3

Metals

Janet Lang

Introduction; identification and function; manufacture, casting, wrought objects; composites, joins, solders, welding; finishing, decoration, inscriptions

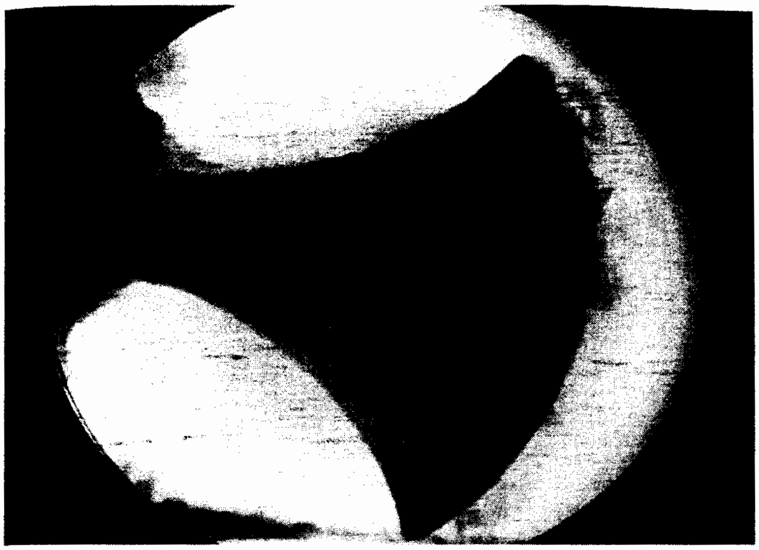
INTRODUCTION

Metals are useful and versatile materials with both strength and ductility, and their exploitation has been a key element in the development of human material culture. As most metals are not immediately available but have to be extracted from their ores, their use implies a certain level of technical expertise, and recognition of technical advance is reflected in the use of the terms 'Bronze Age' and 'Iron Age' to describe the cultural horizons when these metals began to be used extensively. Metals can be formed into a desired shape by casting molten metal in a mould or by working solid metal with tools. Metals can be cut and joined, decorated by chasing or engraving and embellished by the addition of inlays, enamels and stones. The methods used to work the metal and fabricate objects reveal the particular skills of the craftsman and may also reflect the craft-cultural traditions of their society. Radiography has an invaluable role to play in the recognition of these techniques of manufacture and thus contributes to our knowledge of the societies that produced the artefacts, and to our broader understanding of the history of technology.

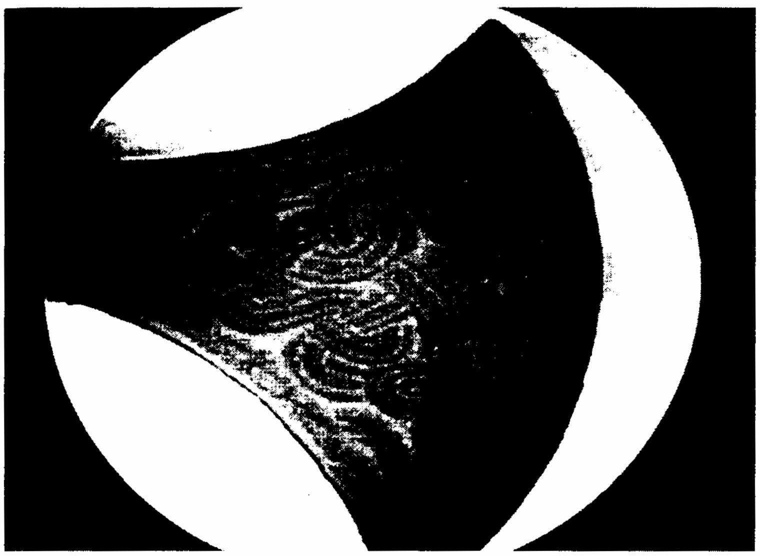
The details of the construction of an object are not always immediately obvious: surface features and decoration may be concealed under layers of corrosion, joins might be internal and sometimes the signs of casting or working can only be found within the metal itself. Radiography can often be used to reveal these hidden clues to constructional techniques. However, it is frequently necessary to use information from other investigatory techniques as well. Examination at low magnification using an optical microscope may precede radiography, and chemical analysis is often necessary to confirm compositional differences indicated by the radiographic examination. This chapter indicates how the information obtained by radiography can help to identify the nature and function of an object, and describes the features by which some of the fabrication processes can be distinguished and decoration revealed using radiographs.

