the age of the bloomery furnaces, medieval times are suggested. Some of the iron furnaces were later re-used as lime kilns. This paper starts by discussing the historical importance of the production and trade of Basque iron in the Middle Ages, and the sources for the raw material. The furnaces are described and discussed. They were 3 to 4 m in diameter and up to 6 m in height, and were not operated by water-power. The chemical and mineralogical composition of the slag is also characterized. Lastly, suggestions are made as to how the furnace was operated.

KEY WORDS: Basque Country, iron "Basque furnace", bloomery, lime kiln, Middle Age.

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INTRODUCTION

The Basque Country, a region stretching around the Bay of Biscay on both sides of the Pyrenees, has been renowned since Antiquity for the great quantity of iron ore deposits, their quality, and the trade established in the Middle Ages between the coastal sites of Bizkaia and Gipuzkoa with the main trading centres in Europe. This trade was based, in a large part, on the variety of iron tools and utensils manufactured for agriculture, navigation and architecture, usage.

Our research over the last few years has allowed us to discover a previously unreported type of iron smelting furnace. These furnaces consist of circular structures, previously known as 'ferrerías de monte' ('mountain bloomeries'), which predate the water-powered furnaces that eventually replaced them. Once abandoned, many of them were re-used as lime-burning kilns, which has led to the assumption that they had always served that purpose. The furnace type, which we have named 'Horno Vasco' ('Basque Furnace') (Orue-Etxebarria *et al.*, 2010), shows distinctive features that make it different from any other bloomery furnace known – most notably, its large size. At the same time, their size and morphology show some similarities with the earliest so-called 'Altos Hornos' ('High Furnaces' or blast furnaces).

The most significant mining areas are those in Bizkaia, on the left bank of the Ibaizabal/Nervión River, such as Somorrostro, Triano, Galdames, Bilbao, etc. There are smaller exploitations in other areas, for example on Paleozoic materials around Peñas de Aia, between Gipuzkoa and Navarra, and Baigorri (Basque-French Country), some of which were exploited in Roman times. Lesser known exploitations are those at Udalatx, on the slopes of the Arrasate Mountain, in Gipuzkoa, which supplied iron for the famous Mondragón swords. Some of the characteristics explaining the fame and value of Bilbao's iron ores are their abundance, high grade and, more recently, its low phosphorus content. For these reasons, Basque iron was the main commodity traded between Basque ports and the main trading centres of medieval Europe, such as those of Brugge, Antwerp, the British Isles, etc.

There are some indications to suggest that the history of metallurgy in the Basque Country started in the Middle Bronze Age (ca. 1500 BC), with the extraction and probable smelting of copper in the Aralar mountain range (Urteaga, 2010). Iron metallurgy, started at least in the 7th or 6th century BC. Excavations on Iron Age settlements carried out in the last decades, especially towards the south of Araba and Navarra, have revealed numerous agricultural tools and weapons made of iron dating to that period at least (San José, 2005; Peñalver, 2008). Whether such metallurgical activities were a local innovation or the result of foreign contact remains uncertain.

What we do know is that the abundance of iron in these Basque mountains is cited by early historians such as Pliny the Elder, whose famous *Historia Naturalis* mentions that on the Cantabrian coast "…there is a rough and high mountain, all of it incredibly made of iron…". Possibly, he was referring to Triano (Somorrostro) mountain, in Bizkaia. Further, Strabo, in his *Geographika*, records the abundance of iron in this region. Strabo had not visited the Iberian Peninsula, so his information must have been borrowed from other source, possibly Greek authors such as Polybios, Poseidonios or Artemidoros (García y Bellido, 1987). It is quite likely that this information derives from the Greek Piteas, given that some information suggests that Strabo would have consulted his work, entitled *Over the Ocean*. It is believed that Piteas, regarded as the greatest explorer of Antiquity, may have known the Basque coast first hand: in the 4th century BC, he reached the Northern Atlantic, exploring the northern coasts of Europe, the British Isles on the tin trade route, and possibly even Iceland (Gómez, 2012).

Recent excavations appear to demonstrate that Gadir was founded as early as the 9th century BC (Parodi, 2012) and bearing in mind that Carthaginians were excellent sailors and trades-people who controlled the tin trade and the expansion of iron metallurgy. It is likely that they introduced iron smelting technology into the Basque Country by sea, or through the Ebro Valley. Another possibility often cited is that Indo-European cultures, particularly the Celts, brought the knowledge of iron to the north of the Iberian Peninsula. Even though these scenarios seem the most probable hypotheses, we should not discard the possibility that indigenous peoples would have mastered iron smelting independently.

The iron industry continued throughout Roman times. Excavations of sites dated from the 1st to the 4th century AD have found iron smelting furnaces at locations such as Forua and Pantano de Oiola (Bizkaia), Arbiun (Gipuzkoa) and Aloria (Araba) (Cepeda, 2001; Martínez Salcedo, 1997). These furnaces are circular or oval in plan, with foundations dug into the soil. The furnace height and diameter rarely exceeds 1m. Finds of Roman settlements with evidence of iron metallurgy are increasingly frequent. This, together with the reported scarcity of confrontations between Romans and Vascons, suggests that there was a good relationship between both communities that may have been based on the trade of iron. It should be borne in mind that, during the Roman invasions of the Iberian Peninsula, Vascons used short, handy swords known as *ezpatak* (in Basque), which would be later copied by the Romans, and whose manufacture required steel (Silván, 1986).

Information is scanty for the period between the fall of the Roman Empire and the emergence of water-powered furnaces in the 13th century. Probably owing to the problems related to the iron smelters' exploitation of wood, ores and water. In 1328 the the King of Castille Alfonso XI granted a specific jurisdiction ('Fuero de Ferrerías') to the smelters of Oiartzun and Irun, in Gipuzkoa. In 1335, this was extended to the iron-smelters in the valleys of Lastur, Mendaro, Ego and, in general, all the bloomeries in the Marquina de Suso Valley, also in Gipuzkoa (Díez de Salazar, 1983). A similar status would be granted to the Bizkaia area in 1440. The abundance of iron making installations was such that, in the 16th century, over 300 water-powered furnaces are documented simultaneously in Bizkaia and Gipuzkoa (Medina, 1548). These furnaces would be progressively replaced by blast furnaces in the 19th century, starting with the Nervión Valley, in Bizkaia.

It was previously known (Laborde, 1979) that, prior to the water-powered furnaces, there were so-called "mountain bloomeries" ("ferrerías de monte" in Spanish), or *haizeolak* (in Basque), given that many slag heaps or slag scatters were recorded. These furnaces did not make use of water-power and everything was done by hand, in a way comparable to Roman technology.

However, the increase in efficiency derived from water power meant that mountain bloomeries were progressively abandoned. Oral histories (Caro Baroja, 1980) indicate that both types co-existed for several centuries in some areas, such as the locality of Zegama, in Gipuzkoa, where the traditional types survived until the 17th century at least. According to Villarreal de Berriz (1775), elder people in Mondragón reported that towards the end of the 16th century iron was still made by hand in several sites of Gipuzkoa.

