Odds and Ends about Researching the History of Iron Technology

Illustration

In what follows I have collected a lot of quotes from various papers; all of them commenting the art of making iron and how to deal with what you find and read. I have highlighted parts in ***bold red italians*** and added comments whenever I felt like doing that.

Be Careful! Don't Believe in "Authorities"

Thus the *introduction of an Iron Age* has been attributed variously to the arrival of Dorians in Greece, to the activities of Assyrians or Philistines in the Near East, or to the collapse of the Hittite Empire and the dispersal of its closely guarded expertise. ***None of these is supported by the archaeological evidence available today***. Equally varied is the range of scenarios postulated to account for its introduction: from progressive technological change, often in a military context—literally the cutting edge of the arms race—to an invention born of necessity, resulting from a bronze shortage. ***Neither of these seems entirely satisfactory, either.***
Source: **Susan Sherratt**: "Commerce, iron and ideology: Metallurgical innovation in 12th-11th century Cyprus". In: Karageorghis, Vassos, Cyprus in the 11th century B.C.: proceedings of the international symposium organized by the Archaeological Research Unit of the University of Cyprus and The Anastasios G. Leventis Foundation, Nicosia 30-31 October, **1993**, 59-106.

- It's not that archeologists and historians liked to make wild claims not supported by factual evidence. They made the best out of the materials they had. Now we have highly sophisticated analytical techniques and the cooperation between sciences, generating cross-breeds like archeometallurgists. Our knowledge about ancient times in general and metal technologies in particular is making leaps and bounds ever since.

It has long been suspected that the famous Ferrum Noricum, the Noric steel referred to by Roman authors, was produced at the Hüttenberger Erzberg (ore mountain) with its rich manganese-containing iron ores. In 1929 excavations at Kreuztratte uncovered features that were interpreted as a *Roman period bloomery furnace*. However, excavations in 2003 showed that the smelting site is medieval (late 13th/early 14th century) and that the furnace is actually a ***post-medieval limekiln***.
Source: Progress report from the Hüttenberg excavations, around 2007

- Holes in the ground that contained something very hot do tend to look the same after some time has passed, and the difference in appearance after a few hundred or a few thousand years is marginal.

The transition to the Iron Age is of course defined by the introduction of a new metal: iron. The discussions on what led to the transition to the Iron Age are still going on and the issue has not really been resolved. Muhly (2006, 30 – 31) in a recent article put forth the following radical suggestion: 'The warriors or freebooters of this period (11th and 10th centuries BC)—in reality probably pirates and plunderers—who looted the tombs of their predecessors, represent the very 'heroes' whose exploits are recorded in the Homeric poems, ***Odysseus is of course the outstanding example***… These warlords wanted readily available weapons close to hand. They were not interested in long distance trade routes bringing supplies of copper and tin from distant lands. They wanted immediate access to weapons with good sharp blades, all the better to massacre the opposition'. He concludes: 'There can be no doubt that iron technology was developed in order to produce a considerable quantity of weapons with good sharp cutting edges'.
Source: Vasiliki Kassianidou: "The origin and use of metals in Iron Age Cyprus" Proceedings of an archaeological workshop held in memory of Professor J. N. Coldstream in 2010; quoting: J. D. Muhly: "Texts and technology. The beginnings of iron metallurgy in the eastern Mediterranean", Proceedings of 2nd International Conference on Ancient Greek Technology. Athens. 2006, p. 31.

Iron Spear 1150 BC

- Counting **Odysseus** and his buddies as prime examples of the **sea people** is indeed a new and radical point of view.
  The iron spear point shown is dated to about 1150 BC and has been found in Abydos / Egypt. It is thought that it came with some Sea People that were settled there during the reign of Ramses IV.
  It takes some experience with forging to produce such an artifact.

High carbon iron was found from a smithy in Roman Carmarthen, Dyfed, from a Saxon context of a site near Thetford, Norfolk, from a 12th to 14th century smithy associated with the castle at New Radnor, and from a bloomery or bloom forging site at Carhampton probably of a 5th to 7th century date. The carbon contents of these samples varied from a semi-cast iron through *ultra-high carbon steel*, to 'normal' eutectoid steels.
It has been ***argued that such finds are accidental products*** of an over-heated bloomery furnace, and they were discarded because the smith did not know how to use the material.
However in this paper it will be suggested that the frequency of such finds, combined with the evidence from experimental work presented in another paper at this conference, raises the possibility that ***the production of hypereutectoid material was a normal part of the bloomery process***. Although it is accepted that it is likely that the cast iron was discarded as being unusably brittle, it will be argued that the ultra high-carbon steels were being selected and were being used. This hypothesis is based on the following:

- the carburization of a substantial length of bar or strip iron *is difficult in a forge*, and the smith could never be sure of the quality of the metal he was producing due to the natural inhomogeneity of bloomery iron. This problem increases with the presence of phosphorus in the metal.
- the forging and welding processes involved in the forging of composite steel and iron tools, and weapons, seen in the Roman and later periods naturally leads to the decarburization of the metal .... . Yet, some of these weapons and tools have close to eutectoid composition steel components, suggesting that the starting material was likely to have been hypereutectoid.
- a block of ultra high-carbon steel was found in a smithy at Carmarthen. The block has clearly been forged and it seems that at one least one piece had been cut from it, presumably to be used to make a steel cutting edge.