IDENTIFICATION AND FUNCTION

When an object is excavated, it has to be described and identified in order to be fully recorded and its significance explained. The identification of an object may present a problem if it is encased in soil or covered with corrosion products and its outline or shape is obscured (see also Chapter 8). For example, soil and concreted corrosion products obscured the horse bit, shown in Figure 3.1, when it was excavated in 1991 at the Anglo-Saxon burial mound (known as the Prince's grave) at Sutton Hoo, in Suffolk. It was radiographed before cleaning, fresh from the excavation, and was identified from the radiograph as an Anglo-Saxon horse bit with gold chip-carved panels, confirming the high status of the burial. It was examined by real-time radiography, which sometimes provides much more information than a normal, two-dimensional image, because the object can be moved about in the X-ray beam, giving the image a three-dimensional appearance. The real-time image



(a)



(b)

Figure 3.2. *Real-time radiographic images of a horse bit, shown in Figure 3.1. (a) with no processing and (b) after frame averaging.*

especially when the process employed differs from that used for comparative material. For example, it was thought, at one time, that Sasanian bowls were constructed from two separate layers soldered together (the double skin technique). However, because recent studies by Gunter and Jett (1992) and Meyers (1978) discovered that Achaemenid and Sasanian silver dishes were formed from a single cast silver blank, hammered to shape, the authenticity of a Sasanian dish found to have a double skin would merit close scrutiny (see also Chapter 9).

Cast Objects

Casting can be carried out in a variety of ways, directly into stone, ceramic or sand moulds or by lost wax (ciré perdue) methods (described below). Moulds may consist of a single piece, or two or more pieces, which are made so that they can be separated, in order to remove the casting easily. When multi-piece moulds are used, traces of porosity and fins where the metal has leaked out between the mould pieces can be detected at the join. Large

Figure 3.1. *Anglo-Saxon horse bit from mound 17, Sutton Hoo, Suffolk, as received from the 1991 excavation, with soil and small stones adhering to it.*

was processed which revealed the details of the chip-carved designs (Figure 3.2, see also Chapter 2). Most of this information could have been revealed by conventional film radiography, using small pieces of film positioned on the soil and corrosion accretions covering the decorated panels. There would have been some loss of image sharpness, however, because the shape is so irregular and the film could not have been placed directly on the metal.

Large numbers of heavily corroded iron objects are found on Roman and medieval sites and standard film radiography is therefore used as a survey tool for identification and for the selection of items which need further attention. In combination with Geographical Information Systems (GIS), radiography has even been used to correlate the state of preservation with the find location in a water-logged environment (Nydam, Denmark) and with the method of deposition (Matthiesen *et al.* 2004).

Several objects can be radiographed at once and a permanent record of badly corroded material is provided. The radiographs are probably the most informative image of this type of material which can be achieved, because iron corrosion may bloat the size and distort the shape to such an extent that, for example, a nail appears to be indistinguishable externally from more archaeologically significant artefacts such as keys or tools. This is discussed in more detail in Chapter 8.

Once details of an object have been revealed by radiography, the function is usually fairly easy to determine. However, there are exceptions, such as the so-called 'bean can' from an Iron Age cart burial at Wetwang, Yorkshire. This decorated bronze cylinder, which is closed at both ends, contains material which rattles and, was thought to be organic remains. In an attempt to image this material, the can was subjected to neutron radiography (Figure 3.3; see also Box 1.1 on p. 3). Although the radiograph shows some lumpy material, this was not identifiable and the function of the can remains a mystery (Dent 1985).

MANUFACTURE

Significance of Method of Manufacture

The method of manufacture is important in the characterization of the object itself and in setting it in a craft or technological context. Such information is used for more wide-ranging research into historical metallurgy and is also required for museum catalogues, displays and exhibitions. Where a group of objects purporting to come from the same workshop or craft tradition are under examination, radiography can provide pertinent information. A study of Renaissance bronzes (Bewer 1995) was undertaken to identify the characteristics of the Florentine workshop of the Flemish sculptor Giambologna (1529–1608) and radiography was considered to be the most informative tool for identifying key technological features. Anglo-Saxon knives from York and Southampton were radiographed as an integral part of studies which enabled the knives to be assigned to appropriate typological groups (McDonnell *et al.* 1991; Ottaway 1992).

Radiography helps to distinguish between the two basic methods of making metal objects, by casting or working, usually as part of a stylistic and technical examination (discussed in more detail in the next section): this distinction may be important,

Figure 3.3. *Neutron radiograph of Iron Age sealed bronze canister from Wetwang, Yorkshire (Harwell Neutron Radiography Service).*