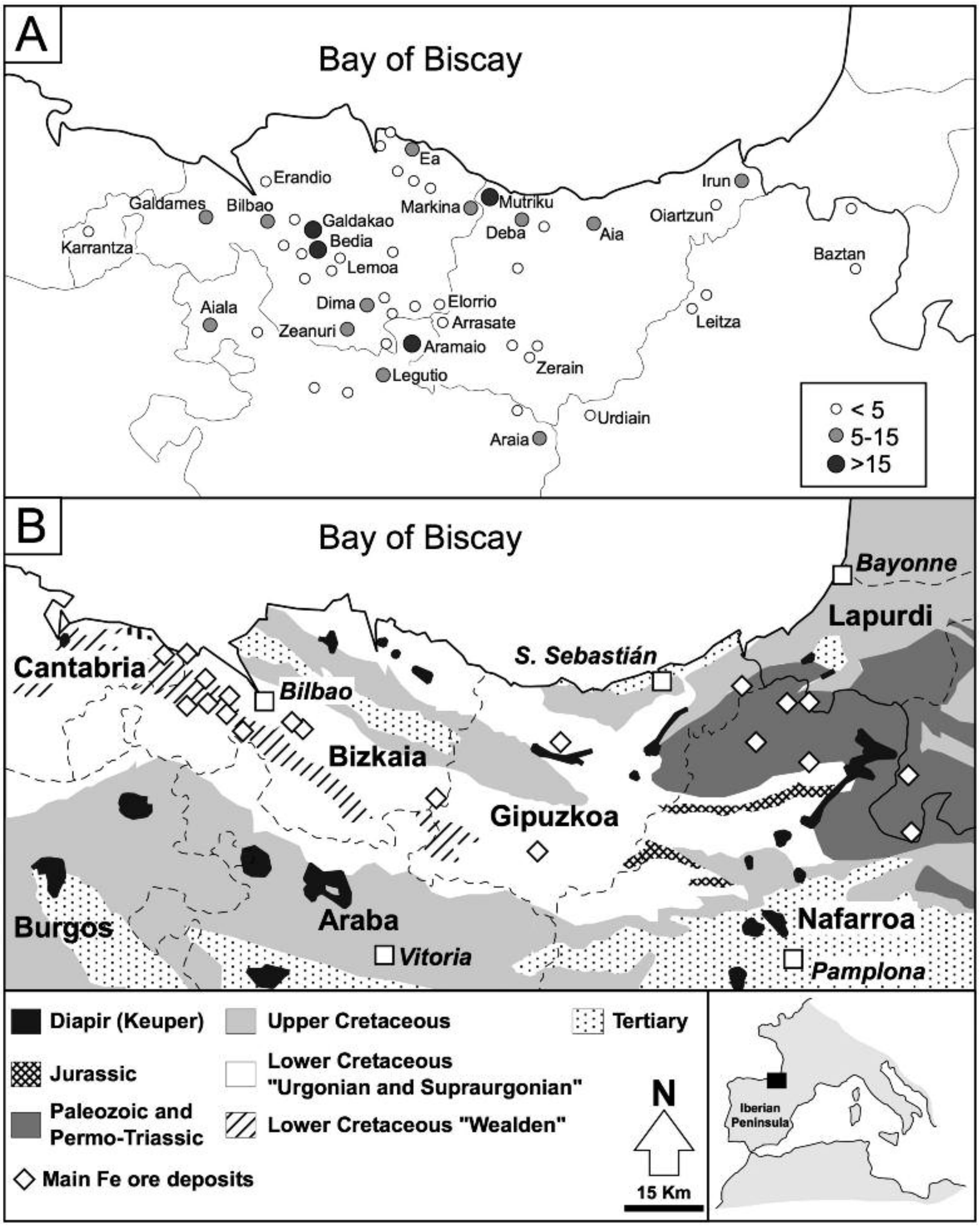

Figure 1. A) Distribution of the furnaces hitherto identified in areas with Urgonian or Paleozoic materials (the symbol indicates the number of furnaces). B) Geological sketch of the Basque-Cantabrian Basin showing the main iron mineralisations (modified after Velasco *et al.*, 1994).

Figura 1. A) Distribución de los hornos encontrados en las zonas con materiales urgonianos y paleozoicos visitadas hasta ahora (el símbolo indica el número de hornos). B) Esquema geológico de la Cuenca Vasco-Cantábrica con la localización de las principales mineralizaciones de hierro (modificado de Velasco et al., *1994).*

Owing to their deterioration through weathering, forest clearing, re-sedimentation, etc., there is a widespread belief that the earliest furnace structures would have disappeared, or be very hard to trace – with slag being the only evidence of their past existence (Gorrochategui and Yarritu, 1984; Etxezarraga, 2004). This view is echoed by Ibarra (1989) when he states that however much has been written about the topic, there is a notable lack of references to material remains that might allow an impression of the structure and arrangement of the mountain bloomeries. As a matter of fact, any finds of *haizeolak* reported in journals or media normally referred to slag heaps. Only in a few cases are their references to actual furnaces, such as the small structure found at the mountain of Crucero in Galdames, interpreted as a furnace base, or that excavated in Oiola, Trapagaran (Pereda, 1992/93), that is just over one metre in diameter, partially excavated into the soil and built with sandstone.

Since 2003, this situation has changed thanks to the research work undertaken by our group (Orue-Etxebarria *et al.*, 2008a, 2008b, 2009). We have documented numerous bloomery smelting furnaces, of pre-hydraulic technology, located in the mountains of the Atlantic Basque Country. These furnaces display specific features, notably their large size, which make them different from contemporaneous furnaces in Europe – hence we have called them "Basque Furnaces" (Orue-Etxebarria *et al.*, 2010). In 2010 we excavated one of these structures for the first time: the furnace of Azarola in Lekubaso (Galdakao), reported in a previous publication (Orue-Etxebarria *et al.*, 2011).

So far we have discovered similar furnaces in every area that we have investigated, adjacent to iron mineralisation. Figure 1 shows the distribution of identified furnaces. The areas of the map lacking documented structures are those which have not been inspected. In addition, the number of furnaces recorded in each location is directly proportional to the number of visits. For example, the left bank of the Nervión River (Somorrostro, Triano, Galdames, Gallarta), renowned for its richness in iron, was only visited once, whereas the areas most extensively surveyed have been Galdakao (36 furnaces) and Bedia (21 furnaces) in Bizkaia, and Mutriku (29 furnaces) in Gipuzkoa (Fig. 1). Notwithstanding the large numbers of furnaces documented, the actual number is likely to be higher: for example, in Galdakao we have only covered about one fourth of the area. Furthermore, there are potentially interesting areas yet to be visited, such as the mining region of Triano-Somorrostro, the area surrounding the calcareous massifs of Gorbea, Duranguesado, Sierra de Aralar, etc., as well as the Paleozoic materials around the Peñas de Aia, and the Leizaran Valley.

IRON SOURCES. MAIN ORE DEPOSITS IN THE ATLANTIC BASQUE COUNTRY

From a geological perspective, the areas most rich in iron mineralisation are those of the Lower Cretaceous period in the Bilbao Anticline, especially the left bank of the Nervión/Ibaizabal River (Fig. 2), and to Paleozoic materials of the Western Pyrenees in Gipuzkoa-Navarra and the French Basque Country (Velasco *et al.*, 1994).

