Dissertation submitted for the degree of MPhil
Ancient History,
UCL, London

Metallurgy and the Development of Etruscan Civilisation

PIETER WILLIAM MOMMERSTEEG

History Department, University College, London

Supervisor: Prof. Michael Crawford

I confirm that this dissertation is entirely my own work. All sources and quotations have been acknowledged. The main works consulted are listed in the bibliography.

Note: This dissertation is an unrevised examination copy for consultation only, and may not be quoted or cited without permission of the Chairman of the Board of Examiners for the MPhil in Ancient History.

Metallurgy and the Development of Etruscan Civilisation

Contents

Acknowledgements

Firstly, I would like to thank Prof Michael Crawford, my supervisor, whose patience, encouragement and professional input has been invaluable and beyond the call of duty. Any errors or misguided reasoning though remain mine alone.

A lot of new material has become available over the past decade which has, I believe, improved our understanding of the latter stages of iron development. I am indebted to Prof C. Giardino for his continued help in up-dating me with information. I am indebted also to Prof Th. Rehren for his contribution to the computational and other aspects in Chapter 7.

The staff at the Library at the Institute for Classical Studies has, as always, been kind and helpful, displaying high levels of tolerance, for which I am very grateful.

Metallurgy and the development of Etruscan civilisation

CHAPTER 1 **INTRODUCTION**

This dissertation assesses the role played in the development of metallurgy in the expansion and establishment of Etruria as an important, if not the most important, community in mainland Italy, in the first part of the 1st millennium. It seeks therefore to link in more detail the influence that metallurgy had on those changes which took place in the social and economic structure of Etruria. This dissertation examines the role that technology and particularly the transfer of technology played in the growth of metal production in Etruria between the 8th and the 1st centuries BC. It describes the period of change, from bronze to iron, together with the establishment of a basic iron technology.

In considering the relationship between metallurgy and Etruscan civilisation several underlying factors contribute to this analysis. At the heart of this lies the question of *how and why* technology developed in ancient times. In general terms, the process began with 'trial and error' experimentation leading to the establishment of a basic technology. This could then be developed further by the incorporation of subsequent developments often 'within the limits of traditional techniques'.[1] This in turn led to either increased productivity, new forms of design eg colour, shapes, improved physical properties or a combination of these. Increases in productivity contribute to economic growth and this finally can impact on civilisation. Various aspects of this sequence will be raised at different stages of the discussion.

The rate at which a technology develops is governed by a variety of factors even within a given field, in metals for example. The difference in development between copper / bronze on the one hand and iron on the other is marked. The former started with the Copper Age progressed relatively

[1] Finley, M.I. (1965) 'Technical Innovation and Economic Progress in the Ancient World' in *The Economic History Review* Vol 18 No1 29-45

uniformly through to the end of the Bronze Age. Iron and iron artefacts precede the Iron Age by some 2000 years. Iron was known from the 3rd millennium, but it was still comparatively rare in the middle of the second millennium, with little being known about its method of manufacture. By 400BC, iron was being produced in quantity, by ancient standards, and it had replaced bronze in many applications. The development of this technology into a workable and transferable one was reflected in the large-scale production of iron in Populonia between the 4th and 1st centuries BC. This technology provided the link between the ever-increasing demand for iron and a plentiful supply of ore. Whilst efficiencies improved over the centuries, the process did not change fundamentally until the 1700s.
How did this technological change come about and why did it take so long?

The structure of the dissertation can be summarised as follows:

In chapters 2-4, a broad outline of the early development of ancient technologies is given. Before discussing that of metals, with copper and bronze providing a natural introduction to iron, two other technologies will be reviewed, namely pottery and textiles. This is to provide a useful background to indicate why these differing ancient technologies developed as they did, and how they progressed from an individual craft activity to the making of goods in large quantities. A core element of this capability is, I believe, the ability and skills to work towards the ability to control processes. The transition from bronze to iron in the Eastern Mediterranean and finally the emergence of Etruria is then discussed.

Chapters 5-7 deal with metallurgy in Etruria, and the importance of the transfer from bronze to iron. Archaeological and archaeometallurgical evidence is reviewed together with the accompanying social changes. Finally, the establishment, at Populonia, of a process of iron manufacture which was capable of delivering large quantities of iron. A new assessment of the amount or iron produced there is put forward.

Chapters 8-10 begin with a brief summary of the economy in the second half of the first millennium. The wide applications of iron in the 3rd and 2nd centuries BC follow together with its usage in weaponry, tools and other applications together with rate of up-take is assessed. The impact on the Roman economy at that time is also discussed.

However before describing the development of ancient technologies, it may be helpful, in the context of this dissertation, to review the differences between science and technology. Whereas science is concerned with knowledge and the understanding of natural phenomena, technology can be described as a means of solving problems with practical solutions. The resolution of such problems depends on the successful application of experience and expertise to the relevant material data and its associated practical environment. In ancient times, the requirement for this expertise was governed by basic needs like survival or protection. The origin of these ancient technologies goes back as far as man himself with the use of fundamentals such as fire and flint stones.[2] These basic requirements of survival were widened in due course to include more general needs.

Ancient technology is rarely documented and the majority of data is available only through artefacts. From the basic element of fire comes heat and, when controlled, the domestic hearth and then the kiln. The resultant products after various degrees of heat treatment, such as pottery and metal artefacts, are in the main the only tangible evidence we have of the progress and control of these technologies. The driving force behind progress in these fields was initially inextricably linked to man's survival; to meet man's basic requirements, to improve process performance or to provide artefacts of beauty or adornment.

The development of ancient science on the other hand was driven by quite different parameters, namely the desire for knowledge and understanding of the natural world. Aristotle wrote 'all humans desire knowledge' (*Metaphysics*

[2] White, K.D. (1984) 6, Redher J.E. (2000) 3; with reference to pyrotechnology

980a21). He clearly established the scientific method that entailed enquiry, and the systematic collection of data, often with experimentation of variables, with the view to deducing from this evidence a formal structure. This not only explained the structure's rationale but also provided a fixed relationship between the variables and hence the opportunity to predict outcomes. This approach or way of thinking, generally attributed to Thales in the sixth century, led to an understanding of physical and mechanical phenomena that in turn provided the potential for new techniques to be invented and existing ones developed. Sometimes science and technology worked together, stimulated by the need to solve a problem. For example, it was used by Archimedes specifically in the field of mechanics, and war engines in particular, when he was asked to help in the defence of Syracuse in the second Punic war (Plutarch *Marcellus 14.9-17.3)*. More generally, although the simple pulley was in use in Assyria in the eighth century,[3] the compound pulley was described in detail by Aristotle *(Mechanical Problems 18.853a-b)* and the principles of its mechanism explained and understood. The exact role that the basic laws of mechanics played in the sequence of the development of the pulley we do not know. But the fact that it coincided with a major increase in activity in civil and temple construction, which in turn involved the manoeuvring of large blocks of stone, is probably not accidental. Sometimes the potential remained effectively unused for several centuries, such as the force pump of Ctesibius (3rd century BC, but described by Vitruvius *De Arch 10.7.1-4*). This perhaps underlines the importance of demand in determining the rate of technological development.

With ancient technology on the other hand, the development of basic skills was essentially one of trial and error and chance. This was an empirical and step by step process requiring careful observation to establish a successful outcome; success being measured solely by its practicality and reproducibility. A successful systematic approach leads then to a technology which is both reliable and transferable. In the ancient world, such developments took centuries if not millennia to achieve and iron is a good

3 White, K.D. (1984) 14

example of such a sequence. The time scales between science based innovation and an empirically developed technology are therefore quite different. The former could be established comparatively quickly but not in fact used until a long period of time had elapsed whereas the latter is developed over a period of time but its advantages are made use of continuously whilst the underlying process also improves.

In general terms, the key factors that influence the rate of development of technology can be summarised as follows:

- availability of basic skills
- accessibility of raw materials
- demand for the new technology

Demand is, I believe, the most critical of these three factors. In the discussion that follows, the link between the *rate* at which a technology advanced and the *demand* for the resultant product is put forward.[4] Specifically, it examines the factors that contributed to the making of iron in Populonia in significant quantities to meet a new and growing demand. What was special about Populonia was the amount of iron produced, making it a major 'industrial' (as opposed to mining) operation, perhaps the first such attested site in the ancient world.

[4] Demand may stimulate technical activity but it does not guarantee success, as alchemists found when trying to convert base metals into gold.

CHAPTER 2 **ANCIENT TECHNOLOGY: pottery and textiles**

Pottery or more specifically the process of firing has much in common with the smelting of metals; both technologies progressed initially with developing and controlling the operation of the kiln or furnace. Textiles have been included because, unusually, written sources are available and they give an indication of how a household activity developed into a more organised and larger scale operation. Both are described as household industries and have their origins in the time of the change of man from hunter gatherer to more settled pastoral activities. Both predate the world of Thales of earth, fire, water and mist by several millennia and by the end of the second millennium were reasonably well developed. I have sought to highlight certain aspects that, in their differing ways, provide an insight into the changes that took place.

<u>POTTERY</u> The process of hardening of clay by fire has been known for a very long time. Clay images of animals were found in Vestonice, Moravia, dating from the last Ice Age.[5] The history of pottery has no single origin. It is anything but one of steady expansion and progress. Frequent set-backs have been accentuated by a lack of development in the industry itself, for the techniques used up to recent times had in the main survived from remote antiquity.[6]

Pots are essentially storage vessels and because of their fragile nature tend to be associated with more settled, pastoral people rather than nomads. Initially the hardening of basic-hand formed clay vessels took place on a simple fire hearth. Furnaces were certainly in use by 7000BC at Çatal Hüyük and the enclosure of fire was a major advance in pyrotechnology.[7] The history of pottery in ancient times can be divided into three aspects with differing time scales for each aspect. The first element was the use of the wheel, invented in the 4th millennium BC, and used in the shaping of pots. This in turn was developed further by the use of the 'fast' wheel which improved the surface of

---

5 Klima B. *Archeologické* 4, 193. (1952) in Scott, L (1954) 376
6 Scott, L. (1954) 378
7 Rehder, J.E.(2000) , 9

the vessel and which was already in use during the Uruk period, c3500 BC, in Mesopotamia.[8] The second element in the development of the technology was the furnace or kiln and its operation;[9] in effect the introduction of an element of control of heat both in temperature and distribution. Running parallel with this, the third element was concerned with the many improvements that were made in the initial preparation and pre-treatment of the clay and the nature of the additives used. However, it is the drying and firing process which took place in the kiln which will be discussed here, starting with a brief summary of the processes involved. After the clay has been modelled, the initial drying stage reduces the water content to about 8-15% by heating to temperatures between 100°C and 200ºC when the pot becomes 'leather hard'. At this stage, its form is retained but it has little strength. It can, though, be decorated – painted or scratched - and also burnished to reduce porosity if necessary. After this, the pot is dried further to a water content of some 3% which requires a firing temperature range between a minimum of 450ºC and up to 750ºC. It is important that the temperature is raised gradually to avoid uneven drying which may lead to surface cracking. In ancient times, the potter would have judged this sequence essentially by visual examination of colour change both of the vessel and the flame of the fire. When the temperatures were raised still higher, to *c*1000ºC, the clay particles fused together and, as a result of complex physico-chemical changes, the vessel had greater mechanical strength and reduced porosity.

The oldest and originally the most common form of firing took place in an open hearth. This was followed by simple mechanisms to retain the heat of the fire. This entailed simply covering the pots with a layer of peat or a mixture of earth and biomass that acted as much as an insulator as a source of heat. Clay containing the appropriate fillers fired by this method was still being used at the end of the 19th century in the Hebrides. But it is the kiln which became the main vehicle for the firing process. Early evidence for the use of kilns for pottery production has been found on scenes shown on cylinder seals

[8] Crawford, H.E.W. (1991) 127
[9] Rehder, J.E. (2000) 10

discovered at a number of sites of the 3rd millennium in Sumeria. These depict domed and two- storey kilns, so described because the source of heat is separated from the vessels being fired by some sort of grating, and these are known to have been in use since the Hassuna period.[10] At Ur there is evidence of 'industrial' or larger scale production in the form of kilns, potwasters and clinker[11] where pottery was clearly produced in quantity over a prolonged period of time prior to the Early Dynastic Period 1, *c*3000 BC.[12] This site was situated within the town boundaries but probably at the edge of the residential area. Volume and large scale production should be seen in this context as comparative in relation to smaller scale domestic production. Whilst we have little idea of the size of production, we can assume that the process was sufficiently well controlled for the enterprise to have been considered practical and acceptable. Running parallel with this, there is quite a lot of evidence for smaller scale domestic production using single-storey kilns.[13] It would seem therefore that the choice of kiln, single or double storey, was related to the quantity of vessels required to be fired.

During the first half of the 2nd millennium in the Aegean region, pots with different coloured fired clay bodies were made. We now know that the colour of pottery is governed by a large number of factors that include;

a) The presence of other materials in the clay including iron oxides
b) The form and distribution of these materials
c) The firing temperature, time and atmospheric conditions in the kiln.

Conditions under which pots are fired in kilns or metal ores smelted in furnaces can be *oxidising* or *reducing* [14] The choice is dependent on the

[10] Merpert, N. & Munchaev, R. (1971) in Crawford, H.E.W. (1991) 127
[11] Woolley, C.L. (1955)
[12] Crawford, H.E.W, (1991)29-130
[13] Crawford, H.E.W.(1991) 130
[14] oxidation/reduction - excess/insufficient oxygen to support full combustion
Firing under *oxidising* conditions (normal heating/burning), the carbonaceous material in the clay is burned out. Iron oxide particles increase in size with firing temperature, and this gives rise to a red or red-brown colour around 700°C, leading to red to deep red above 1000°C. (This applies to non-calcareous clays – for calcareous clay the colour is yellow or green, see Minyan pottery)
Firing under *reducing* conditions (lack of oxygen) leads to the formation of iron oxides with a lower oxygen content – these are dark in colour

conditions required to achieve a particular end result. An oxidising atmosphere is one where combustion or heating takes place in the presence of oxygen in excess of that which is required to complete combustion. This takes place under unrestricted and normal conditions where unlimited oxygen is available. Reducing conditions are such that the process is carried out with insufficient oxygen, which in turn leads to oxygen-related materials, like metal oxides, relinquishing some or all of their oxygen component. Burning charcoal in a restricted atmosphere or space produces CO, carbon monoxide, which in turn removes oxygen from the restricted atmosphere to produce carbon dioxide, CO_2.

To simplify a complex phenomenon, the final colour of a vessel was largely influenced by the presence of iron oxides and the degree of oxidation or reduction of particular materials in the clay. It is these materials that influence the final colour of the clay.[15] [16]

An early example of this can be seen with Minyan pottery, which in the main was made using well refined clay and was fired at high temperatures. This resulted in a hard and good-quality vessel. During the period 2200-1500 BC, the pottery made was greyish in colour, as a result, we now know, of being fired in a reducing atmosphere. Later, 1700-1400 BC, the pottery produced was yellow in colour; in this case the firing took place under oxidising conditions.[17] Whilst the interest in Minyan pottery lies more in its shape and decoration, the control of firing conditions in the kiln marks a step forward in the overall development of the technology.

These developments continued at the start of the 1st millennium. Major changes in both artistic and technical fields took place in Athens in the beginning of the 8th century and continued, both there and in Corinth, throughout the 7th century. In the 6th and 5th centuries, new techniques enabled Red figure and Black figure ware to be made with striking contrasts in

[15] Jones, R.E. (1986) 751-765 particularly 751/2,759 & 762

[16] ‘The practice of introducing a reducing phase has been recognised as one of the oldest techniques of pottery decoration, originating probably in Mesopotamia. It is found for example, in the early Neolothic pottery in Samara – Noll *et al* (1975), 604-8. Jones (1986) 762

[17] Higgins, R. (1981) 68-69

colour between the body of the pot and the applied slip. This was achieved by subjecting the vessel to a sequence of differing firing conditions: oxidising, reducing and then oxidising again. In the initial oxidising conditions, the body of the pot and the slip material fired red. This was due to the iron present in both materials being converted to ferric oxide (haematite). Reducing conditions were then introduced by cutting back the supply of oxygen (closing the air vents and burning more wood). This in turn reversed the initial oxidising process but under these conditions the iron oxide in the slip material combined with other materials to form a hard, dense black non-porous coating which, importantly, was impervious to oxygen. The concentration of iron in the slip was higher than that in the body. This required temperatures of 850º to 1000ºC. With a subsequent change back to oxidising conditions, reverting to the original state, the body of the vessel which had remained porous fired red again but the slip coating which was not porous remained black.[18] Whilst the full scientific explanation was only forthcoming in the 19th and 20th centuries (the above summary is a simplified one)[19], it is not too difficult to appreciate that potters in ancient times would have noted colour changes taking place in both the artefacts and the kiln flame and incorporated them into controlling the process.

In Italy, there is limited evidence of pottery kilns producing large storage vessels in the 8th century.[20] More significantly, during the late 8th and 7th centuries there was an increase in the production of fine ware indicating a transformation of types of production. Bucchero pottery with its distinctive grey/black colour designed to give the vessel a metallic sheen originated in Caere around 700. It was produced by firing in ‘a highly controlled reducing atmosphere’.[21] [22] During the 7th and 6th centuries, *bucchero nero* pottery was being widely exported.

---

[18] Williams, D. (1997) 89

[19] For a more complete explanation of the reaction of iron oxides and ions under oxidising and reducing conditions see Jones (1986) 751-3

[20] Bietti Sestieri, A.M. (1992) 87

[21] Rasmussen, T. (1979) in Rasmussen, T.(1998) 203

[22] Nijboer, A. (1998) 82 The process may well have been more complex. Experiments carried by Cuomo di Capro (1993) 220-1 showed that artefacts fired in a sealed container in which carbon was present gave the same effect.

In sum, pottery making was, and in many ways still is, a very basic technology and the more recent scientific explanations of the various techniques employed have not significantly changed the essential principles of production; many of the basics were already established in the 3rd millennium. However, what I have endeavoured to show here is that during the subsequent centuries a gradual improvement in processing took place, which in turn enabled new techniques to be developed. Better control of heat distribution and temperature meant the risk in making pottery in larger quantities was limited. As a result pottery could be then made in quantities that were in excess of that required locally and in a wide variety of colour and decoration.[23] Reliable processes were established and, whilst they may not have been perfect, they were certainly capable of making usable and tradable vessels to meet the overall demand.

<u>TEXTILES</u> The making of textiles has been included because it provides an example of an increase in productivity resulting in a change from a household activity into a comparatively large-volume operation. It did not involve any fundamental changes in spinning or weaving, rather it achieved the transition through effective and consistent control of the conversion from raw material to finished goods. Overall it is perhaps the earliest example of large volume production enterprises using, admittedly, comparatively low level technology (as opposed to manual dexterity).

As with pottery, the origin of textile making goes back to very early times. Definitive evidence of both weaving and basketry comes from Neolithic cultures of c.5000 BC with fragments of plain woven material (linen) found in the Fayum and at Badan in Egypt.[24] Early textile production was usually carried out in the home and was for domestic use. But in the Gulf area a

[23] For more detail of later Roman mass production pottery see Roberts, P. 'Mass Production of Roman Finewares' ch29 188-198

[24] Crowfoot, G.M.(1954) 431 footnotes 4 &5

range of simple trading networks was already in place from the Samarra period (6th millennium) and by the beginning of the Ur III period (2100-2000BC), there is evidence of widespread commercial networks. At the heart of this was a requirement for metals in Mesopotamia, particularly copper that was available in Magan and Dilmun (today's Gulf States).[25] Sources about foreign trade show firstly that copper was indeed sourced from the Gulf and secondly that its supply was directly linked to an exchange for textiles, which played a significant part in the overall exports from Mesopotamia. Two examples, taken from a large number, are given below to illustrate that garments and wool of specified quality was traded in exchange for copper.

1.	UET III 1689 [26]	5 guzza garments 5 usbar garments of fine quality 5 usbar garments from Ur-Sulgira 2/3 talent of gi-wool merchandise for buying copper from Magan (on behalf) of the temple Nanna Instead of 5 in lines 1-3, 300 might be read
2	UET III 1511	60 talents gi-wool 10 talents gi-wool 20 talents spawn 70 usbar garments 6 kur sesame oil 180 skins (or leather)

On behalf of the temple Nanna, merchandise for buying copper, Lu-Enhilla ... put in a ship for Magan

Leemans has summarised Mesopotamia's trading position as follows: 'copper was one of the main imports and probably textiles were an article of export throughout the whole period'. [27]

What part did technology play in this development of textile production for export? The outline technical processes were already established and

25 Crawford, H.E.W. (1991) 139/141 & (1995) 5
26 Legrain, L. (1947) *Ur excavation texts*
27 Leemans, W.F. (1960) 55

recorded during the Ur period (4000-2900BC) and they can readily be summarised into three phases. Firstly, the preparation of the raw material (in this case wool), namely washing and the removal of extraneous material, together with the preparation for spinning by combing and carding. Secondly, spinning and weaving and thirdly, final washing, degreasing and fulling. But this available information consists essentially of 'administrative records' and yields little evidence that any significantly new techniques were developed. [28] However, if we look at those factors which enable products to be made consistently, then the ability to control the process can be considered as part of the overall technology.

In this case it centred round the best use of the raw material, the wool. The various sheep breeds were recognised as yielding different fleece weights and quality and details were recorded.[29] The fleeces were classified into five groups dependant on fineness of fibre and length of staple and this classification was used to ensure the better fibres were used to make the finer materials. The final quality of the finished product also reflected the amount of work allocated to it.[30] Finally, the apparent control of spinning and weaving was such that definite conversion rates of raw wool to finished area could be applied. All of this indicated a commercial awareness of quality and value.

In addition, textile operations are attested in seven major cities during the Ur III period and we do have some idea of their size. The staffing arrangements included an inspector in charge of the overall establishment, followed by foremen who in turn were responsible for a department or category of worker, e.g. weavers, fullers, basket-makers. This demonstrates a definite division of labour by type of work and hence specialisation. The weavers made up the largest group. In a weaving mill in Girsu the numbers were 1097 women and 626 children and in another unit in Lagash 4272 female weavers and some 1800 children were employed (HSS IV 3). Finally, by looking at the ratio of

[28] Moorey, P.R.S. (1994) 14

[29] For example fat tailed sheep (*udu-gukkal*) yielded wool of high quality (1st and 2nd class) and gave a fleece weight of on average 1.4 minas. Mountain sheep produced mainly 4th and 5th quality wool TU285;1f Waezoldt, H. (1972) 122

[30] Spinning double thread was only done using 1st to 3rd class wool.

numbers employed to rations of barley issued, Waetzoldt estimates that over 15,000 people worked in textile factories alone and at Ur an estimated 13,200 weavers working under 60 foremen are attested.[31]

Output details from these factories are less common. An indication is given by two broken texts that listed the amount of woven textiles delivered to the fullers as 5,800 pieces of cloth. As half the text is missing and the figure relates to two overseers with at least two further names known, the original figure can then probably be quadrupled to give a grand total estimate of some 24,000 pieces. No time period is given so one might presume this is an annual figure. These represented sizeable quantities. All this data was recorded on a regular basis and it is fair to say that the administrative function played a very large role in the running of the day-to-day activities in palace-run kingdoms at that time.

One can only speculate therefore to what degree this detailed information was collected solely for administrative reasons or whether it was also used in the running and organisation of textile operations. We do know however that the system worked. Sizeable quantities were produced in differing qualities and they were traded successfully. There is no clear evidence that this major increase in volume production, compared with household production, was made possible by new techniques but it was the structured approach to raw material usage and the control over conversion that made this 'step' increase in production possible, providing the foundations for a textile industry. Indeed, ‘no other cities could boast such massive textile industries at that time and it is hardly surprising to find these products used to finance the import of copper.’ [32]

SUMMARY During the 4th and the early part of the 3rd millennium, these ancient technologies reviewed underwent changes. There was a move away from simple domestic craft production towards making goods in greater quantities, amounts beyond those required by local households. In the case of textiles, consistency or uniformity of the articles was such that they were

[31] Waezoldt, H. (1972) 99
[32] Potts, D.T. (1990) 147

saleable and tradable,[33] often over very large distances.[34] Techniques did not alter appreciably during that period but the changes were made possible by the way labour was organised and the raw material utilised. In the case of pottery, the development of the simple kiln made the baking of pots in greater volumes possible and essentially, the increase in demand was for basic utility articles. During the 2nd millennium, techniques developed at varying rates. Not many details are known about the making of staple goods. For the more specialist or desirable articles, the influence of product design and colour came increasingly to the fore. In the case of textiles new techniques in dyeing and more intricate weaves were introduced; with pottery the baking of pots in more demanding conditions with specialist additives gave contrasting and visually more attractive effects. But underpinning both technologies was a ready supply of raw material. Only comparatively simple techniques were required to make the basic articles but the more attractive and desirable objects required more complex techniques where process control became more important and an integral part of the system.

[33] In the same way as carpets are made by individual weavers in their own villages in India and sold in major cities.

[34] See comments above; textiles were also traded further to Ashur but their origin in not specified.

CHAPTER 3 **THE TECHNOLOGY OF COPPER AND BRONZE**

Metals seem always to have played a special role in the development of early civilisations, and in this respect copper is a leading exponent; it is therefore the third of the ancient technologies to be reviewed. The major innovations in copper/bronze technology will be summarised; not only the production of copper and alloys but also the mechanical processes employed to maximise their final properties in relation to the finished article. The inter-relationship between the social changes which occurred during the Bronze Age and these technical developments will also be highlighted.

Copper is generally acknowledged as being the oldest of the known metals, with evidence of its existence dating back to the 8th millennium.[35] This is not too surprising because native copper is found fairly frequently in copper deposits around the world. *Primary* native copper occurs mainly in basaltic rocks. It occurs in enormous quantities in the Great Lakes region of America. *Secondary* native copper can be formed by a variety of processes all seeming to involve the reduction of copper from sulphidic copper minerals in the presence of iron oxides. It can occur when sulphidic ores oxidise on weathering to form a complex mixture of oxides, hydroxides etc which subsequently permeate in an aqueous solution into the upper levels of this body of the ore; a sequence of reactions which, under certain conditions, can occur naturally.[36] Also copper oxide ores, such as malachite or azurite, are brightly coloured and were collected as pigments and as material for beads from the earliest Neolithic times. Native copper is often found alongside these ores and the association of metal and mineral must have become increasingly obvious to the first metal-smiths. Examination of native copper artefacts shows they were fabricated by hammering and annealing,[37] and that the work-hardening characteristic obtained by final hammering was recognised.[38]

[35] Muhly, J.D. (1988) in Cradock, P.T. (1995) 122
[36] Craddock, P.T. (1995) 28,94
[37] Annealing: heating a metal to some predetermined temperature below its melting point, maintaining that temperature for some time and then cooling slowly.
[38] Charles, J.A. (1980) 161; Forbes, R.J. (1964) 30

Copper has a melting point of 1083ºC, so when temperatures of around 1100ºC were obtained, which was quite feasible in a charcoal fire, it became possible to make artefacts by casting.[39] Also once these temperatures could be reached reasonably consistently, the practical step for primitive smelting was a relatively straightforward one. Heating various copper oxide ores in a reducing atmosphere in an oven or kiln will produce metallic copper. The reduction process, heating substances in an atmosphere with insufficient oxygen, converts in this case the copper oxide into metallic copper; a schematic illustration is given below. The burning of charcoal in a oxygen deficient atmosphere produces carbon monoxide. [40]

The oldest artefacts were probably made from native copper although it is difficult to distinguish native from smelted copper by analytical means. In the eastern Mediterranean, artefacts have been found dating from the 6th millennium and sites of a primitive workshop have been identified at Çhatal Hüyük in Turkey and at Tal-i-Iblis in Southern Iran. From the 6th to 4th millennium there is evidence of only isolated metal usage or production, a phase of 'trinket technology' as described by Moorey. [41] In the middle of the 4th millennium, a hoard of metal artefacts found at Nahal Mishmar in Sul, Palestine demonstrated a high level of sophistication in casting including the 'lost wax' technique.[42]

But it was not until the end of that millennium and the start of the 3rd that metal production really started to expand and with it, firm evidence of smelting. This originated mainly in the Middle East. The oldest smelting evidence indicates the process probably taking place in crucibles or open hearths under moderate reducing conditions, possibly aided by the addition of air through blow pipes. In the succeeding Early Bronze Age at Feinan, furnace technology

39 Craddock, P.T. (1995) 94,122

40 The reducing agent is carbon monoxide CO formed from charcoal C as follows;
$2C + O_2 > 2CO$. C carbon ex charcoal; O, oxygen – air; CO, carbon monoxide
This gives a reducing atmosphere – where copper oxide is reduced to yield metallic copper : $CuO_2 + CO > Cu + 2CO_2$

41 Moorey, P.R.S. (1994); Craddock, P.T. (1995) 126

42 Craddock, P.T. (1995) 291

evolved with evidence of furnaces, tuyères and importantly slag.[43] Slag is an unwanted by-product of the smelting process.[44] The development of the shaft furnace in conjunction with the removal of molten slag enabled the smelt to be more efficient and to continue for longer. A key element was the addition or use of fluxing agents.[45] These combined with extraneous elements in the mineral to form a slag and, with temperatures in the furnace of 1200ºC, the slag was molten. It could therefore be more readily removed being periodically tapped during the smelting process. As a result of this, there was an increase in the processing efficiency and hence metal yield; the metal coalesced and separated more readily in the furnace. Running alongside this important change, there is evidence of furnaces being sited to utilise prevailing winds. This and the use of blow pipes and tuyères were aimed at introducing additional and subsequently a more controlled supply of air (oxygen) which in turn resulted in higher and more consistent temperatures. The increase in the amount of air and hence oxygen required to achieve these higher temperatures resulted in an improvement in the effectiveness of the charcoal induced 'reducing' atmosphere. And to offset this, a higher proportion of charcoal was required. This factor was to become important in the smelting of iron.

Evidence of sulphide ores being smelted has been found at Norsum Tepe in S Anatolia.[46] These ores were readily available just below the earth's surface and were more abundant than the oxide ores. The process is a two stage one, the first stage being roasting - heating the ore in an open atmosphere in simple terms to convert the sulphides to oxides. In the second, the smelting process, the flux, typically iron oxide, was an important ingredient because the amount of gangue[47] material remaining in sulphide ores after oxidation is

---

43 Craddock, P.T. (1995) 128

44 Slag consists mainly of siliceous glassy material; it is less dense than copper so it will collect on top of the molten copper.

45 Flux is a material which combines with impurities or unwanted material in the ore to form slag; with copper typically iron oxide combining with silica based materials.

46 Moorey, P.R.S. (1994) 244

47 Gangue is an unwanted material arising from the preparation and cleaning of the ore prior to smelting. The crude ore was broken down by hand to remove large lumps and the remainder washed repeatedly.

somewhat greater than that present in copper oxides. Whether the flux was originally added by accident or design is perhaps of academic interest; it did occur naturally in the form of limonite, an oxide of iron, on or very near to sulphide deposits. It can also be formed during the roasting of chalcopyrites. Overall therefore, these changes enabled a lower grade ore, but one more widely available, to be used and in particular sulphide ores and many of these such as chalcopyrites contained both copper and iron.[48] A significant by-product, which occurred from time to time during the process, was the production of small amounts of iron formed by the reduction of the iron oxide. This only occurred under certain atypical conditions but may well explain the occurrence of the few non-meteoric iron artefacts in the early Bronze Age.[49]

Recent analysis of ancient copper and bronze artefacts has confirmed the nature of the changes and the basic time frame in which they took place. Basically, the iron content of ancient copper provides a good indication of the smelting process used. Nearly all copper ores/gangues contain iron in some form. The more efficient the smelting process, the greater the proportion of iron that will be absorbed into the copper during the process. So if the smelting was carried out under poor reducing conditions, as the primitive smelts were, little or no iron would be absorbed. The results show that the slagging process evolved during the 3rd millennium in the Middle East did not spread into the western Mediterranean until later.[50]

In the eastern Mediterranean, the use of small furnaces assisted by natural draft or pot bellows enabled the melting point of copper to be achieved consistently. During the late Early Bronze Age furnaces developed further, using fixed structures some two meters high, and the molten copper could be tapped away. Whilst the improvements in smelting were taking place, the importance of mechanical treatment was being assimilated, principally work hardening which had an effect on the physical properties of the metal. A typical treatment sequence would have been: smelting and reheating followed

---

48 Chalcopyrites: $CuFeS_2$
49 Charles, J.A.(1980) 166
50 Craddock. P.T. (1995) 140

by casting, hammering, annealing with or without further hammering depending on the artefact's end use. Casting was the main technique used to shape artefacts in the Middle Bronze Age but for cutting edge applications requiring hardness and wear resistance, the casting was followed by local hammering which made a noticeable improvement in those properties.