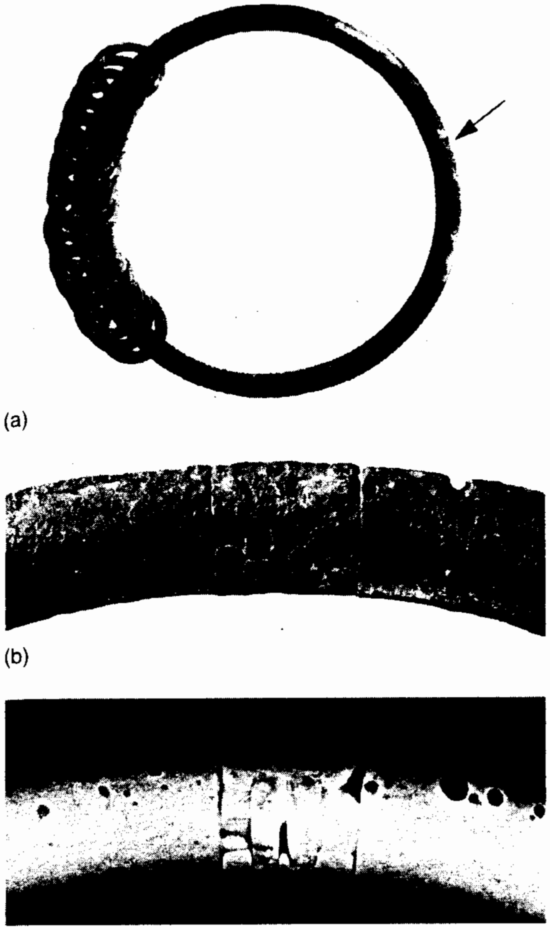
statues are usually cast in separate sections and joined together with molten metal, a process termed flow welding (Mattusch 1996) (see below): the joins can usually be seen on radiographs even when they are not visible on the surface.

Radiography may show concentrations of trapped impurities and porosity, indicating the orientation of the mould when the metal entered it. Computed tomography (CT) is a particularly useful technique for making detailed studies of casting techniques (Heilmeyer 1985; Goebbels *et al.* 1985, 1995). Avril and Bonadies (1991) have described how CT revealed the skill of the Shang Dynasty Chinese bronze casters (13th to 11th century BC) who produced thin-walled, symmetrical vessels by positioning the cores and mould parts accurately. Small variations in wall thickness and the distribution of porosity in different parts of the vessels could be seen on the CT slices. It was also possible to explore the interior surfaces of closed hollow structures, such as handles.

Cast objects can be distinguished from wrought metal objects by metallographic cross sections; this requires samples to be removed from the object, mounted and then polished, which is not only time-consuming but also destructive. Radiography is often a better option, especially for fine metalwork in good condition. Castings exhibit features which can be identified on radiographs, including porosity, thickness variations characteristically different from those produced by working and a coarse granular appearance or texture. The presence of casting faults, cores, chaplets (used to hold the core in position) and cast-on sections also indicates that an object has been cast. These features are described in more detail below.

Porosity

Porosity in metal can be recognized on film radiographs as circular black or dark areas which may be pinhole sized or considerably larger, as seen on a 4th century BC bronze ring from Piceum in Italy, shown in Figure 3.4. The pores are caused by gas trapped in the cooling metal. As might be expected, fine porosity can be distinguished more readily in



(a) (b) (c)

Figure 3.4. *(a) Bronze ring from Piceum, Italy, 8th to 7th century* BC *(GR 1824-4-98.32). The clip join is arrowed, (b) enlargement of the clip which can be partly seen on (a) and (c) enlargement of a positive xeroradiograph of the clip. The dark rounded holes are casting porosity. The radiographic density is relatively uniform and the coarse texture indicates that the ring was cast (Note: Xeroradiographic equipment is no longer available, see Chapter 2.).*

thinner cross sections than in thicker sections; radiography is unlikely to permit identification of the pores if they are minute in comparison with the overall thickness.

Thickness of Castings

Radiographs of cast objects exhibit a fairly even density if the mould into which the molten metal was poured had a uniform thickness and the metal has been properly cast. The thickness of the Picean ring (Figure 3.4) only varies at the edges, where it tapers slightly. Apart from the large pores, this uniformity is reflected in the even overall radiographic density, although in this case the texture of the ring is rather coarse and granular. Unevenness in the thickness of cast metal is indicated on a radiograph by irregular light and dark areas, like those appearing in Figure 3.5, which is an Etruscan mirror discussed by Craddock (1985). However, castings, such as bowls, were sometimes turned on a lathe to remove uneven surfaces and even-up the wall thickness. Figure 3.6 shows a cast, faceted silver bowl from Carthage, the interior of which was turned, probably to remove casting asperities: the base has also been hammered, and the irregular marks can easily be seen on the xeroradiograph. The wall thickness of hollow-cast statues tends to be variable and is particularly amenable to examination by CT (Heilmeyer 1985; Goebbels *et al.* 1985, 1995).