The iron mineralisation of the Lower Cretaceous period ("Urgonian Complex" of Aptian and Lower Albian age and, to a lesser extent, the Supraurgonian), have all been formed in marine environments. In Aptian rocks, the main iron deposits are replacing Urgonian limestone platforms, which have resulted in the formation of famous mountain peaks, for example the Itxina-Lekanda-Aldamin Massif, the 'Peñas' of Duranguesado, the Sierra de Aralar, the Sierra de Elgea-Urkila, etc. In the Lower Albian rocks, iron ores are found in veins, or as nodular concretions, of siderite. The surface weathering of the primary mineralisations produced gossans that are strongly enriched in iron oxides.

The sedimentary materials outcropping along the Bilbao Anticline primarily consist of Lower Cretaceous sediments (between 100 and 125 million years). This rock assemblage, typically exceeding 2000 m in thickness, was formed in a marine area in distension. The main iron ores in this Anticline (Gil, 1991) are the result of a replacement of Urgonian limestone with hot fluids rich in metals (Fe and Mg), which led to a primary mineralisation of large masses of siderite ($FeCO_3$) and ankerite ($Ca(Fe,Mg)(CO_3)_2$). The remobilisation of siderite triggered the infill of fractures, generally in a WNW-ESE direction, generating vein mineralisations. In a later

Figure 2. Open cast exploitation of siderite in Gallarta (Bizkaia), formally listed as cultural heritage.
Figura 2. Imagen de la explotación a cielo abierto de siderita en Gallarta (Bizkaia), declarada como Bien de Interés Cultural Calificado.

stage and through supergenic processes, primary mineralisations were altered, leading to the formation of secondary gossans, iron oxides and hydroxides (hematite, Fe_2O_3 and goethite, FeOOH). These oxi-hydroxide ores are popularly known by miners as ‘vena’, ‘campanil’ and ‘rubio’ and refer to ores with decreasing content of iron. It is likely that these surface outcrops would be the first mineralised zones to be exploited by early iron smelters.

The most important mines were those of the so-called “Iron Mountains” (“Montes de Hierro”): Galdames, Sopuerta, Somorrostro, Gallarta, Triano, La Arboleda. Other important mining areas are around Bilbao city (Ollargan, El Morro, Miravilla, and others). We should also highlight the exploitations of Zerain-Mutiloa (also rich in sulphides), whose iron was transported to the port of Pasaia (Gipuzkoa) for export in the 20th century. Other iron mines are known at Axpe-Arrazola, the foothills of Udala, Legutiano and Asparrena, and both the galleries and open-pit exploitations of Galdakao and Bedia (Adán de Yarza, 1911-1926).

In Paleozoic mineralisations, we should cite the mines of Arditurri-Oiartzun, Berastegi (Gipuzkoa) and Lesaka and Goizueta (Navarra), as well as those of Luzaide, Ustelegi, Aldude, and the mountain of Larla – the latter in the Baigorri Valley (French Basque Country).

In areas composed of Lower Cretaceous and Paleozoic rocks, we have found a great abundance of furnaces. *Haizeolak* have also been found associated with isolated beds of Upper Cretaceous siderite nodules, for example the furnaces of Deba (Gipuzkoa) and Erandio (Bizkaia).

THE BASQUE COUNTRY AND THE IRON TRADE

The link between Basque people and iron is deep-rooted. In the Late Middle Ages, many peasants combined ironmaking with other activities in order to obtain supplementary income. According to Díez de Salazar (1983, 1985), considering that each bloomery would require between 50 and 100 workers involved directly (at the furnace itself) or indirectly (woodchoppers, charcoal makers, miners, mule-drivers, etc.), we can immediately get an impression of the huge economic importance of this activity. In later periods, according to a source cited by Arbaiza (1996), bloomeries in Bizkaia employed 100 people on average. According to cadastral documents from Igantzi (Navarra) dated to 1778-1786, the majority of the 629 inhabitants were linked to this industry (Erdozain *et al*., 2003). Similarly, in nearby Lesaka, in 1824, after the use of water-powered bloomery furnaces had been discontinued in most areas, around 30% of the population were still involved with one of the three iron foundries in the municipality (Erdozain *et al*., 2002, 2003).

Regarding the iron trade, there is evidence that, from the 11th century, iron ores from Bizkaia were transported to ports in Gipuzkoa and Labourd (Laburu, 2006). Further evidence for maritime trade of iron, is found in the Charter of San Sebastián, from 1180, where the commodities going through this harbour are recorded (Orella, 2003) and where “fierro” products are mentioned. Since the Middle Ages, there are numerous references (Childs, 2003; Tena, 2003) to the maritime control of the Atlantic by the Basque commercial fleet, and the relationships between tradesmen from Bizkaia and the most important centres in the Iberian Peninsula, the Canary Islands, the British Isles, Flanders, Brittany, the Mediterranean, etc. Most of this trade involved the export of raw or manufactured iron products, and the import of other commodities. Documents dated to the 12th century refer to the regular export of iron, probably in ingots or bars, from the coasts of Bizkaia and neighbouring areas (Sprandel, 1969). The main destination for these iron exports was England, but iron also reached Brugge, which was an important import-for-export centre (Stroobants, 1985; Finot, 1899; Maréchal, 1953). Also in the 12th century, Jewish traveller Benjamín of Tudela reports the presence of Basque ships in Alexandria in Egypt (Magdalena, 1982). From the 13th century at least, ships from Bizkaia reached Brugge (Maréchal, 1953; Orella, 2003; Priotti, 1996). According to Leizaola (1984), Orella (2003) and Priotti (2003a, 2005), Basque ships reached England but also the Mediterranean for both military and commercial reasons, reaching Cyprus, Beirut or Alexandria.

Against the background of growing numbers of ship seizures, at the beginning of the 14th century there was an attempt at forging a lasting alliance between Bizkaia and England through the marriage of the English King’s brother to the heir of the Lords of Bizkaia, to the extent that English ambassadors were sent to Bizkaia to arrange this. However, it seems that the marriage never took place owing to problems of piracy in La Rochelle with involvement of individuals from Bermeo in Bizkaia (Rymer, 1708). The number of confrontations between Bizkaia and England for maritime control was such, that another attempt was made in the mid 14th century when Bizkaia signed a treaty of permanent peace with England (Fernández Duro, 1894). According to Genova (Italy) archival records reviewed by Heers (1955), when Italian ships first reached the North Sea and the English Channel towards the end of the 13th century, Atlantic maritime trade was controlled by the Basque.

The important settlements on the Bay of Biscay and the intense maritime trade of iron was confronted by the English, who often attacked Biskayan ships on the route to Flanders, sparking complaints from the “Seignory of Biscay” and often requiring that the Basque chief magistrate to travel to London to clear matters. Relevant documents also demonstrate that the most important commodity exported to Brugge continued to be iron, often to be re-exported from this international centre to the North of Europe (Suárez, 1959). In 1443, Basque merchants signed a peace treaty with those in the Hanseatic League, aiming at ending the continuing seizures and piracy (Finot, 1899).