Running parallel with advances in copper technology, the production of copper alloys was taking place. The introduction of arsenical materials to produce copper-arsenic alloys is now generally accepted as a new phase in metallurgical development.[51] Muhly refers to mid 4th millennium arsenical copper metallurgy in Chalcolithic Palestine as the earliest example of this technology. [52] Artefacts have also been found in Susa dating back to the late 4th and early 3rd millennium.[53] Some copper ores contain arsenic compounds and during the smelting of these ores, the arsenic becomes alloyed with the copper to give arsenical copper or arsenical bronze.[54] The early metal-smiths will have noticed the greatly improved physical properties of this new material.

We have no evidence however about how this alloy was made. If mixed arsenical copper ores were smelted together, it would have been difficult to exercise any real control over the final amount of arsenic alloyed to the copper, an important determinant of the alloy's physical properties.[55] But an analysis of a range of artefacts showed that in fact some degree of control was exercised. It is possible that this was done by adding predetermined amounts of arsenical ore, such as enargite or realgar,[56] to re-melted copper heated in a crucible with charcoal.[57] There is no evidence of the addition or even existence of metallic arsenic in ancient times, unlike tin.

51 Charles, J.A. (1980) 168
52 Muhly refers to mid 4th millennium arsenical copper metallurgy in Chalcolithic Palestine as the earliest example of this technology
53 Moorey, P.R.S. (1994) 251 Artefacts were also found in Susa dating back to the late 4th millennium
54 Correctly described as arsenical copper but more loosely and more descriptively termed arsenical bronze.
55 Not least because arsenic is quite a volatile material
56 enargite Cu_3AsS_4
57 Charles, J.A. (1980) 170

In a paper evaluating the evolution of copper alloys in the Aegean throughout the Bronze Age, G. Papadimitriou has analysed the physical properties of a wide range of artefacts. [58] Conclusions are drawn on the effect of the varying proportion of the alloyed metal and the resultant physical properties. Arsenical copper has better hardness properties than copper.[59] It also has better flow or mouldability characteristics than pure copper. So the extra hardness provided a stronger blade and cutting edge and the improved flow properties made casting easier. A further attraction was the feature that, on casting, a layer with a higher proportion of arsenic alloy segregated to the surface. This on cooling could be polished to give a mirror-like surface.

The emergence of tin bronze followed and soon became a material produced widely over the years. Although the period when arsenical bronze was used exclusively was relatively short, it continued to be used alongside tin bronze for some 500 years, albeit it smaller amounts. Its colour and shiny surface made it an attractive material.[60] However casserite, tin oxide, was available and like copper oxide was relatively easily smelted.[61] There is evidence of the existence of metallic tin and that it was a material held in high esteem and traded widely in the Near East.[62] Its usage was however almost exclusively in the making of bronze. Whether it was added to molten copper in the form of its oxide or in metallic form we do not know, but the proportion of tin in the alloy of numerous artefacts tested demonstrated a degree of control maximising the resultant physical properties, an improvement over that for arsenical bronze. The hardness of tin bronze was greater in its cast state than that of arsenical copper and this was enhanced further in the hammered

58 Papadimitriou, G (2008) 20, 271-287.
The Technological Evolution of Copper Alloys in the Aegean during the Prehistoric Period

59 Papadimitriou, G. (2008) 278

	Copper	Arsenical copper (2%-4%wt arsenic)	
Cast metal	50-60	55-70	Vickers hardness
Hammered	100-120	150-160	,,

60 Papadimitriou, G. (2008) 291-2

61 MPt Tin 232°C against Cu 1083°C

62 For details of trade between Assur -Karnesh see Larsen,M.T.(1976) 89-90 & 105 and Veenhof, K.R. (1995) 290-290 & 305

state.[63] Hammering became an independent forming technique and was used to make the first long swords and vessels with thin walls. In addition, tin bronze is stable whereas the volatility of arsenic will not have helped either the consistency of the alloy or the health of metal-smiths subjected to highly toxic fumes. The silvery finish was however special to arsenical bronze. The fact that arsenical bronze continued to be used to a limited extent through the Bronze Age may also have reflected the local availability of tin ores. By the end of the Bronze Age, the metallurgy of copper was well established. The construction and operation of furnaces to smelt a range of ores effectively was in place. The controls necessary to achieve this were known and appreciated, if not understood, and the subsequent alloying and fabrication techniques were widely used.

Running in parallel with these technical innovations and the improvements in production processing came changes in social structures within communities. The technical and social changes were often interrelated. During the Bronze Age, there was a transition from settlements where individual households were able to undertake a wide range of the basic and necessary skills required to survive to settlements where craft specialisation existed. By the late Bronze Age, such specialization was clearly evidenced by numerous workshops in palaces in Crete. Occupations listed included the following: mason, carpenter, flax-worker, fuller, tailor, unguent boiler, goldsmith, and stoker as well as occupations concerned with subsistence or the farm such as shepherd, goatherd, huntsman, woodcutter, baker and ox-driver.[64] Thus by Minoan/Mycenaean times basic survival was no longer the sole or prime concern of the individual. Dramatic growth was achieved in the production of staple items and finished goods, the latter both in quality and range.[65]

---

[63] Table 9 p280 ibid 22 Hardness comparison of arsenical copper and tin bronze after 50% deformation

	Cu/As (3%As)	Cu/Sn(8%Sn)
Cast	50	80
Hammered	140	200

[64] Ventris, M. and Chadwick.J. (1956) 123

[65] Renfrew, C. (1972) 308-339 ‘The scale of increase of production itself coupled as it was with the increased effectiveness of the end products made possible by alloying, became itself a factor in determining the cultural and social changes.’

Technical improvements were enhanced by craft specialisation. For example, basic underlying factors such as better process control, achieved by more efficient oven design and specialist mechanical techniques enabled more effective daggers and more elegant metal figurines to be made. The availability of such prestigious articles stimulated trade, and with that wealth.[66] The emergence craft specialisation was an integral part of the changes in social structures. Not only did this maintain and make the best use of current expertise but it also put in place a mechanism whereby expertise could be handed down from one generation to another; transferability of not only the basic skills but also of any recently acquired techniques. This was particularly relevant in metallurgy where, in general terms, there was limited raw material (ore) required to satisfy an increasing demand.

SUMMARY During the 4th and the early part of the 3rd millennium, all of the ancient three technologies reviewed underwent great changes. Supple identifies two pre-historic 'growth-spurts' which are attributable to the 'convergence of critical technological and organizational innovations.' The first of these refers to Neolithic times and the second to the rise of urban civilisation in the Middle East (the control of water, use of copper and bronze, the wheel, improved building techniques, hierarchy of occupations, writing and administration).[67] In pottery and textiles, there was a move away from simple domestic craft production towards making goods in greater quantities, amounts beyond those required by local households. In the case of textiles, consistency or uniformity of the articles was such that they were saleable and tradable,[68] often over very large distances.[69] Techniques did not alter appreciably during that period but the changes were made possible by the way labour was organised and the raw material utilised. In the case of pottery,

---

66 Renfrew, C. (1972) 391 ‘The rapid development of metallurgy in the 3rd millennium BC and the variety of new products gave new meaning to the notion of goods, There was for the first time a whole range of valuable objects. This particular consequence, a transformation in the idea of wealth, establishes it as the most important craft of the 3rd millennium whose nature was being changed.’

67 Supple (1963) 27-34

68 In the same way as carpets are made by individual weavers in their own villages in India and sold in major cities

69 See above 2. Ancient Technologies – pottery & textiles

the development of the simple kiln made the baking of pots in greater volumes possible and essentially, the increase in demand was for basic utility articles. During the 2nd millennium, techniques developed at varying rates. Not many details are known about the making of staple goods. For the more specialist or desirable articles, the influence of product design and colour came increasingly to the fore. In the case of textiles, new techniques in dyeing and more intricate weaves were introduced and with pottery the baking of pots in more demanding conditions with specialist additives gave contrasting and visually more attractive effects. But underpinning both technologies was a ready supply of raw material and only comparatively simple techniques were required to make the basic articles.

The role that copper and its alloys played in the Bronze Age was as its name suggests a central one. Copper and bronze follow naturally on from gold and silver as desirable materials from which attractive and prestigious artefacts were made. Unlike clay or wool (or flax), the basic raw materials required for pottery and textiles, metallic ores, or at least those which could be used, were limited. This will have exerted pressure on metal-smiths to make best use of those ores available in order to satisfy an increasing demand. The rulers and elites held metals in high esteem so the demand for copper and then bronze artefacts was assured. It was not too surprising therefore that the initial thrust of development was towards more efficient processing and the wider use of raw materials. It is instructive to note that the proportions of alloyed metal,
(7-8% Sn for tin bronze) determined from the recent analysis of several contemporary articles mirrors the optimum levels for maximum hardness for those alloys. This demonstrates a high level of awareness in determining these levels in terms of effective utilisation of tin or to a lesser extent, arsenic but also level of control in the making of the alloys. The ease of fabrication, moulding and/or hammering will have been an important factor and one led to more prestigious articles to be made - long swords, finer daggers. The improved hardness and cutting edge will not have gone unnoticed, however, although it probably remains true that the majority of these items were objects of status, many ending up as funerary artefacts.

I appreciate it is easy to look with 20th century eyes at Bronze Age history but the relationship between demand and changes in technology was present at that time as well as tentative structures whereby technology could be developed and transferred. Both of these issues I wish to refer to later.

CHAPTER 4 **THE ADVENT of IRON 1200-900 BC**

This chapter deals mainly with the development and introduction of basic iron technology which occurred in the eastern Mediterranean. The changes which took place during this period can be separated into two: technical and socio-economic. This chapter will concentrate on the former, not least because of the absence of much meaningful data on the latter. After the collapse of the major Bronze Age civilisations in the eastern Mediterranean, namely the decline of the Hittites, Mycenaean centres and a number of Cypriot cities, little is known about this period.[70] But the possible relevance of this decline in this context lies in the effect it may have had on the rate at which iron technology was taken up. What in fact were the factors which may have limited the rate and extent to which the application of these basic iron-making techniques were converted into the supply of practical usable iron in large quantities?

Four salient features emerge when comparing iron and copper. Firstly, iron is stronger and tougher and capable of being hardened to a greater degree than copper. Not that all these properties were realised with any degree of consistency in the ancient world, but they were noted and appreciated. Secondly, making iron is a more complex and demanding process. It requires greater process control and because of the critical nature of its smelting, errors cannot readily be rectified. Thirdly, iron ore is very much more widespread and abundant and is normally situated on or close to the earth's surface.[71] Finally, whilst copper technology developed continuously, if not uniformly, from the 3rd millennium onwards, iron technology did not.

<u>History</u> Lumps of iron and simple iron artefacts dating back to the 5th millennium are generally accepted as being made from meteoric iron. Some twenty finds can be dated to the 3rd millennium and come mainly from

---

70 This is less true of Assyria where some written records continue throughout this period. The reasons for socio-economic decline in the Levant and Turkey were probably caused by over extension of the political structures p386 & 392-4 in *The Ancient Near East* A. Kuhrt. Routledge (1995)

71 Iron constitutes 5% of the world's mass whereas copper is only 0.05%

Mesopotamia and Anatolia.[72] Of the twelve samples analysed, half originated from meteoric iron and half from smelted iron. [73] During the first part of the 2nd millennium, much of the evidence comes from literary sources. In trading documents found at Kanesh, [74] an important trading centre at that time, the term AN.BAR is accepted as referring to the metal iron.[75] Meteoric iron continued to be used during the Early Bronze Age and references are made to Hittite 'black iron of heaven, Egyptian 'iron of heaven' and Sumerian 'iron of heaven'. Importantly though, experimental work has shown that iron can be produced as a by-product of copper in the smelting of chalcopyrites.[76] This would have provided another source of iron in addition to meteoric iron. The number of artefacts appears to increase during the Early Bronze Age period but was probably somewhat less during the subsequent period, the Middle Bronze Age (2000-1600).[77] During the next few centuries, the incidence of iron objects together with literary references increase but the limited supply of iron itself was reflected in its value.[78] Control of territory of its supply lay definitely in the hands of the rulers and the temples. By the 14th and 13th centuries, iron was used principally in temples and the royal courts as symbolic objects and idols. Quantities appear to have been be limited. Evidence for Bronze Age iron *production* is rare but it does exist in a small number of places. [79]

During the 12th to 10th centuries, the number and types of artefacts increased significantly in the eastern Mediterranean region and this signalled the transition from bronze to iron. Evidence for this is demonstrated in a study of mainly funerary artefacts found dating from the 12th, 11th and 10th centuries. The table below illustrates the scale of the transition. [80]

---

72 J Waldbaum, J. (1980) 69-74

73 Pickles, S. (1988) 4-5 where it was suggested that early iron that contained nickel was made of native or telluric iron. Cited in Waldbaum, J. (1980) 73.

74 Limet,H. (1984) 191-196 Kanesh is in Turkey near present day Kayseri.

75 Waldbaum, J. (1980) 75.

76 Craddock , P.T. (1995) 178-197; Charles, J.A. (1980) 166

77 Waldbaum, J. (1980) 74; Moorey, P.R.S .(1994) 287.

78 10:1 gold:iron ratio Bjorkman (1989) Powell 1990: 95n84

79 Compiled during the reign of Tuthaliash IV in Pleiner, R. 9 'The birth of Iron Smelting' in '*Iron in Archaeology'*

80 Waldbaum, J. (1978) 56

IRON vs. BRONZE – by century and type; Eastern Mediterranean

Century BC	12th		11th		10th	
	Iron	Bronze	Iron	Bronze	Iron	Bronze
Weapons	11	320	54	280	155	134
Tools	27	211	69	185	132+	60
Jewellery	44+	359	97+	616	198+	619
Misc	12	316	28	191	21	86
TOTAL	94+	1206	248+	1272	506+	899

This survey covers artefacts collected and examined over a wide area: Palestine, Syria, Cyprus, Greece, Crete, the Aegean Islands, Anatolia and Egypt. However, some general conclusions can be drawn from this aggregate table. Firstly, there is a definite shift from bronze to iron over the three centuries and secondly, the transition is most noticeable in the weapons/armour and tools sectors.

Before looking further into certain aspects of this transition, the iron-making process will be reviewed in some detail. This may throw some light on the level of control that was established over what has been mentioned earlier as a demanding process and as one of the differences between copper and iron technology.

Technical The melting point of copper is 1083°C and that of iron 1540°C. In ancient times and certainly by the 12th century, the temperature at which a smelting furnace could be maintained and reasonably well controlled was 1200°C.[81] At that temperature, iron is in the form of a hot spongy mass and not molten as in the case of copper. But whereas iron oxide can be reduced at temperatures of between 800-900ºC, it is only at 1200°C that slag [82], formed during the reduction process, is molten and critically, it was the ability to

[81] Sim, D. (1998) 10 quotes examples of higher temperatures achieved in contemporary experimental trials which include: Radwan & Pleiner (1963): 1300°C; Thomsen (1963): 1273°C; Straube (1964): 1420°C; & Pleiner (1969&1991): 1545°C .

[82] See n 43 above

remove the slag during the smelting process that made the reduction of iron ores a practical proposition. [83]

Essentially the operation of the furnaces did not differ in principle between the two metals.[84] Developments in the smelting of copper certainly helped and particularly in the use of fluxes. The discovery of iron oxide as an effective flux for copper smelting would have alerted ancient metal-smiths to the existence and making of iron, albeit in small quantities. This will have led naturally to the possibility of smelting the iron ore on its own. But the gangue and the resultant slag were much greater in the case of iron than with copper, with a corresponding increase in interference or hindrance of the reduction process. [85]

Bloom iron is the product of the smelting process. It is a hot spongy mass when red hot and the impurities it contains (up to 50% of slag) render it hard and very brittle at room temperature. But the slag can be removed by a series of labour-intensive operations. The sequence consisted of re-heating the bloom iron to red heat and hammering it whilst still hot and malleable, to remove the slag and weld the cavities closed to produce a solid mass. To eliminate all the slag and still maintain the necessary heat levels, the process of heating and hammering required to be carried out repeatedly. Care and control was needed to ensure the bloom did not break up and experiments have shown this to be a time-consuming and highly skilled operation.[86] The overall process is called bloomsmithing and the resultant iron, now described as wrought iron, can be forged and welded. Although wrought iron is a relatively hard and tough material, it is no more so than optimally hardened bronze. The full potential of the physical properties generally associated with iron, namely hard but not too brittle and capable of obtaining and retaining a

---

83 Cleere, H.F.(1971) 204 ; Tylcote, R.J (1962) 183-184.

84 The smelting chemical equations are similar to those of copper but the reduction sequence is longer,

$3Fe_2O_3 + CO > 2Fe_3O_4 + CO_2$

$Fe_3O_4 + CO > 3FeO + CO_2$

$FeO + CO > Fe + CO_2$

85 $2FeO + SiO_2$(gangue) > $2FeO.SiO_2$.(slag)

86 Sim,D. (1998) 12 -13 & 17'

cutting edge, can only be realised by further hardening of the iron. The process sequence for this to take place is only effective if the iron contains a small but significant percentage of carbon.[87] The mechanism whereby this is achieved, the absorption of carbon into the iron to form an iron-carbon alloy, is called carburisation [88] and the resultant metal, carburised iron, steel. Iron in this state becomes receptive to subsequent heating and cooling processes which alter its final physical properties. Quenching, the process referred to by Homer in the *Odyssey,*[89] produces a more hardened surface. This is achieved by heating the 'iron' to red heat and then plunging it quickly into a bath of cold water or oil. Iron in this state could be modified (softened) by re-heating the object to temperatures well below red heat and allowing it to cool slowly. [90] Hardened steels are brittle. The brittleness is removed by tempering i.e. by heating the steel to between 210°C and 330°C then quenching in oil or water. This removes the brittleness at the expense of some hardness [91] whilst still retaining its strength. The temperature to which it is reheated also affects the final physical properties and can be judged by the colour of the flame. [92] Annealing entailed heating 'iron' to red heat, holding it at that temperature for some time (5-10 minutes) and then allowing it to cool slowly (as opposed to quickly as in quenching). This renders the 'iron' in the softest possible condition.[93]

[87] Sim, D. (1998) 151 'Iron with 0.15-1.5% carbon is commonly called steel. Wrought iron coming from bloom iron normally contains up to 0.04%C - insufficient for it to be 'hardened' By way of comparison, cast iron, which is extremely hard and tough but very brittle contains between 2-4%C.'

[88] Carburisation; cementation or case hardening

[89] Odyssey *9,* 391-94

[90] Sometimes by burying it in sand or ashes.

[91] Sim, D. (1998) 151

[92] Hodges, H. (1976) 84. 220°C -250°C Yellow: razors, turning tools 250°C-270°C Brown: axes 270°C- 290°C Purple: swords, knives 290°C-330°C Blue: saws, chisels

[93] Sim, D.(1998) 149

Critically however, these operations are only effective if the iron has been carburised and it is in this form that iron is best used for making tools and edged weapons.[94] Exactly how carburisation was carried out and the degree of control exercised is still the subject of conjecture and on-going analytical work. As with all things iron, analysis remains particularly difficult because of its vulnerability to corrosion.

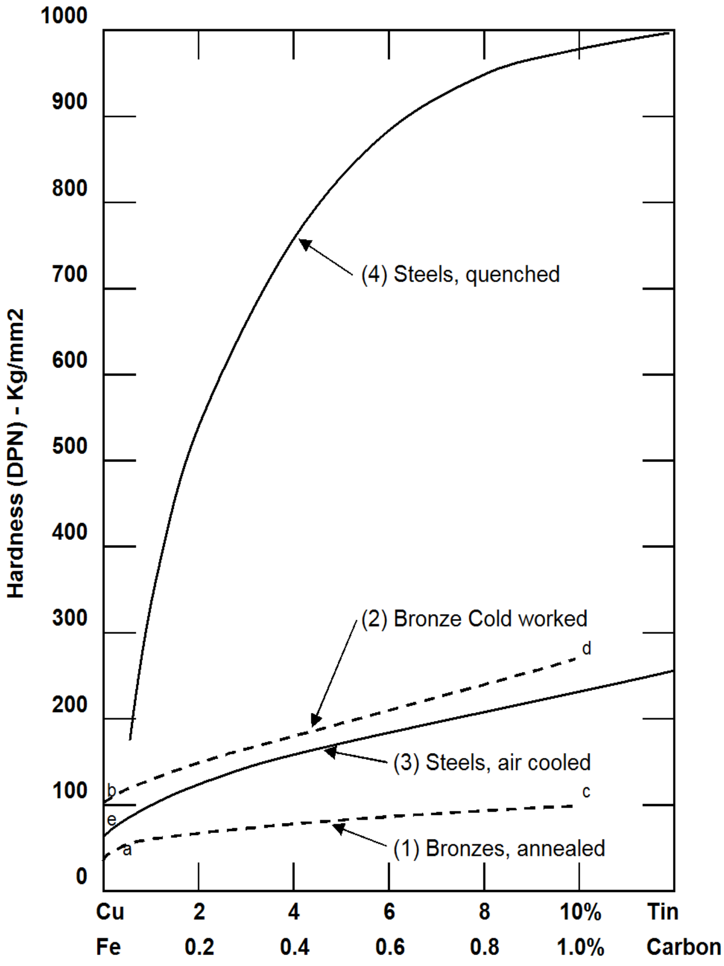


Fig. VI.1. Comparative Hardness of Iron, Steel, Copper and Bronze at varying Carbon or Tin contents. Reproducerd courtesy Cyril S. Smith from " the interpretation of Microstructures of Metallic Artifacts," in Boston Museum of Fine Arts Research Laboratory, *Application of Science in Examination of Works of Art, Proceedings of the Seminar: September 7-16, 1965* (Boston 1967) 40 fig. 39.

Wrought iron can be carburised by heating it to a temperature of c900°C, whilst it is in intimate contact with carbon, for a prolonged period of time in an enclosed system - effectively packing the iron object in charcoal dust in a sealed clay container and heating for several hours.[95] The effectiveness of this solid state transfer (carbon to iron) depends on the temperature of the fire and the duration in the fire, but the rate at which the transfer takes place will be slow.[96] Carbon can be alloyed to iron at the *smelting* stage under certain conditions. If the ratio of carbon in the fuel to iron in the ore is above a certain value, the reduced iron dissolves carbon in amounts increasing as the ratio increases.[97] Higher temperatures also help the absorption of carbon. But it is a reversible two-way process and unless it is accompanied by the necessary increase in reducing conditions, the effect would be reversed. The level of carbon reached is low

---

94 Rehder,J.E.(1989), 27
95 Craddock, P.T. (1995) 252 notes a similarity with production of faience beads.
96 Rehder, J.E. (1989) 27-28
97 Rehder, J.E. (1989) 28

(0.2-0.8%) but is still such that the iron smelted in this way can be hardened after bloomsmithing. It is described as a natural steel bloom. The distribution of the carbon is heterogeneous and very uneven but during subsequent smithing, 'internal gradients in carbon content tend to level out by diffusion.' [98] The absorption of a sufficient amount of carbon at the smelting stage was by no means an easy process. It would have been difficult to carry out intentionally; it is quite possible that it could have occurred occasionally and unpredictably.[99] Overall, it seems likely that in most instances early steels were deliberately carburised or were made from natural steel blooms. [100] Carburisation of wrought iron, in effect a separate operation, offers the ability to control the process and direct the treatment to particular objects, like sword blades. Further analysis remains difficult; there are problems differentiating by which method artefacts had been carburised. A carbon concentration gradient, the principal evidence of carburisation, can be formed in blooms of freshly smelted and forged iron as well as separately carburised iron.[101] Finally, weapons or daggers have been found with a separate strip of carburised steel welded or riveted to an iron blade.

SUMMARY By the end of the 10th century, the distribution of iron artefacts was widespread in the eastern Mediterranean and a significant move towards the use of iron rather than of bronze is evident particularly in the areas of weapons and tools. The change was not complete and one could argue that the making and treatment of iron was still in its development stage. The smelting of iron developed naturally in many ways from that of copper but the resultant metal, iron bloom, a spongy mass, contrasted strongly with molten copper. The subsequent processes of bloomsmithing and the various heating and cooling techniques were more critical than those for copper as was the effect they had on its final properties. Analytical tests carried out on several artefacts show that they had received heat treatments that were not always related to enhancing their properties. Much has been written about carburisation and understandably so because it represents the ultimate goal

98 Tylcote *et al* 1971:352 in Rehder, J.E. 28
99 Rehder, J.E. (1989) 27
100 Craddock, P.T. (1995) 252
101 Rehder, J.E.(1989) 29

in iron-making. Examples of carburised iron artefacts have certainly been found but how this was achieved is far less clear. Recent experimental work has demonstrated that carburisation after smelting is a very lengthy process but it can be targeted. However, carburised iron blooms can result from smelting under certain conditions[102] and this may well have taken place from time to time. This could explain the presence of early 'carburised' iron. Whilst we have no specific evidence of how this form of carburisation was achieved, one can readily conjecture that the blacksmith will have noticed making some iron, initially by chance, that it could be hardened and thus yield the special toughness and cutting edge.

Much has also been written about what many perceive as the rather slow uptake in the use of iron. This is not the place to enter into a detailed discussion. But the widespread collapse of the major eastern Mediterranean civilisations, which occurred during the Late Bronze Age, disrupted trading routes; this in turn will have affected the general socio-economic climate, halting or at least reducing what had been an ever-increasing rate of demand for metals. Following on from this, the impetus to overcome the innate problems associated with making iron will have lessened. It is difficult therefore to gauge the progress iron was making both in terms of total amounts and the range of its uses.

To-day, we understand the nature and significance of these mainly empirically based processes. To the metal-smiths at the time, they were new. Whilst overall socio-economic development in the eastern Mediterranean may have stalled during the Dark Ages, metallurgy and iron in particular continued to develop albeit at a slower rate than might have been expected. One should not underestimate the importance of the making of uncarburised or wrought iron. This was becoming more widely available; iron had arrived but it was not yet fully established. It would appear that it was not being produced in significant quantities (ie tonnes) and it would seem the iron-making process

[102] higher temperatures and fuel:ore ratios

had not been fully mastered at that time.[103] The experience in acquiring and using these new techniques will have been gained largely by trial and error. Heating, cooling and hammering were very basic operations but the sequence and degree in which they were carried out was critical. Overall the expertise lay fairly and squarely in the hands of individual blacksmiths.

Advent of Iron – 1st millennium BC Outside Italy.

So far the discussion has centred round the ancient Near East and the eastern Mediterranean reflecting the main body of evidence which is available. The subject of this dissertation is metallurgy in Etruria and as such will concentrate on the development of metals and iron in particular there during the first millennium BC. This will be the subject of the subsequent chapters.

Whilst the development of iron in Etruria was very important during the first millennium BC, that does not mean that it was necessarily unique or that iron development followed a clear sequential progression emanating solely from a common technical source. Therefore, before continuing an analysis of metallurgy in Etruria, by way of background, a brief summary of iron development elsewhere will be given.

[103] In J Waldbaum's chapter The First Archaeological Appearance of Iron and the Transition to the Iron age' in The Coming of Iron , Muhly and Wertime, results are reported on a limited number of iron artefacts pp32-36. These can be briefly summarised as follows.
Transjordan: Baq'ah valley burial cave 4. 5 of 30 iron anklets or bracelets were analysed, 4 of which were found to be mild steel although without signs of quenching or tempering. In burial caves at Pella and Khirbet Nisya, the metal finds consisted primarily of jewellery both bronze and iron. One iron bracelet was analysed and found to be very similar to those in the Baq'ah tomb.
Cyprus: Palaepaphos-skales cemetery. A total of 182 metal objects of which 30 were iron. Of 6 knives tested (from tombs 49&76), two were not carburized, two were 'mildly' carburised (deliberate or not?), two showed 'slight' evidence of carburisation .None of these artefacts showed evidence of quenching or tempering, though the surfaces are so corroded that evidence for this might have been lost (Stech et al 1985:196) To sum up, it appears that many of the knives were carburised to a varying extent to manipulate the material to advantage, although full-scale treatment does not seem to have been practised.

This is based on R. Pleiner's Early Iron Metallurgy in Europe[104] up dated where necessary by contributions made recently at a workshop in London.[105] As a generalisation, Europe lagged behind Greece by four centuries and about one century behind Etruscan Italy. The Celtic territories, and those which would subsequently be incorporated into the Roman sphere as provinces, were prominent in iron development although lagging behind Greece and to a lesser extent Etruria. [106] Iron artefacts have been attested during the first half of the 1st millennium in countries throughout present day Europe, mainly weapons and funerary objects. Smelting sites were predominantly sited in areas close to the sources of metallic ore with smithing sites based more locally.

In present day Austria, the earliest smelting works date from the late Hallstatt period (HaD). [107] A large centre of production, relating to the 2nd-1st centuries BC, has been excavated in that area. [108] During the Roman period, Magdalensberg already an important copper producing centre developed as a major producer of iron or in fact steel, *ferrum Noricum.* In France, smelting sites have been identified in the South East and in the North (Basse Normandie). During the period of the second half of the 3rd century BC and the last quarter of the 2nd century, iron agricultural tools became more common. From the end of the 2nd century to the last century BC, iron use becomes more common and can be characterised by introducing more iron equipment into everyday life.

This sequence is not too different to that of Etruria, but perhaps a century or so later. Whilst we may have more evidence for the end uses of iron than in Etruria, we have no substantive evidence of amounts of iron produced.

A good example of the impact of Rome and the utilisation of large resources of iron ore occurred in the present day United Kingdom. The generally widely accepted date for the introduction of iron is c800 BC. iron smelting and smithing became established around the 4th century BC. Iron use, as

---

104 Pleiner,R. (1980) and EST-SCH below

105 European Science Foundation: ESF-SCH Exporatory Workshop (ESFW) ' Iron and change in Europe-the first 2000 years' , held in London, March 2010.

106 Pleiner,R. (1980) 391

107 Waschenberg near Bad Wimsbach/Neydharting : Cech,B. ESFW forum notes

108 Northern Burgenland near the border with present-day Hungary

evidenced by smithing debris progressed subsequently. But a major increase in output occurred when the Romans arrived. Major centres have been excavated dating from that period [109] and in fact are still being found as a result of construction work.[110]

The position in Greece is that already at the turn of the millennium, iron was being used for funerary artefacts, jewellery and weaponry. The Greeks were aware of carburisation and certainly used the process. Several steel artefacts have been found [111] although how consistently the process was applied is, to date, not too clear. The usage of iron will have increased over the next few centuries; during the Geometric period, iron became a common material continuing further in the late Geometric/early archaic period. Evidence of the overall amounts of iron produced and their impact on agriculture mining and other end uses is not generally available at present. It should be noted though, that Greece was considered a major producer and user of iron. [112]

In a much wider context, iron was also being used in areas as widespread as China, India, both northern and southern Africa and the Americas. Developments in the Near East are more relevant because they formed part of the general development of iron at the end of the second millennium as we have seen. During the first part of the first millennium, there is evidence of centres of iron production of quite significant quantities. These were at sites in Jordan and Saudi Arabia where more details of the modes of production and in some cases overall amounts are available. However more detailed analysis falls outside the scope of this dissertation.

<u>SUMMARY</u> The path of transition from prestige grave goods to basic individual smelting and smithing units, and then to larger scale operations

---

[109] McDonnell, G; in ESFW forum notes

[110] I am reminded of a very large Roman production centre of iron, 2nd/3rd century AD in Bulwick, Northamptonshire whose existence was discovered by chance during a road widening scheme some ten to fifteen years ago.

[111] Rehren,Th. *et al* (2009) in Asderaki-Tzoumerkioti,E. in ESFW forum notes

[112] It is not the intention in this dissertation to review in any depth the development of iron in first millennium BCGreece.

leading to the more common usage of iron, is similar, with variations in time scale, throughout western Europe.

The centres of smelting tend to arise near the sources of iron ore. Another factor which stands out is the significance of the arrival of the Romans which led to a step change increase in production.

The situation in Etruria differs from other centres, certainly in the western Mediterranean, in that it was not only a major producer of metals but in addition Populonia is considered as the largest attested iron producing site in Europe in the second half of the first millennium.[113] Iron was produced there continuously over a 500 year period. It is this aspect which makes a more detailed study significant, both in terms of its impact on Etruria and its importance in the overall development of iron making. Evidence was available, in terms of mountains of slag, in the 1850s, but the opportunity to assess the amount of iron produced remains and this will be done in a later Chapter. The next chapter analyses though in some detail the emergence of metallurgy in Etruria in the first millennium BC.

113 Pleiner, R. 386 'No other smelting area in Europe including those of the Celts has surpassed it in terms of the amount of production'

CHAPTER 5 **THE EMERGENCE OF ETRURIA** : **Middle Bronze Age – Sixth Century BC**

This chapter outlines the emergence of the Etruscans as a separate entity. The period covered is from the Middle Bronze Age until the sixth century and is based on standard modern sources. It concentrates on the significance of trading with outside communities. Conclusions are drawn about the importance of metals in its development and the potential resource of skilled artisans noted.