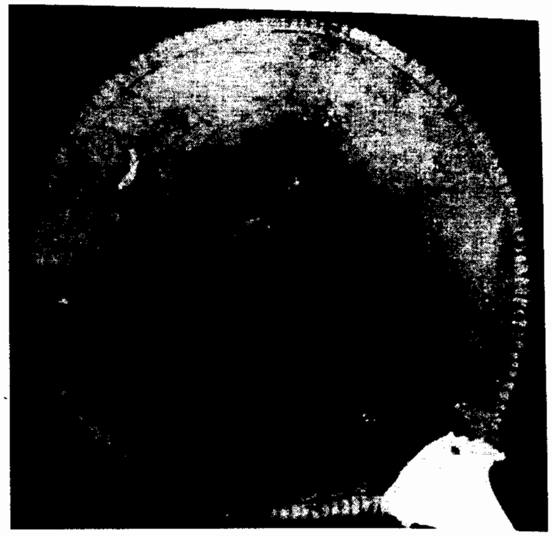


Figure 3.5. *Late Etruscan mirror, Danish National Museum No. 12889. The light (radiographically denser) areas are lead. The dark areas show where the metal is thinner. Traces of the design and cracks in the rim are also visible.*

Cast objects are usually thicker in cross-section than those which have been wrought; this is especially noticeable at the areas of greatest curvature. However, metal thickness cannot always be used as a reliable indicator of how an object was manufactured as it is possible to make extremely thin castings. In the case of the radiograph of an Islamic inlaid brass pen box,

Figure 3.6. *Roman silver bowl from Carthage c. 400* AD *(EC 361). Negative xeroradiograph of the bowl, which was cast: the upper part was finished by turning, while the base was hammered and then scraped.*

dated AD 1281 (Figure 3.7), there is clear evidence that it was cast, although the wall is only 1.5 mm thick. A similar pen box dating to AD 1210, from Iran or Afghanistan, has been published by Atil *et al.* (1985). It also was cast and is interesting because the radiographs show that chills were used. These are small pieces of solid metal placed in the mould to initiate solidification and to promote a small grain size. They can be recognized on radiographs as small dark rectangles, placed in regular positions.

Generally, long exposures, beam hardening filters and high kilovoltages are necessary to ensure an adequate exposure when radiographing thicker cast objects. Copper filters are used to decrease the proportion of low energy components in the beam, which reduces scatter and at the same time increases the proportion of high-energy X-rays, thus effectively improving penetration. Lead sheets in the cassette help further to reduce the scatter and also intensify the image. Thicker lead sheets underneath the cassette itself also help to cut down scatter. A diaphragm can be used to restrict the spread of the X-ray beam, reducing scatter from the area around the object.

Texture

Not all cast objects appear to have an even texture on a radiograph. Some castings, especially large bronze statues, cool slowly which encourages grain growth, resulting in coarse grains which are large enough to show as a texture on a radiograph as in Figure 3.8. High-resolution film and been used to make stereopairs of study cast structures (Williams and Smith 1952; Barkalow 1971). Branched tree-like (dendritic) forms of growth, typical of cast structures, are normally identified under a microscope, but occasionally, if the metal has cooled very slowly, the dendrites are sufficiently large to appear on radiographs (Figure 3.9). Lead is barely soluble in copper (or bronze) and can be seen as discrete globules on radiographs of leaded bronze, such as the Etruscan mirror in Figure 3.5, where the denser lead is visible as small white globules. An uneven density distribution may occur if a casting has been made from different batches of metal of varying composition. Gettens (1969, pp. 129, 152–3) has published radiographs of the base of a fragmentary Chou dynasty vessel: one part of the fragment is much denser than the rest and the interface is zoned. Subsequent analysis showed that the dense metal contained 18.3% of lead, while the lead content of the less dense material was 9.9%. It is clear that this vessel had been cast from two different batches of metal. Figure 3.10 shows a decorated silver dish from Carthage, which has a very uneven density. In this instance, however, the patchy appearance is due to a different cause: parts of the object have suffered severe, localized corrosion attack in the burial environment.

Casting Faults

Casting faults on the surface of an object may be covered by a layer of corrosion or soil and are only visible on radiographs or after cleaning. Splashes occur when the molten metal is poured into the mould: if the mould surface is cool, the splashing metal solidifies and is not remelted as the mould fills up. Cavities or discontinuities such as cold shuts or interfaces (i.e. welds) are difficult to detect, for the reasons explained in Chapter 1: the difference in absorption between the defect and the surrounding sound metal must be sufficient to be detectable. Real-time viewing, if available, makes it easier to locate the best orientation to assess and radiograph a defect. Radiographic studies have shown that contemporary repairs were sometimes made by casting on (see below), making patches (Mattusch 1996), soldering extra material into cavities or even inserting metal spikes into areas of porosity, as in some South American cast gold pendants (Howe 1985).