Towards the beginning of the 15th century, there was a significant presence of Biskayans in Brugge (Pernoud, 1948). By this time, economic relationships with Flanders were very important, and Basque iron remained the main commodity being traded. Their local power was so strong that, in 1414, Franciscan monks of Brugge had to cede a chapel for the burial of Basque merchants (Finot, 1899; Maréchal, 1953). In 1489, the "Casa de Contratación del Señorío de Vizcaya" in Brugge was founded. According to abate Viaene (1933), the Basque were the first merchants of the Iberian Peninsula to have a permanent commercial base and consulate in Brugge.

In August 1474, a delegation of five Biskayan attorneys was authorised to join deputies and attorneys from Gipuzkoa to meet ambassadors of the English King with the aim of signing a treaty of peace and security among their territories (Aguirre, 1989).

While there is evidence that Basque whale-meat, oil, iron and wool were exported to Normandy, and that textiles and wheat were imported, there is little doubt that iron was the main subject of this trade. According to Mollat (1952), iron was part of every single cargo between 1476 and 1483. Towards the end of the 15th century, iron represents 76% of the Basque products being imported in England and practically all the foreign iron reaching England was Basque (Childs, 1981).

By the turn of the 16th century, Antwerp gains importance as a trading port, and 40% of the Iberian merchants involved in this trade were Basque (Doehaerd, 1963). Orella (2005) highlights that iron and iron products such as swords, crossbows or anchors are the main exports of the Basque Country. Aguirre (1991) makes similar points, emphasising the importance of the Basque fleet, which could easily be turned into an armada. Probably, all of this trade was in the hands of aristocrats who controlled the iron-making facilities, the merchants and the masters of ships.

Coastal territories played a critical role in the production, and trade of iron in Europe. The French, English and Flemish were present in Basque ports to buy iron near the production centres, whereas Basque merchants were present in Europe and America in order to sell at the consumption centres. Capitalising on its abundance and quality, Basque iron is exported to the Iberian Peninsula, Italy, Portugal, Flanders, France and the British Isles – and even, from the late 15th century, to America.

Since the mid-15th century, Bilbao became one of the most important market towns of the Spanish Empire, exercising control over the entire Iberian north. In addition to longer distance trade with merchants coming from France, Flanders, Germany, Bohemia, Portugal or Milan, there was a cabotage network supplying iron to Galicia, Portugal and Andalucía, and bringing local or exotic commodities in return (Priotti, 2003b).

During the 16th and 17th centuries, the importance of Bilbao's iron industry can be seen in the fact that English start to use the term 'bilbo' to refer to some swords that were renowned by the elasticity of their blades, as well as 'bilboes' for some shackles that were used for mutineers (Earle, 1896; Malcom, 1998). The term "bilboes" even features in Shakespeare's *Hamlet*, written in 1600.

The Basque Country thus remained as one of the key iron-making centres in Europe (Bautier, 1963), with iron constituting the key economic pillar of trade along the Atlantic coast. In the 18th century, however, competition with Swedish iron and, later, Russian iron (Uriarte, 1988), led to a progressive decline in production during the 19th century, until the appearance of the modern blast furnaces.

TERMINOLOGY AND FURNACE LOCATIONS

The most common Spanish term for those furnaces identified by the research translates as 'mountain bloomery', even though many of them are located on lower slopes and valleys, or close to water streams. One furnace has even been located at the estuary of Deba (Gipuzkoa). The terminology in Basque is wider. The term *agorrola* (in Basque) or 'dry bloomery' has been used in opposition to the *cear-ola* (in Basque) or 'water bloomeries" – the latter description appears for the first time in a text by Villarreal de Berriz (1736) and in a later work by Larramendi, written in 1754, but published in 1882. The use of natural draught for the furnaces has also led to the term *haizeola* (in Basque) or 'air bloomery' (Laborde, 1979), and this is the term we have adopted for our research.

Another term found in historical literature is *jentilolak* (in Basque), literally 'bloomeries operated by pagans', which echoes some legends that speak of, 'superpowered mountain giants that lived in the Pre-Christian era'. Laborde (1979) cites an elderly person whose ancestors used the terms *jentilolak* or *haizeolak*. The term *jentilolak* is also recorded by Mugica (1918). Prada (2008) cites a neighbour from Legazpi (Gipuzkoa) who recalls their parents and ancestors speaking of pagans exploiting iron in Legazpi before the arrival of Christianity. On this theme, philologist José Luis Ugarte (pers. comm.), considers that *jentilolak* should be the term used today, in recognition of the bloomeries long history.

After numerous exploratory visits to Bizkaia, Gipuzkoa, northern Araba and northern Navarra, we have identified almost 300 furnaces (Fig. 1). Most of them are found in comparable locations:

a) They appear excavated into the bedrock (which is never completely calcareous) on gentle slopes – but never on totally flat terrain, as opposed to Roman furnaces.
b) They are found near mining areas (Serneels, 2011). In this sense, it appears that the main constraint is the availability of ore and not that of wood. We have found that, the higher the abundance of iron ores, the higher the density of furnaces.
c) A small water stream is almost always nearby, typically within 100 m and very often much closer than that. In some cases, they appear close to wider rivers or marshlands. Water would have been necessary to mix the clay and sand employed for the furnace lining, as well as to wash the crushed ore to beneficiate

it. The fact that some of these water streams are not permanent might be indicative that the iron smelting activities could have been an 'extra' seasonal job that alternated with the period of greatest agricultural activity, i.e. in the rainy seasons from autumn to spring.

d) The furnaces are orientated towards prevailing winds. The opening in over 90% of them is facing north or northwest. Only a small number show a different orientation, perhaps because of a specific wind direction. Considering the furnace morphology, however, it is possible to argue that orientation was not a key parameter for their performance, given that the draught – be it natural, or induced – would be greatly facilitated by the chimney effect.

MAIN FEATURES OF THE "BASQUE FURNACE"

During 2010, our excavations at the furnace of Azarola (Galdakao) enabled a detailed characterisation of these structures to be established. This included their lower parts (Orue-Etxebarria *et al*., 2011), that completed our field examination of many more. This characterisation becomes very significant when we note the lack of references to similar furnaces anywhere else in Europe, and is the reason why we have opted to formally name this type of furnace, the 'Basque Furnace' – given that the Basque Country is the first place where they have been identified. Of course, this does not exclude the discovery of similar structures elsewhere, beyond the Basque area of influence.

Basque furnaces have an almost circular plan (Fig. 3). The most remarkable feature is their height, generally around 4 m, although some reach up to 6 m. It should be noted, however, that some smaller furnaces, of less than 1 metre in height, have been described, although their precise function remains unexplained. The furnaces are excavated into the rock from the hillside (Fig. 4), so they are almost entirely surrounded by the geological substrate (Serneels, 2011). The front wall is only preserved in some cases.

Figure 3. Lower crucible of a furnace found in Bedia (Bizkaia), partly filled. The diameter in the lower part is around 3.5 m.

Figura 3. Cubeta interna del horno, parcialmente relleno, encontrado en Bedia (Bizkaia). El diámetro en su parte inferior es de unos 3,5 m.