This implies that the smith was familiar enough with this material to be able work with it. An alloy with this carbon content would have to be forged at a significantly lower temperature than would normally be the case.
Source: Chris Salter: "BLOOMERY STEEL - AN OVERLOOKED MATERIAL" in: Abstracts of International Conference Plas Tan y Bwlch 19th – 25th September 1997: Early Ironworking in Europe, archaeology and experiment

It is proposed that bloomery steel was deliberately used at much earlier date than has been generally accepted, and will question the extent to which piled steel was used. The use of steel in the pre-Roman, Roman and post-Roman periods in tools and in material from ironworking sites will be examined. It is hoped that this, together with experimental and theoretical work, will show that the method commonly proposed for the manufacture of early steel, *carburisation and piling*, was a difficult and very skilled process to perform without specialised hearths or other equipment. It is proposed ***that most early steel was in fact produced directly*** in the smelting process. In addition, it will be suggested that many, but not all, of the quoted examples of carburised and piled steel are in fact *misinterpreted* bloomery steel structures.
Source: Chris Salter: "EARLY STEEL IN BRITAIN: INTRODUCTION, PRODUCTION AND USE ", in: Abstracts of Second International Conference Plas Tan y Bwlch 17th – 21st September 2007: Early Ironworking in Europe II, archaeology, technology and experiment.

I do share Chris Salter's believes. You just cannot carburize volumes of iron an a hearth fire.

Running Bloomeries

Apart from the experimental series described above, two tests were conducted with a bloomery furnace with *natural air flow* as well. This type of oven, first described by A. Quiquerez during the nineteenth century, has been encountered twice during recent excavations in the Central Jura region. *Both tests were inconclusive*, a third will take place this autumn. The successful replication of a reduction process in a bloomery furnace of the Boécourt type depends on a number of parameters. Recording and analysing ten experiments has permitted us to master several of these:
- determining the optimal size of a forced air system for a given furnace
- establishing the correct rhythm and duration of bellow strikes
- load calibration, spacing and size
- furnace door management
- getting slag to flow outside the oven
- immediate removal of the bloom from the hot oven.
Other problems still have to be resolved, for instance:
- low heat resistance of the inner furnace lining
- an insufficient understanding of gas flux inside the furnace.
Source: Ludwig Eschenlohr1: "RECENT IRON SMELTING EXPERIMENTS IN SWITZERLAND AND THE INTERPRETATION OF ARCHAEOLOGICAL FINDS" in: Abstracts of International Conference Plas Tan y Bwlch 19th – 25th September 1997: Early Ironworking in Europe, archaeology and experiment

Everybody needs to learn the hard way that the Goldilock principle strictly applies

The analyses of the slags produced during the experiments showed that in general they contain little manganese. The material composition indicates that the formation of tap slag in these experiments is connected with the formation of iron: *the more tap slag is formed, the more iron is obtained*. It is clear from the analyses that the formation of tap slag is necessary in order to extract iron from the ore, whereas the dense slag hardly participates in the formation of iron.
Source: Marianne Senn , Peter Lienemann , Urs Gfeller,, Adrian Wichser: "FROM BLOOM TO BAR: MEASUREMENTS AROUND AN EXPERIMENTAL BLOOMERY FURNACE", in: Abstracts of Second International Conference Plas Tan y Bwlch 17th – 21st September 2007: Early Ironworking in Europe II, archaeology, technology and experiment.

- Here we might have the "secret" of successful iron making. Compare to what Lee Sauder has to say on this.

Traditionally, iron samples with steel structures from Iron Age have generally been considered as more or less accidental products and reflecting a poor, heterogeneous or less successful, outcome. However, in our analytical work and in the evaluation of a number of bloomery sites ***we have found more evidence for deliberately produced bloomery steel***. From a number of excavations of Swedish Late Bronze Age and Early Iron Age sites, small iron ingots, currency bars or iron items, have presented steel structures which were not achieved by later carburisation but from primary production. As single finds, these were however sometimes difficult to interpret in a wider perspective but together they have created more pronounced evidence for steel production in the smelting process.
Source: Lena Grandin & Eva Hjärthner-Holdar: BLOOMERY STEEL – ON PURPOSE OR JUST AN ACCIDENT NEW EXAMPLES FROM EARLY IRON AGE IN SWEDEN , in: EARLY IRON IN EUROPE, International Conference Hüttenberg, Carinthia, Austria 8th – 12th September 2008.

- More evidence for bloomery steel

The need to use local clays and bog-ores of a similar composition to those found on the excavations is self-evident, given that one of the main aims was the production of typical slag. ***It was also decided not to use any instrumentation in the belief that it was important to develop an intuitive feel for the processes and to learn by experience***. Inevitably we made many mistakes, from which we learned a great deal, the most significant being to change too many variables between smelts, in a misguided attempt to shorten our learning curve.
The alignment and relative positions of the nozzle and blowing hole is crucial, to limit both any blow-back and any Venturi effect.
With small bellows or a piston blower the 1200^{o} zone was about 100mm across and with the large bellows it could be up to 200mm across, depending on the force used. On several occasions, it was tried to run a furnace blowing through two opposing holes (for which there is some archaeological evidence), in an attempt to form a larger and more central hot zone, perhaps with the bloom not attached to either wall. This was not successful, even with large 30 litre hand-bellows, and the result was invariably two separate blooms.
The variation between the charcoals was quite dramatic, in terms of flame colour, burning rates and bed stability. Surprisingly, considering the frequency with which oak was used in antiquity, it seemed to be least satisfactory, as it burned less readily and the hot zone stayed closer to the front wall, with more clay melting.
Source: Peter Crew: "Twenty-five years of bloomery experiments: perspectives and prospects", in D Dungworth and R Doonan (eds) 2013, Accidental and Experimental Archaeometallurgy [25] (London: Historical Metallurgy Society), p. 25-50

- Learning by experience is good but laborious and frustrating. Note the first law of practical science.