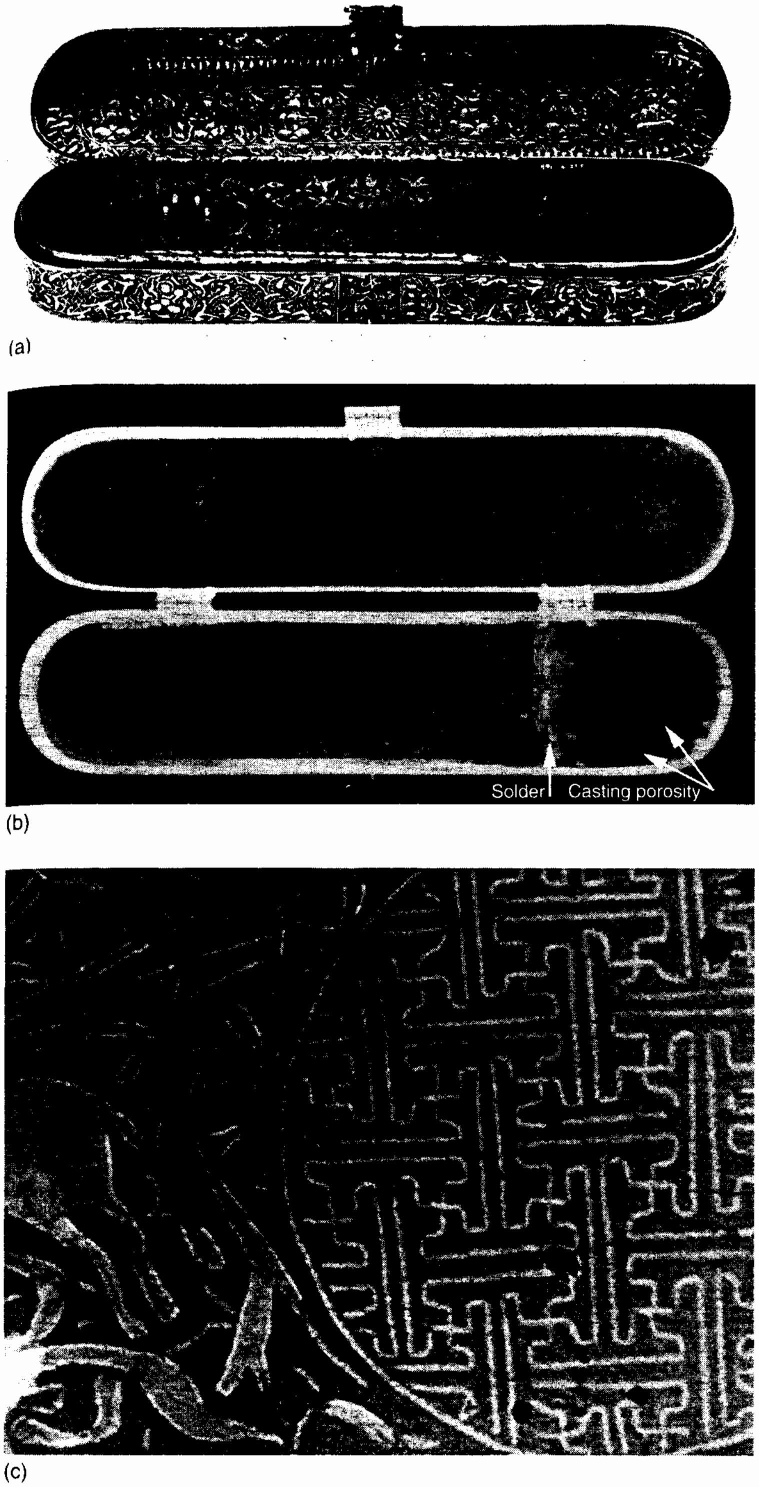


Figure 3.7. *(a) Cast Mamluk pen box (OA 1891-6-23.5) inlaid with gold and silver, (b) the radiograph shows dense areas, such as the gold inlay of the sun in the middle of the lid, and the tin-lead solder smeared across the base on the left appear light (arrowed) and (c) an enlargement of the right hand end of the base shows traces of a cast texture and porosity appears as black spots which are also indicative of casting.*

Cores and Chaplets

Cast objects may be either solid or hollow. To make a hollow casting, it is necessary to have a core, often made of clay, to prevent the metal filling the whole cavity. Hollow casting is used to reduce the weight of the vessel or to economise on the quantity of metal required to make the casting. The process of casting with a core is illustrated by Goldman (1985) and Mattusch (1996). The core is held in place within the outer mould by small bars or pegs known as chaplets, which protrude out from the core, through the cavity to be filled with metal, into the mould wall. Their remains can sometimes be seen on the surface of the casting. The number and location of the chaplets provides useful information about the mould design. If they are covered in corrosion or are otherwise invisible, radiography helps to show their location. When both sides of the object are superimposed on the radiograph, it may be necessary to take radiographs at different angles to determine in which wall the chaplets are located. An early example of hollow casting is an arsenical copper Sumerian ibex, *c.* 2500 BC, radiographed by Meyers (1978), which has a ceramic core supported by two copper rods. In a study of Classical statues Mattusch (1996) found that all the chaplets were rectangular in shape; those remaining *in situ* are made of iron and are therefore easy to pick out on radiographs as iron is less dense than bronze. A variation in the material used to hold the core in place is found in gold castings from South and Central America, where thorns, wooden pegs and extensions of the core itself were employed. The organic material burned out, leaving holes which were sometimes plugged, either by further casting or with shaped plugs. Small local variations in these technical processes were recognized by Howe (1985), using radiography.