The maximum internal diameter is generally between 3 and 4 m. This maximum dimension is reached some 70 cm above the base, where the furnace is narrower,

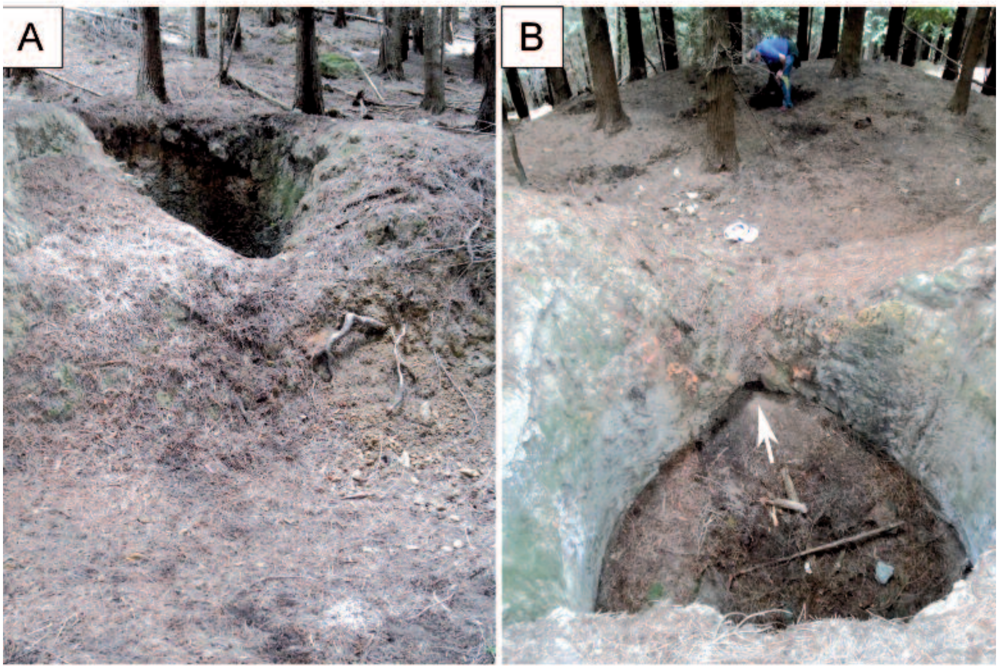

Figure 4. A) External view of a furnace identified in Bedia; note how it was made by digging into the rock substrate. B) Another view of the same furnace, with the arrow pointing to the upper part of the front opening.

Figura 4. A) Aspecto externo de un horno de reducción de hierro localizado en Bedia, en el que se puede observar su ubicación excavado en el sustrato. B) Aspecto interno del mismo horno, la flecha indica la posición de la parte superior de la abertura frontal.

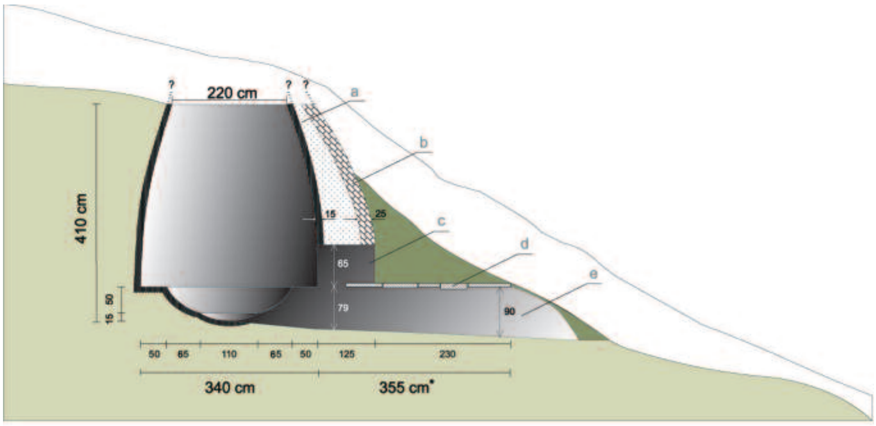

Figure 5. Drawing of the Azarola furnace; a) a layer of clay and sand lining the furnace inside, b) sandstone used to reinforce and insulate the wall, c) location of the opening, on the lower part of the furnace, above the channel, d) sandstone slabs covering the channel, and e) channel for the exit of slag and the inlet of air.
Figura 5. Croquis en alzado longitudinal del horno de Azarola; a) capa de arcilla con arena tapizando la parte interior del horno, b) piedra arenisca, utilizada para reforzar la pared y conseguir un buen aislamiento, c) posición de la abertura de evacuación, en la parte inferior del horno, situada por encima del canal, d) losas de arenisca cubriendo el canal y e) canal de evacuación de la escoria y entrada del aire.

resulting in a profile that resembles that of the 'crucible' of modern furnaces. From the widest diameter, the width becomes narrower, resulting in the shape of a truncated cone (Fig. 5). Our calculations indicate, for the largest furnace so far documented (in Ea, 4 m in diameter and 6 m in height) a total volume of 50 m^3 (Fig. 6). The furnace of Azarola has a volume of 23 m^3. By way of comparison, some of the largest furnaces found in the literature include the famous *Stuckofen* of Styria in Austria, with water-powered bellows, that reached 3 or 4 m in height (Pleiner, 2000: 138), to albeit with a much smaller diameter. Walloon blast furnaces are similar to these and reach up to 4.5 m, but again they are narrower (den Ouden, 1985).

The front of the Basque furnace is generally reinforced with a wall of sandstone blocks (Fig. 7). The thickness of this wall tends to be around 1.5 m, with the rest of the furnace dug into the hillside. Sometimes, the upper part of the shaft contains stones or fragments of scorified wall, which were probably used to repair the furnace after use. Most frequently, the front wall has not been preserved in situ. However, where preserved, it normally shows an oval arch of some 60-70 cm in height (Fig. 8).

In the few cases where the inner furnace lining has been preserved, this is made of a mixture of clay and sand that reaches up to 15 cm in thickness, often showing the hardening and vitrification that resulted from intense heat exposure. Sometimes this lining shows clear slag residues (Fig. 9), normally in the lower half of the shaft. Even though this remains to be confirmed through more excavations, it appears that the lower part, in the area closest to the arch, generally contains the highest concentration of slag. This would be consistent with similar observations made in other furnaces around the tuyere ports (Crew, 1995; Pleiner, 2000). Sometimes, inclusions of magnetic slag appear as small nodules within the furnace lining. Less frequently, it is possible to see the prints of hands or other instruments used to apply the lining.

In the lower part of the furnace, a channel connects the 'crucible' with the exterior, running for a few metres. This is a bit narrower at the base, with a width between 35 and 45 cm, and a height between 60 and 70 cm. It is generally covered by sandstone slabs (Fig. 9). This channel would allow the tapping of slag (type C in Serneels, 1993) and the entrance of air, facilitating combustion through chimney effect. Furnaces with a

Figure 6. View of the largest furnace recovered so far (in Ea, Bizkaia), with some 4 m in diameter and around 6 m in height.
Figura 6. Imagen del horno más grande encontrado hasta ahora (municipio de Ea en Bizkaia). Tiene unos 4 m de diámetro y alrededor de 6 m de altura.

similar functioning, although smaller in diameter, have been recorded in Scandinavia, where they are considered typical of the later Middle Ages (Stenvik, 2003a, 2003b). The shape of these *haizeolak* is also similar to Pelet's (1973) type 7, but again with a larger size.