The origins of the Etruscans go back to prehistoric times and their background at that stage was probably no different to that of other rural Italic settlements. As indigenous peoples of Central Italy, they evidently developed from a sparsely populated group of subsistence farmers into a more structured society of chiefdoms. Throughout this period and beyond, the key assets of Etruria were:

- good arable land
- extensive metal resources
- good communications

Already in the fourth and third millennia, exchange mechanisms developed for materials such as obsidian and flint. During the second millennium, essential conditions for establishing long-distance relationships developed with local communities participating in traditional systems of circulation and exchange. Raw materials and goods such as amber and metals circulated from their areas of origin on a wide interregional scale, although these long distance movements were limited quantitatively.[114] There were regional differences. In the north, contact and exchange took place with the adjacent European regions through the numerous passes and wide valleys. Systematic relationships between Tuscany and the S. Po plain suggest that terramare groups depended on the mining resources of Etruria.[115] The Adriatic and Tyrrhenian coasts were instrumental in facilitating North-South networks. In the most southerly areas, there was a Mycenean connection, again related to the acquisition of metals. [116]

---

[114] Bietti Sestieri, A.M. (1997) 373
[115] Andreotti, A. & Zanini, A. (1997) in Bietti Sestieri, A.M. (1997) 376
[116] Bietti Sestieri, A.M. (1998)

In Etruria, in the general area of the Colline Metalliferi, the Bronze Age sites seem to fade away and settlements concentrate in the places of the coming Etruscan cities, Volterra, Populonia (Poggio del Moline, Villa Barone) and Vetulonia.[117]

The pace of the social changes which had taken place throughout Italy during the second millennium increased during the Late Bronze Age and these trends were further intensified towards the end of that period. A major demographic expansion took place around 1200 BC when a critical transition from village to proto-urban societies took place, a process of nucleation developing into urbanisation. Some signs of 'urban' or 'proto-urban' life were already present in the early Iron Age communities of the ninth and eighth centuries and it is generally accepted that urbanization was underway by the end of the seventh century.[118] The size and structure of these communities began to increase, which was reflected in the size and formality of the cemeteries. This led to the stabilisation of settlements in a number of more densely inhabited centres. The transition from a basic subsistence economy into a more structured one led to an increase in wealth and in turn to an increase in population.[119] Settlements increased in the river valleys such as Fiora and Albegna and other fertile areas.[120] The additional supply of food required to sustain this increase in population was satisfied by making more arable land available. The additional food supply was achieved by making great strides in reclaiming marginal land by skilled irrigation, by good husbandry and by the introduction of new crops. Plant production was complemented by the number and use of domestic animals, including their by-products. The transformation in scale and intensity of agriculture that took place increased production in staple foods, enabling the increase in

[117] Giardino, C. (1995) 307
[118] Spivey, N. and Stoddart, S. (1990) 39-40
[119] Rasmussen, T. (2005) 71-72
[120] Barker, G. & Rasmussen, T. 51

population to be sustained,[121] and by the final Bronze Age, a diverse and relatively sophisticated mixed economy had emerged. [122]

With these developments came changes in social structure and the emergence of chiefdoms. Elites began to be distinguished clearly in the archaeological record. Persons of higher rank established themselves in the beginning of the eighth century, a factor clearly demonstrated in the artefacts found in tombs.[123] Prestigious artefacts, not only in pottery and bronze but also ivory, gold, silver and iron found in monumental cemeteries from the later eighth century. These illustrated the presence of conspicuous consumption, certainly in funerary provision, if not in living accommodation about which we know little.[124] The establishment of an elite level in society led to a more defined territorial demarcation resulting in more systematic control being exercised over trading routes. The elites would appear to have begun to take more control over natural resources and an ever more hierarchical structure developed. This was more marked in Etruria than elsewhere and contributed perhaps to its cultural separation from the rest of Italy. [125]

That these changes took place in Etruria ahead of other areas in mainland Italy is not too surprising and they followed changes which had taken place in the eastern Mediterranean. Etruria's fundamental assets were extensive mineral resources and, at that time, Etruria was emerging as a maritime people with trading links with Sardinia and Corsica. These advantages were underpinned by fertile agricultural land. The increasing exploitation of indigenous metal resources became a factor in the development of the Etruscan economy and played a part in changing the nature of the social framework. Trading networks, with the resultant cultural influences, were initiated. Important in the development of these were the earlier trading contacts established between Sardinia and Cyprus. This was evidenced by

---

[121] Cambridge Ancient History, Chap12 626

[122] Spivey, N & Stoddart, S. (1990) 63

[123] Bartoloni, G. (2003) 30 "si fa evidente il processo di differenzione economica all'interno del corpo sociale – le tombe contengono materiale ..visibile segni di dislevello sociale" *in Le società dell' Italia primitiva. Lo studio delle necropolis e la nascita delle aristorazie.*

[124] Barker, G. and Rasmussen, T. (1998) 117-8

[125] Bietti Sestieri, A.M. (1997)

the widespread presence of ox-hide ingots from Cyprus found in some 26 sites in Sardinia. Contact between the two communities went back to the 13th century and continued until the 11th. The political system in the Eastern Mediterranean collapsed during the earlier part of that period and, with it, probably the established and complex exchange systems. As a result, the supply of precious metals to Cyprus would have been cut off. Cypriot copper activities continued and their search for alternative sources of precious metals became directed towards Sardinia although it was not only a source of such metals.[126] The island was on the way to the Iberian Peninsula with its even richer metal deposits. For Sardinia, the attraction lay in the supply of good quality copper. This exchange may have resulted in Cypriot smiths and traders travelling to Sardinia and providing a natural mechanism for the transfer and interchange of metalworking techniques and technical knowledge.[127] Sardinian metallurgy, which dated back to the Copper Age, flourished; this close and complex interaction with Cyprus made it one of the most developed metal regions in the western Mediterranean. [128]

In a sense, the contacts and relationships between Etruria and Sardinia were similar to those between Sardinia and Cyprus. Both communities had indigenous metal resources and an established level of metalworking expertise, essentially in copper and bronze, and there is widespread evidence of the commercial relations between the two communities. But in the light of Sardinia's contact and exposure to eastern Mediterranean communities described above, Sardinia's contribution was technically more advanced and influential. Nuragic material was found in several early Iron Age contexts in Etruria and it is possible that these funereal materials document the presence of Nuragic individuals in Villanovan communities.[129] A range of 'incontestably' Sardinian artefacts have been found in 8th century tombs in Vetulonia and

[126] Lo Schiavo ,F. (2003a) 305-312
Lo Schiavo, F. (2003b) 313-315
Kassiannidou, V. (2003) 333- 342

[127] Bartoloni, G. (1993) 113 "commonly believed that , after the collapse of the Mycenaean empire, ie at the end of the Bronze Age, artisans from the island of Cyprus settled in Sardinia …"

[128] Giardino,C. (2003) 496

[129] Giardino,C. (2003) 502

Vulci and apparent traces of Etruscan influence in Sardinia.[130] In addition the presence of imported artefacts and the type of burial methods suggest Populonia received goods from the east from 1000 BC.[131]

Excavation work, especially behind the promontory of Piombino, indicated that in the Late Bonze Age, settlements were sited “preferably along the coast” which would have facilitated contact using small vessels with the easily reached Tyrrhenian islands opposite.[132] During the period of around the eighth century, the amount of metal and products made from copper and bronze in circulation increased dramatically in response to an increasing demand from other Mediterranean countries. The diversification of bronze objects [133] was reflected in the gradual adoption of Proto-Villanovan styles influenced by the close contacts which were developing between Etruscan settlements in the south and those in the north.[134] In addition to the increased number of bronze artefacts being made, the range widened to include subsistence tools such as awls and farm implements, together with the traditional uses for weaponry and prestige items like pins, fibulae, swords, knives and axes, shaft-holed and winged.

There is evidence of early exploitation, probably Copper Age, of metal ores in the Fiora valley and Monte Amiata areas. These began to flourish in the Late Bronze Age and several hoards attest this.[135] There is also direct evidence of metalworking in the form of moulds, tuyères and casting residues. In the Colline Metallifere area however, there is little *direct* evidence to support the relationship between the increase in metalworking and sites for metal extraction and smelting. A bronze sickle coming from Campiglia Marittima is the only proto-historic find from this area. [136] This absence of evidence could be due to lack of systematic research, or it may be that these particular metal

---

[130] Pallottino, M. (1974) 85-86
[131] Scullard, H.H.(1967) 142
[132] Bartoloni, G .(1993) 101-103
[133] Bietti Sestieri, A.M. (1973)
[134] Potter, T.W. (1979) 49
[135] Giardino, C. (2003) 494
[136] Giardino, C.(2003) 494 citing Bergonzi & Cateni (1979) 251

deposits were not recognised during the Late Bronze Age.[137] It could also be because the copper ores were in the form of oxides and therefore sited on or near the surface. Their mining and smelting would have been comparatively straightforward and the activities of both surface ore extraction and smelting would have left few traces. These activities of course may well have ceased before the Late Bronze Age.

Towards the end of the 10th century, settlements sited earlier along the coast appear to have been abandoned and the only known settlements were located close to the main Etruscan mining centres of Populonia and Vetulonia. [138] Further settlement clusters grew around metal ore sites and this suggests perhaps that control of mineral resources was becoming more critical. An indication of local metal-smiths working the indigenous copper ores is demonstrated by the fact that most of the metalwork found in copper age burials in Etruria is restricted to within 100kms of the Colline Metallifere. [139] Mines and furnaces are notoriously difficult to date. At San Carlo, between San Silvestro and San Vicenzo, a series of furnaces for smelting copper have been found together with several clay 'moulds' and some pieces of metal which have been attributed to the Copper Age, but recent work has cast doubt on this, stating the mine to be mediaeval.[140] However, pits around Serrabottini and galleries at Cornacchino on Mount Amiata (inland from Populonia) are probably from the Etruscan period [141] and may well have been the source of ores for the traders at Tarquinia and Veii. In the mining areas many of these settlements were either between the ore resources and the sea or close to the sea. In the Villa del Barone, a village settlement and necropolis were excavated. In Poggio del Molino a basic imprint of living areas was found, together with hearths or furnaces, but without specific evidence to show they were related to smelting or metal work.

Evidence of copper production.

---

137 Giardino, C. (2003) 494
138 Bartoloni, G. (1993) 101
139 Barker, G and Rasmussen, T (1998) 49 : and map in Giardino, C.(2003) 495 Fig 2
140 Barker, G and Rasmussen, T. (1998) 205-6
141 Zifferero, A. (1991)

Evidence of copper production in the gulf of Baratti has been found in the form of copper slag. Descriptions of these were initially provided by Fossa Mancini[142] and D'Achiardi[143] in the 1920's and In the later part of the last century these slags were described in more detail by Sperl,[144] Voss[145] and Crew.[146] This interest in metalworking on this site continued and has led to comprehensive studies being carried over the past ten years. These will be discussed in more detail later when assessing the amounts of iron produced but the interest here is in evidence of copper production. Stratographic examination showed a clear sequence of slag layers. In simple terms, the bottom layer contained copper slag; above this was a layer of mixed copper and iron slag; uppermost, and the thickest layer, was iron slag. Radiocarbon measurements showed the 'copper' layer dates from the 9th to the 8th centuries BC. Ancient Populonia successfully exploited therefore the ore resources of the surrounding areas. The intermediate layer was dated from the 8th to 7th century and as this contained both copper and iron slag it indicated a transition from copper to iron working.[147] Compositional analysis indicated that the smelting of the copper was carried out efficiently because the slag contained comparatively small amounts of copper. To achieve this, the metal smiths would have needed to exercise effective control in terms of furnace temperature, reduction conditions and optimum ore dosages; a high level of both operational and technological skill had therefore been attained. [148]

Overseas trading in metallic ores

Trading in metallic ores and metals strengthened Etruscan overseas communications, which were mainly with Sardinia and Corsica at that time and were reflected in the increasing quantity of Sardinian imports, predominantly in northern Etruria. Etruria's overall influence in the Western

142 Fossa , Mancini-E. (1922) 225-231
143 D'Archiardi, G. (1929) 397-404
144 Sperl, G. (1980)
145 Voss, O. (1988) 91-100
146 Crew, P. (1991) 115
147 Chariarntini,L., Benvenuti, M., Costagliola, P., Fedi, M., Guideri, ,S., Romualdi, A. (2009) 1632
148 *supra* 1635

Mediterranean increased following these changes and, as a result of this maritime presence, the emerging Etruscan cities were perhaps instrumental in preventing the Greeks from trying to establish colonies there. These developments played an important part in initiating changes in the social and economic structure. In this context, specific evidence of ‘overseas’ trading from Elba is described in this extract from Diodorus 5.13.

Off the city of Tyrrhenia known as Populonium there is an island which men call Aethaleia. It is about one hundred stades distant from the coast and received the name it bears from the smoke (aithalos) which lies so thick about it. For the island possesses a great amount of iron-rock, which they quarry in order to melt and cast and thus to secure the iron, and they possess a great abundance of this ore. For those who are engaged in the working of this ore crush the rock and burn the lumps which have thus been broken in certain ingenious furnaces; and these they smelt the lumps by means of a great fire and form them into pieces of moderate size which are ion their appearance like large sponges. These are purchased by merchants in exchange either for money of for goods and are then taken to Dicaerchia or other trading-stations, where there are men who purchase such cargoes and who, with the aid of a multitude of artisans in metal whom they have collected, work it further and manufacture iron objects of every description.

Aethaleia – Elba
Dicaerchia – Puteoli, Campania

This general trend would continue and grow in importance. The increasing exploitation of local ore sources may well have been accelerated by the influence of the Phoenicians.[149] They were trading actively throughout the Mediterranean in the 10th and 9th centuries. The traditional date for the foundation of Carthage is 814, with settlements as widespread as Huelva (Tartessos) in the West and Al Mina in the East and these Phoenician settlements included Sardinia and Sicily. Early Greek settlers founded colonies on the most southerly coasts of Italy and whilst the motives for some were land and a new life, the search for metal ores would also have been important to them.

In this connection the Euboeans were no exception when they settled in Pithekoussai in 770 and metals and iron in particular, were their principal interest.[150] There is certainly some evidence for iron working on Pithekoussai

[149] Guido, M. (1963) 51-3
[150] Osborne, R. (1996) 114-5; Tandy ,D.W. 69 *ff*

in the form of iron slag, the original ore of which can be traced to Elba, and terracotta tuyères. Whilst the archaeological evidence to date is somewhat limited, it is sufficient to demonstrate that the inhabitants were exploiting the resources of Elba. The settlement at Pithekoussai was a sizeable operation with some 5,000-10,000 inhabitants[151] both Greek and non Greek. Whether its principal role was to acquire iron ore and process or partially process some of it into bloom[152] and then ship it to the Greek mainland or eastern colonies such as Al Mina[153] is less certain; [154] there is little evidence for any significant iron-making facilities on the island.

The comparatively large population of Pithekoussai would indicate that that it was a flourishing trading centre, confident in a continuous supply and an appropriate array of goods including iron ore for exchange. Phoenicians were amongst the inhabitants and included craftsmen and artists.[155] This is understandable because there was a Phoenician presence in Calabria before the formation of Pithekoussai.[156] Evidence of Levantine trading links and presence on the Island is attested in the form of artefacts such as seals, scarabs and aryballoi and other luxury goods of eastern provenance [157] The settlement at Pithekoussai acted essentially therefore as a distribution and trading centre [158] rather than as a producer of goods.[159]

There is evidence of Euboean contact with mainland Italy prior to any settlement; in Veii as early as 800 [160] and around 775, Greek pottery appears at a cemetery there. By the middle of the 8th century Pithekoussai and subsequently Cumae (c730BC) became an integral part of a large-scale and elaborate system for the movement of goods between that part of the western Mediterranean and the East and Al Mina, in particular working through several

---

151 Osborne,R. (1996) 114; Tandy,D.W. (1997) 71 .
152 ‘although some of it was processed on the Island, the majority was moved by ship unprocessed (Snodgrass).
153 Tandy, D.W .(1997) 68-9
154 Osborne R. (1996) 114
155 Ridgway, D (1992) 118; Osborne, R. (1996) 115 “It is not clear whether this evidence points to Phoenicians or to north Syrians, and in general it looks as if, by whatever process, Greeks and Phoenicians pursued metal resources in essentially different areas.”
156 Ridgway, D. (1992) 111
157 Tandy, D.W. (1997) 67; Osborne, R. (1996) 115
158 Osborne, R. (1996) 118
159 Tandy, D.W. (1997) 69
160 Coldstream, J.N, (1968) 335; Tandy, D.W.(1997) 66

Greek mainland coastal settlements, confirmation of an active East–West link. [161]

Settlements such as Veii and Tarquinia grew steadily, both materially and culturally. The radical social and economic changes mentioned earlier namely, the emergence of ‘proto urban’ settlements, a higher degree of settlement hierarchy and a more systematic control over natural resources and trading routes, were most evident in southern Etruria This was reflected not only in the greater stability of such urban settlements but also in the development of craftsmen’s and artists’ skills. A major contribution was made by Greek craftsmen, either visiting or recently settled. Ideas were exchanged and new skills learned. “Both sides were pleased to participate…the local ironworking skills of the Etruscans improved as the number of chevron *shyphoi* brought in by the Euboeans increased – ‘a clear case of cause and effect’ [162] In turn, the arrival of Euboean potters led to a flourishing local production and, in the field of metalwork, the fact that both the quality and quantity of the work improved rapidly owed much to the expertise from overseas. Artisans began to specialise and work in a more ‘industrialized’ environment.[163] One result of this interchange of ideas is readily seen in the field of pottery. Black Figure pottery was very popular and made extensively in Athens and Corinth in the seventh and sixth centuries. Its colour combination was very distinctive and required controlled changes in the firing process to produce the desired effect.[164] Its popularity then spread to Etruria, where in time it was produced locally. This would have been a major step forward for local potters whose output previously had been simple *impasto* ware and they would have doubtless been assisted by immigrant Greek potters. Etruscan-made Black Figure pottery was subsequently exported to Greece. Techniques then moved a further step forward with the introduction and production of *bucchero* pottery which was developed in Etruria and was subsequently exported widely. The special feature of this type of pottery was its surface which had a highly polished metallic sheen. The popularity of this pottery with its metallic imitation

---

[161] Tandy, D.W. (1997) 70-71
[162] Tandy, D.W.(1997) 67 & Ridgway, D. (1992) 137-8
[163] *Cambridge Ancient History* chap 13
[164] See Chapter 2 Pottery above

effect may well have been influenced by the overall demand for all things metal. From a technical point of view, it was fired in a highly reducing atmosphere and used a highly refined type of clay, possibly with the addition of carbon black.[165]

As far as metalworking was concerned, the techniques enabling a more visually attractive detail to be added to objects such as granulation, filigree, embossing, and lamination were in evidence. Those techniques, in conjunction with improvements in the more basic elements of metal smithing gained from both local and immigrant craftsmen, is reflected in full the range and style of metal objects made.

It is logical to suppose that the mobility of overseas craftsmen was an important step in the transference of techniques in both pottery and metalworking. It would seem to have been particularly effective because the indigenous craftsmen had the basic skills and motivation to absorb and learn. Immigrant and local specialists worked successfully side by side, to the overall longer term benefit of the Etruscans. In the eighth century, Assyria's aggressive expansion into Syria and Phoenicia led to displaced or disaffected artisans looking westwards.[166] As far as Greece was concerned, the role of warrior/explorer is exemplified in the legends of Homer in the Odyssey, with the ritual of the *symposium* and the exchange of gifts being an important part of their travels..

The main distribution of imported exotic or luxury goods is found mainly in southern Etruria, rather than in the north, and it can reasonably be assumed that the wealth created there reflected the increased level in trading activities. This wealth enabled luxury commodities to be bartered to support the lifestyles of the elite classes. Corinna Riva makes the point that the specifically eastern origin of such goods was important to elites because it enabled them to articulate political power and to negotiate socio-relations in

[165] Rasmussen, T.(1979) cited in Barker, G. and Rasmussen, T. (1998) 203
[166] Kuhrt, A (1995) 409; Barker G. & Rasmussen, T. (1998) 119

their own societies. The exclusive access they had to eastern goods through the providers of those goods enabled them to do this.[167]

Whilst there is much evidence of Etruria importing goods from a variety of sources, evidence of what was exported is very limited; 'everything suggests that the riches Etruria was able to export were un-worked metals from Etruscan mines.'[168] The position had changed by the 6th century with the export of pottery to Greece and wine to settlements on the southern coast of France.[169] The cities in the south such as Tarquinia and Veii appear to have benefited earlier from these exchanges than those in the metal rich areas in the north. A Greek colony in Cerveteri and a sanctuary at Gravisca (the port of Tarquinia) support the presence of such trading. The reason for the earlier rise of the southern settlements may lie in the fact that it was those centres which specialised in brokerage.[170] They had direct access to wider markets and with that access to a greater number of trading contacts and hence markets.

It would seem possible therefore that the initial trading in metals or their ores took place between the elites in the north, who seemed to be increasingly exercising control of the resources, and traders in the south.[171] In northern Etruria, there appears only a limited trace of an early Greek presence to be found. In Vetulonia, a large number of bronze objects have been found whereas imported Greek objects such as painted vases are scarce. This difference between north and south narrowed over time; Populonia having developed initially more slowly as a trading centre.This difference between settlements, such as Tarquinia and Veii in the southern part and Populonia in the north, is perhaps reflected in Populonia's late entry into the Etruscan League of twelve cities (Servius,*ad Aen., X, 172).* The development of Populonia will be covered in detail in the next chapter. In the meantime, suffice to say that by the early part of the first millennium, it had established

167 Riva, C. (2010) 46-47
168 Pallottino, M. (1974) 87
169 See p53\ in this chapter & n174
170 Pallottino,M. (1974) 87
171 This does not exclude of course the metal resources situated in the Tolfa hills between Cerveteri and Tarquinia.

itself as a metal working area with copper and bronze and with this development; a basic network of artisans' skills would have been built up. In addition, Populonia was exceptional as being the only one of the twelve cities to be located by the sea. This enabled it to exercise some control of the coastline and provided, through the presence of their ships, a defence against potential predators. It also gave it access to the other sources of ore, particularly those from Elba. At the turn of the millennium, the technical and artistic influence of Populonia came naturally from Sardinia, but later on some of the Greek inspired innovations and techniques would doubtless have come from southern Etruria.

Reverting to more general factors, the widespread presence of Etruscan ships doubtless played a significant role in their control over the sea routes. The development and expansion of trade in the Tyrrhenian and western Mediterranean meant that Greek, Phoenician and Etruscan seamen were all involved and the interregional nature of the trade is illustrated by the widespread origin of goods found in a shipwreck off the Giglio. In addition to Etruscan goods, these included Phoenician amphorae, Corinthian and Spartan pottery, and Corinthian bronze-work.[172] Areas of influence, namely those requiring protection to prevent acquisition by other parties, were all trade related at that time. Whilst no power maintained a standing fleet, powerful groups of ships were assembled to protect or expand important commercial trading routes.[173] In this sense, the Etruscan ships were no exception. The Etruscans had developed in the sixth century a large trade in wine-containing amphorae shipped not only to Sardinia but also to the southern coast of France,[174] and Etruscan sea power enabled that trade to take place. The conflicts between Greek colonists and Etruscan maritime traders in relation to keen commercial and territorial competition around the coasts of Italy gave rise to accusations of piracy by Greek authors. But the Greeks were unable to establish colonies giving direct access to metal ores.

[172] Barker, G. &Rasmussen ,T. (1998) 215 ref Bound 1990 'In search of an Etruscan wreck' *Minerva* 1.1: 3-6
[173] Starr, C.G. (1989) 54
[174] Morel J-P. (2007) 492 Evidence that in the first part of the sixth century, practically all the wine drunk in Massalia came from Etruria ; Bats et al (1992) *passim* 263-78

They did however establish a colony at Massalia around 600BC. When Carthage imposed control on the Phoenician colonies in western Sicily and Sardinia, it gained entry into the Tyrrhenian Sea. With Carthage and Etruria having common interests, they combined their naval forces to defeat the Phoceans in a battle off Sardinia, (540BC). In the main, the Etruscans were involved in coastal activities, although the development of Etruscan shipping culminated in their domination of the Tyrrhenian Sea.[175] J-P Morel, when commenting on the prevalence of land communication rather than sea, writes that 'this did not prevent the Etruscans from being counted as one of the "thalassocracies" of antiquity from frequent naval warfare or from vigorous maritime commercial expansion.' Their ships enabled the export of numerous amphorae and Etruscan vases to take place.'[176]

SUMMARY

By the end of the 8th century a series of 'urban' settlements had been or were in the process of being established in Etruria and many were taking a more active role exploiting their mineral resources. Evidence as to how this was achieved is limited but one may conjecture as follows. Firstly, the Etruscan elites may have introduced some form of control over the natural resources with the elites in authority and by siting settlements strategically. Importantly. control was maintained despite intense 'interest' shown by both the Phoenicians and the Greeks. And it would seem the method by which it was achieved proved to be successful. External relationships remained good, no major internal conflict ensued and the ruling classes, at least, prospered. Secondly, they possessed within their communities the basic underlying technical expertise in working with metals that would have been developed over many earlier centuries.

The wide-ranging changes in Etruria which occurred during this period, 9th to the 6th centuries, were influenced greatly by contact with both Sardinian and Greek traders and craftsmen. That the arrival of the Greeks had a profound

---

175 Pallottino, M.(1974) 89
176 Morel, J-P.(2007) 494

impact on the lives of native Etruscans is not in doubt,[177] but the background experience and influence of the earlier Villanovan settlements in the north and the indigenous skills and expertise acquired by early Etruscans should not be underestimated. Etruria emerged at the end of this period having a diverse 'economy' based on farming and metal working. This in turn supported a maritime presence. Whilst much of the discussion above has been directed towards metal resources, agriculture remained at the heart of the Etruscan economy. The Etruscan countryside is naturally fertile and the steps taken to improve its potential output by better utilisation of existing land and the reclamation of previously unworkable land ensured that they could support a growing population. Etruria was not alone in this improvement in agricultural productivity although in grain production archaic Etruscan yields were remarkable, some three times greater than that of Latium. [178] Agricultural output did also improve in other areas of mainland Italy at that time (700-500BC); but not to the same degree;[179] with Etruria producing, on occasion albeit rather later in the fifth century, a surplus of grain alleviating shortages in Rome on several occasions[180] Running alongside this agricultural economy, however, were successful activities in both mining and 'manufacturing' which covered pottery as well as metal smelting and smithing. The latter would have been principally related to bronze at that time (first half of the 1st millennium). Finally, the Etruscans built on and extended their overseas activities resulting in an economy which was both land and sea based,

This period of very active interchange of culture and ideas brought about by overseas contact can be viewed in the context of influential changes which were taking place throughout the eastern Mediterranean; 'increased levels of interaction through long-distance movements of human groups transformed the Mediterranean into a *ciment liquide,* an open stage for the cultural exchange of cultural stimuli.'[181] Metal ores and metalworking skills provide a constant theme; Phoenicians, Sardinians and Greeks sought supplies of metal

---

[177] Cornell, T.J. (1995) 187
[178] Cristofani , M. (1986) 77-156 in Morel J-P (2007) 492
[179] a more general study is undertaken in Chapters 8 and 9

[180] Chrisofani, M. in Morel.J-P. 493 n65 and Livy 2,34,5 & 4.52,5
[181] Riva, C (2010) 55 citing Gras, M. (1995) 4

in the western Mediterranean and the rise of interest in sources of iron will have accentuated that.

This was a period of great movement of goods driven by desire rather than need for overseas objects which conveyed status to the consumer. Together with this movement of goods came the movement of people[182] and with it a potential and practical mechanism for effective technology transfer. The results of this were clearly shown in the presence of imported artefacts and the introduction of new skills. Etruscan craftsmen were not without metalworking skills with their knowledge of making copper and bronze artefacts. Contact, arising from the trading of metallic ores, gave them the opportunity to improve and update these skills which they took. In the main, the beneficiaries were the Etruscans and principally the local elites who retained control over their indigenous sources of raw material. During the beginning of that period, Etruria developed as a maritime community, thus protecting its coastline and opening up opportunities for safer or more widespread trading. No Greek settlements or colonies were established in the area of Populonia and Elba.

The Etruscans appeared therefore to be an ‘outward’ looking community effective in adding value to their considerable natural resources and interested in expanding their overseas trading contacts as part of this. Significantly, though, it was the large resource of metal ores which distinguished Etruria from the majority of the other Mediterranean countries and which was the basis of much of the widespread overseas interest. The approach taken to exploit these assets is noteworthy. The elite were motivated by a strong desire to ensure that their status would be defined in terms of exotic and luxury goods and this status would continue to be reflected in funerary goods as displayed in the princely tombs – a tradition going back to earlier Villanovan grave goods. An integral part of this aspiration was the ability to acquire these objects, hence the aim of generating wealth or added value which was required to achieve that goal. The metalworking experience of local craftsmen

[182] Foxall, L. (2005) 234

enabled them to extend and update their expertise by learning from and working with artisans from Sardinia and Greece. 'The rise, in the sixth century, of a class "nouveaux riches" originating in manufacturing and trading and claiming equal status with the old landed aristocracy documents the scale of social mobility' [183] The fruits of this successful technical transfer led in turn to a thriving 'industry' which embraced pottery as well as metalworking. One can only speculate about the underlying characteristics of the Etruscan community but their strong motivational attributes and successful exploitation of key resources indicated an entrepreneurial and resourceful attitude.

[183] Cristofani, M. (1986) 114 in Morel, J-P (2005) 494

CHAPTER 6 **METALWORKING IN ETRURIA: first millennium BC**

1 Introduction

The last chapter covered the general progress which took place in Etruria essentially during the Late Bronze Age and early Iron Age; the social changes which took place, the impact of extensive metal resources and the influence of overseas communities. This chapter concentrates on metalworking and essentially that which took place at Populonia. After an introduction summarising the period 8th to the 6th centuries, the transition from bronze to iron as evidenced by both archaeological and metallurgical studies is covered as well as analyses of the ratio of bronze and iron funerary objects. A description of the available archaeological evidence of the actual smelting sites relating mainly to the period 6th to the 5th century follows. This chapter concludes with examining more general evidence relating to Populonia's growth in prosperity, changes in social structure and patterns of working which took place between the 6th and the 2nd centuries BC.

2 Populonia: 8th – 6th centuries

Populonia continued to grow from a group of settlements at the turn of the millennium into a single established community. During the last quarter of the 8th and the first quarter of the 7th century BC, a new and significant expression of status was demonstrated by the construction there, by the aristocratic elite, of a new type of tomb, *camera a pseudo cupola con avancorpo* e *crepidine cilindrica.* The elite controlled both the sources of the ore, their working and outlets to the sea, all of which will have contributed wealth and prestige. [184]

During the 6th century the layout of the necropolis altered, indicating that changes in social structure were taking place. These structural changes hint that they were connected with the exploitation of iron now coming under the control of the *polis*.[185] Together with individual sepulchres in large tombs, there are tombs for middle-class individuals including foreigners, Greeks and *Italici,* associated with controlling and managing production operations,

---

[184] Romualdi, A. (1993) 93
[185] Romualdi, A. (1993) 102

particularly those relating to iron.[186] Details of evidence for the sites of iron smelting are given below.

3 The transition from bronze to iron in the 8th and 7th centuries

Apart from two hoards of copper ingots found near San Michele (18th to 17th century BC), there is little or no evidence to date of copper production until the 9th to 8th century.[187] In the Gulf of Baratti, the presence of ancient copper slags was reported in the 1920's by Fossa Mancini,[188] D'Archiardi, [189] Sperl, [190] Voss, [191] and Crewe.[192] In the latter part of the twentieth century and the early part of this century, the relative importance of the extent of copper slag was raised and will be discussed further in the next chapter.