The lost wax process is used for more complex subjects and remarkably thin and complex castings

Figure 3.8. *Detail of radiograph of an Egyptian statue (EA 60719), showing a coarse cast structure. Damage allows a single thickness of metal to be radiographed: porosity (black areas), lead (white areas), a chaplet (arrowed) and metal seepage into the core. 7 mA, 5 min, 170 kV.*

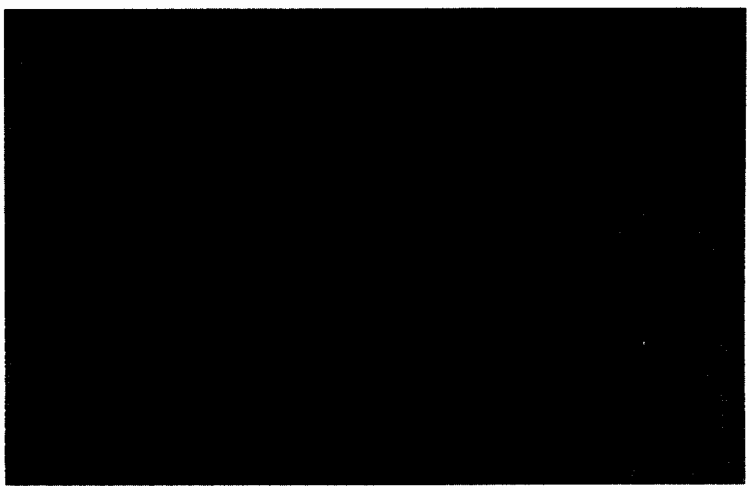


Figure 3.9. *Enlargement of a radiograph of a cast silver object showing a dendritic structure of grains, with different orientations. Some interdendritic porosity can be seen.*

can be achieved. In its simplest form, direct wax casting, which is used mainly for small castings, the subject is modelled in wax before being encased in clay moulding material. The wax is melted out by heating and the molten metal is then poured into the empty mould cavity. A radiograph of such a casting shows featureless solid metal, perhaps with a little porosity. The wax was sometimes modelled over a clay core (described by Mattusch 1996, p. 167), which can be recognized as an area of lower density on a radiograph. A more complex process, indirect wax casting, can be used to make large items, including statues in sections. A wax mould is made by filling a clay mould of the subject with wax, and then, before the wax sets, pouring most of it out, leaving a coating of wax on the mould surfaces. The hollow wax is filled with core material; finally, the wax is melted out and molten metal poured in to fill the cavities left after all the wax has been removed. It is characteristic of this process that wax is often retained in the extremities (e.g. fingers) so that the core material is prevented from entering these parts. Radiographs often show that the main part of the casting is hollow, except at the extremities, which have been filled with solid metal. Casting technology, explored mainly by radiography with some compositional analysis, featured in a study of Khmer cast bronzes (7th to 13th centuries) carried out by (Bourgarit *et al.* 2003). The figures varied in height between 7 cm and 86 cm. It was possible to determine if the figures were solid or hollow cast, with or without armatures and if direct or indirect wax casting had been used. The thickness and evenness of the walls were noted. Separately cast limbs and soldered or mechanical joins could also be distinguished.

Casting On

Casting on is another technique which may be identified by radiography. It is used as a method of construction, as well as for making good a poor casting or repairing a badly damaged object. A mould of the missing area is modelled on to the object and filled with molten metal after heating both mould and object; if they are not preheated, the join will not be sound. The cast-on segment may show a difference in thickness, density or porosity, or the join may appear as a discontinuity on a radiograph, especially if the surface has not been adequately cleaned with flux beforehand. Chinese bronze casters seem to have used the technique both to repair damaged or inadequate castings (Gettens 1969, pp. 12, 113) and also as a constructional technique (*ibid.* pp. 78–9).