In all the furnaces explored so far we have not found any other perforation on the walls in addition to the arch. This indicates that, if bellows were used, these must have been placed near the front opening.

Among the many findings of recent research, we wish to highlight those in the areas of Olaeta, in Aramaio (Araba), where we have recorded three double furnaces (two in Amezola y one in Inola). In these cases, two shafts appear excavated in the rock, separated by a 1

Figure 7. Front of the furnace of Erletxe in Galdakao, showing the sandstone wall that reinforces the structure.
Figura 7. Parte anterior del horno de Erletxe en Galdakao, en el que se puede apreciar la pared de piedra arenisca reforzando la estructura.

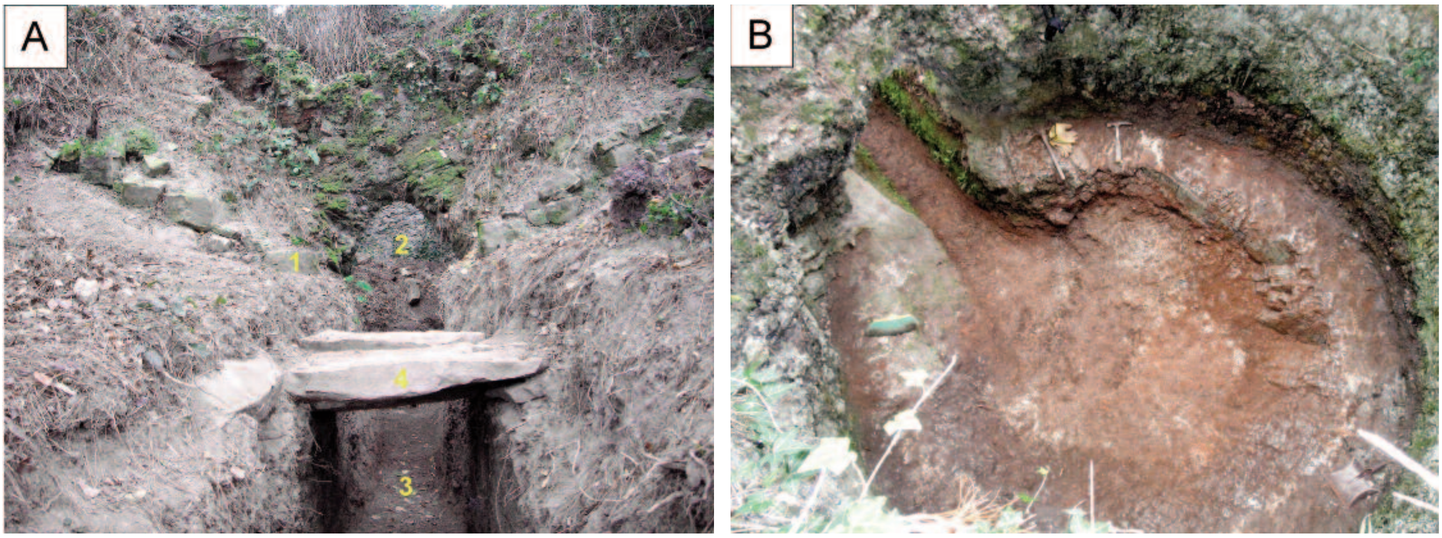

Figure 8. A) View of the front part of the furnace of Azarola (Galdakao): (1) base of the stone wall reinforcing the front part of the shaft, (2) arch, (3) channel, and (4) sandstone slabs covering it. B) Image of the furnace base after excavation, showing the exit channel.
Figura 8. A) Aspecto de la parte anterior del horno de Azarola (Galdakao): (1) base de la pared de piedra reforzando la pared anterior de la cubeta, (2) arco de la abertura (3) el canal y (4) losas de arenisca cubriendo éste último. B) Imagen del fondo del horno (crisol) excavado, con el canal de salida.

metre thick wall but connected by an opening (Fig. 10). Only one of the shafts has a front opening, while the other one is totally sunken into the rock. Apart from this peculiarity, both shafts resemble all the other single shafts recorded elsewhere. Recently, we have also found a poorly preserved double furnace in Menagarai, in the Aiara Valley (Araba) and another one in Urkiola (Bizkaia). Excavations will be needed in order to determine the technical advantages that such furnaces might have brought.

Of the many *haizeolak* we have visited in the last few years, only in one case we have found a pair of shafts where both of them have a front opening (in Aia, Gipuzkoa). This is formally more comparable (although

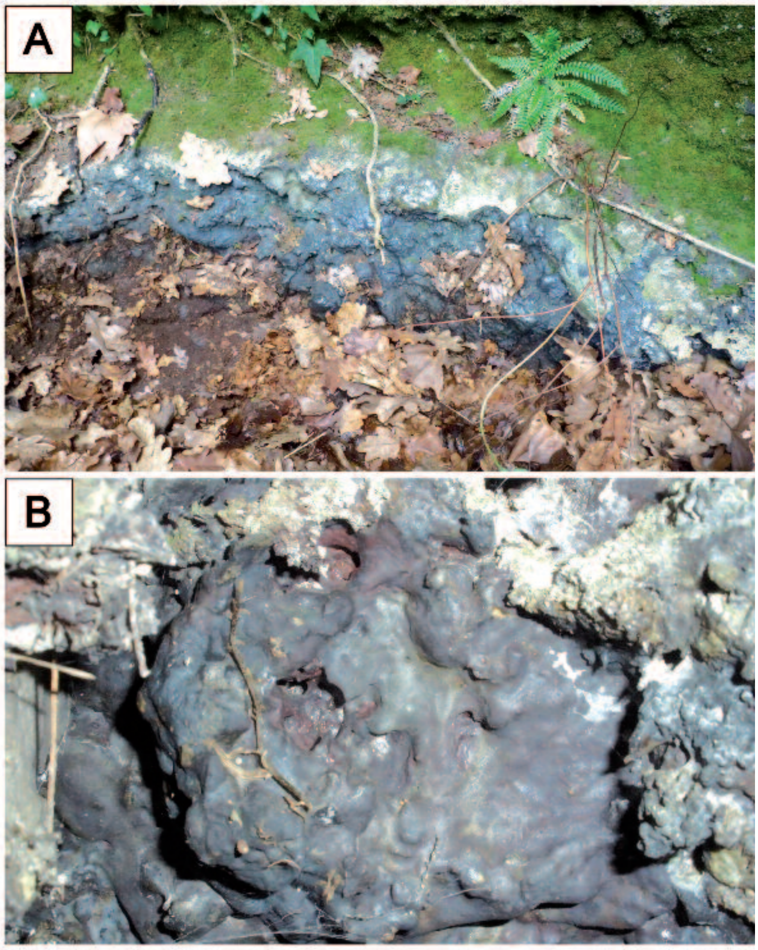

Figure 9. Iron-rich slag in the furnace inner walls. A) Slag on the upper part of the crucible (Galdames).(Photo courtesy of J.L. Ugarte). B) Detail of the inner wall of a furnace in Galdakao (Bizkaia).
Figura 9. Impregnaciones de escorias ferruginosas en el interior de los hornos. A) Escorias en la parte superior del crisol (Galdames). (Foto de J.L. Ugarte). B) Detalle de la pared interna de un horno de Galdakao (Bizkaia).

larger in size) to 'furnace pairs' in Boécourt (Eschenlohr and Serneeels, 1991) and "fours jumelés" in Bellaires (Pelet, 1993). Also in Dima and in Igorre (Bizkaia) we have found furnace pairs, but these are some 3 m apart.