Bronze artefacts found in tombs in Massa Marittima and Populonia and more recent analysis work on copper slags confirm the date of 9th to the 8th centuries for the beginning of copper and hence bronze production. The analysis work and the resultant conclusions referred to here are based on work carried out by the University of Florence.[193] Previous analyses were carried out on scattered samples of ill-defined provenance. In this recent and extensive programme, the layers from two stratigraphic columns of deposited slag were assessed. They indicated a number of heterogeneous layers from which it could reasonably be deduced that they represented a discrete sequence of deposited metallurgical waste. The bottom layer is essentially a layer of copper slag containing 'abundant pieces of copper slag.' Above that are intermediate layers containing a mixture of iron, sand, and copper waste and finally the uppermost layer, and by far the largest, contained iron slag (80%).[194]

---

186 Romualdi, A (1993) 105
187 See above Ch. 5 p41
188 Mancini, E. Fossa.(1922)
189 D'Archiardi, G. (1929)
190 Sperl, G.(1980)
191 Voss, O. (1988) 91-100
192 Crewe, P.(1991) 109-115
193 Chiarantini,L., Benvenuti,M., Costagliola,P., Guideri,S., Romualdi,A. (2010) 1626-1636
194 A straightforward assessment of the thickness of layers shown clearly in Fig 3 p1628 (re: footnote 10); layers K&L iron slag 80%; bottom layers D/Z and W/Y mainly copper slag(10%) intermediate layers C&P mixed slags(10%). Estimated with the aid of a ruler

This research shows that the copper working taking place at the Baratti site was significant, although it was not by any means as large as that for iron working, and dates from the 9th to the 8th centuries. Detailed mineralogical and compositional analysis indicated that the copper was smelted in a well controlled and highly efficient way which would have required high technical skills. Finally, the analysis and radio carbon dating of the intermediate layers indicated the transition period, copper to iron, as occurring in the 8th to the 7th centuries. This agrees with the increasing number of iron artefacts found in tombs. The stratigraphic results also suggest that 'after an undefined (presumably short) time span of co-existing copper and iron production, metallurgical activity at Baratti definitely focussed on iron.'[195]

The evidence this work has provided, confirms the more general historical view of the progress of metal-working, and iron in particular, gained from the study of artefacts in Etruria. In general terms, Italy was some 200/300 years behind the eastern Mediterranean communities in the transition from bronze to iron. There is evidence of only a few isolated iron objects dated to the Late Bronze Age in central Italy. During the 10th and 9th centuries, the number of iron artefacts began to increase. A few small objects and fragments, which relate to that period, have been found but generally the number is small. Iron objects, generally weapons and fibulae, appeared to increase during the 9th and 8th centuries. But it was during the 8th and 7th centuries that the number of iron artefacts increased significantly; several examples were excavated at the Villanovan site of S Vitale near Bologna. The transition from bronze to iron started in the middle of the 8th century and increased greatly during the Orientalising Period;[196] a change which signals the start of the making of meaningful amounts of iron and their use in a wider variety of applications.

[195] Chiarantini *et al;* (2010) 1632
[196] Giardino, C. (2003) 491

4 Recent data on smelting and smithing in Etruria and southern Italy, 7th and 6th century BC. [197]

Smithing: Recent archaeological work in Rome on the Capitoline hill and in Caesar's forum has uncovered several forges dating to the 7th century BC The activity of the forges there extended to at least the 6th century AD when iron items were produced for the construction of large temples. The presence of so many forges is further evidence that in Rome (and possibly throughout Etruria) iron was becoming a common material as early as the 7th century.[198]

Smelting/smithing: From the work and excavations carried out in Rome and in southern Italy, it would seem that the activities of smelting and smithing were often located in different locations. In the Capitoline excavations, abundant smithing slag and hammer slag was found and whilst fragments of bloom were found, there has been no evidence of primary smelting.[199] Recent studies on iron-working centres in Roman times in Southern Italy (Campania, Apulia, Calabria, and Basilicata) indicate that forges were located inside cities, that is, close to the centres of population and the market, with only a few in country settlements serving local needs.[200] Comparative evidence exists from different places and periods for the separation of smelting from smithing. New evidence of primary iron production from local iron deposits comes from a site in southern Apulia although it is from rather later times, Roman-Byzantine.[201] This may provide a tentative association with a 9th century AD site in northern Apulia being a smelting centre and hence not merely an 'iron workshop'.

5 Transition Bronze to iron: funerary artefacts

These recent finds generally support the detailed evidence underpinning the time frame of the transition from bronze to iron. This evidence can be seen in the analysis of funerary objects found in tombs in Populonia and Massa

---

197 Benvenuti,M. Corretti,A. Giardino, C. in notes given in ESF Exploratory Workshop, London, 2010

198 De Santis et al in press Giardino, C. in ESF workshop

199 Giardino and Lugli, (2008) Giardino, C. in ESF workshop

200 Quercia, A. in press Giardino, C. in ESF workshop

201 Giardino,C. and Spagnolo,V. in press Giardino,C. in ESF workshop

Marittima. A. Minto compared the proportion of iron and bronze weaponry objects, *armi*, between the Villanovan and Orientalising periods excavated at Populonia. The weaponry objects were subdivided into spear heads or lance tips, blades, daggers and axes. This comparison clearly illustrates the scale of the transition.

Summary of the comparison: [202]

	Items analysed	*bronze*	*iron*
Villanovan period,	27	26	1
Orientalising period:	132	27	105

Whilst the evidence comes from tombs and funerary items and therefore does not reflect general usage, it does show that these objects were considered prestigious and of value.

This transition is similar to that which occurred in the eastern Mediterranean between the 12th and 10th centuries,[203] reflecting a two to three century delay in Italy in the uptake of iron technology; this point will be discussed in more detail later. In Minto's analysis, the proportion of iron to bronze in the Orientalising period is very marked, although the extent may perhaps be partially explained by the looting of bronze artefacts; it does not however alter the measure of the transition.

As far as *end use* applications were concerned, artefacts were sub-divided in this analysis as follows: lance, giavellotti, spade e daghe, pugnali, asce, coltelli, elmi, scudi and schinieri. Within this group, asce (axes) (11) and coltelli (knives) (10) were all made from iron, whereas elmi (helmets) (6), scudi (shields) (2) and schinieri (greaves) (6) were all made from bronze. The overall significance of these figures lies not only in the end use of the iron artefacts, but also in its total.

A more detailed analysis was also carried out based on data published in *Studi Etruschi* and *Notizie degli Scavi* between 1917 and 1938, relating to

---

[202] Minto, A. 1943; 68/9 and 108/9

[203] Chap 4 above p31 Table IRON vs BRONZE

artefacts excavated in Populonia and Massa Marittima by A. Minto and his colleagues. It determined the number of iron artefacts found and their uses including those other than weaponry. [204] The details are given below and can be summarised as follows:

	Weaponry (armi)	65%
	Utilitarian items (utensili)	20%
	Personal effects (personali)	15%
Based on	Total number of artefacts	99

Sources	POPULONIA			MASSA MARITTIMA			TOTAL	
	1	2	3	4	5	6	*%*	
ARMI								
Lancia – cuspide/ punte	2	9	8	10	4	10	43	
Lama spada/ coltelli	3	2	3	4		2	14	
Ascia/ accetta -	1		1	2	2	2	8	*65*
UTENSILI								
Alare	1	5	1	4			11	
Spiedi		1	1	3	1	1	7	
Ferro di cavallo		1	1				2	*20*
OGGETTI PERSONALI								
Fibula			2		3		5	
Armilla tubulare						2	2	
Candelabri	1		1	1		1	4	
Reggivasi					3		3	*15*
	8	18	18	24	13	18	99	

Sources:

1	Notizie degli Scavi	1917
2	,,	1921
3	,,	Vol X 1934
4	Monumenti Antiche	Vol 34
5	Studi Etusche	Vol LX
6	Monumenti Antiche	Vol 35

The weapons group contains items similar to those in the earlier summary, namely lance/spear tips, swords, knives, axes. That these comprise two-thirds of the total points to the fact that the usage of iron was directed towards its potential special properties of enhanced hardness and its ability to create and

[204] Data included in the weaponry section for Populonia will have been included in the summary above

maintain a cutting edge. Of the remaining items, 20 are described as utilitarian; of these 18 are spits and firedogs, applications which may have made use of iron's higher melting point than bronze. The last section, personal objects, includes fibulae, bracelets, candelabra and pot/vase supports. These probably reflect a straight replacement of iron for bronze, perhaps indicating the element of prestige in the earlier days and followed by increased availability of iron later on. Whilst we have no real evidence of the extent of iron production in the 8th and 7th centuries, it is the number of iron artefacts found in comparison with the previous two centuries which is significant and indicates that the technology of iron was becoming established.

Excavation work done at Satricum in Lazio showed evidence of iron-working from the second half of the 7th century. In one votive deposit, by far the largest numbers of artefacts were made of iron with scarcely any bronze tools present.[205] As indicated above, because of possible theft of bronze objects, the significance lies more in the extensive number of iron artefacts present rather than the very small number of bronze ones. The processing of iron, scarcely documented in the 8th century, intensified significantly during the 7thcentury. Reference has been made to the selective use of the 'special' properties of iron, but evidence to demonstrate that iron produced actually delivered these properties is difficult to establish and direct technical evidence is limited. Two knives and two axes have been examined metallographically.[206] Three of the samples had a cutting edge hardness of 245-290 Hv with medium to high carbon steel levels and demonstrate a degree of carburisation. These hardness levels indicate some measure of 'control' in achieving an increase in hardness of iron over that of hardened bronze;[207] however, these levels fall well short of those obtained by quenching where levels of 800-900Hv are achievable. The fourth item, an axe, had a low level of carbon in the iron and was relatively soft,135-187 Hv.

---

205 Nijboer, A. (1998) 251-257
206 Nijboer, A. (1998) 248-9
207 See graph Fig VI.I Chapter 4 p34

During excavations in Populonia carried out by Prof Bartoloni (2004), some 20 iron artefacts were assessed visually and the three least corroded samples[208] were then examined by Prof Giardino.[209] The corrosion, exhibited by the iron oxide levels (Fe 75-90%: O 25-10%), was such that no meaningful conclusions could be drawn about carburisation hardness levels. Corrosion damage is widespread with iron artefacts in western Europe,[210] more prevalent in fact than in the eastern Mediterranean countries which have a much drier climate. The corrosion made detailed archaeometallurgical analysis extremely difficult.

To sum up therefore, during this period there is a strong case for saying that a basic iron technology was being established. The overall number of artefacts produced, whilst not great in number, was significantly greater than previously. The momentum grew during that time and the emphasis on the usage of iron in weaponry indicated that some measure of control over iron processing was beginning to become established. The control required for the process to be effective needed an experienced operator to assess the 'optimum' conditions for smelting and the subsequent smithing and forging - very much the skills of an individual artisan. The Etruscan metal-smiths, already very well versed in the workings of copper, were beginning to understand the basics of working with iron. This phase also marked the beginning of Populonia and its surrounding area as a centre for iron-making.[211]

---

208 The samples were chosen from artefacts excavated from Tomb 7; US129 8th C; Tomb 8 , US 337 late 6th C; and Tomb 38, US 361 late 7th C and the examination carried out at my request.

209 Analisi metallografia ottica ed electronica d'oggetti in ferro da Populonia Claudio Giardino - submitted to a congress in Rome June 2005 ; samples examined under a Cambridge MK 250 electron microscope

210 Waarsenberg (1994) 432 writes 'although the North West necropolis has produced a fair amount of iron weaponry and utensils, most pieces have decayed beyond recognition' from Nijboer, A.; 245

211 Minto A. 105. 'il graduale trapasso dal bronzo al ferro nella fabbricazione delle armi, che monstra, con altri prodotti della metallotechnica populonese, la preziosità del ferro rispetto al bronzo, nella prima fase del periode orientalizzane, preziosità particolarmente notevole per il maggiorcentro minerario, industriale e commerciale del nuovo metallo sulle coste tirrene.'

6 Populonia; Iron in the 6th and 5th centuries

During the 6th and 5th centuries the production of iron took a major step forward. It had progressed from the making of speciality iron artefacts into large-scale production by the 4th century BC. All known European bloomeries dating between 600 and the end of the millennium were overshadowed by the production of iron at Populonia.[212] The raw material source which enabled this large production of iron to develop was the high quality ore available from Elba. This began to be exploited systematically in the second half of the 6th century and which coincided with the development of the extensive slag deposits in Populonia.[213] Basic production of iron existed already on Elba [214] but the consensus view is that it was not developed fully because of the insufficient supply of wood to produce the necessary charcoal and the comparative ease of transporting the iron rich ore to Populonia.

The available evidence to be considered next in this context is that of the buildings, furnaces and ancillary facilities associated with iron-making. The site at Populonia in the Gulf of Baratti has been excavated extensively. Martelli carried out work on the 'industrial' quarter buildings at Porcareccia between 1977 and 1980.[215] This showed that iron working took place there from the 6th century onwards, 'at least a century earlier than previously thought.' [216] The settlement was situated outside the city walls but not far from the urban centre. A road, probably from the Hellenistic period, linked this quarter to the upper city.

The position was well sited, close to the coast and so convenient for receiving or delivering shipments. It had a good water supply and was suitably exposed to make use of the prevailing wind for ventilation and draughts. The site was developed in phases starting from the end of the 6th and proceeding through to the 2nd century. An important feature within the settlement was the proximity of two areas: the zone 'di abitazione' and that of 'l'attività metallurgica': the

---

[212] Pleiner, R. (1980) 385.
[213] Cristofani, M. and Martelli, M. (1979) in The Etruscans; (1998), 206, Barker & Rasmussen
[214] See p 48 above Diodorus
[215] Martelli, M. (1981)
[216] Benvenuti et al, (2000) 68

living and working areas. Iron slag, tuyères and rudimentary furnaces were found together with fragments of *bucchero* pottery, enabling the material to be dated to 540-530BC.[217] The development of the site was evidenced by a series of clay floors stratified and placed on different layers of slag deposits. The walls in the necropolis were made of regular stone blocks and covered with red plaster made from lime and sand. Numerous pottery fragments were found in funerary urns relating to the first half of the 6th century and continuing into the 3rd century. They included pieces from a Corinthian *aryballos* which contained inscriptions which referred to *allogeno di condizione servile* and *personaggi di rango servile.*[218] In another fragment, an inscription in Etruscan gave the name of the object's owner together with an indication that some of the workmen employed there were foreign and of low status.[219] The significance of status of some workers will be discussed later in the chapter. Below the floor in several rooms, a system of water channels passing through openings in the walls looked as if they had conveyed waste water to an external ditch. In the later phases, probably the 3rd century, a furnace was found with a grating. This was very similar to that found in the settlement of Madonna di Fucinaia near Campiglia Marittima. The furnace at Populonia was situated outside the buildings and whether it was used for roasting ores or firing pottery remains open at this time.[220] In the Casone necropolis, fragments of furnaces and bellows were found. The comparative paucity of evidence of furnaces is probably a reflection of the fact that furnaces had a limited life and were often damaged gaining access to the bloom iron. So furnaces were replaced regularly and as the slag built up, metal-smiths moved on to new sites.

A more complete excavation has been carried out at a site in Rondelli in the Gulf of Follonica, a bay adjacent to Baratti. It is a settlement dated between the 6th and 5th century.[221] It covered an area of some one thousand square

---

[217] Romualdi, A. (1993)106 L*a Polis nel Periodo Archaico e L'attivita di Lavorazione del Ferro*

[218] Maggiani, A. 184 L'Inscrizioni di età Tardo-Classica ed Ellenistica in *Populonia in età Ellenistica: i materiali dale necropoli* Firenze: Il Torchio. Ed Romualdi, A (1993)

[219] Romualdi, A. (1993) 108

[220] Martelli, M. (1981); Romualdi, A. (1993) 106/110.

[221] Ciampoltrini,G and colleagues *see* Aranguren,B.M.

metres and was developed in stages. The site was divided into two, the areas being quite clearly defined and adjacent to one another. One area was domestic, a ‘zona abitativà', the other was a working area - a ‘zona industriale', where iron processing took place. As far as the living area was concerned, briefly, in the earlier phases the nature of the stake holes indicated that they supported a roof probably covered with perishable materials. There was also evidence of domestic hearths. In the later phases, foundation walls were found which were constructed of cut stone and related to a rectangular building 4.5 metres by 7 metres. Stake holes and ceramic fragments indicated that it was covered with a tiled roof. A variety of artefacts including imported pottery such as Phoenician-Punic amphorae and pieces of black painted Attic ceramics enabled this phase to be dated to the 5th century.

Of more interest here, though, is the ‘zona industriale', an area identified by the presence of furnaces (or at least their bases) and large quantities of slag. Twenty one furnaces were found, although the amount of slag and related fragments and debris indicate the likelihood that there were several more. The furnaces were made from clay set in a foundation made in the ground, some 80 centimetres wide and 30 centimetres deep. A layer of bricks was positioned on the rim of the hole, bound together by sandstone and clay. The body of the furnace was then built on top of this. Fragments of the furnace (normally destroyed after the smelting process) and pieces of air intake tubes, tuyères, were identified in the residues. The furnaces were probably positioned in a battery or line, as is suggested in the later phases where the remains are better conserved. In addition, a large basin 2.5 metres deep and 2.5 metres in circumference, partially excavated from the residue, was found. This is likely to have been used to prepare the clay mixture for the making of the furnaces. In the later phases, furnaces were identified with a raised rim made of stone as well as some with a semicircular section, the straight edge of which was also of stone. By way of background interest, archaeometallurgical analysis of the residue found in one of the furnaces showed incomplete reduction of the iron oxide - an early example of faulty processing. As far as structures were concerned, two types of stake holes were found. The larger type had a diameter of 35 cm and was probably used for pillars to support a tiled roof. The overall results of the Rondelli excavations indicate a move towards a larger scale of smelting operation; a change from the traditional individual metal-smith working alone to a number of metal-smiths working at a single location. [222]

7 Populonia: 4th to 2nd century BC

Early in the 4th century, in contrast to a recession in the southern cities of Etruria, Etruria Padana and the more northern parts of Etruria flourished with Populonia playing a singular role exhibiting some aspects of a city from Magna Graecia. [223] Between the end of the 4th century and the first half of the 3rd century, Populonia expanded at an exceptional rate by Etruscan standards, as evidenced by a large increase in population and together with the continuing expansion in ironworking. This in turn was reflected in the size and scale of the necropolis with the wide variety of tombstones. Populonia also became an important distribution centre for goods made in the southern cities of Etruria as well as those from Roman and Faliscan settlements. Monetisation in the form of bronze and then silver coins was introduced probably to aid trading transactions. Numerous pottery fragments from overseas countries were found. These indicated that people from varying social backgrounds came from Greece, Spain and other parts of Etruria as well as Campania, Sardinia and Corsica. [224]

A brief lull in Populonia's progress in the middle of the 3rd century was evidenced by a reduction in the number of sepulchres and ceramic fragments relating to that period and the apparent cessation of activity at the iron workings at Poggio della Porcareccia. This 'mini crisis', which coincided with the Roman acquisition of Etruria, was comparatively short lived [225]and by 259BC Livy wrote of Etruria supplying iron to help in the building of ships for

---

[222] Subsequent investigation has shown that the operation at Rondelli 'provides a precise archaeological parallel to the commercial network and iron working described in detail by Diodorus, 5,13. Ciampoltrini,G and Firmati, M. (2002/3), 33-36

[223] Romualdi, A.(1993) 118

[224] Romualdi, A (1993) 122-125

[225] Romualdi, A. (1993) 125-126

the Roman navy.[226] Thereafter, Populonia continued to flourish both economically and socially,[227] the benefits of which spread throughout Etruria. It resulted in the reconstruction of a vast urban area and the construction of new buildings. By the end of the 2nd century Populonia had become an established maritime trading city. [228] Over the last eight centuries it had been transformed from a Villanovan settlement into a prosperous city.

8 Changes in social structures and working patterns

Reference was made in the introductory section to settlements being formed in Etruria in the late Bronze Age and the start of a trend towards urbanisation and centralisation. During the Iron Age many of these settlements grew into centres with urban characteristics, [229] and with this came an increase in craft specialisation, 'inherent in the development of urban centres'.[230] The trend towards workshop production in the overall context of specialisation and 'urban' development applies of course to all crafts with established technologies. In the case of pottery, the evidence in support of this is comparatively widespread, with iron it is more limited.

Outside Etruria in Satricum, there is widespread evidence of workshop production. In Populonia, the changes in social structure and organisation in the 6th century gave rise to the formation of a *polis.* One might conjecture also that a trend towards managers or persons being employed full time to take a more direct role in the running of smelting operation was taking place; that person possibly coming from overseas.[231] Whether they were experienced

---

[226] Livy, 28,45

[227] At an informal seminar (Sept 2005) held in the Parco Archaeolgico di Baratti, a summary of recent work carried out in Etruria was given This included *Indagini archeologiche nel golfo di Baratti, nuovi dati sulla produzione del ferro.* which included a contribution by Guideri, S. Benvenutu, M Chiarantini, L. from the University of Siena. Their view was that metallurgy boomed in the 2nd century BC after the region passed under Roman control and that change implied a change in the way iron production was organised.

[228] Romualdi, A. (1993) 126 & 129

[229] Bietti Sestieri, A.M. (1997)

[230] Nijboer, A. (1998) 35-37

[231] Romualdi, A. (1993) 105 ‘Con ogni probabilià invece negli individui sepolti nelle tombe a cassone quel ceto intermedio, formatosi anche con l’apporto di elementi stranieri, greci ed italici, che dovere controllare e gestire I commerci e tutte l’attività manifatturiere, in particulare quella del ferro.’

metal-smiths or just good organisers we do not know. The inference is that iron making was becoming a more organised activity.

The significance of the excavation work at Rondelli is the identification of adjacent but clearly defined areas of '*industriale*' and *'abitativà'*. This indicates an important trend in the *way* metal-smiths worked; a change from the traditional 'individual' way of working with the experience and expertise closely linked to an individual, the itinerant metal-worker, towards a more communal way of working or at least artisans working side by side. This was not exclusive to Populonia. The work carried out at Satricum, detailed workshop production of iron. Here the transition from copper/bronze to iron took place in late 8th century. The separation of living and working quarters was not new either; there is evidence of this in pottery production in Sumerian times. But in the case of iron, it may be considered an important step in the process of making larger quantities. As has been emphasised earlier, iron making involved a series of physically strenuous and critical processes. The proximity of iron workers working together would have facilitated the interchange of ideas and techniques. If they worked communally, it would also have spread the not inconsiderable risk. The investment in terms of ore, charcoal and physical effort was great. A 5-10% conversion rate and little realistic opportunity to recycle incorrectly smelted iron (unlike copper) would seem a powerful incentive to co-operate. All of this may have helped progress the smelting procedures towards a more reliable process. There is some indirect evidence to support this and that is the employment of unskilled or lower grade labour. The more controllable the process, the more an experienced metalsmith can delegate the less critical parts of the process. One may surmise therefore that this development would make it possible for less experienced workers to undertake some of the work. With iron production in ancient times, increases in quantity were obtained not by using bigger furnaces but by increasing the number of furnaces. Given the fact that ore and charcoal were freely available, the availability of experienced metal-smiths may well have been a factor.

9 Summary

A critical contribution to the growth of Populonia and its resultant prosperity was its approach. Initially based on making bronze and then iron in volume, it reflected an industrial approach.[232] Populonia became a rich city and successful trading centre. This arose from its ability to harness the plentiful supply of metal ore present in the Colline Metallifere and subsequently iron ore from Elba. It required experienced metal-workers to smelt the ore efficiently. The expertise gained in copper smelting would have been a great benefit in mastering the production of iron. It would also have enabled the transition from bronze to iron to take place comparatively quickly. To this must be added the readiness of local artisans to embrace outside expertise; this, as has been described earlier, was influential. Finally, running alongside this development of technical expertise, was the way in which iron production was organised; more communal working and the introduction of using less skilled labour in the process.

It was these factors which provided a rationale and a sequence of operational steps which resulted in the establishment of a basic iron technology being established; a technology capable of producing usable iron in volume.

The amount of iron produced and the high level of output is, by common consent, the feature which distinguishes Populonia from other western European centres at that time. It is this aspect which will be discussed further in the next chapter.

[232] Scullard, H.H. 144

CHAPTER 7 **OUTPUT OF IRON FROM POPULONIA: quantitative aspects**

We now come to the question of amounts of iron produced at Populonia.
The evolution of iron technology together with the development of workshop production units was not original or specific to Etruria. What was exceptional, however, was the sheer size and scope of the operations in Populonia over a 500 year period. This can best be illustrated by attempting to estimate the amount of iron produced.

The importance in general terms of Populonia, as an iron making centre, is not in question. It is evidenced by authors such as *Livy 23,45* and *Strabo* V 2.5/6,' Populonia was the most important iron making centre until the early empire.' This is supported by the evidence outlined in the previous chapter. Estimates of the amount of iron produced at Populonia, however, have been the subject of debate with estimated outputs ranging from a high figure of 1,000 tons a year to a low of just over one ton a year. The case for the higher figure was put forward by Voss [233] and this estimate was reviewed in an article by Crew [234] which put forward the much lower figure.
All the projected outputs from Populonia are based on the volume and then weight of the slag deposited on the site. It should be noted that both authors acknowledge the imprecise nature of any calculation. Voss comments that the important figure of the total tonnage of slag is not too well documented [235] and Crew in his concluding remarks says 'Much of this note is clearly speculative, being based on very uncertain evidence and making many assumptions.[236] Notwithstanding that, arguments will be put forward here to suggest a more realistic figure is one that lies between these two figures. Taking account of the comments by Voss and Crew, it suggests an order of magnitude rather than a specific figure.

[233] Voss, O. (1988) 91-100
[234] Crew, P. (1991) 109-115
[235] Voss, O. (1988) 92
[236] Voss, O. (1998) 114

The relevant data was obtained by observation and basic measurement which provided an estimate of the overall amount of slag deposited on the site at Baratti. It goes back to the middle of the nineteenth century, when Simonin reported the size of the slag deposit at the Baratti beach as follows; a mountain of slags with an average height of 2 metres over a distance of 600 meters along the beach.[237] A further assessment of the site and the size of the slag was reported in articles by Dompé, [238] Fossa-Mancini. [239]and D'Archiardi [240] written between 1921 and 1927. These gave an estimate of the area of the site covered by slag of 200,000m² and to a depth of more than 2 meters *in* some places. (my italics)

The basic problem with estimating slag deposit volumes is that from about 1915 and continuing into the 1960's, substantial quantities of slag were removed for re-smelting at Piombino and beyond. Earlier estimates cannot be checked therefore. So we are faced with the question of accuracy of the estimates of the total volume of slag on the site; it is one of scale.

An assessment of this data together with factors which influence the determination of the total potential weight of iron produced from the volume of slag will be reviewed. Voss's calculations of the total iron output were based on slag deposits of 400,000m³ (an area of 200,000m² and a depth of 2m).

The main reasons put forward by Crew to question Voss's output estimate concern two main areas:

1. An exaggerated assessment of the total volume of slag/deposit produced during the overall period of smelting activity at Populonia and the subsequent conversion of this into the quantity of iron slag
2. Queries about the composition, origin and dating of the slag; the significance of earlier copper smelting

[237] Simonin, M.L.(1858) writes "Sous Populonia, c'est une veritable montagne de scorie de fer, que l'on voir encore aujourdhui vers le ravage et le long du rivarge lui-même, sur une longueur de plus de 600 mètres et un hauteur moyenne de 2 metres, une immense depot de ces scories, que viennent batter les eaux de la mer"

[238] Dompé, L. (1921).

[239] Mancini, E. Fossa. (1922)

[240] D'Archardi,G.(1929)

This last point will be discussed firstly. The extent of slag arising from copper smelting naturally materially affects the amount of iron produced on the site. This was considered a significant, albeit debatable point, when Crew wrote his article in 1991; it is now far less so. Crew referred in his concluding remarks to the need to clarify uncertainty about the provenance and dating of the different slags. This referred to the relative importance of copper and iron smelting and the appropriate dates, Etrusco-Roman or mediaeval. This aspect has now been largely clarified in the past ten years as a result of extensive analytical work carried out on the site at Baratti [241]by Benvenuti in 2000 and more recently by Chiarantini [242] in 2009

The existence of copper slag together with iron slag does complicate the issue. Its presence is not in question. Copper slags have been recorded in the Porcareccia area.[243] Minto recognised that this related to an earlier phase of copper/bronze production but was superseded in the 5th century by iron. There were also indications that a significant proportion of the slag accrued from a relatively later period of metalworking but within the period under review. And indeed, the more structured programme of archaeometallurgical studies mentioned above confirmed this. The results referring to early copper smelting were quoted and discussed in the previous chapter.[244] In brief, the chronological sequence obtained from that data can be summarised as follows: copper smelting 9th to the 8th centuries BC, copper to iron transition 8th - 7th centuries BC, mainstream iron smelting from 6th century BC onwards. The question of whether some of the slag was of Mediaeval origin was raised by Crew. There is evidence of large copper slags, radiocarbon dated to the 12th and 13th centuries AD at Madonna di Fucinaia,[245] on Elba, and on the coastal region of Tuscany but there is no direct evidence for this mediaeval slag on the Baratti site. Two types of iron slag were identified by Voss which related to radiocarbon dates of 465 and 170 BC both plus or minus 100. Both fall into the category of Etruscan or Etrusco-Roman iron production. Recent

---

241 Benvenuti,M *et al* (2000) 67-76
242 Chiarantini,L.*et al* (2009) 1626-1636
243 D'Archiardi, G. (1929) Minto, A. *Studi Etruschi 23 291-319;* Martelli, M (1981) and others
244 Chapter 6, above 59-60
245 Voss, O (1998) 97

work clarifies both the dating issue of the copper smelting, namely 9th to 7th centuries BC as well as the question of quantity of copper slag. An analysis of the cross section of the various layers of the stratigraphic columns was given.[246] A visual assessment showed the layers attributable to copper based slag were of the order of 5-10% of the total.[247] Crew had earlier estimated this figure could be of the order of 50%. None of the samples tested were dated later than the end of the first millennium.

The next area to consider is the estimate of the overall amount of deposit, then slag and finally iron slag. Voss begins with the estimates reported by Simonin, Dompé, Fossa Mancini and D'Archiardi of 400,000m³ of slag, covering an overall area of 200,000m². [248] SimonIn's estimate of 600 metres of beach line covered with slag would, I believe, have been a reasonably accurate one. It should be added though that no depth dimension is given. Similarly, the figure of 200,000m², 20ha, from Dompé *et al* in the 1920's would also have been derived from a reasonably systematic approach. This area was determined after all at a time when the removal of slag for reworking was at its earliest stage. Minto outlines on a scale map two areas as follows; '*Le zone tratteggiate sono riprodotte nelle carte special'* (c25ha) and *'Limite approssimativo della zona industriale con resti dei forni e discarichi di scorie* (c100ha). Although the book and map were published in 1943,[249] Minto had been working on the site since the early 1920's. It is reasonable to assume then that an area of 20ha may be on the low side. One may comment though on the accuracy of the figure of the mean depth, one of 2 meters over the whole site. Although we are told that there were certainly places where the slag was 2 meters deep and more, an indication of its depth is clearly demonstrated in photographs taken of the site before the major removal of the slag for re-smelting.[250] These showed the slag to be deeper than the height of the tombs which were subsequently brought to light when the slag was removed. However, it would have been very time consuming to have

---

246 Chiarantini,L *et al* (2009) 1628 layers, Z and W&Y are predominately copper based slags;
247 Chapter 6 p58 n194
248 Site map and schematic diagram from Crew; see Appendix 1
249 Minto, A. (1943) maps at the end. See Appendix 2
250 Minto, A.(1943) TAV VII 1&2 and Wrubel, W. *Studi Etruschi 3* 397-409 TAV XLV-XLVII

assessed the mean depth throughout the whole site and it was after all not a core part of the findings of their work. Also slag may well have been deposited in a series of mounds rather than uniformly spread around the site. On balance therefore allowing for a possible questionable estimate of the slag depth over the whole site, perhaps an average of between one and two metres would represent a more cautious approach. This would equate to total of slag and debris of 300,000m³. In any event, whether the reduction is in the depth or area of the site, a reasonable and perhaps conservative assumption would appear to reduce the overall volume of slag/deposit by 25%.

Crew comments that a deposit covering 20Ha would effectively cover the whole site [251] and considers the total volume to be just too large. (I believe this point has been adequately covered in the paragraph above.) His comments are based on comparative data of output from early iron working sites in the UK, Sweden and Poland. Crew also makes the point that with at an output of 1,000 tonnes per annum, the result of Voss's calculations, the resultant impact on the demand for charcoal and therefore woodland would be too severe. This output figure would require a total of 2-3 million tons of charcoal that in turn would require 2-3,000 square km of forest, or every year between 2 and 6 square km. Both factors bring into question the high level of output of 1,000 tonnes a year. To overcome these reservations, Crew restricted his calculations to an area covering San Cerbone and Casone only (2.5% of the total site). Here the slag was known to be of Etruscan origin. From this area, a figure of 9,000 was arrived at, using the basis as outlined in his article, which converts to a production of 1,400 tons of metal over the 500 year period.[252] Whilst this is a valid exercise to estimate the output of this particular area, it cannot be taken as an estimated output of the site as a whole. It represents only 2.5% of the total site, albeit the area we know most about. Therefore the slag on the majority of the site remains unaccounted for. This approach will not be pursued further.