Wrought Objects

From the earliest times metal was worked to shape by hand hammering. To shape the metal by hammering, working is carried out on the outside (raising) or from the inside (sinking): these processes are

Figure 3.10. *Xeroradiograph of a Roman silver bowl (AF 3279) and two ladles (AF 3283, 3285) from Carthage c. 400 AD. The frog dish has been damaged and is quite heavily corroded in one area. It has been repaired since excavation with soft solder (white areas) and the cracked area is supported by fibreglass and resin which is invisible on the radiograph. The corrosion obscures the worked texture which shows on the rest of the bowl. The two ladles were also worked but were heavily turned, as shown by the many concentric lines.*

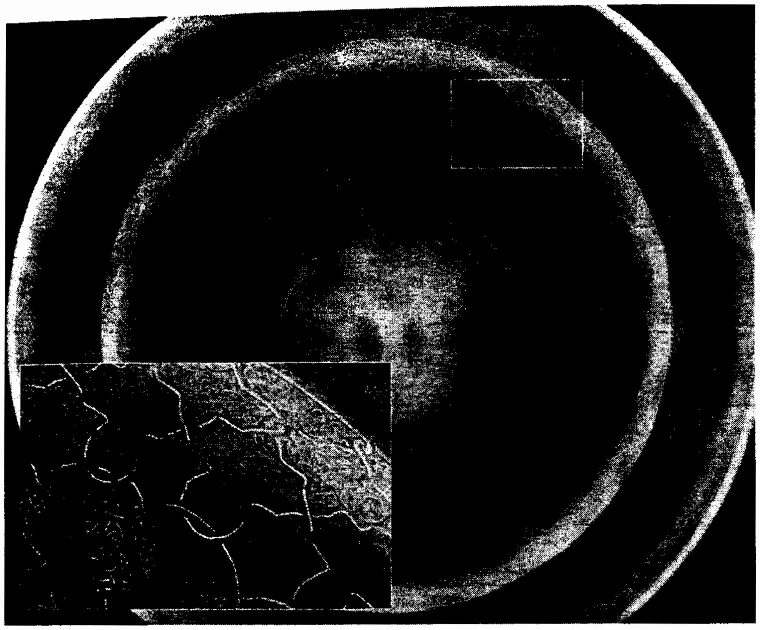


Figure 3.11. *Veneto-Saracenic Islamic brass tray (OA 1957-2-2.3) c. 1500* AD. *The radiograph shows the regular impressions of the hammer marks and traces of a silver inlay, which only remains in the keying, are visible on the original radiograph (see also Plate 3.1).*

illustrated very clearly by Tylecote (1986, p. 113). An uneven thickness, clearly visible on radiographs, is produced where the metal has been thinned by the hammer blows, often in a regular pattern (Figures 3.6, 3.10, 3.11). The radiograph of the wrought brass tray (Figure 3.11; see also Plate 3.1) shows the hammering marks spiralling outwards from the centre, which can be compared with the irregular radiographic density of the cast Etruscan mirror shown in Figure 3.5.

Fibring is most obvious on radiographs of swords, especially pattern-welded swords which were constructed from rods or strips of ferrous metal, heavily worked and forge-welded together, side-by-side, to form the blade. During prolonged unidirectional working, the microstructure becomes elongated and fibrous which shows on the radiographs as slightly irregular light and dark lines or bands, parallel to the main axis. Enlarged microfocus radiographs of mail from York show the fibrous structure of some of the rings (Tweddle 1992, figure 468).

Porosity is unlikely to be found on well-worked objects, because the small cavities are welded up during working and larger pores would be likely to cause fracture: the casting porosity seen in Figure 3.4 is not found on wrought objects.

Some indications of the process used to shape a vessel may be obtained by comparing the thickness of its centre, sides and rim, which is usually easy to see on a radiograph. When an object is raised, the thickness of the sides and the rim are reduced in comparison with the centre of the base. Sinking, on the other hand, tends to thin the material at the centre, while the walls and the rim remain relatively thicker. However, a thicker rim cannot be regarded as a sure indication that a vessel was made by sinking, because the rims of many raised bowls are 'knocked down' by edge-hammering, to strengthen them and improve their appearance. It should also be noted that both raising and sinking may be used on the same object, so that a distinction cannot always be made between the two techniques. Radiographs may be of assistance in showing how the thickness varies and hence the likely contributions of the two techniques. The dimensions of an object can also be decreased by working: radiographs of narrow tapering vessels, such as flagons, may show vertical lines, not visible on the outer surface, where the metal has been compressed by working to reduce the diameter towards the base (Megaw and Megaw 1990). The wall thickness of a vessel may also be altered by the finishing processes (e.g. turning on a lathe, see below).

Metal can also be pressed into a mould or die to make the basic shape or to imprint a design into the surface. Usually pressing or stamping can be identified by visual inspection, but sometimes the evidence is accessible only on a radiograph. Schorsch (1995), for example, discusses an Egyptian 12th Dynasty necklace made from hollow gold beads, which showed puckers on their inner surfaces, suggesting that they had been shaped by being pressed into a mould.