In a number of furnaces we have found remains of lime, both near the opening and on the inner walls; we also recorded scatters of limestone fragments (7-20 cm in size) in the exterior, mostly around the top opening. This evidence suggests that they are likely to have been used as lime kilns, but it does not obscure the remains of iron slag.

All in all, the most remarkable features of these furnaces are their large size and peculiar profile, which might make them a precursor of the modern blast furnaces.

SMELTING FURNACES OR LIME KILNS

Before the publication by Orue-Etxebarria *et al.* (2008a), where these structures are first described as bloomeries, both medievalists and local communities around these locations believed that the structures were the remains of lime kilns. This is probably due to the fact that some of them were indeed reused as lime kilns (Herrero *et al.*, 2012). Some local villagers even reported their own involvement in lime-burning in some of these, up to the 1950s and 60s. Examples of these re-used furnaces include those of Aia, Legazpi, Irun, Mutriku, Deba, in Gipuzkoa, Gopegi, in Araba, Leitza, Urdazubi, Elizondo, in Navarra etc. We have also found scatters of small fragments of limestone around some of the furnaces in Galdakao, Elantxobe, both in Bizkaia, Manurga, in Araba, Mutriku and Deba in Gipuzkoa, etc.

While some furnaces were re-used as lime kilns, purpose-built kilns followed designed that were sufficiently different from those of furnaces so as to allow their easy differentiation in the field:

Location. In most cases, lime kilns are located near limestone outcrops, except for some cases where they were built near settlements. On the contrary, most *haizeolak* are placed far from these areas.

Toponymy. After a large number of field campaigns we found a strong connection between the basque affix 'ola' and the described bloomeries. In particular, place names with 'oleta' suggest 'a place with some bloomeries' – as has been determined several times in the field.

Abundance of metallurgical furnaces. Bloomery furnaces tend to appear in clusters wherever raw materials, in the form of iron ores, were available. For example, in the hamlet of Utsine in Bedia (Bizkaia), made up of some eight houses, we documented the remains of a lime kiln but as many as 12 furnaces. It would make no sense for such a small hamlet to keep a dozen furnaces. Similar cases are documented in other areas such as Markina, where six furnaces are found around a single farmstead, or Mutriku, with eight furnaces around the farmstead of Okelar.

Morphology and structure. Generally, lime kilns are cylindrical, with a diameter ranging between 1 metre (known as 'French type') and a few metres (Fig. 11). However, *haizeolak* are much wider and have the largest diameter in the lower third rather than at the bottom, resulting in a pear-shaped truncated cone. Another important difference appears in the way in which they are constructed: lime kilns normally showing external elements on the outside, as well as less pointy openings; furthermore, lime kilns are internally lined with stones rather than clay, and they lack the channel that connects the lower part with the exterior.

Mineralogical evidence. In some cases we have found iron-rich slag within the furnaces or in nearby slag deposit. More importantly, these slags sometimes appear impregnating the inner lining of the furnaces. This feature is not always traceable because of the furnaces being full of soil, or because the vitrified inner lining has not survived.

Even in those cases where slag-bearing furnace lining has not been preserved because they have been re-used as lime kilns, their past use as furnaces can be demonstrated through excavation. This was the case of the Azarola furnace in Galdakao where, following the excavation (Basterretxea and Orue-Etxebarria, 2011), the analysis of samples from the bottom of the furnace pointed to iron smelting (Herrero *et al.*, 2012).

Figure 10. Double furnace of Amezola (Aramaio), where the presence of two shafts separated by a 1 m wall can be noticed. The arrow points to the opening connecting the two.

Figura 10. Horno doble de Amezola (Aramaio), en el que se pueden observar dos cubetas separadas por una pared de más de 1 m de grosor y unidas por una abertura señalada por una flecha.

Figure 11. Inner view of a lime kiln (Leitza, Navarra), with the inner wall lined with sandstone and an approximate diameter of 3 m.

Figura 11. Aspecto del interior de un calero (Leitza, Navarra), con la pared interior tapizada de piedra arenisca y un diámetro aproximado de 3 m.

MINERALOGY AND CHEMICAL COMPOSITION

We have analysed over 250 samples of slag or vitrified wall linings of furnaces from different locations (Gil *et al.*, 2008; Herrero *et al.*, 2012). These included petrographic studies (both reflected and transmitted light), X-ray diffraction (XRD), and chemical analyses by X-ray fluorescence (XRF) and electron probe microanalyser (EPMA) at the SGIker laboratories of the UPV/EHU.

Two types of slag were identified. The most abundant, black or very dark, with a 'metallic' lustre and/or magnetic, have an obvious ropy texture, with several layers of tapping, with a lower surface that often contains soil inclusions. The other type appears as irregular lumps, more porous, without any signs of flowing and with frequent inclusions of charcoal or metallic iron. In addition, we studied the rocks in which the furnaces are excavated, fragments of the stone walls, or thermally altered ceramic linings.

The largest slag fragments, in spite of being broken, reach over 42 cm in width. Some of these have a 'fan' shape (Leroy, 1997), with a width of 36 cm and a maximum high around 10 cm at the point where the slag would be dripping (Fig. 12).

In the dark slags, the most frequent mineral assemblage is fayalite (Fe_2SiO_4) + wüstite (FeO) ± hercynite ($FeAl_2O_4$) + glass, with occasional blebs of metallic iron. However, magnetic slags made up of fayalite + magnetite (Fe_3O_4) + glass have been found too. Minor phases include traces of hematite (Fe_2O_3) and, locally, post-depositional goethite (FeOOH) filling porosities. Under the microscope, the typical structures appear skeletal or symplectite like. Chemically, they are characterised by their high levels of FeO (55-80%wt), and lower quantities of SiO_2 (12-35%) and Al_2O_3 (0-6%). Minor quantities of Ca, Mg, Na, K and Ti may derive from ore minerals but also from fuel ash or contributions from the furnace wall material. Levels of P_2O_5 are generally below 0.5%.

Wall lining is generally made of glass rich in silica, quartz-cristobalite-trydimite (SiO_2), mullite ($Al_6Si_2O_{13}$) ± hercynite. Some samples showed small amounts of corundum (Al_2O_3) and hematites, as well as minor fragments of local rocks such as sandstone or shale. These samples are very rich in SiO_2 (62-90%) and Al_2O_3 (5-20%) and their colours range between dark green through red to black, depending on the Fe content (which is generally below 10%). They are poor in Na_2O and MgO, and CaO levels generally do not exceed 2% - except for those cases where there is obvious evidence of the furnaces having been reused as lime kilns.