[251] An area of 20ha with a beach length of 600m would mean the slag deposits would extend 330m inland. See Appendix 1

[252] Crew, P. (1991) 112-113

To return then to an estimate of the amount of iron produced on the whole site, the first step is to translate the total volume of slag in its broadest form, i.e. true slag and debris into a weight of iron slag. Voss's figure was 400,000m³ of 'slag'. It is suggested above that this be reduced to 300,000m³. In addition, the proportion of copper slag as part of the total slag was mentioned by Crew. This was assessed, rather roughly, as lying between five and ten percent based on recent studies.[253]

A second factor to be taken into account is the percentage of debris in the slag that is charcoal, furnace lining material and large stones from the furnace structures. Voss estimates this at 20% and Crew at 60%. No mention is made in a detailed stratigraphic analysis of the slag [254] that over half of the deposit or slag tested was debris. Nor I guess would it have been particularly relevant in a detailed compositional analysis of the slag. The 60% figure is based on a visual assessment of the existing beach. However, more accurate data relating to slag deposits has recently become available and based on experimental work; and a figure of 50% debris in the total deposit has been estimated; this figure will be used. [255] I am indebted to Prof Th. Rehnen for providing this information as well as that for a correct density figure to be used (see below). The net result in the total volumes of *iron* slag of these suggested changes are ;

Original <u>volume</u> assessment	400,000 m³ of slag/debris
Less 25% for depth adjustment	300,000 ,,
Less 7½% deduction for copper slag	280,000 ,,
Less 50% allowance for debris	<u>140,000 m</u>³ of iron slag

This compares with the estimate of 320,000 m³ given by Voss which was based on an initial volume of 400,000m³of slag/debris with a 20% allowance for debris and no allowance for copper slag

The density of the iron slag is required to convert its volume into weight. Voss used a figure of 5. Crew put forward a figure of 3.5gm/cc based on work by

---

253 See n 194 above

254 Benvenuti *et al* ; (2000) 72

255 Rehren, Th. (2001) *Meroe, Iron and Africa* Mitteilungen der Sudanarchaolischen gesellschaft zu Berlin. MittSAG 12,2001, 103

Sperl. [256] Figures quoted by Benvenuti [257] separate the densities (specific gravity) of furnace conglomerates < 3 gm/cc, furnace slags 3-4gm/cc and tapped slags >4 gm/cc. However these figures do not take account of porosity, the amount of material that lies between the pieces of slag. A more accurate overall effective slag heap bulk density figure, based on experimental work, would be 2. [258]

To convert the volume of iron slag into a weight of bloom iron Tylecote's experimental work on conversion rates was used. [259] In addition, Crew has suggested that the result of part smithing could account for 20% of the slag and this has been taken into account.

Following on from the table above;

Total figures for the 500 year period.

VOLUME of iron slag		140,000 m^3
Less 20% due part smithing		110,000 m^3
WEIGHT		
Weight of iron slag; density @ 2		220,000 tonnes
Conversion of slag to bloom iron ÷ 4.[260]		55,000 tonnes
Bloom iron > IRON	less25%	40,000 tonnes
<u>Average annual output -500 year period</u>		**80** tonnes per annum

The 25% reduction figure used is to convert bloom iron into bar iron, a suitable state for transfer to the smithing operation. At that stage, a further loss will be sustained at the smithing stage may be as much as 25% but for the purposes of determining amounts of usable iron' available to satisfy the market, the loss will be off set by incorporating reusable iron. It should be stressed that these proportions and amounts reflect orders of magnitude only.

---

256 Sperl, G. (1980) 13 in Crew, P. (1991) 110

257 Benvenuti,M. *et al* (2000) 69

258 Florisch, N., Llubes, M., Téreygeol, F., Ghorbani, A., Roblet, P. communication through Th. Rehren

259 Voss:88 and Crew, 110 Tylecote's 'Mechanism of the Bloomery Process in Shaft Furnaces' 1971 yielded a slag to iron ration of 3.2:1.and a later result in Denmark but for 2nd to 3rd century AD 5.3:1

260 Ref footnote 259 above; a figure of 4 has been used

All 6 digit figures have been rounded to the nearest 10,000 but adjustments made on the original figure

This estimate of output over a 500 year period equates to an average annual output of 80 tonnes a year. An average annual output figure is also helpful in that it enables the output at the latter part of the period to be arrived at. The output began effectively from a very low level in the 6th century and reached its peak during the 3rd century.[261] The highest output would therefore be roughly double the average figure or about **150 tonnes pa.**

Another approach to translate slag weight into iron weight is based on purely theoretical considerations of unknown ore quality and analysed slag chemistry.

A theoretical conversion rate based on an actual slag analysis, FeO 70%: SiO_2 30% and estimates of the ore composition of 80:20 and 85:15 FeO:SiO_2 gave a conversion rate, 100Kg slag to 39 or 78 Kg of iron depending on the quality of ore. [262] That is 3 to 6 times greater than conversion of 13kg from 100kg slag arrived at by the estimated determined above. Significantly though, Rehren's calculations illustrate the massive effect that ore quality has

---

261 Romualdi, A. (1993) & an unpublished paper Guideri, S., Benvenuti, M., Chirantini,L. given at a seminar at Populonia (2005)

262 These calculations are based on a model designed by Prof Th Rehnen
For comparative purposes, we may calculate an optimum conversion from slag to metal using compositional data from slag from the Baratti site and two grades of ore; good and meduim. Details of the analysis of both tapped and furnace slag from three parts of the site, poggio della Porcareccia, Casone, and Baratti beach deposit, gave an average FeO % of 72

Using a slag composition of 70:30 FeO:SiO_2 being derived from using two grades of ore; one 80% FeO, 20% SiO_2 and the other 85%FeO.15% SiO_2, the theoretical amount of iron resulting from these combinations can be calculated relating to 1<u>00 Kg slag</u>

<u>ORE</u>	FeO	SiO_2	<u>SLAG</u>	FeO	SiO_2
1)	80	20		70	30
	120	30		70	30

net FeO; 120 - 70 = 50 FeO x 0.778 >> 39
<u>100kg of slag is equivalent to 39kg Iron</u>

2)	85	15		70	30
	170	30		70	30

net FeO 170-70=100 x 0.7778 >> 78 kg iron
<u>100kg of slag is equivalent to 78Kg Iron</u>

In the calculations above: based on 220,000 tonnes slag, this yielded 40.000 tonnes of iron Or 100 kg slag yielded 18kg iron on iron yield, which may well have been a major reason for selecting the rich ore from Elba as the basis of this industry. Richer ore not only implies higher metal yield, but also a much better ore to fuel ratio due to the lower amount of slag that needs to be formed and melted. [263]

The average output figure of 80 tonnes per annum could therefore be viewed as being on the low side

It would be correct also to mention other factors which would have impacted on the output at Populonia but about which to date no reliable information is available. These may be summarised as follows:

- although the details of the area and volume of the slag/debris cannot be checked, at least tolerance levels can be introduced. The extensive metallurgical data however has been taken from only one part of the site.
- no account has been taken, in terms of output, of the 80 metre stretch of beach which is now underwater due to a rise in the sea level of some 2 – 2.5 metres.
- It is believed that significant quantities of bloom iron were taken from the site for smithing elsewhere.
- Importantly, as has been stressed, the estimates have been used in calculations, some more speculative than others so the derived output figure of 150 tonnes pa must be seen as one that reflects an order of magnitude.

One way of assessing whether such an output figure is reasonable or not is to estimate the facilities required to produce such an amount. The charcoal required to produce Voss's original total estimate of 600-1,000 tons pa (300-500,000 tons total output) was 4-5,000 tons. The reduced estimate of 150 tons of iron production would then require 800-1000 tons pa of charcoal, still a considerable quantity but one that could be supplied from about one half of a

[263] Rehren,Th. private communication

square km of woodland.[264] The other resource is, of course, production capacity or the number of furnaces required. Although we are dealing with large scale production by ancient standards, the production unit was a batch of smelted iron from one furnace, a comparatively small figure. Rough estimates can be given as follows; a furnace (slag tapped) can be loaded three times for each smelt. This would yield some 3x5 kg or 15Kg of iron. If the furnace operates say 2-3 times a week and for 45 weeks a year it would produce 1.7 tons pa. This may be on the high side as it assumes efficient operation but on that basis an annual output of 150 tons a year would require 80-90 furnaces. This would equate to 4-5 workshops using the figure of 20 furnaces per workshop (21 were found at Rondelli). At the end of the period at Populonia, with the output at its maximum of 150 tonnes a year, 90 furnaces in 4-5 such workshops would be required; not an insuperable number.

These output figures are large by any standards in ancient times. In the 17th century, the output of iron and steel in the present day United Kingdom was some 25,000 tons a year.[265] And the population, at that time, was five and a half million. An output in the low hundreds some 1800 years earlier must count as a major achievement.

In Populonia, to achieve that level of production, advancement in two critical areas would have been necessary. Firstly, a reliable and practical process would need to have been in place, an integral part of which will have entailed an understanding of key practical elements necessary to exercise control of the process. The development of such a technology would have been a basic prerequisite to enable iron to be produced in volume, a transformation from a speciality craft activity into a high volume (comparatively) commodity enterprise. Not that the iron produced was uniform and consistent in to-day's terms. Surveys have been carried out which showed the carbon contents

---

264 Voss, O. (1988) 98 Averages of the quoted figures have been used in this summary. For an iron output figure of 400,000 tons, the charcoal usage is 2.5 m tons over a 500 year period. This gives an annual figure of 1,250 tons of charcoal being required in the production of 100 tons of iron. 1ha of woodland can produce 20 tons of charcoal. So 45 Ha (1/2 km^2) of woodland would be required each year On a regenerative period of 60 years, this is sustainable.

265 Aiano, R. in White,K.D.(1984) 216

covered a wide range,[266] evidence therefore that the carbon content of iron produced was variable. [267] However, production in Populonia was sustained over a 500 year period suggesting the iron produced was usable and satisfied a demand.

The second area where changes are likely to have taken place was in the way production was organised. As has been mentioned earlier here, we have evidence of semi-skilled or unskilled workers, 'foreign and of low grade' being used [268] perhaps to perform the less critical parts of the process, bloomsmithing for example. One could surmise for example that a skilled metal-smith would then have more time to concentrate on the more critical aspects of the process and/or cope with the increasing production requirements.

The Roman acquisition of Etruria and certainly in Populonia appeared to have an impact. A marked increase in the amount of iron production coincided with the new Roman presence and was reflected by an expansion of new buildings. The improvement in the social and economic conditions has been attributed in part to the increased activity in iron production and in turn to a change in the organisational system.[269] The rise in production levels during the 3rd and 2nd centuries BC implied a major reorganisation.[270] That the Romans would take an active interest in mining and smelting operations is not too surprising. The demand for iron was increasing and they rightly considered the supply of metals to be of strategic importance. Evidence is available of attested appointments for officers to control or manage mining operations. In particular, '*procurators ferrariarum'* were senior Imperial officials and for privately leased ironworks '*conductores ferrariarum'* [271] Whilst these appointments refer to operations outside mainland Italy and were attested during the early years of the Empire, they demonstrate the importance

[266] The carbon content, degree of carburisation, is an important factor determining the physical properties of the iron and illustrates the
[267] Rehder,J.E. (2000) 131-132
[268] Maggianni, A.4 see previous chapter p67 n215; Romualdi, A. (1993) 108
[269] Romualdi, A. (1993) 126.
[270] Guideri.S. Benvenuti,M, Chiarantini,L (2005) unpublished; Seminar at Populonia..
[271] Rehder,J.E. (2000) 41

attached to mining by the Romans. It is likely therefore, that Rome took an active interest in the overall management at Populonia including, for example co-ordinating the supply of ore and charcoal. Their ability to manage sizeable projects is not in doubt.[272] There is no evidence, however, of their involvement in any of the technical aspects.

To conclude, it is perhaps this first in 'industrial' scale operations in a technically difficult field that is one of the Etruscans' most noteworthy achievements. Building on their metallurgical expertise gained with their copper/bronze working background and the material benefits arising from that, they exploited initially local and then Elban ore resources. This background expertise will have contributed in the development of an iron smelting process comparatively quickly and effectively. Whilst being open to outside help and advice from overseas artisans, they retained full control over the whole operation despite active overseas interest in the earlier days from Greece and the Phoenicians. As the iron activities expanded, so did the wealth of Populonia. Etruria and Populonia were by no means first in the early stages in iron technology development, in fact they lagged behind Greece by some 200 years and probably even more so with Cyprus, but Populonia was the largest iron producer in western Europe at that time for which we have evidence.

Reverting finally to part of the introduction of this dissertation, namely the development of technologies, what the Etruscans achieved fulfilled the three criteria required to establish a technology, namely the successful bringing together of a supply of accessible raw material, the availability of basic skills and a demand. The establishment of iron technology in Etruria can justifiably be described as a major achievement and this is demonstrated by the ability to produce in volume on a sustainable basis. It provided the important link between a supply of good raw material and an ever increasing demand. The demand, an important stimulus, will be covered in some detail in the next chapter.

[272] In mining for example Magdalensburg

CHAPTER 8 **THE DEMAND FOR IRON: the economic background**

Introduction In the last chapter an estimate of the production of iron at Populonia was put forward. Populonia is acknowledged as one of the most important ironworking centres in Europe in the first millennium BC.[273] What makes this achievement particularly noteworthy was the fact that availability of iron grew from effectively small amounts in the 6th century to a peak, in Populonia in any event, by the end of the 3rd century. The iron used in the earlier centuries, 8th to 6th was mainly for prestige artefacts as evidenced by those found in tombs. Where did all this 'new' iron go, what was it used for, and what were the circumstances which resulted in iron changing from a prestige metal to a basic commodity item? To try and explain this and give some credibility to an output figure of c150 tonnes a year, an assessment will be made to determine the potential amount of iron used by the end of the 3rd century. This assessment will start with an overall view of the economy.

1 The Ancient Economy This economy was first and foremost based on agriculture and one which was, during the latter half of the first millennium BC, a time both of economic expansion and of an increase in population. Between 800BC and AD200 the population in the Mediterranean basin rose from 20m to 40m, with some regions including Italy experiencing a more rapid growth.[274] As far as mainland Italy was concerned, a number of factors contributed to the growth in the economy. These included overseas conquests, a consequent increase in the use of slave labour, urbanisation and the development of trading networks. Increases in productivity did not figure highly. Nearly fifty years ago, Finley argued that the concern for citizen status put a break on the development of markets in land, labour, and capital, and therefore on technology and trade. [275] In the 1980's Hopkins reiterated the overriding importance of agriculture and referred to 'cellular self sufficiency'

---

[273] Benvenuti *et al* (2000) 67. Also, 'Populonia became a major industrial centre in the Hellenistic period once the iron ore of nearby Elba was mined on a large scale' Humphrey,J.W., Oleson,J.O., Sherwood, A.N. (1998) 219.
[274] CEH, 'Introduction' 9-10
[275] Finley, M.L. (1965) 11-35.

with each farm, district and region growing and supplying their basic needs. This marginalised the importance of trade and the status of traders. However, in a wider context of things, during the first millennium BC and the first half of the first millennium AD, the size of the agricultural surplus increased slowly whilst the proportion of the total population engaged in non-agricultural production and services also grew. So during the early centuries AD, food producers were growing proportionately more food to allow for more non-agricultural workers. This modest increase in productivity was brought about by political change and social and technical innovation. [276] Since then the debate has moved on to encompass the area of economic performance more widely. "The ancient Italian economy did not just support a small elite in luxury; it raised living standards to well above subsistence level for millions of peasants and city dwellers. People lived longer, ate better, occupied more comfortable homes, and enjoyed more numerous, more varied and higher quality goods than their prehistoric forebears …" [277]

Hitherto, discussion has centred round Etruria, but the overall geographical area of consumption is naturally greater than just Etruria. At the beginning of the fifth century BC, Etruria was independent with a league of twelve cities in some form of association. By the 2nd century BC however, most of mainland Italy was subject to Rome and this is the area which will be covered here. The Italian economy will be reviewed to provide a framework to assess the changes in consumption or demand and following that, to discuss how any such changes may have influenced the overall requirement for iron.

2 The Italian economy: 400 BC- AD 100.

Changes in population, productivity and living standards will be analysed to provide evidence for evaluating the economy and consumption in general, but before that, a selective summary of events between the 4th century and the time of Augustus will be given. This summary is divided into three periods; mid 4th century –end 3rd century, 200-133 and 133 to the time of Augustus. This is designed to illustrate any underlying factors which may have influenced the

[276] Hopkins, K. (1983) 'Introduction' xi-xii.
[277] CEH. 'Introduction' 6.

important balance between satisfying demand at a time of increasing living standards and a possible increase in population. New technology or simply an increase in productivity will enable living standards to increase at a time of increasing population. Technology appeared to play only a small if not insignificant role in the ancient economy. [278] I suggest though that during this period an increase in productivity did play a role, essentially developments based on improving traditional techniques.

A brief and rather selective summary follows. It is based on general sources with an emphasis on the economy.[279]

<u>Mid 4th Century –end 3rd Century</u>. This period is characterised by the Romanisation of Italy which was essentially completed by the end of the 3rd century. As a result of the conquest or colonisation of Magna Graecia and Etruria "societies that were certainly brilliant and prosperous were henceforth increasingly weak relative to Rome. This period profoundly transformed Roman political and social structures exemplified by the appearance of coinage and more general economic change." [280] These acquisitions also resulted in development in agriculture and trade. Agriculture remained the main engine of the economy and the *ager Romanus* grew from 5,000 to 27,000 km² between 338 and 264BC. [281] The addition of 'new' land was achieved by conquest, or retrieval of marginal land by improved drainage; In addition, the production and export of wine in newly designed 'Greco-Italic' amphorae added value to the agricultural base. Craft related activity, although less important than agriculture, was becoming more evident. Good quality pottery was being exported to Marseilles and Carthage and their respective zones of influence, opening up trade in the Mediterranean. This followed the manufacture and export to Greece of *bucchero nero* from Caere during the second half of the 4th century. Although Italian craft production flourished, large scale export had barely begun to develop and its volume was not

---

[278] Finley, M.L. (1965a) ; 29-43 and more recently Schneider, H.(2007) CEH, 144. although Wikander, suggests that position is not as clear cut as that; in Wikander, O. (1984) *Exploitation of Wind Power or Technological stagnation?*
[279] Crawford, M.H. (1992). Morel, J-P. (2007) 487-510.
[280] Pedroni, L. (1993) 13-16 in Morel. J-P.(2007) 497
[281] Morel, J-P. (2007) 499.

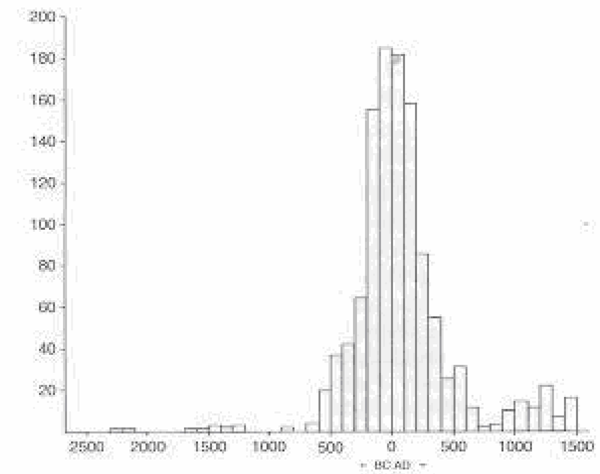
comparable to the massive increase which occurred during the following period.

200-133BC This was a period of great change in which Rome conquered basically the entire Mediterranean basin and acquired rich assets and tribute from overseas. It also acquired an influx of slaves in addition to free specialists, artists, skilled craftsmen and technicians. Slaves were generally unskilled and were employed under strict supervision. The production processes became standardised as evidenced by large workshops producing pottery. These wares were mass produced and their ranges narrowed to encompass more basic utilitarian goods with a minimum of artistic input. Working conditions for slaves and free workers converged as the craft element of production became less and was incorporated into the process control of large scale production work. This utilised the skills learnt controlling temperatures and the nature of the atmosphere in kilns. Better control led to more clearly defined parameters, reducing risks and making the production of larger quantities practical. The majority of the articles produced were effectively commodity products and many were exported. This approach, sometimes referred to as the slave mode of production, undeniably stimulated the economy.

But agriculture continued to lead the economy. Landowners involved in subsistence farming introduced olives and wine as cash crops, some helped by a treatise by Mago, a Carthaginian agronomist, on olive cultivation and viticulture. New roads opened up parts of central Etruria previously inaccessible; a naturally fertile area, which was developed extensively. In 133BC problems arose with insufficient land being available for distribution to veterans returning from service. The dissatisfaction and ensuing strife came to a head with the assassination of Tiberius Gracchus. ‘However, the long period of factional strife that was about to commence would not change the economic structures that were formed during the period.’ [282]

[282] Morel, J-P. (2007) 499

Late Republic The period from 133BC to the time of Augustus was one of social and economic expansion despite or perhaps because of the upheavals of the Social War with the resultant granting of citizenship to the Italian allies. The wealth flowing into Italy from conquests in the Mediterranean and later North Africa was immense. Higher living standards stimulated demand for products such as wine and olive oil and with that an increase in agricultural productivity.[283] Trade accelerated rapidly in the mid-second century.[284] Overseas trading grew further, led by exports in wine, olive oil, and commodity pottery, evidenced also by the number of shipwrecks found in the Mediterranean. A graph of dated shipwrecks from the Mediterranean shows this clearly. [285] With specific reference to that data, Hopkins writes 'In the period of imperial expansion and in the High Empire (200BC - AD200), there was more seaborne trade in the Mediterranean than ever before, and more than there was for the next one thousand years.' [286] The demand for more food brought about by changes in living standards and some increase in population was met in part by imports of large quantities of grain from places such as Sicily. [287] But the output from domestic agriculture also grew. Some of the increased wealth of the elite was directed towards the acquisition of land. Not that this increase in the provision



Mediterranean shipwrcks by century, using mid-points of date ranges (Parker 1992, Fig. 3)

[283] Kron, K.G. (2008) 86-97
[284] Harris, W.V. (2007) 533.
[285] Parker, A.J. (1992) 549 fig 3 above shows the number of shipwrecks in the Mediterranean in each of the years from 200BC to 200AD was more than double those for the preceding or succeeding years
[286] Hopkins, K. (1980) 105-6. and Jongman, W.M. (2007) 612
[287] Tenney Frank in *ESAR* Vol, 69 referring to the third century BC " Although the vast imports of grain from Sicily sufficed to feed the army and the urban poor of Rome, it left the rest of Italy to provide for itself,."

of food was limited to large estates: a recent study and archaeological field work has highlighted the important contribution made by the smaller farmer.[288]

3 Factors indicating growth. Three factors have been chosen to demonstrate growth in the Italian economy; size of population, living standards, and productivity/technology.

Size of population There are still on-going differences of opinion about this topic. Most estimates start with the official census figures, the collection of which was an important formal part of Roman government. The debate is not so much about the actual census figures, it is more about defining who was actually included in those figures. Secondly, following from that, queries arise as to how best to take account of those excluded. The resultant overall total population is dependant then on a variety of issues, the resolution of which requires detailed and professional assessment. Here though is an outline of this work designed to give an estimate of the increase in population which occurred in the previous 500 years and the size of the overall population at the turn of the millennium. Underlying the different approaches, the query about the census figures is more about their interpretation rather than the actual figure; this applies to the censuses taken in 265/4 and those following. Figures before that are unreliable, [289] but are quoted here to give a rough order of magnitude. The earliest originates from the 6th century, in the reign of King Servius Tullus, being 80,000. Dionysius then gives totals for adult males as follows;

498BC, 150,700;[290] 493BC, 110,000;[291] 474BC; 103,000.[292]

The first of the more reliable census figures, collected in 265/4, was 292,000. The average of this and the next three censuses is 273,000.[293] There is no significance in choosing four census years; it is designed just to give a figure

[288] Rathbone, D.W. (2008) 305-332 and Kron, J.G. (2008) 71-120.
[289] Brunt, P.A. (1987) 3-120
[290] DH 5.75.3
[291] DH 6.96.4 A comparison of the figures for 498BC and 493BC makes it difficult not to conclude that the figures represent different census populations. Elio Lo Cascio *People, Land and Politics, n* 54;205.
[292] DH 9.36.3
[293] 265/4: 292,000. 252: 298,000; 247/6: 242,000. 241/0: 260,000 Average 273,000.

representing the number of adult male Roman citizens in the mid 3rd century. By the end of the 2nd century the average figure was close to 400,000 (394,000 in 115/4BC and 463,000 in 86/85BC). This difference of some 125,000 or 45%, which appears significant, is generally explained by the number of allies being incorporated as Roman citizens. Things appear to change markedly between 86/85BC and 70-69BC

147/6-131/0	average	322,500
125/4		394,736
115/4		394,336
86/85		463,000
70/69		910,000

The significant increase in the census total for 70/69 is generally taken as the result of the partial inclusion of the Latins and Allies enfranchised after 90BC. I will not attempt to summarise let alone explain the various steps involved in arriving at an estimated total population. These are well presented in *People, Land and Politics.* [294] However, for the purposes of the argument here, two factors emerge, on which there appears to be general agreement. Firstly, the population of mainland Italy was large at the time of the turn of the millennium with estimates ranging from 5-12 million, perhaps from 6-10 million.[295] Secondly, the population rose between 500BC and the time of Augustus particularly in the last two centuries BC in the view of the 'high counters'.

In most post-industrial revolution economies, the gross domestic product and per capita income have tended to increase with population growth. The fact that the economy and income may actually increase rather than just keep pace with population growth is made possible essentially by improvements in technology in its widest sense. Pre-industrial economies did not normally achieve this. Their growth was slow and either in line with population changes or was achieved at the expense of the living standards of the mass of the population. During the latter part of the first millennium, given some increase

[294] Brill, Leiden. (2008) abbreviated here as PLP

[295] Low counters: demographic stagnation or decline in the free citizen population of Roman Italy; 5-6m. High counters: Political and social development, background of population increase; 10-12m.

Moderate/compromise estimate : 7½m ; PLP, 187 in population, what evidence is there for believing this was translated into an increase in the size of the economy and in per capita income?

Living standards. The following basic data lends support to the premise put forward that in spite of some increase in population, the overall standard of living increased. The mean height of Roman males has been estimated as approximately 168cm,[296] (5'6"), implying a relatively high level of nutrition. By comparison, the average height of males at the present time is some 175 cms (5'9"). Another measure indicating increased living standards and prosperity is meat consumption. Jongman suggests meat consumption as a suitable indicator rather than cereals where a decline in grain consumption might imply an increased standard of living because of a shift away from a basic foodstuff. Similarly, an increase in the consumption of luxuries might be caused by an intensification of social inequality. Meat would have been too expensive for the very poor, but attractive and affordable for those living above subsistence levels and not subject to excessive consumption by the very rich. [297] As such therefore, it is a sensible item to choose to reflect general prosperity. Data obtained from mammal bone depositions showed that levels reached a peak in the first century AD with levels increasing from the 2nd century BC and declining again in the 2nd and 3rd centuries AD. Comparable data from mammal bones in the Provinces of the Roman Empire shows an even more marked increase from the 2nd century BC, peaking at the 2nd century AD. [298] Whilst we do not have comparable data for earlier periods, pre 200BC, I think it is a reasonable assumption to say these trends reflect growth at that time.

Two other factors illustrate growth in the size of the economy. Firstly, there was an increase in urbanisation with the many associated activities which accompanied it. These included not only major building projects but also the provision of an infrastructure required to provide the necessary basic facilities. Secondly, there was an increase in trade during the first century BC and the

[296] Kron, K.G. (2008) 80/81
[297] Jongman, W. M. (2007) 613
[298] King, A. (1999) 168-302 (figs 22.1-22.2)

first century AD as evidenced by the number of shipwrecks found in the Mediterranean relating to that period. [299] "Increased trade contributes to economic growth through increasing the effective size of the market reached by producers, enabling economies of scale and division of labour; …It also facilitates urbanisation and the growth of cities beyond the capacity of their immediate hinterlands to supply them." [300]

These indicators support the notion of the Italian economy expanding as described earlier with increasing wealth and trade. In addition the agricultural base was not only capable of sustaining an increased population but also providing some increase in living standards.

<u>Productivity and Technology</u> The development of basic technologies was described in Chapters two to four, and referred to pottery, textile and metals, iron in particular. By the end of the third and the beginning of the second century BC, iron became a metal available in comparatively large quantities, as shown in Populonia, In any review of general factors which influence economic growth; an increase in productivity remains an important factor in enabling growth to be sustainable alongside *per capita* income.

By way of background, there has been general agreement that both the Greeks and the Romans were slow in translating the acknowledged achievements of Greek science and mathematics into practical and effective technologies. In Greece, during the latter part of the first millennium, the influence exerted by Socrates and Plato led to the understanding that it was the acquisition of knowledge above all else which was important as opposed to the practical application of such knowledge, which was viewed as an inferior activity. There are many examples of this, the most well known are the absence of harnessing wind and water to provide power and the geared press. In practice, when the need arose, innovative technology was in fact used to solve problems. The use of the catapult in the defence of Syracuse and the use of the pulley in the construction of large buildings are examples. The Romans admired and embraced much of Greek culture. A balanced view of the transition and utilisation of innovation in the Graeco-Roman world can

---

[299] Parker, A.J. (1992) 49
[300] Bowman, A.. and Wilson, A.. (2009) 'Introduction: Approaches' 30-31

perhaps be summarised as follows; the Greeks' interest in science and philosophy was directed towards understanding the rational order of things rather than their use in solving practical problems (with certain important exceptions). The Romans on the other hand excelled in building and developing the contribution of others and their society thrived on organisation and improving its effectiveness. [301] Views that the contribution of ancient technology did not compare with those of literature, philosophy and medicine are and have been widely held.

In the 1960's, M Finley gave a list of technical innovations including amongst others the cog wheel, screw, wind and water mill, screw press, ….and torsion catapult adding the comment that it did not add up to very much. [302] However, this view underestimates the contribution made by technology. The Archimedes screw and gearing were used in mining to remove water from below ground and in agriculture for irrigation. The introduction of gearing enabled power generated by flowing water to be transferred for use in grinding grain. The press employed in the production of olive oil and wine initially exerted pressure directly by the use of a lever. This was subsequently improved again early in the first millennium using a screw to facilitate controlled exertion of pressure via the lever. More recently (1980-2000) much evidence has been found bringing forward the use of wind and water in Roman times, from the 5th and 6th centuries to the 2nd and 3rd century AD. O. Wikander published a study in 1984 [303] which effectively queried the earlier commonly accepted view, that although the ancient world knew about the water mill, it was not until the early middle ages that its use became common. There is evidence attesting its use in the 1st centuries BC and AD based on archaeological finds with some literary sources. [304]

---

[301] Humphrey J.W. Oleson, J.P. and Sherwood, A.N.' Introduction' xvii
[302] Finley, M.L. (1965a). in 'Technical Innovation and economic progress in the ancient world.'
[303] Wikander,O. (1984)
[304] See 303 above Also, it is interesting or reassuring that the use of wind and water power were not entirely absent in the earlier Roman times. For whatever reason, if it transpires that its usage was limited , the question remains as to why the demand was limited. The question of availability of cheap/slave labour has been put forward, but that does seem to agree with the critical approach taken by owners of orchards/vineyards to the use of labour.(see next chapter).

Whilst it may appear that the introduction of latent technologies and their uptake, did not appear as rapid as one might have expected with post industrial hindsight, it would seem this was not entirely the case. For example water power was harnessed some two centuries earlier than previously thought and perhaps earlier than that. In effect, the implication here is that the introduction of these technologies, with a resultant increase in productivity, has been under-valued in the past. Whilst recognising that this does not alter the fundamental view that technology/productivity was not a substantive issue in the ancient economy, nonetheless, it may be put forward as being of some significance. Limited improvements in productivity can influence the fine balance between per capita growth and a stagnant economy. Efficiency gains were not restricted to the introduction of 'new' technologies; basic improvements in productivity also played a part. These were achieved by developing existing technologies further and/or by making better use of existing resources. Evidence is available of improvements in labour usage and farm management.

Much of the newly acquired wealth of the elite was directed towards acquisition of land resulting in a shift to larger estates. Although operating in the main as absentee landlords, their interest did not stop with the status of ownership and a great deal of capital, labour and care was spent on every *iugerum*. [305] Important contributing factors included the improvement in more effective organisation of labourers. These were often slave labour with freedmen as overseers. Crop rotation and mixed farming was a major contributor in bringing about the better use of land. Cato wrote about the importance of regular visits by the landowners as follows;

> When the proprietor has arrived at the farmhouse and has paid his respects to the protective deity of the household, he should tour the farm that same day if he can; if not then at least on the following day. Once he has ascertained how the farm has been tended, what projects have been carried out and what still remain, he should summon his overseer the next day and ask him what work has been done what is left to be done; whether the tasks have been completed on time; whether the remaining work can be finished; what is the yield of wine and grain and all other products. From this information he should then make up an account of the number of workmen and

[305] Kron, J. G. (2008) 89 citing Pliny *NH* .14.49.

> the number of working days. If the results are not evident, and the overseer claims that *he* has been diligent but the slaves have not been healthy, the weather has been poor there were public works to take care of – when he has made these and a thousand other excuses, refer him to your calculation of work done and number of hands. [306]

He then continued to list jobs which could be done in wet weather. This detailed and businesslike approach would not disgrace a modern management consultant. It also implied that some land owners were well versed in the details of managing land which indeed Cato was. Finally, the general improvement in the physical strength of all males, following an increase a rise in living standards, led to a stronger and hence more productive worker; changes in diet stimulating agricultural production. Pliny *NH* 18. 39-43 says the landowner 'led in his farm servants, sturdy people, all well clad and well cared-for.' [307] Cato advises getting rid of items such as 'slaves past their prime or prone to illness, time worn oxen and cattle, wool, hides and obsolete wagons. It would seem therefore that better management and labour utilisation together with improved land reclamation and crop selection were key elements in improving the running of a farm.