Often, at the end of a smelt, we add an additional charge of fresh ore to decarburize the bloom. In this instance, since the additions of hammer scale had kept the slag quite fluid (thus iron-rich) throughout the smelt, we felt it unnecessary to add this decarburizing charge. We added a final 4.5 kg of charcoal to the furnace, and burnt it down to near the level of the bloom. We removed the access door, and wrestled the bloom from the furnace. We then proceeded with all our ritual observances, in which hammers and *beer* figure prominently.
Source: W. H. Lee Sauder and Henry G. Williams III: "Practical Bloomery Smelting", Open access Internet

- **Lee Sauder** and **"Skip" Williams** are self-educated top experts at running bloomeries and thus know about the importance of beer in metallurgy. They may also have stumbled on some big issues in iron smelting, so I devoted a *whole advanced module* to their work.
  Addressed are the still open questions of how to make wrought iron or just low carbon iron in a bloomery and how to keep the iron from re-oxidizing while it moves down. Answers given are convincing but often run contrary to common (theoretical) wisdom.

Advanced Link

Sauder / Williams revolutionize iron smelting

Places

Cyprus currently offers our best-documented record for the development of iron technology in the 12th and 11th centuries B.C. Yet ... in spite of the abundant archaeological record ***it is still impossible to explain*** just why iron technology developed so quickly in Cyprus or what the background of that technology might have been.
Source: Muhly 1992

It is now widely agreed that ***Cyprus*** appears to play a leading role in the development of what Snodgrass (1971, 1980, 1982) has called “utilitarian” iron in the eastern half of the Mediterranean; that this development began to take place as early as the 12th century; and that one of its earliest and most prominent manifestations was the iron knife with bronze rivets.
We are left, then, with the big ***“why” questions: “why Cyprus?”, and “why the 12th century?”***, and a subsidiary question ... “why so much concentration on knives?”.
With this in mind, let me return to the 12th century Cypriot knives and suggest that this choice of artefact for the first venture in utilitarian iron (though likely to be at least partly a function of the purely technological considerations already mentioned) was, in effect, nothing short of brilliant. A knife in the 2nd millennium in the eastern half of the Mediterranean is a gloriously ambivalent sort of artefact: at one extreme it is a purely practical, everyday cutting tool; at the other extreme it is a personal ornament with the potential for display and statusenhancement which personal ornaments may entail. It is not in any important ideological sense a weapon, even though in purely practical terms it could at a pinch be used as one.
One can draw a clear contextual distinction between this kind of iron use and that which we see appearing from around the beginning of the 12th century in Cyprus and surrounding regions. The latter represents the development of a partial bronze supplement in which emphasis shifts from a material of high preciosity value boosted by a combination of effectively (though not intrinsically) restricted resources and technological factors, to a relatively unrestricted material comparatively low on the convertibility dimension, whose overriding value lies in the added value of its manufactured properties. From around this time it expands (more slowly in some regions than in others) to enter a primarily utilitarian sub-élite market. At this stage in its development iron can be likened to a material like pottery or glass whose raw materials are also unrestricted and whose theoretical convertible value is heavily outweighed by the added value entailed in the manufacture both of the glass itself and its finished products.
Source: Sherratt, Susan: "Commerce, iron and ideology: Metallurgical innovation in 12th-11th century Cyprus", p. 245, Karageorghis, Vassos, Cyprus in the 11th century B.C.: proceedings of the international symposium organized by the Archaeological Research Unit of the University of Cyprus and The Anastasios G. Leventis Foundation, Nicosia 30-31 October, 1993, 59-106, Athens: A.G. Leventis Foundation

The significant number of early iron artefacts which sometimes outnumber those made of bronze, as well as the presence of some of the earliest known artefacts made of steel, led Snodgrass (1982, 290) to the conclusion that ***Cyprus was one of the first areas to make the transition to the Iron Age***. This proposition is also accepted by others (*Muhly* 2006, 29; Sherratt 1994, 71). Furthermore, it has been argued that the island played a leading role both in the development and the dissemination of iron metallurgy (Muhly 2003, 145; Sherratt 1994, 60).
Some scholars, however, have expressed their ***doubts on the matter*** for a number of reasons. The first was the established belief that there are no iron ores on the island and, therefore, iron could not have been produced in Cyprus, thus it could not be the instigator of this new technology (*Muhly* 2003, 146; Karageorghis 1994, 5). I have argued elsewhere that, on the contrary, ochre and umber which are abundant in the Troodos foothills qualify as good iron ores (Kassianidou 1994, 76)! There is absolutely no need to suggest that iron was produced in Cyprus from, either, re-smelting of copper slag (Snodgrass 1982, 292; contra Kassianidou 1994, 78), or ores imported from Italy (Snodgrass 1980, 361) or from pyrite (Snodgrass 1994, 168), an iron mineral which even today is only used for the production of sulphuric acid.
Cypriot metallurgists who already had almost a thousand years of expertise with sulphide ore smelting, during which some iron may have been accidentally produced, would have been the first to come across this new material and the first to have tested it employing the tools and skills of their trade (Charles 1980, 167; Gale et al. 1990, 188; Pickles and Peltenburg 1998, 90; contra Merkel and Barrett 2000). This seems to be confirmed by recent excavations at the site of Tell Brak (Shell 1997, 121).
Source: Vasiliki Kassianidou: "The origin and use of metals in Iron Age Cyprus ", p. 229, CYPRUS AND THE AEGEAN IN THE EARLY IRON AGE The Legacy of Nicolas Coldstream; Proceedings of an archaeological workshop held in memory of Professor J. N. Coldstream (1927–2008) Edited by Maria Iacovou; BANK OF CYPRUS CULTURAL FOUNDATION