The chemistry and mineralogy of the samples can be mainly explained with reference to the $FeO\text{-}SiO_2\text{-}Al_2O_3$ phase diagram (Osborn and Muan, 1960), which indicate furnace temperatures above the wüstite-fayalite-hercynite eutectic (1148ºC) and reducing atmospheres (Gil *et al.*, 2008).

The analytical results confirm the use of these furnaces for direct or bloomery smelting – a process leading to relatively low yields and producing very iron-rich slags.

THE IRON SMELTING PROCESS

Considering the lack of documentary references and the scarcity of excavations, it is hard to speculate about the actual functioning or these furnaces, or the processing of the metal after it was smelted, beyond stating the fact that they were involved in bloomery smelting of iron (Gil *et al.*, 2008; Orue-Etxebarria *et al.*, 2008a; Herrero *et al.*, 2012). The reason is the slag we found inside or around the furnaces. We need to excavate more furnaces to know the rest of the parameters of the process.

In this type of furnaces, the reduction takes place in the solid state, taking advantage of the physical and chemical properties of

Figure 12. Large slag (36 cm) collected in a deposit located less than 1 km from the furnace of Azarola in Galdakao (Bizkaia).
Figura 12. Escoria de gran tamaño (36 cm) recogida en un escorial situado a menos de 1 km del horno de Azarola en Galdakao (Bizkaia).

the iron oxides, of the slags and of carbon monoxide (Sauder, 2011). Based on our fieldwork and observations around the furnaces, we believe that the main ores would have been hematites (and perhaps goethite), but it is possible that also siderite was used, given that some of the double furnaces were associated to accumulations of this mineral. It is also likely that charcoal was used as the only fuel, given that, for the moment, there is no evidence of the use of mineral coal in the Basque Country before the 19th-century blast furnaces. In the other hand, the huge dimensions of these furnaces could speculate to use directly beech or oak wood or possibly the use of mineral coal in a later reuse.

$FeCO_3$ might require additional calcination and oxidation steps to produce Fe_2O_3. This could take place in additional structures or during the early stages of use of the furnaces, but would in any case lead to a higher consumption of fuel.

At the end of the process, two products would be obtained: the mass of metallic iron or 'bloom', and the silicate slag. The metal would be worked on the anvil, whereas the slag would be discarded. Being quite resistant to atmospheric weathering and corrosion, slags tend to be the best preserved elements of the process (Rehren *et al.,* 2007).

A key condition of the process was to maintain the temperature between 1100 and 1200 ºC. Temperatures of 1100ºC or higher were needed for two reasons: 1) to ensure that slag was liquid and could be separated from the metallic iron by gravity (Senn *et al*., 2010), and 2) to ensure that the speed of the reduction process by CO was high enough (Kronz, 2003). Temperatures in excess of 1200/1250ºC, however, would not be convenient because of the risk of reaching the iron-carbon eutectic, which would lead to cast iron being produced.

Temperature control would be overseen by a specialist who would adjust the amount of air let into the furnace. Given the large size of these furnaces, we believe that a forced draft system would have been necessary, probably from the front opening. However, we have not found any tuyeres or other evidence denoting the existence of bellows, and it is also possible that they functioned by convection through the chimney effect (Pelet, 1982). This would be favoured by their good insulation, their remarkable height, truncated cone shape, and the front opening.

FURNACE DATES

Notwithstanding the large number of structures documented, only in a few cases has it been possible to recover datable material. A first attempt was made with charcoal collected from the slag deposit of Arteta (Galdakao, Bizkaia), which was dated by liquid scintillation counting of benzene at the University of Barcelona's Radiocarbon Dating Laboratory (Mestres *et al*., 1991). The calibrated date range was 1035-1235 AD. A second data was obtained from the slag heap of Artetagana (650 m SW from Isasi Goikoa, Galdakao), where an agglomerate of charcoal and iron ore was found. The AMS radiocarbon dating (Beta Analytic Laboratory) for this sample results in a calendar age of AD 1020-1160. Importantly, and in contrast with other dates obtained for Basque *haizeolak* (see below), the charcoal samples used for dating were disseminated within the slag or associated with the raw hematites.

Most of the dates found in the literature were obtained from loose charcoal samples collected from furnaces or slag heaps. For example, at Oiola or Loiola (Trapagaran, Bizkaia) radiocarbon dates gave dates ranging from the 10th to the 13th centuries (Pereda 1992/93), whereas the bloomery of Ilso Betaio (Sopuerta, Bizkaia) was dated between the second half of the 10th century and the 11th century (Etxezarraga, 2004). In some slag deposits of Legazpi (Gipuzkoa), the dates obtained range from the 11th to the 14th century (Urteaga, 2002). According to Fernández (2008), slag collected from Callejaverde (Muskiz) yielded dates in the 13th century. Slag deposits at the sites of Salbartondo II and Campillos, in the mountain of Tellitu de Galdames (Bizkaia), were dated to the 10th-11th centuries (Franco, 2007). Lastly, during works arranging water supply to Mutriku (Gipuzkoa), some furnaces were destroyed, from which charcoal samples were obtained that yielded an 11th century date (Javier Castro, pers. comm.).

Overall, most of the dates fall in the range from the 10th to the 13th century (High Middle Ages), with a single date bringing the chronology to the 14th century. It is proposed to sample further furnaces and expect to record earlier dates, given that it is unlikely that iron was not smelted in earlier medieval times.

CONCLUSIONS

Thanks to the work of an interdisciplinary team, we are now in a position to define the main features of the Basque Furnace. Considering its shape and other aspects – notably its large size – we believe that this furnace is a precursor to the modern blast furnaces.

In spite of widespread assumptions that mountain bloomeries would have either been destroyed or very hard to identify on the ground, the intense fieldwork efforts of the last ten years have allowed us to record many of them. The analytical study of samples of slag and furnace walls confirm that these structures were used for iron smelting. Such furnaces have so far been identified in Bizkaia, Gipuzkoa and the northern parts of Araba and Navarra. Our intention is to extend the survey to cover other areas rich in iron mineralisations, such as the French Basque Country, La Rioja, Burgos and Cantabria. If we extrapolate the number of furnaces recorded from those areas that we have surveyed more intensively, such as Galdakao, Ea and Bedia in Bizkaia, Mutriku and Deba in Gipuzkoa or Aramaio in Araba, it is plausible that thousands of them may have existed in the Basque Country.

As for the slag heaps, it is known that, given their high iron content, many were re-smelted in subsequent periods (Bouthier 1982), which makes it harder to find significant deposits in the field. Even in recent times, several individuals in Legazpi (Gipuzkoa) and Leitza (Navarra) remembered collecting slag on hillsides and river valleys, to be used in blast furnaces. Another elderly person reported that, before the World War II , the Germans paid the locals for any slag they could offer. Slag lumps have also been used to repair tracks since ancient times (Bouthier, 1982) – a practice we documented in Aia, Irun, Otxandio, Galdakao, etc.

The coexistence of these big furnaces with the hydraulic operated ones during late medieval times, allows to propose the hypothesis of that some of this mountain structures could have provided material to be later processed in the hydraulic iron furnaces or in smithies.

The strong Basque tradition of iron smelting, particularly renowned since the late Middle Ages in the form of the commercial links with the Netherlands and the British Isles, can be better understood now that we know the earlier medieval practice.

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