SUMMARY Improvements in agricultural output generated by an increase in productivity, with or without new technology, seemed to have squared the circle of balancing an increase of population on the one hand and providing sufficient food on the other. [308] It was such that it not only maintained basic subsistence levels and but also led to an increase in living standards and hence economic growth. This is rightly recognised as a major achievement.

What part did iron play in this development and what role if any did it have in contributing to overall economic growth? I suggest that the production of usable iron in quantity can be described as a technological advance in its own right. Iron was available at a much earlier date but not, it appears, in any great

[306] Cato. *On Agriculture* 2.
[307] Perhaps taking a romantic view of the past.
[308] Kron, J.G. (2008) 88. 'I do agree with Toynbee on an important point. He is surely right that Italian agriculture was booming in the second century BC.' .

quantity or at least not backed with sufficient evidence. The Etruscans using their metallurgical expertise in conjunction with a ready supply of ore from Elba developed a practical technology with the result that by the end of the 3rd century, substantial quantities of iron were being produced. Sometimes nascent technologies precede their requirement or practical use. In this case, I suggest it was a general increase in demand, outlined above, which provided the stimulus for the increase in the requirement for iron and hence its supply. Cato discusses in *On Agriculture,* 2*.* the procurement of next year's requirements and the sale of superfluous items. Amongst a list of the latter, is a reference to *'Iron tools not worth saving'.* The significance of the worn-out iron tools would seem to be that iron tools were straightforward replaceable commodity items.

What is clear then is that by the beginning of the first century BC, iron had become an established commodity material; one which was widely used as a basic tool in routine applications and replaced when necessary. In an important sense, therefore the production and usage of substantial quantities of iron can be described as a technological development, albeit one of degree, not kind. The introduction of iron on this scale led to improvements in productivity, either directly or indirectly, resulting in more effective use of resources. Examples include the use of iron tools in agriculture, dagger blades in weaponry and clamps and nails in construction. Such productivity improvements are difficult to quantify; they are not as spectacular as those that arose from the industrial revolution, but they are nevertheless real and, as has been indicated above, likely to have been significant in terms of the economy at the time. An important field of modern research is the interdependency of technological and economic development in the ancient world. [309] This is a wide and very relevant topic, a detailed discussion of which lies outside the scope of this dissertation, but I believe that iron does play a part in such a study. However in general terms though, it would appear that it is essential demand which determines the rate of technological change and its rate of up-take. Important reference has been made to demand and by

[309] Schneider, H. (2007) CEH, 147

inference the demand for iron in particular. Applications of iron need to be identified and the main users subjected to more detailed scrutiny to try and establish an order of magnitude of the quantity of iron being used towards the end of the 3rd century. An assessment of where iron was used follows in the next chapter.

Chapter 9 **APPLICATIONS for IRON: 300-100BC** [310]

Introduction In the previous chapter, a general economic background was put forward which included comments on technology and productivity together with their potential influence on growth. This chapter examines the main applications of iron. In doing so, it illustrates and confirms the wide variety of end-uses and the comparatively quick up-take and acceptance of the metal. It also covers the impact resulting from that transition. Five principal areas of iron application will be looked at from which the two sectors, representing the greater amount of iron used, will be chosen. Then in the following chapter, the total amount of iron used will be estimated.

Evidence from contemporary authors and a limited number of artefacts exists on the types of artefacts being used during this period. For military equipment, Polybius is the principal source quoted in this discussion with archaeological evidence available in the form of weapons. Cato and Varro writing in the first century BC and Pliny and Columella in the first century AD provide detailed information about both the type and in some cases the numbers of implements used in agriculture.

By way of introduction, an extract from Pliny, is quoted written in connection with mining but it mentions *inter alia* an extensive range of iron applications.

> Next, an account must be given of the mines producing iron, a substance which serves the best and worst part of the apparatus of living. Indeed, with iron we plough the earth, plant trees, trim the living vine props, compel the vines to renew their youth yearly by trimming them of spent growth. With iron we construct buildings, quarry stone, and we use it for every other useful application *NH.* 34.138-13

The principal areas of application will be divided as follows:

Weaponry and Military equipment
Agriculture
Construction
Mining

[310] References to ancient authors writing in the 1st century AD are made. These are considered relevant because the applications of iron about which they write will have not have changed significantly since the previous century.

Weaponry and Military equipment

Introduction Evidence of the types of military equipment used in Republican times, particularly around the end of 3rd century BC and the beginning of the 2nd, derives mainly from the writings of Polybius. Some archaeological evidence comes from 2nd and 1st century BC sites such as Numantia (133BC) and the siege of Alesia (50/49BC) but more evidence is available from the 1st century AD. Major changes took place in the Roman army after the 2nd Punic war in both size and organisation. The conventional size of the army was four legions, two per consul, but that would have been increased in times of war, as would have been the case during the conflict with the allies and then Carthage. It reached some 30 legions at the battle of Pharsalus between Caesar and Pompey and peaked at some 60 legions at Actium, before returning to 30 early under the control of Octavian. Some of the evidence which will be put forward relates to these later periods, but I suggest the overall impact on the amount of iron used in the basic items of equipment was dependent more on the size of the army than any changes arising from the design or application of new equipment. Where that did arise, it can readily be identified and will not be included in any quantitative analysis. In determining numbers of armed soldiers, account has to be taken of allied troops as well as legionaries. It should be recognised that, at the turn of the millennium, it was likely that an army on the move would try and ensure the availability of more local sources of iron. This would be in the form of iron billets The army had their own blacksmiths. [311]

In this analysis, reference will be made to artefacts made from iron at the earliest date generally available for which we have evidence. The basic description and evidence of the equipment is based largely on the text in MC Bishop and JCN Coulston's Roman Military Equipment.[312] The sectors covered are: the *pilum/*spear , the sword/dagger , body armour, and ancillary equipment.

---

[311] Sim, D. (1998) 64-65
[312] Bishop, M.C. & Coulston, J.C.N. ((2006) 2nd Edition , Oxbow Books, Oxford.

Applications

P*ila/* Spears The *pilum* was designed as a close range javelin to penetrate the enemy armour by virtue of the directly applied force of a thrust rather than its velocity. Its construction consisted of a wooden shaft to which an iron shank was attached and finally a barbed metal head.[313] The iron shank (some 50cms long) bent on impact. This proved an advantage in preventing its re-use by the enemy; an aspect which was improved by Marius and refined by Julius Caesar. Examples have been found on a number of sites, the earliest possibly being dated to the last quarter of the 3rd century.[314]
The *pilum* existed in both light and heavy forms. Spears were primarily designed as for close-order fighting, "ubiquitous in any period and notoriously difficult to classify."[315] It consisted of a barbed iron head, a wooden shaft and an iron butt [316] but unlike the *pilum,* not designed to be thrown.[317] The *triarii* , or veteran troops, were armed with spears rather than *pila.*[318]

Swords/daggers: The sword, *gladius,* was part of the basic issue for a Roman legionary. Polybius refers to the *Spanish Sword,* as encountered initially in Spain by the Roman army and subsequently adopted by them. [319] An early example was found at Šmihel (in present day Slovenia) with a suggested date of 175BC.[320]

Daggers: It is quite possible that the dagger was not in general use in the Roman army until the 1st century BC. It is not mentioned in Polbyius but some evidence has been found at the site of Alesia.[321] The blades of both swords and daggers that were available, were made from iron.[322]

313 Polybius VI, 23
314 Bishop, M.C. and Coulston, J.C.N. (2006) 52-53
315 *Supra* ; 76
316 Polybius VI, 23
317 Bishop, M.C. and Coulston, J.C.N. 53
318 Polybius VI, 23
319 Polybius III, 114; and Connolly, P.(1975) 18
320 Bishop, M.C. and Coulston, J.C.N. 56
321 *Supra* 57
322 Confirmation from JCN Coulston by private communication

Body armour The shield was protected against sword attack by an iron rim attached along the top and bottom.[323] Livy stated that was first adopted during the Latin wars of the 4th century BC. [324]

Cuirass: Bronze mail and small sheets were used in Republican times and the bronze cuirass continued to be used by legionaries and auxiliaries in the first century AD. However during that century, the '*lorica segmentata'* was introduced. It consisted of strips of iron articulated on leather straps.[325]

Helmets: As with the cuirass, they were made from bronze in Republican times but iron was introduced in the Imperial Gallic helmet which was then used, although not exclusively. With a stylised eyebrow trimmed with brass piping decorated with brass bosses, they were described as the finest helmets produced by the Romans. This was a complimentary reference which probably had more to do with the decorative additions than the fact the helmet was made from iron. The iron content in body armour, the cuirass and helmets was negligible at that time.

Ancillary uses Iron implements were used in the construction of camps; the work carried out being the preparation of the site and the provision of necessary facilities. Quite simply the implements required are not too different from some of those used in agriculture, namely clearing a site, digging a defence ditch and providing drainage. The tools used were therefore, essentially, spades, shovels, pick axes, mattocks, axes and saws. The procedure for setting up a Roman camp was laid down in great detail and included the precise configuration of the tents and the open spaces.[326] Part of the installation was the construction of a ditch, *fossa,* one metre deep and a stockade, *agger,* of at least two metres wide which ran around the complete perimeter of the camp, a length of 800 meters per side for a camp of two legions. This work was shared between the Roman legionaries and the allied troops, two sides each. Digging such a ditch around the camp entailed removing some 1600 m^3 of earth with the forming of an associated rampart, all of which would have been quite an arduous task and would have required the

[323] Polybius VI, 23.
[324] Livy VIII, 8.
[325] Bishop, M.C. and Coulston , J.C.N. 9.
[326] Polybius VI, 27-32.

appropriate earth moving tools. For regular camp construction, three main tools have been put forward; a pickaxe or *dolabra,* a turf cutter and a trenching tool.[327] These are based on archaeological finds but not associated with a specific period. However, the *dolabra* is mentioned as a classic military tool [328] and referred to, albeit in a later period, the early 2nd century AD, in a letter from a naval recruit with aspirations to join a legion. He requests from his father a *dolabra,* amongst other things, and repeats the request in a subsequent letter because the original one had been taken from him by the *optio*. [329] It was used not only in digging but also tree felling and log splitting.[330] Polybius writes about the detailed procedure involved in setting up a camp as follows 'The Romans …. prefer to undergo the fatigue of digging and other defensive preparations for the sake of having a consistent and uniform plan for a camp which is familiar to everyone.' [331]

Tethering pegs: These items were comparatively common in Republican times and can be described as sturdy iron spikes, some 330gms in weight, with loops through which a ring is attached. Their use is likely to have been as tethering pegs for horses or mules. They are evidenced by finds in Numantia. [332]

Tent pole attachments: Given the fact there were eight to ten legionaries billeted in each tent, a legion would require sixty tents. To this one would need to add tents for officers as well as those for functional and administrative purposes. The number of tents would therefore be significant and, with some two to three poles per tent, the number of tent poles more so. The reference for this is rather late and is contained in Diocletian's Prices Edict as follows:

Tent pole with iron fittings	400denarii
Tent pole without iron fittings	200denarii

This was at a time when the lowest wage for a labourer was 25 denarii. [333]

[327] Connolly, P.(1975) 33
[328] Bishop, M.C. and Coulston, J.C.N. 116- 117 . Evidence of wooden pegs from Newstead (AD) 'often identified as tent pegs, they are more plausible as tethering pegs for animals for as Schulten pointed out, a legion would have needed 35 pack animals just to carry them' but see also footnote 60 below
[329] Connolly, P.(1975) 18 and Youtie,H.C. and Winter, J.G. (1951)
[330] Wright, K,D. (1967) 64
[331] Polybius VI, 42
[332] Bishop, M.C. and Coulston, J.C.N.; 69. refers to iron pegs being used sometimes
[333] Details as provided by Prof M Crawford from the Diocletian Edict c300AD

This would imply that tent poles with iron fittings were in use at that time and perhaps that the extra benefits and properties of the iron fitting were worth the additional cost. However the practicalities would mean the availability of local sources of iron could well have been the deciding factor.

Naval Construction During the middle of the third century between 264 and 241BC, the Roman Navy became established and gained control of the Mediterranean Sea. (which it retained throughout the time of the Empire). The establishment of the fleet underwent an initial learning curve, success followed by a major setback caused by design failure and finally the overwhelming defeat of the Carthaginian fleet. Many ships were built during that 25 year period, of the order of some 400-500, 200 of which were constructed in preparation for the final battle within three months following the loss of 270 wrecked at sea. Iron was not used in the building of the ships' frames; wooden planks were joined together by means of morticed joints and dowels. Iron may well have been used for re-enforcing rams, and it was certainly used for general carpentry work. There is widespread evidence for numerous iron nails found in shipwrecks but they refer mainly to their use in general joining applications but not, it would seem, in the construction of the main frame.

Impact

<u>Factors affecting change</u>*:* The key issue here is one of replacement of bronze by iron for use in blades and spear heads. The better physical properties of iron would have been a compelling reason for this transition to take place. Polybius refers to the inadequacy of enemy weapons in that the blades of Celtic swords were ineffective after only one slash whereas the Romans were advised, well as it turned out, to use the point of their weapons.[334] This indicates that the edge retention of blades of neither side was noteworthy. However, some recent analysis of Roman weapons has been done which indicated that the weapons of the early Principate were not complex in their construction, Some Roman sword smiths were able to carburise iron and

[334] Polybius II

quench it for hardening and (possibly) temper. [335] The substitution of iron for bronze may also have played some part in the Roman Army's ability to expand as needs dictated; this, as has been shown, was sometimes rapid. It would be hard though to imagine the Army being denied supplies of a material such as bronze if its shortage limited its expansion. The fact that blades of swords and daggers were principally made from iron in Republican times [336] indicates the up-take of iron was significant.

The use of iron in tools employed in the construction of the camps would have been as a replacement for wooden tools. Time constraints may have been an important consideration in camp construction so the fact that iron was a more effective material than wood may possibly have provided an incentive to change, subject to local iron availability.

Agriculture

Introduction The approach will be the same as in the previous sector where the various uses of iron will be examined. Initially, a brief description of the tools used in the day to day cultivation of land will be given. This covers land used for the production of grain and domestic horticultural applications as well for vineyards and olive orchards. The literary sources available are detailed and informative describing the tools employed and how they were used, particularly in the case of viticulture. The principal authors are Cato, Varro, Pliny, Columella and Palladius. The overall impression is one of diversity; a wide variety of tools designed for a particular purpose often reflecting the requirements of different ground conditions.

Applications The tools being considered were all involved in basic land husbandry, the clearing and cultivation of land to produce food, and at the heart of this lay good husbandry including careful tillage of precious top soil. The tools are referred to by one or more of the above authors and for

[335] Bishop, M.C. and Coulston, J.C.N. (2006) 241;
[336] See note 319 above

convenience they will be divided into three groups, although several items overlap.

1 Tilling and preparation of the top soil as a seed bed or for planting trees/vines and ensuring areas are weed free: spade/shovel, lighter weight rake/hoe.

2 Annual fallowing, preparation of site or change of crop.

The ox-drawn plough was an essential part of the farmers' equipment in the small holding economy of early Rome.[337] But the breaking up of clods of earth after ploughing or digging was carried out by heavier weight spades, hoes, forks or mattocks do*labrae. S*aws and axes were used for more basic land clearance work of trees and scrubs.

3 Harvesting: Sickles and scythes,

Cato, in *On Agriculture* 10-11, specifically mentions iron tools in a full inventory given for what was considered necessary to run a 240 *iugera* sized olive orchard. These included the following,

> *Iron tools:* 8 iron forks, 8 hoes, 4 spades, 5 shovels, 2 four-pronged drag hoes, 8 mowing scythes, 5 reaping sickles, 5 pruning hooks, 3 axes, 3 wedges, 1 mortar for grain, 2 tongs, 1 oven rake, 2 braziers

The list covers a range of presses, livestock and associated equipment.

It also gives a list of the equipment needed for a 100 *iugera* sized vineyard, and whilst the number of presses, livestock and their ancillary equipment is reduced more or less proportionally, the remainder of the list including iron tools is quoted as being similar to the larger olive orchard. [338] The list also includes forty wooden shovels (or scoops).[339] In this context, these *palae lignae* seem likely to refer to short handled trowels used to plant vines. Wooden shovels were largely used for shifting grain and were cheap, 4 denarii in Diocletian's *Edict.* [340] The strong indication here is that iron was used when physical demands or soil conditions warranted it and wooden tools used where practical or where there were financial constraints. However, we do not have comparative price data.

---

[337] White, K.D. (1967) 13
[338] Humphrey, J.W., Oleson, J.P., Sherwood, A.N. (1998) 85
[339] Cato 11.5
[340] In White, K.D. (1967) 31:8

As regards harvesting and haymaking, references are made to scythes and sickles with iron blades. For harvesting, 'grain was reaped by using a balanced sickle with an iron blade.' [341] For haymaking, *Pliny* (*NH,* 18. 258-263) refers to "whetstones that can be used with water for keeping the iron sharp" and to two sorts of scythe, a shorter one (Italian) for easier manipulation and a longer one for use on the larger estates. Saws can be included here. These latter applications utilise the cutting edge properties as referred to earlier. For axes, adzes, pick-axes, mattocks, hatchets and hoes, the advantages of iron are clear cut; head weight and an edge. To-day's design differs little from those used at that time.

Impact Land was being cultivated and food produced, albeit on a subsistence basis, long before iron was used. There is evidence of bronze still being used for tools at the end of the first millennium but, from the limited archaeological evidence available, not extensively so. Iron was different; its advantages were recognised essentially because of its superior physical properties. These gave iron tools an advantage over wooden ones. As a result, labour could be used more efficiently and yields increased by better husbandry (deeper plough furrows and finer tilth).

While much of the detailed evidence refers to larger farms and hence to landowners who had the resources and motivation to improve farming methods, Pliny wrote about the prejudice directed at the efficiency with which Gaius Furius Chresimus, a liberated slave, ran his modest farm (facing a potential conviction for sorcery). In his defence. Chresimus gave one of his reasons for efficiency as "splendidly made iron tools, ponderous ploughshares and well-fed oxen. the substantial mattocks…" *NH* 18. 39-43. [342]

In this case, and contrary to the general view that farmers of smallholdings were conservative and resistant to innovation, Chresimus, by obtaining more bountiful crops from his farm than his neighbours did from their very large estates, demonstrated the contribution iron tools could make. This will be referred to further when the rate of up-take of iron tools is discussed in the

[341] White, K.D. (1967) 107
[342] White, K.D. (1967) 92-93

next chapter. Suffice to say that here is evidence from two types of farmer writing positively about the effect of iron tools on the overall efficiency of their land cultivation.

Construction The undertaking of major civil building projects, associated with extensive urban development, entailed significant activity in general construction work. Associated with this was the provision of a necessary supply of water and other ancillary services to conurbations, often in the form of aqueducts and roads. The Pont du Gard, which enabled water to be supplied to Nimes, was built in the first century AD and is still virtually intact. It is a fine example of Roman civil engineering. In all projects where large blocks of stone were an integral part of the construction, iron clamps were used to locate and secure the blocks. Their position was then consolidated by pouring molten lead down holes drilled with an iron drill between the stone blocks.[343] Physical evidence of such usage can still be seen on many ancient Roman building sites.

There are other references for the application of iron in building work. In a contract for the temple of Serapis in Puteoli in the late second century BC, reference is made to a construction in front of the Temple in *CIL* 1.698=*ILS 5317* in column ½ as follows; 'Above let him attach the decorated sima with iron. Above the topping beams let him place fir cross beams, 0.5 foot thick each way, and let him fasten them with iron' and later in the same column, 'Let him fasten all the lower rows of roof tiles to the facing with iron.' [344] We have little indication or evidence as to which applications were the major users of iron; building clamps certainly and basic nails would have been a major end use. Nails were used widely in carpentry in both civil and domestic applications. Sources from the ancient writers include a very detailed passage outlining the construction for the Arsenal of Philon in Athens in the later part of

[343] *IG* 2/3² 1666.38FF (fragmentary) ' The metopes are to be made……and bound with clamps and secured with dowels and then lead is to be poured all around…' in Humphrey, J.W, Oleson, J.P. Sherwood, A.N. (1998) 266

[344] *Supra* 269-270

the fourth century. This section is part of the specification for a roof in *IG* 2² 1668;

> He shall place planks on top, 0.5 feet wide, and 2 *dactyls* thick, fastening them with iron nails…

and in a commentary of the importance of carpentry for making vaults from Vitruvious, *On Architecture,* 7.3. 1-2

> These lathes, once they have been arranged into a curved shape, are to be secured to the floor above or to a roof by fastening them to wooden ties with many iron nails.

Finally, to illustrate usage by default, a reference by Pliny (*NH* 36 36.100) is made to a vault 'with rafters that have no iron nails … they 'are arranged in such a manner that the beams can be removed and put back without the aid of scaffolding'.

To generalise therefore, in construction, iron was used very much for basic items such as nails and clamps; important applications with widespread uses. There are very few references to iron being used to exploit its tensile strength properties.[345] Columns of brick, stone or sometimes bronze and lintels of wood and again sometimes of bronze were the materials used in the main. Pleiner does refer to the use of 'huge iron beams as supports in the construction of *Thermae*. The heavy iron beams are made of iron which is unconsolidated and spongy at the centre.' [346] (There is no date attached to this reference and perhaps should it be given too much weight). The small number of literary references and the limited archaeological evidence available would indicate its application, in this context, was small. However for nails, there is ample archaeological evidence in museums in Etruria (and elsewhere) to-day. Covering a period from the 6th to the 4th century, some eighty nails are on display at the Bologna Museo Civico Archeologico as part of its normal collection. They are displayed mainly in groups of four or eight and are in varying condition. Included are eight large nails in good condition dated 460 BC and used in a coffin.[347] The eighty nails should not be taken to indicate the total quantity of these iron artefacts; they are but a small

[345] Humphrey, J.W. Oleson, JP. Sherwood, A.N . (1998) 276 Examples of where iron is used as a lintel are in the Propylia at Athens and in the temple of Zeus Olympius at Agrigento.
[346] Pleiner, R. I*ron in Archaeology* 271
[347] Bologna museum; the eighty objects are from Certosa , Tomba 228, Cippo funerario, n157 and Certosa, Sepulcro Savenna in which the coffin nails are in case 114

representation with the remainder carefully housed in store. I suspect the same is true in the majority of museums. Iron artefacts, even those not corroded, are not intrinsically attractive to the casual visitor and as a result are not widely displayed. Evidence, both literary and archaeological, is available for quite extensive iron usage for nails and clamps. However in such an exercise such as this, the quantity used is extremely difficult to estimate;

Mining This sector is another major part of the wider Italian economy. As with construction, iron was used to a large extent in the more basic tools; those needed in the actual mining operation, essentially for shovels and pick-axes used in the extraction of the ore from the mine face. They were also used to break down the ore and help separate the gangue as far as possible; a very labour intensive part of the process. The weight and shape of iron mortars and other tools depended on the nature of the ore. The significant technological input in mining was the removal of underground water by the use of the Archimedes screw.

Other sources of evidence; cargoes from Shipwrecks

This item has been included to give some indication of the form and extent to which iron was transported and traded overseas. The graph shown on page 89 above showed a peak in the number of shipwrecks between 150BC and 150AD which reflected the marked increase in Mediterranean trading.[348] Out of an overall total of some 1200 shipwrecks, 36% were found in 'Italian waters' and 23% near the southern coast of France. Analysis by cargo type showed by far the greatest number of items found was amphorae. These accounted for some 70% of the total whereas metals accounted for 8% and of this figure, iron was 10% (ie just less than 1% of the total).[349] In essence therefore, even taking into account the extensive corrosion that occurred to iron objects in sea water, the evidence of the overseas exchange of iron at that time (400-0BC) was limited. The evidence we do have consists mainly of iron bars. A shipwreck found off the coast of southern France and dated 110-100BC,

[348] Parker, A.J. (1992) 549 fig 3 shows the number of shipwrecks in the Mediterranean in each of the years from 200BC to 200AD. See Chapter 8 p89 above.
[349] It should be noted that these figures relate to quantities not value.

contained five to ten tons of iron bars with an average weight of thirty kilos. [350] Another in a similar location and dated in the late 2nd century contained fifty long iron bars. [351] Although there were a high density of shipwrecks around the coasts of Sardinia, Corsica and north-west Italy, only a few contained iron as part of their cargo. There is one, dated 75-25 BC and located at Capo Testa. Part of the cargo was again in the form of iron bars.[352]

Hence the iron artefacts which have been found were mainly in the form of iron bars; available for conversion into finished articles? Their use as iron pillars or lintels is unlikely because they do not appear to be made with specific dimensions in mind. However, the quantity appears limited. This may have been due to natural corrosion but even metals such as copper and bronze only account for some five to ten percent of the total number of objects found; that compares with the figure for amphorae of some seventy per cent. The transport of iron ore is outside the scope of this analysis.

SUMMARY This analysis of iron usage and its applications illustrates there is evidence to support the fact that iron was widely used and accepted by the 1st century BC.

For military equipment, the advantages of iron are more readily recognisable. They centre round the ability to provide and retain a cutting edge for swords and daggers. And there were other more utilitarian uses as have been described. Polybius writes clearly about the weaponry of the Roman legionaries during the Italian wars and the subsequent Punic campaigns. Etruria's contribution of iron to Rome to help in the building of ships for the navy at the time of the Punic War(s) was suitably acknowledged.[353]

Archaeological evidence stems mainly from the 1st century BC and the 1st century AD. It is unlikely that any major new weaponry relating to the latter period will have been developed and not to have been referred to by the ancient authors.

---

[350] Parker, A.J. (1992) 77

[351] *supra* 373

[352] *supra*. 258

[353] Livy XXVII.45

As far as agriculture was concerned, the iron tools made were basic ones and their usage indicated that there were advantages in using iron, essentially replacing wood and bronze. By the time Cato and Varro were writing, certainly by the end of the 2nd and the beginning of the 1st century, iron seemed to have been accepted as a practical and useful material, a normal component for basic implements. We do not know whether the transition to iron took place without drama or major setbacks. There are no references to this in the literature. [354] In the case of military weaponry, there is no mention of difficulties in supply or shortcomings in physical properties. In reality though, such introductions are never as quite straightforward as such a statement would imply

The transition to iron would have been influenced by the availability of bronze and iron's improved physical properties. At the same time, the overall economy was growing and with that the demand for metal artefacts including basic agricultural tools. The strength of the Roman army continued to grow in importance as the major instrument in acquiring or conquering new territories. All of which will have stimulated the overall demand for iron. Critically, a 'reliable' supply of iron would play an integral role in enabling this expansion to take place.

Following this initial analysis there are two areas which indicated the amount of iron used was greater than the others, in military equipment and agriculture. It is these two sectors which will be looked at in more detail in the next chapter.

[354] A negative reference but making a completely unrelated point.:-Pliny's *Natural History* 34. 138-139 was given on p13 illustrating the many uses of iron in mining and agriculture. The passage however goes on say ' But we employ iron as well for war, slaughter, and banditry, not only in hand to hand combat, but also on a winged missile, now fired from catapults, now thrown by the arm, now actually fletched with feathers. I think this last to be the most criminal artifice of human integrity, in as much as we have taught iron to fly and given it wings so that death might reach a man more quickly.'
However, this adds nothing to the debate and can perhaps be viewed as moralising.

Chapter 10 **QUANTITIES: an assessment of the annual iron usage at the end of the 3rd and beginning of the 2nd centuries BC.**

Introduction An attempt will be made in this chapter to estimate the total annual amount of iron which was used towards the end of the second century BC. This assessment follows on from the previous chapter where the main applications of iron usage were identified. The rationale behind this approach is to see how widely and in what quantity iron was used and it is the latter, quantities, which will be tackled in this chapter

By ancient standards, the output of iron at Populonia is acknowledged as noteworthy and significant. Although the actual output calculations, as we have seen, are based on slag heaps over 2000 years old, I believe the approach taken to arrive an output figure given in chapter 7 is valid. Should the estimated quantity of iron *usage* be of the same order of magnitude as the estimated *output* figure, then these two figures would go some way towards explaining how and why this comparatively rapid transition to iron took place.

Outline approach I should stress at this stage that the computations which follow are designed to give a ‘global’ figure; this exercise is not a thorough or detailed market survey. Although detailed figures are in fact used in the initial calculations, they are used to provide an accurate a basis as possible from which further extrapolation can sensibly be made. The assumptions made are many but they are noted and explained. In some cases, they are compensating and therefore less significant than they may appear at first sight.

An overriding factor in such an exercise is the assessment of the *rate* at which iron replaces other materials. In addition, growth in any particular sector must also be considered. The basic advantages of iron have been described in some detail but they do differ in the different areas of application; these will be covered within the discussion of the individual sectors. The two principal areas which appeared to account for the largest amount of iron usage will now be analysed further. These are Military Equipment and Agriculture and the analysis of each sector will be done in three parts.

a) Scope of analysis: Identifying and defining the overall size of the relevant area and within that area, the various factors which will have influenced the rate of substitution.
b) Equipment: Determining the type and then number of the particular iron implements involved and their annual usage. This takes into account the 'expected' life of the equipment. For example an axe will have a longer life than a hoe and this is reflected in the depreciation rate attributed to the article.
c) Quantities: Assessing the weight of each implement or piece of equipment and then combining it with the appropriate frequency of use to give the total amount of iron used by each sector.

Military weapons and equipment

Scope of analysis Livy wrote, at the time 340BC, 'There were usually about four legions enlisted, each with 5,000 foot soldiers and 300 horses to each legion.' [355] So the size of the Roman army in the second half of the 4th century was therefore about 20,000 soldiers and 1,200 cavalry.
However at times of conflict and war, the number of legions would be increased and with that an additional number of allies would be called upon to fight. More detailed figures are available for the period of 225BC and after.
PA Brunt's in *Italian Manpower* quotes figures from Livy [356] commenting that they seem to be trustworthy; as follows:[357]

	Infantry		Cavalry	
Army	Romans	Allies	Romans	Allies
Ti Sempronius	8,000	16,000	600	1,800
P Scipio	8,000	14,000	600	1,600
Gallic	8,000	10,000	600	1,000
Total	24,000	40,000	1,800	4,400

This gives us a total of some 70,000 men and a ratio of Romans to allies of approximately 1:2. It also shows the proportions varied from army to army. Earlier figures from *Polybius* refer to a 1:1 ratio so an army of 4 legions, being equivalent to some 20,000 legionaries, would total some 40,000 men. The number of legions varied greatly, particularly during the Hannibalic War, where the number raised varied from six in 218BC, rising to twenty-five in

[355] Livy;VIII, 8.
[356] Livy, XXI,17 in Brunt, P.A. (1987)
[357] Brunt, P.A. (1987) 678

212-211 BC and then returning to fourteen in 201BC.[358] Between 200BC and 170BC the army's strength varied between six and twelve legions but mostly fell between eight and ten legions with a total manpower ranging from 120,000 to 170,000. [359]

With all this in mind, these figures represent the total manpower in the army reflecting the many changes which took place.

350-300BC Livy VIII, 8	'standard' 4 legions	1:1 ratio Romans:Allies		40,000
218BC Livy XI 7	see table above	1:2	,,	70,000
200-170BC	average figure			145,000

For this exercise, the manpower figure of 70,000 will be used.

<u>Equipment</u> Until around the late 2nd century, each soldier equipped himself with a helmet, a sword or *gladius,* 2 *pila,* a shield, and some form of body armour. The basic personal weaponry carried by each legionary is therefore not too difficult to define. However, in addition to their traditional weaponry, an earth moving tool, such as a sturdy spade/shovel and/or a *dolebra,* the latter described as a classic military tool,[360] would form part of the infantry's equipment. When the army was on the move, the setting up a new camp required digging new defensive ditches and ramparts. Shovels and pickaxes would have been needed to do this. As far as the availability of the iron required for the equipment was concerned, during the later overseas campaigns, in Spain and Gaul, it is possible that locally resourced materials would have been obtained to supply an army of increasing numbers. We know that the Romans learnt about the *gladius Hispaniensis* in Spain and incorporated its advantages.

As described in the previous chapter, helmets were made from bronze; iron helmets were only introduced gradually in the 1st century AD. With body armour, bronze began to be substituted by iron in the *lorica segmatata,* again over a period of time during the 1st century AD. Iron was used in part of the shield and was adopted already in the 4th century BC, [361] but this only

[358] Brunt, P.A. (1987) 418
[359] *supra* 424
[360] Bishop ,M. C. and Coulston , J.C.N. (2006) 117
[361] Livy VIII, 8

consisted of a rim attached to the top and bottom. The amount of iron involved here was probably too small to affect this overall assessment.