Somebody is right about something and some will be right no matter what the final verdict will be.

In the **Levant** in the 11th century the number of practical iron objects found at sites and in general areas which have produced 12th century examples also increases quite substantially (Fig. 2). The pattern of diversification seems very similar to that of Cyprus, with the first hafted axehead and socketed spearheads possibly appearing within this period (at Tell-el-Farah (S.), Tell-es-Zuweyid and Hama), suggesting that the pattern of technological innovation quite closely mirrored that of Cyprus, and may well have derived directly from the island; though the continued appearance of iron jewellery and other trinkets at sites such as Tell-el-Farah (S.), Tel Qasile, Megiddo, Tel Zeror, Hama and Kinneret (Waldbaum 1978, 25, 28, fig. IV: 2; Muhly, Maddin and Stech 1990) suggests that, as in the Aegean (v. below) iron still retained some of its preciosity value, at least in some levels of society. At the same time, however, there are indications that during this century parts of the Levant began yet another process of import substitution. Evidence of primary iron processing in the Transjordanian plateau around this time (McGovern et al. 1986, 272–8; Negbi 1991, 219 n. 17), together with an iron ingot from Stratum V at Tel Miqne (apparently in a traditional Levantine association between metal-working installations and temples) suggests that, by this stage, at least parts of the Levant were no longer dependent on Cyprus for usable iron objects or the processed iron with which to make them. That—not surprisingly—as in Cyprus, ***iron production may at least in an initial stage have been very closely associated with copper extraction*** is suggested not only by the iron-rich slags (with the iron possibly initially introduced in the form of a flux: Rothenberg 1972, 232; cf. Wertime 1980, 16) of the Arabah where copper was extensively exploited down to the later part of the 12th century, but also by the evidence from Timna of 12th century objects made of iron which was almost certainly obtained—at least initially—as an adventitious by-product of copper-smelting (Gale et al. 1990). At least some level of activity appears to have continued at Timna well into the 11th century (Dorneman 1983, 169 n. 2; and cf. e.g. some of the "Midianite" pottery from site 2 illustrated Rothenberg 1972, fig. 32 (especially 14), which is similar enough to some Proto- White Painted and Cypro-Geometric I pottery to suggest that their dates are likely to be at least roughly similar). That, after the Egyptian withdrawal from both Timna and the central Jordan valley towards the end of the 12th century, itinerant metalworkers (including possibly ironworkers) established themselves on the inland route up from the Arabah to the Judean Hills and the coastal plain seems quite likely (Negbi 1991, 216–9).20

Source: Sherratt, Susan: "Commerce, iron and ideology: Metallurgical innovation in 12th-11th century Cyprus", p. 245, Karageorghis, Vassos, Cyprus in the 11th century B.C.: proceedings of the international symposium organized by the Archaeological Research Unit of the University of Cyprus and The Anastasios G. Leventis Foundation, Nicosia 30-31 October, 1993, 59-106, Athens: A.G. Leventis Foundation

A major iron smelting operation was found at Tell Hammeh in ***Jordan***, dating to ca. 930 CalBC. A large smithing workshop was found at Tel Beth-Shemesh, ***Israel***, dating to ca. 900 CalBC. Both sites feature significant quantities of various types of slag, a diversity of technical ceramics, charcoal and ash, and were excavated using especially developed techniques.

Source: Harald Alexander Veldhuijzen: "SOLID EVIDENCE: EXTENDED RESEARCH INTO EARLY IRON SMELTING AND SMITHING AT TELL HAMMEH, JORDAN, AND TEL BETH-SHEMESH, ISRAEL", in: Abstracts of Second International Conference Plas Tan y Bwlch 17th – 21st September 2007: Early Ironworking in Europe II, archaeology, technology and experiment.

The work done by such scholars as Vincent Desborough, Anthony Snodgrass and Jane Waldbaum has greatly increased our knowledge of ironworking in early **Greece**. The problem of studying the introduction of the new technique is, however, a general lack of evidence for both smelting and smithing procedures.
The *earliest traces of local production of iron*, which we find already in the *11th and 9th Centuries*, comes from the north of Greece. Then there is a break in the material and we have no further evidence of iron production *until the end of the 8th and beginning of 7th century*. From that period there is a slight increase in the number of sites with iron smelting and smithing. Judging from the evidence this is the real inception of the Iron Age in Greece.

Source: Christina Risberg (University of Uppsala, Sweden): EARLY IRONWORKING IN GREECE - MYTH OR REALITY?, in: Abstracts of International Conference Plas Tan y Bwlch 19th – 25th September 1997: Early Ironworking in Europe, archaeology and experiment.

In the 10th century, the pattern of iron use, particularly in Attic and Euboean graves (Snodgrass 1971; 1980, 348–9), suggests that iron may have continued to hold some residual attraction as a relatively exotic "precious" (or semi-precious) material, albeit one whose additional practical advantages had already become fully apparent (cf. Snodgrass 1989, 28). It seems likely that, as Snodgrass (1980) has argued, native ***Greek*** ironworking began to develop gradually during this century, probably again, initially at least, in areas where it could be extracted as a by-product of copper exploitation (Bakhizen 1976; Photos in Koukouli-Chrysanthaki 1992, 800– l).
It seems (cf. Snodgrass 1980) to have developed first in some particularly suggestive regions: along the eastern coast of the Greek mainland and possibly in the North Aegean— regions often close to or themselves rich in precious metals such as silver and/or gold as well as copper (and often where traces of silver cupellation are found in the PG period: Snodgrass 1971, 248), and lying in the path of the circum-Aegean routes which we have good reason to suppose Cypriot (or later Cypro-Phoenician and Phoenician) ships were using—or at least articulating with—in the early part of the 1st millennium, in the quest for such materials. The movement of iron and iron objects around this "koine" (Snodgrass 1980, 349) is likely to have been shipborne, and its exchange primarily on an ad hoc commercial basis.

Source: Sherratt, Susan: "Commerce, iron and ideology: Metallurgical innovation in 12th-11th century Cyprus", p. 245, Karageorghis, Vassos, Cyprus in the 11th century B.C.: proceedings of the international symposium organized by the Archaeological Research Unit of the University of Cyprus and The Anastasios G. Leventis Foundation, Nicosia 30-31 October, 1993, 59-106, Athens: A.G. Leventis Foundation

The study of ancient technologies is still often disregarded by **Italian** archaeologists. Because of their background in humanistic studies, they are more interested in the artistic and typological aspects of archaeological research. ***The results of scientific researches applied to archaeology sometimes are simply ignored or improperly used***. Because of all these problems, it is impossible at present to draw a reliable distribution map of the ancient metallurgical sites in Italy.
The direct evidence for iron metallurgy (***in the pre-Roman Iron Age***) is very poor; also for the period following the Celtic invasion at the beginning of the 4th century BC. Most of the slags found on the sites seem to be the results of smithing and finery activities rather than the by-products of mineral reduction. Amongst the sites in Northern Italy where some mineral reduction must have been carried out we may remember Milan and Genoa (where Elban hematite was used). In the Etruscan area, beside the well known site of Populonia, there was a number of minor sites along the Tyrrenean coast where the ore was disembarked and/or smelted (Felciaione and S. Giuseppe near Follonica, Grosseto). The Etruscan smelting furnaces were stone and clay structures, no tuyeres were found and the slags are tapped.
Source: Costanza Cucini Tizzoni, Marco Tizzoni: "EARLY IRON IN NORTHERN AND CENTRAL ITALY: A CRITICAL REVIEW OF THE EVIDENC", in: Abstracts of International Conference Plas Tan y Bwlch 19th – 25th September 1997: Early Ironworking in Europe, archaeology and experiment.

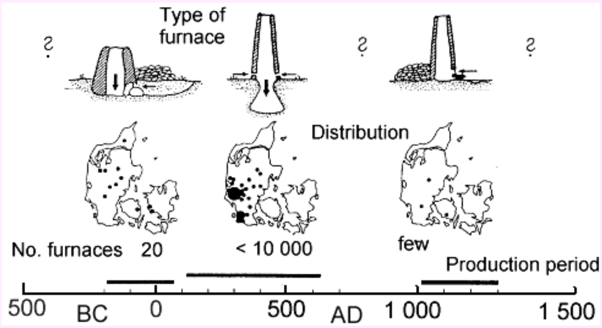
- This statement applies, or better applied, to many "classical" archeologists at least in Western Countries.

The most ancient witness to iron production in the **Iberian Peninsula** (*Spain*) is archaeologically associated with *Phoenician contexts* or within the area of their influence. However, research on the Phoenician presence in Spain has provided very few studies on the siderurgy during the abovementioned chronological phase, even if many settlements have yielded abundant materials connected with iron metallurgy.
We will focus this paper on the analysis of the siderurgic materials coming from two Phoenician settlements, Cerro del Villar and La Fonteta, which have been studied more in depth and which we consider more emblematic for its varied archaeometallurgical findings.
These (*dug-out metal workshops*) have been identified as smithing workshops active between the end of the VIII century B.C. and the beginnings of the VII B.C. At the same time, abundant evidence of iron production has been found in the Phoenician colony of La Fonteta (Alicante). This site has also provided abundant archaeometallurgical materials that can be mainly connected to post-reduction processes. The chronology of the habitat spans approximately from the beginnings of the VIII century to the middle of the VI century B.C.
Some *obeloi* have been found in one of the site structure, the original function of which is not yet understood, though it was used as a dump in the first half of the 6th century. These iron spikes can be dated between the last quarter of the 7th century and the first quarter of the 6th century B.C.
Source: Salvador ROVIRA-LLORÉNS, M. Carme ROVIRA-HORTALÀ: "PHOENICIAN METALLURGY IN WESTERN EUROPE: AN ARCHAEOMETRIC STUDY ON IRON SLAGS FROM CERRO DEL VILLAR (MÁLAGA, SPAIN) AND LA FONTETA (ALICANTE, SPAIN)" in: EARLY IRON IN EUROPE PREHISTORIC, ROMAN AND MEDIEVAL IRON PRODUCTION; International Conference Hüttenberg, Carinthia, Austria 8th – 12th September 2008, p. 90 and follow-up article

- This statement applies, or better applied, to many "classical" archeologists in at least Western Countries.