<u>Quantities</u> These is based on usage for swords, *pilae* and shovels/pick-axes and is calculated on the basis of, for ease of comparison, kilograms of iron per soldier. The dimensions used are taken where possible from Bishop and Coulston, *Roman Military Equipment.* However information on thickness is difficult to find. Of the limited number of artefacts I have examined, many were badly corroded and I have made a best guess. However, in general terms the greater the thickness assigned to an article, the longer it will last, so in terms of annual usage the resultant effect is not quite as critical as it might first seem. Using the dimensions given or estimated, the volume of the implement was calculated and this then was converted into weight using the specific gravity figure for iron, 7.8. A depreciation rate is estimated to reflect the length of time the article will last before it needs to be replaced.

L -length; W-width: t-thickness: D- diameter

<u>Sword blade</u>	Size: :L 60-70cm; W-45-50mm; t 5 mm [362] Weight: 1.2 kg
Depreciation:	2 years:[363]

Annual weight of iron required to equip a soldier for blades <u>0.6kg</u>

Pilum	Shaft (iron element): L 30-50cm; Diam; 10mm[364] Weight: ¼ kg Usage; each soldier issued with 2 *pilae* and because they were designed to deform on use; total usage 4 pa

Annual weight of iron required to equip a soldier for *pila;* <u>1kg</u>

<u>Shovels (*Rutrum*)</u>	Roman shovel-shaped spade ; L 24cm W 24 cms but tapering [365] assume to half the maximum width giving an average ‘width’ of 18cm thickness; assume 5mm with a two year life. weight for *Rutrum/Dolabra*: 1½ kg
Dolabra	an equivalent weight; needs to be of ‘reasonable’ weight to be effective – assume same weight as *Rutrum*
Weight	1½kg [366]
Depreciation	4 years

Annual weight of iron required to equip a soldier for shovels/mattocks; <u>0.4kg</u>

---

[362] Bishop, M.C. and Coulston, J.C.N. Dimensions: length and width – p 55 fig 25
[363] A comparatively long depreciation rate is applied – 2years.. It takes account of the extreme penalty of the legionary losing his sword Livy VI,37 ‘Again, those who have lost a shield or a sword or any other weapon on the battlefield often hurl themselves upon the enemy hoping they will either recover the weapon they have lost, or else escape by death from the inevitable disgrace and the humiliations they would suffer at home.’
[364] Bishop, M.C. and Coulston, J.C.N. 53 Dimensions, fig23
[365] White, K.D. (1967) ; 177/8
[366] White, K.D. (1967) 64 I have assumed one *dolabra* type of tool or spade per legionary.

Total weight of iron required to equip a soldier, (0.6+1+0.4) **2 kg**

Total amount of iron to required to equip 70,000 legionaries would be **140 tonnes.**
By comparison, the equivalent figure for 40,000 and 145,000 legionaries would be 80 and 290 tonnes

There are several factors which indicate these figures may be on the high side. During this period, it was the responsibility of individual legionaries to arm themselves, so whether iron was universally used, particularly in the earlier times, is perhaps debateable. Also, we do not know whether allied troops were armed to the same level as legionaries. We do know however iron had advantages over bronze, that iron was definitely used for *pilae* and that it made sense to use iron in tools in the construction of camps. From this, one can reasonably surmise that the switch to iron would have been driven by advantages which were both beneficial and apparent to the users. The total amount of iron required to equip an army of 70,000 men on a yearly basis is therefore estimated at 140 tonnes on an on-going annual basis but it does assume a 100% substitution of iron for bronze or other materials. All of which would indicate that even if these calculations are high by as much as a factor of two, military weaponry would have been a significant user of iron and equally, the size of the army was an obvious determining factor.

Agriculture

Scope of analysis The estimates are based on information both literary and archaeological. Those for the type and, number of implements come, as has been stated earlier, from the writings of Cato (late 2nd century), Polybius (2nd century), Varro (1ST century) and Pliny (1st century AD). I have assumed that there was no essential change in the way those implements, as described in the first century AD, were used perhaps one hundred years earlier.[367] So the descriptive data has been taken into account but quantitative data relating to the later periods has not been used. The design and shape of the tools comes from archaeological data.

[367] Cato *On Agriculture* and Pliny *NH* 34. 138-13 wrote as if the iron tools were standard implements; tried and accepted .

It is important to say at the beginning that the rate at which other materials were substituted by iron is an overriding issue. Land had been cultivated and food produced for many generations before iron was available. More detailed evidence will lead to at least some indication of the extent of this substitution. This will be discussed at a later stage.

To progress further, three key factors need to be resolved; firstly the total area of land being considered, secondly the weight, or at least the iron content, of individual implements and lastly, within that total area, the types of farm being used in the cultivation of the land.

1 The area of land under consideration. The total area of the *ager Romanus* in 264BC was 27,000km² having expanded from 5,500km² in 338BC. [368] It expanded further to 160,000km² in the first half of the 1st century.[369] This significant rise in area of the *ager Romanus* does not mean of course that additional land was created but that existing cultivated land was incorporated into the total figure of land owned by Roman citizens. This is probably related to the Roman census figures and property qualification,

Figures are available for the number of free inhabitants of Italy in 225BC by group together with the area occupied by each group and can be summarised as follows from table below, Free Inhabitants of Italy in 225BC [370]

All free persons	Population	Territory /Km²	Density
Romans	923,000	25,615	
Latins	431,000	10,630	
Etruscans	274,000	19,085	
	1,628,000	55,340	29.5
Balance+	1,124,000	52,300	21.5
Total		107,810	

+Samnites, Apulians, Abruzzi peoples, Umbrians, Lucanians

[368] Morel, J-P. (2007) 499
[369] Lo Cascio, E. (2008) 245
[370] Afzelius, I. 98-106, 133-5 in Brunt, P.A.(1987) 54

This period, the last quarter of the 3rd century, is the period of particular interest here. Within those figures, the total area of the subsection covering the Romans, Latins and the Etruscans is 55,340 km², but for the purposes of this exercise a base figure of 50,000km² would seem a reasonable starting point.

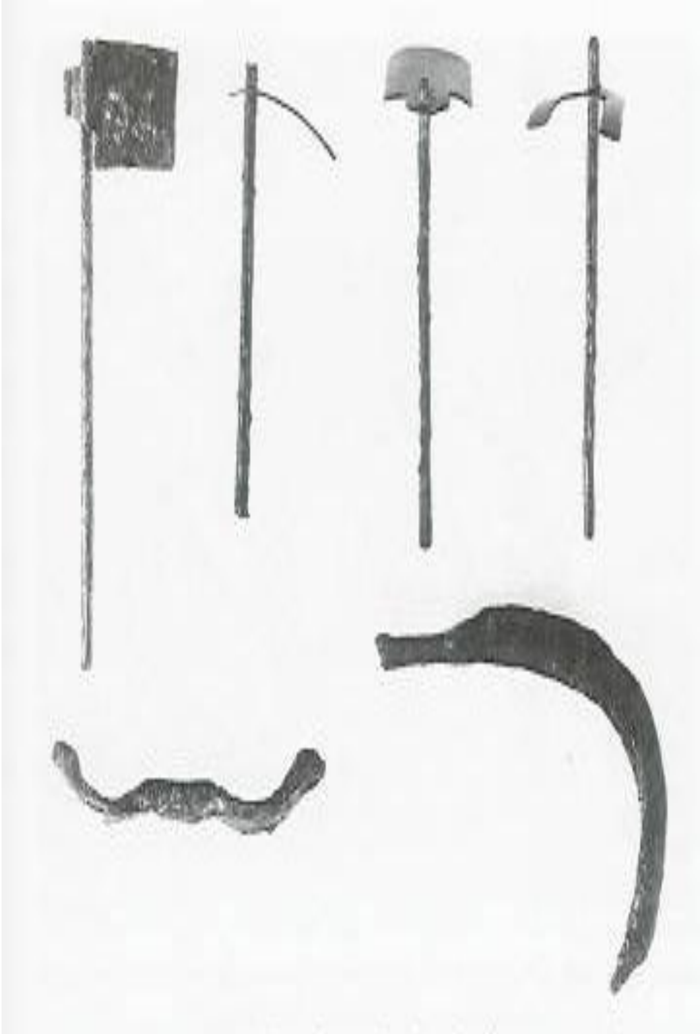
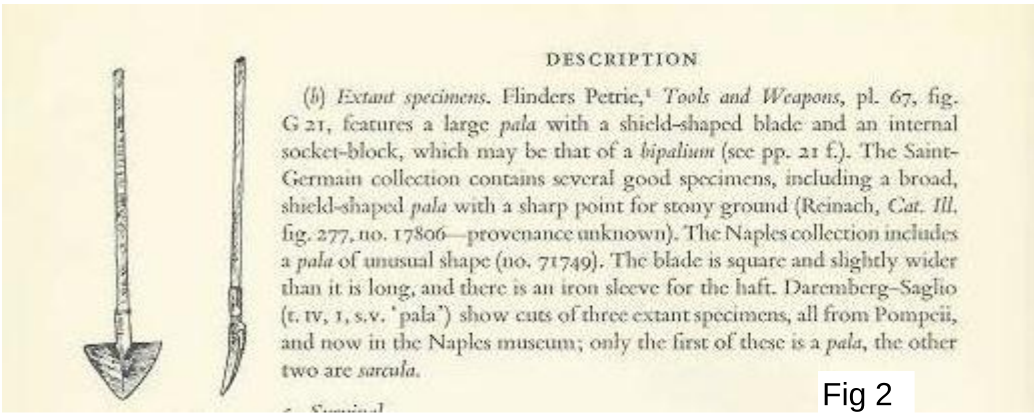


Figure 69 Etruscan models of agricultural tools (from a votive deposit at Talamonaccio). Above: hoes and mattocks. Below: a yoke and a sickle. Different scales. (Photograph: Museo Archeologico, Florence, Soprintendenza Archeologica per la Toscana)

Fig 1

<u>Equipment</u> A full description of agricultural implements is clearly described in KD White's *Agricultural Implements of the Roman World.*[371] Whilst most physical dimensions are available, thickness measurements are not and estimates have been used. The initial impression gained is how small the cultivating tools, like the spade, fork, and hoe, appear in comparison with similar articles of to-day. This is illustrated by models of agricultural Etruscan tools from the Museo Archeologica in Florence. Fig 1

<u>Palae</u> (fig 2) Whereas a modern light spade or fork weighs some 1½ kg, one would guess the ancient equivalent, which is pointed and still used in southern Italy to-day, to be no more than half of that if not



DESCRIPTION

(b) *Extant specimens.* Flinders Petrie,[1] *Tools and Weapons*, pl. 67, fig. G 21, features a large *pala* with a shield-shaped blade and an internal socket-block, which may be that of a *bipalium* (see pp. 21 f.). The Saint-Germain collection contains several good specimens, including a broad, shield-shaped *pala* with a sharp point for stony ground (Reinach, *Cat. Ill.* fig. 277, no. 17806—provenance unknown). The Naples collection includes a *pala* of unusual shape (no. 71749). The blade is square and slightly wider than it is long, and there is an iron sleeve for the haft. Daremberg-Saglio (t. IV, 1, s.v. 'pala') show cuts of three extant specimens, all from Pompeii, and now in the Naples museum; only the first of these is a *pala*, the other two are *sarcula.*

Fig 2

---

[371] White, K.D. (1967)

less. [372] An estimate based on quoted dimensions confirms this. For the purposes therefore of estimating a total overall weight of iron used, an average weight in a spade or shovel has been taken as ½ kg. [373]

Hoes and forks. Detailed descriptions are available [374] and illustrations of Etruscan examples shown in Fig 1 above. They appear to be very light weight and a figure of ¼ kg estimated. They are assumed to have been used for top soil preparation rather than the more arduous function of clod breaking.

Fig 3 re sickles

Scythes and sickles. Data available on the length of the cutting edge blade has been used together with actual weight measurements obtained from the two examples of sickles, 63390 and 63391 examined in the Petrie museum and illustrated in Fig 3. 63390 weighed 54 grams but it was heavily corroded; 63391 is in good condition and weighed 120 grams. It was in fact a sleeve in which a saw would have been inserted. To estimate the weight of the blades for scythes, as opposed to sickles, a thickness gradient from 1.5mm to 0.5mm has been assumed. This results in an 'average' estimated blade weight of ¼kg for scythes and 1/8 kg for sickles.

Axe-heads, mattocks, pick-axes/*dolabrae.* Although a wide variety of these implements are well illustrated in KD White's book, [375] any form of detailed calculation remains difficult. However, two examples of an axe heads, both in excellent condition, were examined and weighed 1 kg each. Modern mattocks

[372] The Roman trenching spade, referred to in the analysis, appears heavier.
[373] I have taken an average of the weights calculated from the dimensions for the *palae* described on p177 n90 for items 1 & 2. item 1 made of two plates 'for trenching and turning over the soil' and item 2 as shown in Fig 2. normally used for turning over light soils., especially in gardens and orchards.
[374] White, K.D. (1967) 37-40
[375] White, K.D (1967) 59-68

and axe head weigh up to 3kg. But for the reasons given above, namely that ancient agricultural tools appear lighter, a figure of 1kg is used. [376]

To sum up this section therefore, available archaeological evidence and some reasoned guesswork has been used therefore to arrive at estimated weights of the iron content in the various tools. These are as follows;
spades and shovels, ½ kg; hoes, forks and scythes ¼ kg and sickles 1/8 kg.
In terms of 'life expectancy' or the depreciation of the tools in question, to-day one would expect such tools to last for up to 10 years or more, whereas it is not unreasonable to assume these ancient ones would have had a more limited life. The tools will have been made by hammering the iron into sheet form rather than by moulding and appeared thinner than the modern equivalent With this in mind, a four year life has been assumed for spades, and shovels, and two years for forks, hoes and scythes/sickles. Repeating a point made earlier, the greater the thickness ascribed to these implements, the heavier they will be but the longer they will last. For axes, wedges and mattocks, being sturdier, a life of up to ten years has been assumed,

<u>Quantities</u> The number and proportion of the different farm implements is dependent on the farm size and the type of farm. With this in mind, two types have been chosen for more detailed analysis. Firstly, a medium sized orchard and a vineyard and secondly a small holding, essentially a subsistence farm.

1 240 *iugera* olive orchard. . This particular example has been chosen because very detailed descriptions of the equipment, and in particular *iron* equipment, are given by Cato. [377] They are as follows:

8 iron forks, 8 hoes, 4 spades, 5 shovels, 2 four-pronged-drag-hoes,
8 mowing scythes, 5 reaping sickles, 5 pruning hooks, 3 axes,
3 wedges, I mortar for grain, 2 tongs, I oven rake, 2 braziers.

Using the unit weights, determined above and applying them to Cato's list, an overall figure of iron usage is calculated. This is summarised in kg per *iugerum* for ease in making comparisons.

---

[376] Note this differs from that ascribed to the military version; the latter assessed as being heavier for reasons of type and frequency of use.
[377] Cato *On Agriculture* 10-11Cato was an land owner with estate management experience.

For the 240 *iugera* orchard we have;

		Kg		Kg	years usage		net kg/pa
4 spades	@	½	)				
5 shovels	@	½	)	9x½ > 4½	4		1
8 forks	@	¼	)				
10 hoes	@	¼	)	31x¼> 7¾	2		4
13 scythes/sickles [378]	@	¼	)				
3 wedges	@	½	)	3x½ > 1½	10	)	
3 axes	@	1	)	3x1 > 3	‘’	)	½
46							
		Total		5½ Kg / 240 *iugera*			
		Or		0.02Kg per *iugerum*			

The estimated iron content of implements used to cultivate this kind of property is therefore 0.02 kg/*iugerum.*

For a 100 *iugera* vineyard: An equivalent general list is put forward with the major items scaled down, however, for vessels and furniture, *iron tools* and miscellaneous items they are similar to the equipment for an olive orchard.[379] In fact reviewing Cato's list [380] for the vineyard in more detail, proportionally more iron tools are used resulting in a significantly higher iron/*iugera* figure.

		Kg		Kg	years usage	netkg/pa
6 spades	@	½	)	10x½> 5	4	1
4 shovels	@	½	)			
10 forks	@	¼	)	12x¼ > 3	2	1½
2 drag hoes	@	¼	)			
50 sickles	@	1/8	)	64x1/8> 8	2	4
14 knives misc	@	1/8	)			
4 wedges	@	½	)	4x2 > 2	10)	¾
5 axes	@	1	)	5x1 > 5	10)	
		Total		7¼kg/100 *iugera*		
		Or		0.07 kg/*iugera*		

On this reckoning, there does seem to be a large difference between the two but it is recognised that the operation of a vineyard is far more labour intensive and hence a requirement for more equipment

378 Using ¼kg rather than 1/8 kg for each of the 5 sickles does not make a significant difference to the final figure.
379 Humphrey, J.W., Olsen, J.P., and Sherwood , A.N. 85 Ref Cato *On Agriculture* 10-11
380 Cato *On Agriculture* 2, 11

The iron content of implements to required to cultivate an even split of olive orchards and vineyards is therefore the average of these two figures, 0.02 and 0.07 namely 0.045, or effectively 0.05 kg/*iugera* or 50 gms.

2 Small basic Farm

With regard to the equipment needed to cultivate arable land for the production of grain, hay and basic domestic produce, we have fairly detailed archaeological evidence about the types of tools being used but no literary references as to the number employed. Within reason, the essentials will not have changed fundamentally between that time and feudal times or in fact to any period of heavily labour based farming. The differences in equipment are probably more related to the type of soil being cultivated. In addition, for such a general evaluation such as this, the effect of overall size of farm or estate should not affect the amount of equipment required per *iugerum* too greatly; there are few benefits of scale for this type of farming.

The amount of equipment needed to cultivate arable land is less than that for vineyards and orchards, with the plough being the major contributor. In the 390's BC, a typical citizen allotment was 7 deemed to be *iugera* and in the early 2nd century, the majority of attested citizen allotment sizes ranged between 5 to 10 *iugera.*[381] There were of course many farms between 10 and 100 *iugera* in size, the larger of which would have been involved in growing a variety of crops and creating surplus produce for onward sale. However a typical small sized farm of say 15 *iugera* (approximately 9 acres) which could be run typically by a family and whose main aim was the production of food for the family has been chosen.

Farms of this size will have been run with simple equipment and be based on the plough undertaking the basic tilling of the ground with spades or hoes being used for the final preparation of the soil for seeding. Harrowing could be done by using wooden planks with protruding nails drawn by oxen or mules. The tools required are therefore related to preparing the ground after ploughing. In addition, for the harvesting of grain and hay, sickles and scythes

[381] Rathbone, D.W. (2008) 307

would have been needed. Given these tasks, the number of tools is most likely to have been related to the number of labourers required, in this case the small holder and family. A mattock or an axe will have been needed.

The weights of the iron content of the tools are as those used in the calculations for an orchard with the addition of the ard of a plough,
The tools requirement may be then be broken down as follows;

			Kg unit	Kg total	Depreciation years	kg/pa
2	Spades/shovels/hoes	@	½	1	4	¼
2	Sickles	@	1/8	¼	2	1/8
1	Mattock	@	1	1	10	0.1
1	Plough ard	@	½	½	2	¼

Total/15 *iugera* farm: ¾ kg

Total: 0.05 kg/*iugerum*

The fact that the rate of iron usage has turned out to be of the same order for both types of farm should not be taken as significant. The orchard/vineyard figure is based on more reliable data for tools used. In arriving at a figure for the small holding, more assumptions relating to the type of soil and hence choice of tool and the general organisation of the plot had to be made. But looking at the broader picture, as far as agriculture is concerned, one can at least put forward a figure of the amount of iron used in the cultivation of a *iugerum* , reflecting both estate and subsistence farms, as being of the order of 0.05kg or 50 grams.[382]

<u>Rate of substitution; bronze or wood to iron</u>

There remains, in this assessment, the most critical factor to be determined and that is the rate of uptake in the use of iron.

Estates The evidence on the use of iron tools and their quantity relies almost exclusively on Cato's *On Agriculture.* When deciding how much emphasis one should place on his contribution, one should bear in mind that Cato was a man of great and proven ability, competitive, determined and

[382] This detail is given to aid following the computations, not to reflect a degree of accuracy.

successful in both political and military fields. On the other hand one might query how typical his views were. Importantly though in this context, he had a sound background knowledge in estate management. This is demonstrated in *On Agriculture,* 2. Cato was quite clear of the advantages of iron in the improvement in the running of his estate. He wrote of the importance of a supply of good iron tools although not in excess of those required. He differentiates between iron tools, particularly spades/shovels, and wooden ones. The proportion of comparatively small number of iron *palae,* four, against six ploughs and forty wooden shovels tells us he was aware of the effectiveness of equipment in general. For him, iron tools were not just a status symbol. That Cato would comment upon iron, not only in this way, but also by making additional comments such as mentioning the best places to acquire particular iron tools and the fact that it was worth replacing them after signs of wear lends credence to this view. Overall, all of this suggests strongly his aim was to maximise his return on investment; selling surplus, as appropriate, and keeping production costs to a minimum. Much of the sense of *On Agriculture* is still relevant to-day. The question remains though is how far sighted were other estate owners or how quickly did they respond to the advantages of iron? We have one piece of evidence possibly suggesting that the adoption of iron may not have been as quick as that for Cato. The particular case of Gaius Furius Chresimus, implied that his neighbours with their large estates were less efficient.[383] We do not know in this case whether an element of jealousy existed, or how inefficient they were, or even the extent iron tools were used on these estates. So on balance, because labour was a direct cost for the larger estates and not cheap comparatively speaking, one would have thought that the use of iron tools to improve efficiency would have been a sufficiently attractive incentive for most of them.

To put forward a rate of up-take of iron implements can only be highly speculative. Accepting the point that, in the running of estates where in fact vineyards were a highly profitable activity, owners had the resources to make best use of their properties, a case may be made for an estimated up-take

[383] Pliny *NH* 18.39-43

rate of say two-thirds referring to the period of the end of the 3rd century and the beginning of the 2nd century BC. This will be put forward for the initial calculations of quantities. In effect, two thirds of the amounts of iron extrapolated from the list of iron tools put forward by Cato.

Small holdings

In contrast to the 'acceptance' of iron implements in estates, the up-take in the small holdings would probably have been quite different and is likely to have been slower. As background, earliest evidence concerning early settlements indicated that of the fairly large population, the majority was engaged in subsistence farming on small holdings. [384] The need to maximise productivity on such limited sized plots accentuated the importance of working the soil with speed and ingenuity, in effect promoting an intensive small holding farm economy. [385] Gains would probably have arisen in improved crop yields; better working of the soil, deeper plough furrows. In terms of written evidence, we have the strong endorsement for iron given in the evidence from the enlightened Chresimus. Here iron tools played a part in improving productivity in farms of modest size.[386] The farm employed 'sturdy people' to achieve this and presumably it resulted in increased goods for sale. Recent research has shown that there is evidence in productivity gains for small holdings. We also have good reason to believe that a small farmer/allotment owner was working the land efficiently. [387]

Whilst the evidence indicated that the use of iron tools generally provided an advantage over wood and bronze, its acceptance and the realisation of these advantages may not have been so immediately clear cut or appreciated by the small holder. Agriculture was, and remained well into the Middle Ages, a very conservative business. The peasant farmer has been described as conservative in outlook and averse to innovation. So the benefits, particularly for a family farm, may not have been so readily apparent. Labour savings tended to be realised only when labour outside the family was needed. Also,

[384] Kron, J.G. (2008) 87-97
[385] White, K.D. (1970) 1
[386] Pliny *NH* 18.39-43.
[387] Kron, J.G. (2008) 97-107

in the case of spades, shovels and maybe hoes, existing wooden tools had served them well in the past. The wooden spades, *palae lignea* would have been cheaper [388] and effective under certain circumstances and wooden shovel blades, shod with iron, *pala cum ferro*,[389] were available providing a practical compromise tool.

On balance therefore, it is I believe reasonable to assume that the up-take by the small farmer was significantly lower than by the estate owner and with that a much lower rate of substitution. With this in mind an initial figure of 20% transition to iron based implements will be put forward. In effect, during a year in the period under consideration, end of the 3rd to the beginning 2nd centuries, 20% of the tools used would be of iron.

Before extrapolating this data into tonnes of iron used, let me first apologise for quoting figures to the second place of decimals (albeit kilograms). They derive from weight estimates of individual implements and as explained are designed to show that, when converted into tonnes by more speculative multipliers such as size of sector, rate of up-take, life of implements etc, the resultant total will demonstrate an *order of magnitude* of usage. Secondly, the fact that the iron usage per *iugerum* is essentially the same irrespective of the type of farm at 0.05 kg/*iugeum* is not significant. For estates, it is an average figure per *iugerum* of 0.02Kg for orchards and 0.08kg for vine-yards [390] and for small holdings, the 0.05kg figure is a straight estimate.[391]

Because the rates of up-take are significantly different between estates and small holdings, namely 2/3rds for estates and 1/5th for small holdings, an estimate the total area of each category is required. Taking into account of the period in question, and the very limited data available, an estimate of the division of the land in question of 20% estates and 80% small holding ratio will be used The iron usage figure therefore will be derived, essentially for a

[388] A. Fenton, (*Proc. Soc,. Ant. Soc.,* XCVI, 1962-3,264F.) notes that wooden digging spades were being imported into Scotland from Norway, and sold for 5d each. In White KD 1967 p31
[389] White, K.D. (1967) 27
[390] p118 above
[391] P119 above

typical year for the period under consideration, using the up-take of iron tools for estates or small holdings as given above. It will represent an annual usage.

OVERALL TOTAL

1 Agricultural section for an area of 50,000km² (see pp113/4)

1km² = 100Ha = 400*iugera* (1ha equivalent to 4 *iugera*)

	Small holding	area 80% of 50,000km² > 40,000km² > 16m *iugera*	
		16m*iug.*@0.05kg/iug. =	800tonnes
	Up-take	20%:	160 tonnes
	Estates	area 20% of 50,000km² > 10,000km² > 4m *iugera*	
		4m *iug.*@ 0.05 kg/iug =	200 tonnes
	Up-take	67%	130 tonnes
TOTAL	for a land area of 50,000 km²area		**290 tonnes**

2 Military weaponry total is:

Total weight of iron required to equip a soldier			2 kg
	Total amount of iron pa required to equip:	**70,000** legionaries	**140** tonnes ,,

Therefore, the overall total is 290 + 140, **430 tonnes**.

Computations of this kind tend to over estimate figures; the higher figure being too optimistic an estimate of up-take of iron being assumed. From a purely subjective point of view, the use in agriculture seems high in relation to the use in weaponry. We know little about price or for that matter availability of iron implements save for the reference from Cato as to the best places to buy them.[392] One could perhaps argue for a more gradual uptake. Some of the data used is soundly based as in the type and design of iron artefact used, but some of the data or assumptions are perhaps less so as in the weight of iron in each artefact type. The weight of implements and their life span were if anything estimated at the lower end, at least for the agricultural sector. Some of these assumptions balance one another. The weight of individual implements, axes excluded, is not too great, so the impact of the balance of the proportion of the different tools chosen is therefore not too significant. Overall, a range of the usage of iron can be estimated as being of the order of

[392] Cato, *On Agriculture* 135.1-2

between 300 and 500 tonnes a year. These figures do not take into account the iron used in construction and the many other ancillary uses.

However, what this total estimate of 300 – 500 tonnes pa. does illustrate is that the usage of iron was such that the proposed output from Populonia, at 100-200 tonnes pa., although lower, is of a comparable order of magnitude in an exercise such as this. No allowance has been made of other possible sources of iron although there is no evidence of any very large other source in Italy.[393] These figures show, if nothing else, that there was a requirement for the output at Populonia.

Summary

So in conclusion, the specific argument being put forward in these last three chapters is that the estimated amount of iron being used towards the end of the 3rd century was of the order of 300-500 tonnes pa. and that this estimated usage was more realistically at the lower end of the spread. But given the nature of these estimates and the assumptions made both in the output and usage figures, they are of the same order of magnitude. What has also been established I believe is that,

- By the end of the 3rd century and the first half of the 2nd century BC, iron had become an established commodity material and it was available
- It was widely used in a range of basic implements and applications
- By implication, the iron produced was usable – 'fit for purpose' the modern euphemism for quality
- The estimated output of iron from Populonia was large but the estimated usage of iron was even greater
- The widespread use of iron will have played some part in improving productivity and contributed to economic growth

The contribution to improving productivity was achieved by making labour more effective; in agricultural terms by introducing better husbandry, in

[393] Although recent evidence has discovered a source in Apulia and supplies from Magdalensberg towards to the end of the millennium would have contributed.

construction and basic building by the use of clamps and nails. For weaponry, iron was a suitable material, it was available and its supply, it would seem, could respond to rapid increases in demand.

.

The technical achievement to produce iron in these quantities lay in the ability to produce usable iron. Iron's widespread and continuing use made it clear that there was a definite demand. Its usage, albeit often to provide basic implements, would have in turn have stimulated further improvements in iron technology. Iron production, at least in Populonia, accelerated from effectively small amounts in the 6th century to the large quantity by the end of the 3rd century. This we have seen was matched by a significant increase in demand and suggests that the availability and use of iron had some impact on the rate of the economic expansion which occurred.

How this technology was transferred and developed from essentially a specialist craft to a technically controlled and comparatively reliable process will be discussed in the next chapter.

Chapter 11 **THE TRANSFER OF TECHNOLOGY**

Previous chapters have followed the progress of some ancient technologies with prominence given to metals and iron in particular. This historical sequence of where and when the changes took place has given an insight into their development. A feature of the rate at which the technology of iron progressed was the length of time it took to develop into an established process. The earliest finds date back to c 5000 BC and were probably meteoric or telluric. This was followed by some evidence of smelted iron in 3,000 BC, [394] and thereafter, its development continued into the later part of the 1st millennium. Two general factors influence this rate of technological development; firstly, the ability to master the necessary techniques and secondly, the impact of the demand or requirement for the results of the technology. It is the first aspect which will be discussed here.

As with most ancient technologies, it progressed in a step by step approach achieving success either by design or chance. It relied on the artisan's individual skills of observation and their ability to identify important changes in conditions or materials, in fact anything that affected the outcome. Reference will be made here solely to iron. The smelting and smithing of iron, as explained in the earlier chapters, is quite a complex sequence of operations following on, as it did, from copper and bronze technology. There is no written evidence about the smelting of iron in the ancient texts and only a little about smithing, although frequent reference is made about the physical demands on the ironworker. Like many crafts, techniques were presumably passed from father to son working alongside one another over a period of time. Improvements were obtained empirically by noting conditions and variables which led to better processing.

We now know that, in conditions prevalent in those times, factors contributing to better control included firstly, the grade of ore used (iron oxide content),[395] secondly, the ratio of the weight of ore to charcoal which affects furnace

[394] Craddock, P.T. (1995)
[395] Ores from specific areas make a significant contribution to the final properties of the smelted iron. The presence of manganese in the ore in the Magdalensburg region and nickel

temperatures and carbon uptake.[396] The step by step improvement in control over the furnace operation and the identification of what was important led to a more consistent process; a basic mechanism of transfer. In effect, the more clearly the operations were defined, the more readily the process could be transferred.

The mechanism by which expertise could become more widely distributed has been summarised by K.D. White illustrating the various ways such information was transmitted. Migration, trade, and war and conquest are reviewed. [397] Much literary evidence in the form of legends is available to support the concept of itinerant craftsmen and the smith is figured in high esteem. Smiths were well known as being travellers and their mobility acknowledged.

The transfer of technology using trade routes is essentially one way whereby the artisan could migrate. In the second half of the second millennium, trading in ores and metals took place in the eastern Mediterranean and included countries and communities such as the Hittites, Mycenae, Cyprus, and Crete as well as Jordan. In the late 13th century the major political powers in the Near East collapsed as did that of Mycenae in the 12th century BC. Accompanying that, and following the rise of the Assyrian empire, a realignment of trading routes was established towards the western Mediterranean. The Phoenicians acted as middle men in organising and facilitating trade between Assyria and Egypt including supplying the Assyrians with significant quantities of iron. In the late eighth century, Assyrian expansion into the Syrian states resulted in their taking a more controlling role, and this in turn led to the Phoenicians extending their trading network well beyond their traditional eastern Mediterranean into the more westerly Mediterranean. [398] This initiated new routes, with the movement of people, skills and technologies, with the Phoenicians taking the lead beginning in the late 8th and early 7th centuries. Phoenician traders were highly successful in

---

in the ore from Euboea both yielded iron of good quality as defined by their physical properties.