The method has been developed upon artefacts from, mainly, **Scandinavia**. On this material it has proven its validity. For example, it can be shown that a major part of iron objects - knives, nails, ships' anchors, battle axes etc. - found in ***Danish*** Viking context are *not* of Danish origin, but were imported from ***Norway***.
Source: Vagn F. Buchwald: ON A METHOD TO DETERMINE THE PROVENANCE AND CHARACTER OF ANCIENT IRON OBJECTS ", in: Abstracts of International Conference Plas Tan y Bwlch 19th – 25th September 1997: Early Ironworking in Europe, archaeology and experiment.

The Iron Age began in **Denmark** 500 BC, but it is only in the last two centuries BC that iron was used for tools, implements and weapons and not only for ornaments.
Source: Olfert Voss (National Museum, Copenhagen, Denmark): DANISH IRON SMELTING FURNACES FROM 500 BC TO 1600 AD" in: Abstracts of International Conference Plas Tan y Bwlch 19th – 25th September 1997: Early Ironworking in Europe, archaeology and experiment.



Bloomeries in Denmark

- What we see from the picture is that there is no smooth development of technology. There are periods when apparently not much happened at all. This is also true for other countries.

Iron Age Early sites with good 14C dates in **Ireland** include those at Newrath (Waterford Bypass), 1st-4th centuries BC, Cherryville (Kildare Bypass), 3rd-4th BC and a 3rd-5th century BC site in Co. Mayo. Evidence from these early sites indicates the use of slagpit smelting furnaces with shallow sub-shaft pits of 450-500mm diameter. Two other sites that are also probably early, but currently without 14C dates, Tullyallen 6, Co. Louth, and Adamstown 1 (also on the Waterford Bypass), have yielded complete in-situ "furnace bottoms". In both cases these weighed approximately 18kg, were rather friable, and showed very limited down-wall flowage on the blowing side. At all of these sites a large proportion of the slag assemblage comprised small blebs, flows and prills which solidified below the main "furnace bottom". Later Iron Age sites (1st-4th centuries AD) are not well represented in the schemes investigated by the author, although the metallurgical activities at the sites at Ballydavis, Co. Laois, probably span this period. The "Royal" site at Ballydavis A (which has 14C dates spanning the whole of the Iron Age) yielded evidence for smithing, whereas the nearby Ballydavis B site (currently undated) yielded one (and possibly two) slagpit smelting furnace. This was however much smaller than the earlier examples, being only 300mm diameter.
Source: Tim Young: "EARLY IRON-MAKING IN IRELAND: TOWARDS A NEW MODEL", in: Abstracts of Second International Conference Plas Tan y Bwlch 17th – 21st September 2007: Early Ironworking in Europe II, archaeology, technology and experiment.

- Not much doing before 400 BC, it seems.

Mysterious Manganese

Therefore the ***manganese** had a key but mysterious role* in the Ferrum Noricum Process. And no doubt, it is as marvellous that Plinius tried to describe the complex behaviour of manganese, then unknown. «Mirumque, cum excoquatur vena, aquae liquari ferrum postea in spongeas frangi ».
Source: Edmond Truffaut: "BEHAVIOUR OF MANGANESE IN STEELMAKING BLOOMERY THE FERRUM NORICUM PROCESS: A HYPOTHESIS", in: EARLY IRON IN EUROPE, International Conference Hüttenberg, Carinthia, Austria 8th – 12th September 2008.

As I mentioned above, addition of ***manganese ore*** to our charge has a ***pretty dramatic effect on the resulting iron***. So much so, that this is the only thing I've ever considered keeping as a trade secret. But I'm just not that kind of guy. I assume this is a matter of slag chemistry only, but I have no idea what's really going on here.
Source: Lee Sauder: Update on the 'Practical Treatise'" Winter 2010-2011; Lee's homepage (http://www.leesauder.com/

A less startling inconsistency involves the exploitation of the two ore varieties at Llwyn Du. Experimentation with ***Mn-rich ores*** was clearly less costly than anticipated and shows that ironmakers were well attuned to ore color differences if not to their properties. The pattern of declining importance of Mn-rich ores in phase B3 seems to imply that the ironmakers decided to reject the black ores. However, the resurgence of Mn-rich ores in Group 2 slag suggests that they quickly realized *its value in providing higher iron* yields when smelting with a slower, less reducing strategy. If so, then why were Mn-rich ores not utilized in the faster more reducing recipe? One possibility is that black Mn-rich bog ores and red Fe-rich bog ores may have been encountered at different rates on the landscape.
Source: Michael F. Charlton, Peter Crew, Thilo Rehren, Stephen J. Shennan: "Explaining the evolution of ironmaking recipes – An example from northwest Wales"; Journal of Anthropological Archaeology 29 (2010) 352–367

- In this paper (and the references given therein) a very thorough analysis of slag formation is made.

Experiments with Mn-rich bog-ores:
The first trial smelt, in F5, used the dust retained from processing the RP6 and RP7 ore batches, used for the earlier bog-ore experiments. To ***increase the Mn content***, this was blended with 10% of a Mn ore from Manatawan, Africa. ***The smelt was a total failure***, probably because of the very fine ore, as was XP95 blown at a high rate.
For the last five experiments we modified the Sauder-Williams (2002) idea, blowing very much harder, between 1000 and 1200 litres per minute, with correspondingly high charcoal burning rates. In XP92 36kg of bog-ore were smelted, producing a 7kg block of cast iron, but in the normal position of a bloom (Fig 23). Clearly the conditions had been too hot and too reducing for smelting a porous bog-ore, resulting in low-iron slag.
Source: Peter Crew: "Twenty-five years of bloomery experiments: perspectives and prospects", in D Dungworth and R Doonan (eds) 2013, Accidental and Experimental Archaeometallurgy [25] (London: Historical Metallurgy Society), p. 25-50

- Manganese does provide for a puzzle, indeed. Since manganese ore will not be reduced to elemental manganese in normal bloomeries, there will be no (beneficial) manganese in the iron later. This has been found many times in experiments. What manganese apparently can do is to:

  1. Change slag properties in a beneficial way.
  2. Change the carbon-iron interaction in a beneficial way, so that
  3. It is easier to produce steel instead of wrought iron in a bloomery
  4. Something else that is good.
  5. All of the above.

  At present I don't know why adding some manganese oxide seems to be so good. I'm not sure if anybody else does. We will find out.
- What we learn from most of the above is that in iron smelting ***the Golidlock Principle strictly applies***.

Mysteries Around Forging, Fire Welding, and Phosphorous

Let me start with stating that the more I look into forging, the more mysterious fire welding becomes While the principle is clear and many modern smith seem to have no problems doing it, the following points worry me:

- Sprinkling (quartz) sand on the hot surfaces to be welded as a **"flux"** to liquefy the oxide or scale would only work around 1200 ^{o}C (2192 ^{o}F), a bit high for *ancient* smithing.
- Nowadays other fluxes are used. The ancients also must have had "better" fluxes but not much seems to be known.
- It appears that only iron / steel can be fire welded but not, for example (alloyed) copper or gold. Is that true? And if yes, why?
- Hypereutectoid steel, e.g. wootz steel, cannot be fire welded as stated by some writers on occasion. Is that true? And if yes, why?
- How does a bit of phosphorus (or other impurities) change fire weldability. There seems to be a difference.

A large part of the problem lies in the fact that scientists typically are not doing "fire welding" in their laboratories. Smiths' do it all the time, but the two rarely met throughout history. We simply do not have a good enough data base.

- The quotes below are therefore rather interesting:

Eventually Hector Cole made two knifes from half of the XP27 bar. The knives were difficult to *forge*, because of the high *phosphorus*.
Source: Peter Crew: "Twenty-five years of bloomery experiments: perspectives and prospects", in D Dungworth and R Doonan (eds) 2013, Accidental and Experimental Archaeometallurgy [25] (London: Historical Metallurgy Society), p. 25-50

- This is in direct contradiction to Lee Smith's claim hat phosporous iron is particular easy to forge and in contradiction of much else I have read. But Peter Crew is not lying; what he and Hecor Cole observed has happened.

For all the bog-ore smelts the blooms were removed cold the following day and the attached slag was hammered off. ... The reheating was carried out in a circular hearth, based on the evidence from Crawcwellt, where the base of a redundant furnace had been used. *It is not easy to re-heat even a 2kg bloom, especially if it still contains a lot of slag*, which prevents the heat spreading. It is a slow process, needing up to 20 or 25 heats before the part-refined bloom can be brought to full welding heat for the final consolidation to a billet. One memorable weekend we had a group of blacksmiths at Plas and it was interesting that they found it equally difficult to refine the blooms.
Source: Peter Crew: "Twenty-five years of bloomery experiments: perspectives and prospects", in D Dungworth and R Doonan (eds) 2013, Accidental and Experimental Archaeometallurgy [25] (London: Historical Metallurgy Society), p. 25-50

- Lee Sauder agrees.

This metal seemed to be of good quality *until it was drawn down to a thin bar*, when it cracked into several pieces. Despite multiple fold welds, there was only a marginal improvement in its quality.

- The prove of a bloom lies in forging! There are reasons why the standard pieces of iron /steel as used for trading were often thin or contained thin parts.

AN INVESTIGATION OF THE ***WHITE WELD LINE PHENOMENON***

Certain composite ferrous artefacts which have been manufactured by the welding of separate components during the forge-welding process display a distinct ***yellow-white strip at the welding interface***. The first systematic investigation of this "white weld-line" phenomenon was conducted by Tylecote and Thomsen in 1973, which concluded that the characteristic white weld-line was primarily the result of ***arsenic and/or nickel enrichment*** due to oxidation and segregation of these elements during welding and further forging processes. Yet in the 34 years following this work, there has not been any further research into this issue, despite the advancements made in the analysis of archaeometallurgical artefacts during this time.