[396] Rehder, J.E. (2000) 122-144

[397] White, K.D. (1984) 10-12

[398] Kuhrt, A. (1995) 409

developing exchanges of luxury 'oriental' goods in exchange for amongst other things metal and ore. Their areas of influence were widespread and covered the coasts of Spain, S Italy, Sardinia, Corsica and the south of France. Trading vessels would therefore provide a natural mechanism for artisans to gain access to 'new' countries. This applied to many types of craftsmen. The influence of potters is well known but in the case of metal-smiths, the attraction of communities with metal resources was also clear. The result of their contribution is evident in their influence which brought about improvements in both craft techniques and design. Several Italic communities changed substantially their social and economic life because of these overseas trade exchanges.[399] In Etruria, there is evidence of Sardinian, Phoenician and Greek individuals being integrated within Etruscan society.[400] At the turn of the 2nd to the 1st millennium, the introduction of new trading routes was undoubtedly a major factor in transfer of technology by mobile artisans.

Another method of the transmission of techniques can occur as a result of war or conquest. During the Assyrian empire, the temples were an important source for attracting skilled craftsmen of all trades. The artisans, now subjects after conquest, were transported to Ashur to work there. [401] Also in 2 Kings 24.14 describing the overthrow of Judah by Nebuchadnezzar 'And he carried away all the mighty men of valour…. and all the craftsmen and smiths; …'

So far the narrative, adopted here of the development of iron, has been a chronological and geographical one. It has followed iron making activities through evaluation of artefacts and provided a natural sequence of development.

The itinerant metal-smith fits in well with that sequence and the evidence provided in the near eastern and eastern Mediterranean countries, and the *available* evidence to date would then support that. But during the 1st

[399] Vianello, A. (2009) 49-50
[400] Torelli, 132-137
[401] Kuhrt,A. 533-4

millennium more places of iron making in Western Europe have become known and the production of iron, together with the presence of iron artefacts, albeit on a more sporadic basis, is described in chapter 4. Much of the transfer followed the general flow of information in its widest sense from east to west leading to improved techniques as movement progressed.

The logical development from the Near East to the western Mediterranean is based on sound archaeological evidence. But that was not necessarily the only route. The development of iron making almost certainly took place independently in other places such as Africa and the Americas or even parts of northern Europe, but detailed evidence is limited. Iron working developed from copper working with many of the details of the furnace operation being a common factor. Those skills were acquired by trial and error; there was no magic formula involved. After all, ancient technologies derive from practical experimentation. There is good reason to believe iron technology developed 'independently' in various parts of the world. So expertise could have been acquired either through experienced itinerant metal-smiths, empirical trial and error or a mixture of both. What was different in the final development of iron smelting in the second half of the first millennium in Europe, was the rate at which the necessary experience was acquired and used successfully.

The end result of this long gestation period of iron production was a process capable of making large quantities of iron. Evidence of this is the comparatively large output of usable iron achieved at Populonia realising the mantra 'more reliability, less risk. [402]

Most new technologies associated with significant increases in volume are often related to fundamental changes in method or technique. In the case of iron, this was not the case or at least was not the case until in fact the 1700's. The basic unit of production remained the simple furnace, the operation of which continued in the hands of the skilled metalworker. But, a more reliable

[402] Scale is not the only way to demonstrate reliability. There are other advances in technology which relate to specialised techniques. The combination of science and technology provides a fruitful avenue for innovative technologies. These can be applied to particular applications.

process indicated that the necessary expertise could become more readily transferable; and, with a more controllable process, changes in the structure and organisation could be introduced to improve output levels. The utilisation of semi-skilled and menial labour lends some support to this. We also know that at the time of the Roman acquisition of Etruria, there was a brief lull in iron production followed by a significant increase in production. We can surmise from this that the Romans applied their acknowledged organisational skills to increase output and ensure optimum output levels were achieved.

Given the significant production levels achieved in Populonia and taking into account the widespread increase in the production and use of iron throughout Europe, I believe we can confidently say that a process for smelting and smithing iron had been established.

CHAPTER 12 **SUMMARY and CONCLUSIONS**

This dissertation summarises changes which took place in Etruria during the 1st millennium BC. It has endeavoured to show a link between the technical advances and the socio-economic development of Etruria. These advances were made initially in copper/bronze and then in iron. Etruria's natural resources of abundant fertile land and access to the sea were significant advantages contributing to their underlying prosperity but they were not exclusive to Etruria. The Etruscans had established themselves as a community with a more stable social structure than neighbouring communities already in the Late Bronze Age.[403] However, their natural sources of metallic ores in the Colline Metallifere and subsequently, a plentiful supply of iron ore in Elba were exclusive and significant. But it was the way in which these resources were used to generate great impact, both politically and economically, which made it notable. In addition it was the expertise, both technical and organisational, required to produce iron in large volumes (by ancient standards) which established Populonia as a major 'industrial' provider of iron. This was, I believe, exceptional.

Technology has been given some prominence here because it can provide a link between some of the socio-economic changes, which took place principally in the late 2nd and 1st millennia, and advances made in metallurgy. The rate at which technologies progress are generally influenced by the combination of two factors, 1) the ability to master the basic technologies necessary to produce an article or service and 2) a demand or need, actual or potential, for the technology.

At the heart of the technologies of pottery and metals was fire or the effect of heat. For pottery, it was the kiln, preceded by the hearth and for metals, the furnace, preceded by the crucible. The initial demand for pottery was purely practical, vessels to store food. The basic requirements for producing simple pottery in larger numbers sufficient to supply more than one household, centred round creating uniform temperature conditions in the kiln. Thereafter,

---

[403] Bietti Sestieri, A. M. (1973)

the provision of contrasting coloured effects was made possible by control in the kiln of oxidising and reducing conditions coupled with the correct choice of clay. Pottery, stylishly designed with attractive colour combinations then became a ‘fashion’ object. Technical advances were subsequently geared towards these effects, e.g. *bucchero nero* pottery.

From the beginning, the attraction of metals lay in their colour and tactile properties. This applied to copper and later bronze. This attraction was helped by their limited supply and their usage was understandably geared towards the making of jewellery and luxury items. Early technology was geared towards the utilisation of a wider range of ores. In addition, improved smelting and smithing techniques, and the use of alloys delivered better physical properties, such as hardness as well as working characteristics like mouldability. Luxury items, including daggers and swords, remained the main usage of bronze, the latter perhaps as much as a status symbol as an offensive weapon. Both sectors advanced by way of better control of furnaces and kilns and an appreciation of what an oxidising or reducing atmosphere can achieve. The effects of subsequent mechanical treatments on the end physical properties were appreciated and used to widen the applications of bronze.

Reverting now to Etruria, it has a long history of copper-working going back originally to the Copper Age. Although it was not extensively evidenced in the 3rd and 2nd millennia, it was clearly attested in Populonia from the 9th century onwards and this has now been shown by stratigraphic analysis of slags in the Bay of Baratti. The Etruscans appeared to have retained control over the full range of the operations from the mining of ore, through to smelting and smithing, to the making of finished artefacts. Copper/bronze was traded in any of those states, i.e. ore, blistered copper, metallic copper or artefacts. It was the increase in wealth of the elite, arising from their involvement with metals, that enabled them to acquire luxury goods from abroad. This provided the elite with important outward visual symbols enabling them to demonstrate their social status. Importantly they retained control.

Skilled workers from overseas brought with them specific expertise and were made welcome. As a result of increasing commercial activity, trading routes were protected and expanded, sometimes in the face of the opposition from the Phoenicians. Trading activities were not limited to metals, a thriving trade in pottery and wine with Marseille, and the coastal communities in between, developed in the 6th century. Overall though, it was the exploitation of the metallic ores which contributed to Etruria's success, made possible by the outward looking and entrepreneurial attitude of the Etruscans. This provided the stimulus for the overall creation of wealth in Etruria. Indeed, one might argue that Etruria was at its most influential during the 6th and 5th centuries.

I do not argue that metallurgical advances were the most important element in the social changes which took place in Etruria. Evidently, the establishment of elite classes and urbanisation would have occurred anyway, However, I believe the advances in metallurgy contributed significantly to both the extent and influence of those changes. Exchange was the basic mechanism for establishing trading networks and trade was instrumental in contributing to both political and economic influence. Metallurgy provided added value to basic ores by the production of basic metals, intermediate products and finished artefacts.

Iron does not fit so readily into such a neat chronological sequence as copper and bronze. Recognised as a different material, probably meteoritic, back in the 5th millennium, it was acknowledged in Anatolia in the middle Bronze Age, when its value exceeded that of gold. During the 12th to 10th centuries, the number and types of artefacts increased significantly in the eastern Mediterranean region. In Etruria, the transition from bronze to iron took place between the Villanovan and Orientalising periods as evidenced by the comparison of bronze and iron funerary artefacts. Metallurgical analyses of stratigraphical samples taken from the slag heaps at Populonia date the transition from copper to iron working during the 8th to the 7th centuries BC. Thereafter, from the 6th century onwards, iron was produced at Populonia reaching peak levels in the 3rd and 2nd centuries BC.

The social changes which took place were reflected in the size and style of the tombs and sepulchres. At the end of the 8th century, new types of tomb were evident reflecting the status of an aristocratic elite. In the 6th century, changes in the layout of the necropolis suggested that with the structural changes taking place, some tombs excavated were for middle-class individuals associated with controlling production operations relating to iron. Early in the 4th century, Etruria flourished. That the growth of Populonia and an increase in wealth was due in large measure to iron making activities is not too surprising. Allied to this was the fact that Populonia had by then become an important distribution centre for goods including those not related to iron. By the end of the 2nd century, it had become an established maritime trading city. What though initiated this steep increase in the production of iron during the 3rd and 2nd centuries? It was instigated, I believe, by the rise in demand, a demand related to weaponry, agriculture and construction. The need for iron to equip an expanding and ever active Roman army is easy to understand. The size of the army at various times during the period in question is well documented as is their equipment, so the iron used on an annual basis can be estimated. Iron usage for tools in agriculture is not quite so straight forward in that whilst the tools themselves are well documented; their usage depended on the type of farm and the degree of substitution of iron for bronze or wood. The advantage of using iron tools was acknowledged by the ancient authors, Cato in particular, and by the end of the 2nd century, iron was considered a commodity material. Construction and general building work was an important sector but no attempt has been made to try and estimate the weight of iron used. The main usage will have been in basic nails and any estimate would have been no more than pure conjecture.[404] One can only say that about half the nails would have come from reused iron.

The total annual usage of iron for weaponry and in agriculture, as outlined in the chapter 10 was estimated at about 300-500 tonnes a year. The annual output at Populonia was estimated to be about 100-200 tonnes. Factors contributing to the difference are firstly that Populonia, whilst being the largest

[404] 30 of to-day's 150mm nails weigh 1 kg. So,30,000 nails would weigh one tonne.

attested site to date, was not necessarily, or even likely to have been, the sole source of available iron. Secondly, some of the variables relating to the uptake of iron may be optimistic. The important point is that the estimated output from Populonia does not seem excessive in relation to overall estimated usage at that time. As has been stressed throughout, these estimates reflect an order of magnitude. The significance of the estimated output figures is the rapid rise in production over the 500 year period and in particular during the period after the Roman acquisition of Etruria.[405]

A salient feature arising from this is that demand was a major factor in effecting the increase in supply. In doing so it influenced the rate of development of iron technology, because to achieve those levels of output, a tried and trusted method of smelting and bloomsmithing would have had to have been in place. The relationship between the rate of development of the technology and demand may go some way to explaining the rather long and erratic development of iron but that is the nature of technology. The influence of the complex nature of smelting is another factor which forms a part of this dissertation. Of its complexity, Rehder writes that "the uncertainties involved in controlling the operation of a smelting furnace …seems to account for the long development period that the archaeological record shows for the smelting of iron" [406]

The evidence is present in Populonia for the transition from bronze to iron, which was then followed by the production of iron starting with small quantities in the 6th century BC and building up to an estimated 150 tonnes a year in the 3rd century. The important point is not the exact amount of iron produced but that it was sufficiently large to require an established process to be in place to produce usable iron. The basic process elements may not have been new but the production in such large attested amounts was. The importance of Populonia is that it provided *evidence* of that.

---

[405] This increase in output occurred at various stages in other parts of western Europe too and was usually geared to the arrival of Roman influence.
[406] Rehder, J.E. (2000) 143

The availability of iron on such a scale made an impact and provided a significant contribution in key areas during the initial period of the Roman Empire. It quickly became the most widespread metal, and a commodity which influenced the lives of most people. However, the availability of iron, both its scale and the speed of its introduction, appears almost without mention in the literature, both ancient and contemporary. This contrasts with extensive references to science and comments on the delay in which science was applied. The Greeks expressed some distaste for banausic occupations and with it the view that manual or technical activities were unnecessary and in fact undesirable. Some of this prejudice may have filtered down the ages.[407] But be that as it may, I believe the achievement at Populonia was a major one

Conclusions.

1 Metallurgy did influence Etruscan civilisation, in terms of its political and economic nature. A notable aspect of the Etruscans was that their natural resources were fully exploited and used amongst other things to develop strong overseas trading networks supported by a maritime force.

2 An analysis of the size and composition of the slag heaps gave an estimated annual output of 100-200 tonnes per annum towards the end of the 500 year period (6th to 2nd centuries) when production was at its peak.[408]

---

[407] In the 1963 Harold Wilson, the Prime Minister at the time gave a speech at the Labour Party Conference introducing what he described as the 'The white heat of technical revolution.' This emphasised the importance of technology in the development economy of the country and its role in converting science based expertise into practical saleable technology. As part of that, its importance in college education was highlighted; " while the chemist is exalted, the chemical engineer is told and sit somewhere below the salt" Some things have changed but not a lot. A degree of any provenance in any subject is considered more desirable by many than a technical qualifications of to-day. And not surprisingly the country is short of technically trained people. New initiatives are currently being devised to rectify the shortage! This situation contrasts with mainland Europe where technical Universities are highly thought of and which have been in existence for 50+ years.

[408] This compares with an estimate of 1000 tonnes pa from Voss (1988)) and 1 tonne pa from Crew (1991)

3 The usage of iron during this period of the Roman Empire (3rd to 2nd centuries) was estimated as c400 tonnes per annum, a sufficient amount to absorb the estimated output from Populonia. Also in the context of the nature of these estimates, they are of a similar magnitude.

4 The development of iron was a long and tortuous one. What the evidence from Populonia has shown is that a process had been established which demonstrated that it was practical and capable of being transferred.

5 The amount of iron produced was very large by ancient standards

6 The arrival of iron on an ‘industrial’ scale made an impact on the early development of the Roman Empire. This is reflected in the wide range of applications for iron and the speed and extent in which it was adopted.

BIBLIOGRAPHY

CEH (2007) Cambridge Economic History of the Greco-Roman World Eds. Scheidel, W., Morris, I., Saller, R. Cambridge University press

Andreotti, A and Zanini, A. (1997) L'sediamneto di Fossa Nera (Lucca) *Rivista di Scienze Preistorica,* 47 in Bietti Sesetieri,A.M. (1997) 376

Aranguren, B.M.*et al* Aranguren, B.M.,Ciampoltrini, G., Firmati, M,, Giachi,G., Marchesi, L., Pallecchi,P., Rendini, P, Tesi,P.L.(2004) unpublished *Attività metallurgica negli insediamenti costieri dell'Etruria centrale fra VI e V seculo a,C.: nuovi dati di scavo*

Bachhuber, C and Roberts, Gareth, R (2009) Eds. *Forces of Transformation*

Bakhuizen, S. C. (1976) *Chalcis in Euboea, Iron and Chaldcidians Abroad* Brill, Leiden.

Barker,G. and Rasmussen, T. (1998) *The Etruscans,* Blackwell, Oxford.

Bartoloni, G. (1993) *Populonia: characteristic features of a port community in Italy during the first Iron Age*

(2003) *Le società dell'Italia primitive. Lo Studio delle necropolis e la nascita delle aristocrazie.* Roma, Carocci Editore

Bats, M *et al* (1992) '*Marseille, les colonies massaliètes et les relais indigenes dans le trafic le long du littoral méditerranean gaulois'*

Bergonzi and Cateni (1979) 'L'età del Btonzofinale nella Toscana Maritimma' in *Atti della XXI Riunione Scientifica dell' I.I.P.P.; Il Bronzo Finale in Italia* (Firenze, 1977 249-264.

Benvenuti, M., Mascaro, I., Costagliola, P., Tanelli, G., Romualdi, A. (2000) 'Iron, Copper and Tin at Baratti, (Populonia); smelting processes and metal provenances,' *JHMS* 34 (2) 67-76

Bietti Sestieri, A.M. (1973) 'The metal Industry of continental Italy, 13th to the 11th Century BC, and its connections with the Aegean' in *Proceedings of the Prehistoric Society*

(1992) *The Iron Age Community of Osteria dell'Ossa,* Cambridge University Press, Cambridge.

(1997) 'Italy in Europe in the early Iron Age' in the *Proceedings of the Prehistoric Society* 63 371-402

(1998) 'The Mycenaean connection and its impact on the central Mediterranean societies' in *Dialoghi di Archeologicca* 6 (1) 23-51

(2003) 'A reconstruction of Historical Processes' in *Papers in Italian Archaeology VI* Eds, Attema, P., Nijboer, A., and Zifferero, A.

Bishop, M.C. and Coulston, J.C.N. (2006) *Roman Military Equipment* 2 ed. Oxbow Books, Oxford

Boëthius, A. (1994) *Etruscan and early Roman Architecture* Yale University Press, New Haven

Bowman, A. and Wilson, A. (2009) Eds. *Quantifying the Roman Economy ,* Oxford

Boardman, J (1999) *The Greeks Overseas* 4th ed. Thames and Hudson, London.

Brunt, P.A. (1987) *Italian Manpower 225BC-14AD* rev. edn. Oxford University Press

Brendel, O.J. (1995) *Etruscan Art* 2nd ed, Yale University Press, New Haven
Burkert, W (1992) *The Orientializing Revolution* Harvard University Press, Camabridge MA
Camporeale, G (1985) *L'Etruria Mineraria* Milan
Charles, J.A. (1980) The Coming of Copper in *The Coming of the Age of Iron* Eds. Wertime, T and Muhly, J Yale University Press.New Haven
Chiarantini, L., Benvenuti, M., Costagliola, P., Fedi, M., Guideri, S., Romualdi, A. (2009) *Journal of Archaeological Science* 36 1626-1636
Ciampoltrini,G see Aranguren,*et al*
Ciampoltrini, G. & Firmati, M. (2002/3) The Blacksmith of Fonteblanda in *Etruscan Studies 9;*29-36
Cleere, H.F. (1971) Iron Making in a Roman Furnace *Britannia 203-207*
Coldstream, J.N. (1968) *Greek Geometric Pottery.* Methuen, London.
Connolly, P. ((1975) *The Roman Army* Macdonald
Cornell,T.J. (1995) *The Beginnings of Rome* Routledge. London
Craddock, P.T. (1995) *Early Metal Mining and Production* Edinburgh University Press
Crawford, H.E.W. (1991) *Sumer and the Sumerians* Cambridge University Press
Crawford, M.C. (1992) 2nd Edn *The Roman Republic,* Fontana, London
Crew, P (1991) 'The Iron and Copper slags at Baratti, Populonia, Italy.' *JHMS* 25 (2), 109-115.
Cristofani, M. (1986) "Economica e società" in *Rasenna, Stioria e civilità degli Etruschi;* 77-156 Milan
Crowfoot, G.M. (1954) Textiles, Basketry and Mats in *The History of Science* Singer, Holmyard, Hall and Williams, Clarendon Press, Oxford
D'Achiardi, G. (1929) 'L'industria metallurgica Populonia.' *Studi Etruschi* 3, 397-404
De Santis *et al* De Santis, A., Mieli, G., Rosa, C., Matteucci, R., Celant, A. Minniti, C. Catalano, P., De Angelis, F. Di Giannantonio., Giardino, C., Giannini, P. in press *Le fasi di occupazione nelll'area centtrale di Roma in èta protostorica: nuovi dati dagli scavi nel Foro di Cesare,* Officina di Etrusclogia.
Dompé, L (1921) 'Antichi depositi di scorie ferrifere presso I ruderi della città etrusca di Popukonia' in *La Miniera Italiana* V , 295-6, Roma.
Fedeli, F (1983) *Populonia e suo Territorio.* Firenze
Fedeli, F.,Galiberti, A., Romualdi, A. (1993) *Populonia e il suo Territorio , profilo storico-archeologico.* All'Insegna del Giglio, Firenze.
Finley, M. L. (1965) Classical Greece in Second International Conference of Economic History, Aix en Provence. Paris
(1965a) 'Technical innovation and Economic progress in the Ancient World' *Economic History Review* 18; and more recently Schneider, H. in *Technology* chapter x in CEH 144
Forbes, R.J. (1964) *Studies in Ancient Technology* Tech IX, 30
Fossa, Mancini, E. (1922) 'L'arte mineraria e matallurgica al tempo degli Etruschi: cioche hanno rivelato gli scavi di Populonia *La Miniera Itlaliana* VI (8), 225-231
Foxhall, L (2005) Village to City: Staples or luxuries? Networks and Urbanisation in *Mediterranean Urbanisation 800-600BC* eds. Osborne, R. and Cunliffe, B. British Academy, Oxford University Press.
Giardino, C (1995) T*he Western Mediterranean between 14th and the 8th centuries BC.* BAR 612, Oxbow, Oxford.

(2003) 'Metallurgy in Italy between the late Bronze Age and the early Iron Age : the coming of iron' *Papers in Italian Archaeology VI* Eds, Attema, P., Nijboer, A., and Zifferero, A.

Giardino, C & Lugli, F. (2008) ' Il tempo di giove Capitolino e le origigi del colle Capitolino' in *Metallurgia*

Giardino, C. & Spagnolo, V in press 'Lo sfruttaamento antico delle risorse ferrifere Pugliiesi: Nuovi dati', in *Archeometallurgia* ed. Giardino, C.

Gras, (1995) *La Méditerranée Archaïque.* Ed. Armand, C.

Greene, K. (2002) Technical innovation and economic progress in the ancient world: M.I. Finley reconsidered.' *Economic History Review.*

(1992) How Technology was transferred in the Roman Empire? in Wood, M. and Queiroga, F. Eds *Current Research on the Romanization of the Western Provinces.*

Gualtieri, M. (1997) *Iron in Calabria in the 9thn and 8th centuries* University Microfilms International, Ann Harbour.

Guido, M. (1963) *Sardinia* Thames and Hudson, London.

Hartmann. N. (1985) The use of Iron in the 9th and 8th century Etruria in *Papers in Archaeology* IV BAR series 245, 285-94

Harris, W.V. (2007) 'The Late Republic' in *The Cambridge Economic History of the Greco-Roman World.* Eds. Scheidel, W. Morris, I. Saller, R. Cambridge University Press

Higgins, R. (1981) *Minoan and Mycenaean Art* Thames and Hudson, London

Hodges, H (1976) *Artifacts* Duckworth, London.

Hopkins, K (1980) 'Taxes and trade in the Roman Empire (200BC-400AD) in *JRS*

(1983) 'Introduction' in *Trade in the Ancient Economy* Hopkins, K and Whittacker, C. London

Humphrey, J.W., Oleson, J.P. and Sherwood, A.N. (1998) *Greek and Roman Technology; A Sourcebook,* Routledge, London and New York.

Jones,R.E. (1986) *Greek and Cypriot Pottery* British School of Athens. Occasional Paper 1, Athens

Jongman, W.M. (1997) 'The Early Roman Empire Consumption' in *The Cambridge Economic History of the Greco-Roman World* Eds. Scheidel, W., Morris, I., Saller, R. Cambridge

Kassiannidou, V (2003) ' Cypriot Copper in Sardinia, yet another case of bringing coal to Newcastle' see Lo Schiavo *et al* below

King, A. (1999) 'Diet in the Roman world: a regional inter-site comparison of mammal bones' in *JRA 12: 168-302*

Kron, J.G. (2008) 'The much maligned Peasant' in *People, Land and Politics,* Brill, Leiden

Kuhrt, A. (1995) *The Ancient Near East,* Routledge, London.

Larsen, M.T. ((1976) *The Old Assyrian City State and its Colonies* Copenhagen

Leemans, W.F. (1960) *Foreign Trade in the Old Babylonian Period* Leiden.

Limat, H, (1984) Documents relatifs au fer à Mari in *Mari. Annales de recherches interdiscipline* Vol 3, recherché sur les Civilizations.

Lo Schiavo, F. (2003a) 'Ox-hide ingots in the Mediterranean and central Europe'

(2003b) 'Cyprus and Sardinia'

Both ariticles in *Archaeometallurgy in Sardinia from the origins to the beginning of the early Iron Age.* Lo Schiavo, F., Guimlia-

Mair, A., Sanna, U., Valera, R. (Eds) Montagnac Editions, Monique Mergoil.

Maggiani, A. (1992) 'Le inscizione di età trado-classica ed ellenistica' in *Populonia in età ellenistica: I materiali dale necropoloi:* atti del seminario, Firenze, 1985

Martelli, M. Scavo di edifice nella zona 'industriale' di Populonia in *L'Etruria Mineraria* Atti Firenze III 161-172

Mc Cann, M. Bourgeois, J. Will, E. (1977) 'Underwater excavations at the Etruscan Port of Populonia' in *Journal of Field Archaeology* Vol 4

Merpert, N. and Munchaev, R. (1971) Yarim Tepe: *Sumer* 27:23-32

Minto, A. (1943) *Populonia.* Instituto di Studi Etruschi, Firenze.

Morel, J-P. (2007) 'Early Rome and Italy.' In *The Cambridge Economic History of the Greco-Roman World.* Eds. Scheidel, W., Morris, I., Saller, R.

Muhly, J.D. (1988) ' The beginnings of Metallurgy in the Old World' in Maddin (ed) *The beginning of the use of metals and alloys,* MIT, Cambridge, MA

Nijboer, A (1998) *From Household Production to Workshops.* Dept. of Archaeology, Groningen, The Netherlands.

Oleson,J.P. (2009) *The Oxford Handbook of Engineering and Technology in the Classical World.*

Osborne, R. (1996) *Greece in the Making.* Routledge, London.

Pallottino, M (1974) *The Etruscans,* Allen Lane, London

Papadimitriou, G. (2008) 'The Technological Evolution of Copper Alloys in the Aegean during the Prehistoric Period' in *Aegean Metallurgy in the Bronze Age: proceedings of an International symposium, University of Crete, Rethymon, Greece, 2004.* ed. Iris Tzachilli

Parker, A.J. (1992) *Ancient Shipwrecks of the Mediterranean and the Roman Provinces,* Oxbow books, Oxford.

Pedroni, L. (1993) *Richerche sulla prima monetzione di Roma.* Naples

Pigott, V.C. (1999) 'Intoductory Comments' *The Archaeometallurgy of the Asian Old World*

Pleiner, R. (1980) 'Early Iron Metallurgy in Europe' in *The Coming of the Age of Iron* Eds. Wertime, T and Muhly, J. 375-415 New Haven

(2000) *Iron in Archaeology* ; Chapters 1-5 7-109, Prague

Roberts, P. (!997) 'Mass-Production of Roman Finewares' in *Pottery in the Making: World Ceramic Traditions;* , Ed. Freestone, I. and Gainster, D.,188-93 British Museum Press

Potter, T.W. (1979) *The Changing Landscape of Southern Etruria.* London, Elek.

Potts, D.T. (1990) *The Arabian Gulf in Antiquity* Clarendon Press, Oxford.

Quercia, A. in press *forge e ferro dell'Italia meridionale in età romana* in *Archeometallurgia,* ed, Giardino, C.

Rasmussen, T (1979) *Buccero Pottery from Southern Etruria* Cambridge University Press.

(2003) 'Urbanisation in Etruria' in *Mediterranean Urbanisation 800-600BC* eds. Osborne, R. and Cunliffe, B. British Academy, Oxford University Press.

Rathbone, DW. (2008) 'Poor peasants and silent sherds' in *People, Land and Politics,* Brill, Leiden

Rehder, J.E. (1989) 'Ancient Carburization of Iron to Steel' in *Archeomaterials 3; 27-37*

(2000) *The Mastery and Uses of Fire in Antiquity* McGill-Queens.

Ridgway, D (1992) *The First Western Greeks.* Cambridge University Press.

Riva, C. (2005) The culture of Urbanisation in Etruria in *Mediterranean Urbanisation 800-600BC* British Academy, Osborne, R.and Cunliffe, B. Oxford University Press.

(2010) *The Urbanisation of Etruria.* Cambridge.

Romualdi, A. (1992) *Populonia in età ellenistica: I materiali dale necropoloi:* atti del seminaro, Firenze, 1985

(1993) in *Populonia e suo Territorio (*see Fedeli. F.)

L'Orientalizzante e la cultura dei Principes. 92-101

La Polis nel Periodo Arcaico e L'Attività di Lavorazione del Ferro. 102-117

Il periodo Classico (V – Prima metà IV seculo A.C.) La crisi della città Etrusche e la Ricchezza di Populonia 118-121

Dall'Ellenismo (Fine IV – Inizi I seculo A.C.) all' Epoca Romana. 122-132

Sauder, L & Williams, S (2002) 'A critical treatise on the smelting and smithing of bloomery iron' *36(2) Historical Metallurgy*

Scheider, H (2007) 'Technology' in *The Cambridge Economic History of the Greco-Roman World.* Eds. Scheidel, W., Morris, I., Saller, R. Cambridge University Press.

Scott,L. (1954) 'Pottery' in *The History of Science* Singer, Holmyard, Hall and Williams, Clarendon Press, Oxford.

Scullard, H.H. (1967) *The Etruscan Cities with Rome,* Thames and Hudson, London.

Sim, D. (1998) *Beyond the Bloom: Bloom Refining and Iron Artefact Production in the Roman World; BAR*

Singer, Holmyard, Hall, Williams, (1954) *A History of Technology.* Clarendon Press, Oxford

Snodgrass, A. (1980) 'Iron and early Metallurgy in the Mediterranean' in *The Coming of the Age of Iron* Eds. Wertime and Muhly, New Haven

Sperl, G (1980) Über die typologie urzeitlicher, frügeschichtlicher und mitte-lalterlicher Eisenhüttenschlacken' *Studien zur Industrie-Archäologie VII,* Österr.. Akademie der Wissenschaften, Wien.

Spivey, N and Stoddart, S. (1990) *Etruscan Italy,* Batsford, London.

Starr, C.G, (1989) *The Influence of Sea Power on Ancient History* Oxford University Press, New York and Oxford.

Supple, B.E. (1963) *The experience of economic growth: case studies in economic history* Random House, New York

Tandy, D.W. (1997) *Warriors into Traders* University of California Press, Berkeley

Torelli, M. (2005) *Storia degli Etruschi* Bari laterza.

Treister,M.Y. (1996) *The role of metals in ancient Greek history* Brill, Leiden.

Tylecote, R.F. (1962) P*rehistory of Metallurgy in the British Isles* Arnold, London.

Tzachilli,I. (2008) 'Recent Developments' in *Aegean metallurgy in the Bronze Age: proceedings of an International symposium, University of Crete, Rethymon, Greece, 2004.* ed. Iris Tzachilli

Veenhof ,K.R. (1995) 'Kanesh: An Assyrian Colony in Anatolia' in *Civilisations of the Ancient Near East* Ed. Sasson, J.M. New York

Ventris and Chadwick (1956) *Documents in Mycenaean Greek*

Vianello, A. (2009) ‘Late Bronze Age Exchange networks in the West Mediterranean’ in *Forces of Transformation; the End of the Bronze Age in the Mediterranean* Eds. Bachhuber, C. and Roberts, R. Gareth

Voss, O (1988) ‘The Iron Production in Populonia’ in Sperl, G. (ed) Proceedings of the Congress “Il primo ferro”, Populonia/Piombino, 1983, PACT, vol 21 91-100

Waetzodlt, H. (1972) *Untersuchungen zur neu Sumerischen Textile Industrie* Rome

Waldbaum, J (1978) ‘The Transition of the Bronze Age to the Iron Age in the eastern Mediterranean’ *Studies in Mediterranean Archaeology 54* Gotenborg.

(1980) ‘The Coming of Iron’ in *The Coming of the Age of Iron* Eds. Wertime and Muhly, New Haven

(1999) ‘The Coming of Iron in the Eastern Mediterranean’ in *The Archaeometallurgy of the Asian Old World* Chap. 2 27-57

Williams, D. (1997) ‘Ancient Greek Pottery’ in *Pottery in the Making* , Ed. Freestone, I. and Gainster, D., British Museum Press

White, K.D (1967) *Agricultural Implements of the Roman World* Cambridge

(1984) *Greek and Roman Technology* Cornell University Press

Wikander, O. (1984) *Exploitation of Wind Power or Technological Stagnation? A Reappraisal of the Primitive Forces in the Roman Empire.* I studia utgivna av kungl. Humanistika Vetenkapssamfundet I Lund 1983-1984

Woolley, C.L. (1955) *Ur excavations, Vol 4, The early periods.* London

Youtie,HC and Winter,JG (1951) in *Papyri and Ostraca from Karamis, Papyri* in the University of Ann Arbour, Michegan collection vol 8 no 467&468

Zifferero, A. (1991) Miniere e metalurgica estrattiva in Etruria meridionale ; per una lettura critica di alcunidati archeologici e minerari. *Studi Etruschi* 57, 201-41