Thus, newly discovered white weld-line specimens have merely been recorded and catalogued, and their potential to inform and advance the current understanding of the blacksmithing process has remained untapped. In order to address this issue, specimens displaying this white weld-line from four separate Saxon period sites in England have been systematically analysed via optical microscopy and SEM-EDS compositional analysis. The optical microscopy of these samples revealled the characteristic white bands to be uniform and consistant, suggesting they are the result of a ***purposeful*** rather than an accidental process. Furthermore, the distribution of arsenic across the weld-line within these samples suggests either the deliberate use of a brazing agent, as previously suggested and dismissed by Tylecote and Thomsen (1973), or the addition of an ***arsenic-rich flux*** during the forge-welding process. It is also possible that such an addition resulted in a reduction of the plasticization temperature of the iron components being welded, which in turn would produce the superior welds observed within these samples. ***The white weld-line phenomenon marks the emergence of a new and advanced blacksmithing technology within post-Roman Britain***, indicating either the development of indigenous smithing practices through systematic, long-term evolution, or the importation and acceptance of foreign technologies.

Source: Vanessa R. Castagnino and J.G. McDonnell: "AN INVESTIGATION OF THE WHITE WELD LINE PHENOMENON", in: EARLY IRON IN EUROPE, International Conference Hüttenberg, Carinthia, Austria 8th – 12th September 2008.

It looks like fire-welding was indeed more tricky than just sprinkling the very hot surfaces with quartz sand. Here is more of the same:

INVESTIGATING THE EFFECTS OF ***PHOSPHORUS*** ON THE IRON MICROSTRUCTURE AND ITS IMPLICATIONS ON THE IDENTIFICATION OF THE ALLOY IN ARCHAEOLOGICAL ARTEFACTS

This research project examined the iron alloys in use within Early Medieval England and their implications for the development of ***specialized smelting and smithing technologies***. One such alloy, found in far higher quantities than expected, was ***phosphoric iron***. Phosphoric iron is term coined by archaeometallurgists to generally describe a very "low" carbon iron (<0.1%C) with a relatively "high" phosphorus content (0.1-1%P). In previous studies this alloy has been routinely identified through its microstructural characteristics, most notably the presence of ***"ghosting"*** after etching in Nital and/or increased grain size, as well as an increased hardness (in excess of 150 Hv 0.1 compared to c 120Hv 0.1 for ferrite).

The role and significance of phosphorus in iron is poorly understood. One significant property of the alloy is its impedance of carbon diffusion, hence its role in preserving carbon content in steel components of pattern-welded artefacts. ***The current understanding of phosphoric iron shall be challenged by this project.*** Over one hundred artefacts have been analysed utilizing metallographic analysis in the un-etched and etched condition, grain size measurements, and micro-hardness tests. These investigations were supported by the SEM-EDS analyses of all microstructures and EPMA analysis of selected samples.

The results of this regime have demonstrated that the previous identifying features of phosphoric iron, such as ghosting, large grain size, and increased hardness are insufficient to characterise and distinguish phosphoric iron from feritic iron. Data will be presented on the interaction between carbon and phosphorus, with the carburisation of phosphoric iron also being addressed. Ultimately, the resultant data indicates that a reassessment of the traditional archaeological definition of phosphoric iron is necessary, and the means by which it should be identified re-examined.

Source: Samantha R. Rubinson and J.G. McDonnel: "INVESTIGATING THE EFFECTS OF ***PHOSPHORUS*** ON THE IRON MICROSTRUCTURE AND ITS IMPLICATIONS ON THE IDENTIFICATION OF THE ALLOY IN ARCHAEOLOGICAL ARTEFACTS" in: EARLY IRON IN EUROPE, International Conference Hüttenberg, Carinthia, Austria 8th – 12th September 2008.

A FLUXING MISCONCEPTION

While the use of a fluxing agent during past blacksmithing processes such as ***forge-welding*** has generally been considered a means of preventing or at least inhibiting the excessive oxidation of iron at the high temperatures necessary of the welding process, the use and purpose of such fluxes in antiquity may have been more diverse and served a number of possible functions. Indeed, fluxing agents do function to some extent as an oxidation inhibiter, but it is suggested here that this may have been a secondary factor to its primary purpose. Extensive research into the so-called ***"white weld-line"*** phenomenon has suggested the deliberate and repeated use of an arsenic-rich fluxing agent within high-quality knives from the Saxon period, which served to reduce the plasticization or softening temperature of the iron being joined, thus resulting in the production of a weld with far superior properties.

his work shall outline the nature of this specific flux usage and explore its implications for the welding process utilized during the manufacturing of other composite artefacts. This work shall also attempt to address the "Sand Fallacy" perpetuated within archaeometallurgical literature through the detailed examination of the composition of weld-line slag inclusions within composite ferrous artefacts from the Saxon period. This term is used here to describe the almost universal ascription of the fluxing agent employed during the forge-welding process solely to sand. One key study by Joosten et. al. (1995) has demonstrated that ***the use of pure sand may not have been universal***, as several weld-line slag inclusions within a medieval sax displayed very ***high manganese contents*** which suggested the use of a fluxing agent other than sand. This is also suggested by the composition of the weld-line slag inclusions presented here, which display a compositional variability in excess of that expected were sand alone the only flux employed.

Source: A. B. Daoust and V. R. Castagnin; "A FLUXING MISCONCEPTION", in: EARLY IRON IN EUROPE, International Conference Hüttenberg, Carinthia, Austria 8th – 12th September 2008.