COMPOSITE OBJECTS

Large numbers of objects were made from several separate components which may or may not have been fabricated by the same processes: radiography can indicate how they were made. Schorsch (1995) describes how hollow spherical 12th Dynasty silver beads, made from two flanged hemispheres, were joined by a form of soldering. Radiographs show the joins and also how the hemispheres were punctured, allowing the insertion of two small cylinders made of rolled-up silver sheet through which a thread was passed to string the beads. It is unusual to find an object with as many components as the 18th century Tibetan Dakini statue radiographed by Delbourgo (1980), who found that it was made from 34 pieces; hammered copper was used for the limbs and cast brass for the hands, ears and bracelets. The joining methods used to assemble composite objects are varied and many of them can be identified by radiography, as discussed below.

Mechanical Joins

Mechanical joins take many different forms. A dowel might be used to secure one component to another or to a base and their use has been identified radiographically in objects as diverse as a Sumerian ibex (Meyers 1978) and the Irish Derrynaflan chalice (Ryan 1983).

Another type of mechanical join is effected by using rivets or pins. Minute rivets could be seen in the radiographs of a late Bronze Age Cretan gold ring (Müller 1994). Rivets located in an archaeological complex by radiography can help to identify the nature of fragmentary metal within the complex, or even yield archaeological information about the original location and orientation of a missing substrate to which the pins were originally attached (e.g. the Essendon Iron Age shield complex discussed in Chapter 2).

Sometimes mechanical joins are made in order that the object can be undone or disassembled. Radiography contributed to the understanding of the complex fastening on the Picean ring (Figure 3.4), which consists of a bronze clip holding the knobbed terminals of the ring together. Holes in the clip locate on the knobs and secure it in position (Middleton *et al.* 1992). The ends of some Iron Age bronze torcs are permanently fixed together with a bead of metal while others are joined by simple hooks or removable clips. Radiography helps to distinguish which type of join was used: in an example of the fixed join published by Borel (1995), the free ends of the torc can be seen clearly within the bead.

Without radiography it would have been difficult to determine how the Iron Age Basse Yutz bronze flagons from Lorraine were made, as these well-known, outstanding examples of early Celtic metallurgy are complex in their construction. The flagons are not easy to radiograph because they are tall and narrow with awkwardly shaped tops and spouts. However, by using small pieces of film it was possible to see that the base was not joined to the sides but entirely separate, and that the spout and cover were pinned together (Figure 3.12), unlike the spout assemblage of the stylistically similar Dürrnberg flagon (Hundt 1974) which was cast. It was clear that although there are some modern soldered repairs at the neck, none of the original joins was soldered. According to Craddock (1990) '... the whole assemblage was packed with resin ... this served both to hold it together and render it watertight, leaving just a central pouring channel free ...'. The ewer (Figure 3.13), elaborately enamelled in the Renaissance style and attributed to the Limoges workshops, is constructed from several components. Radiographs show that the upper and lower parts of the vessel were tied together with small twists of wire before the join was secured by brazing with a high melting point alloy (probably copper/silver). The handle, base and top spout section were also brazed on. This must have taken place before enamelling. Subsequent repairs can also be seen on the radiograph (Figure 3.14).

Complex objects, such as a portable sundial (Johansson 1986), or mechanical devices such as locks (Tuğrul and Soyhan 1996) and watches, can also be radiographed to provide information on details which are otherwise inaccessible without taking them to bits. A watch made by John Cooke, dated 1670, which had been recovered from the foreshore of the River Thames was radiographed at the British Museum to determine if the pins which

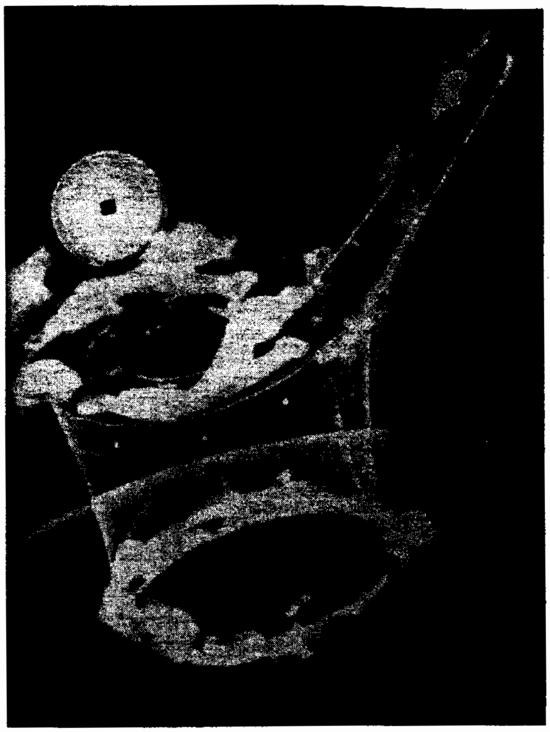


Figure 3.12. *Radiograph of the top of the 4th to 5th century* AD *Iron Age bronze flagon from Basse-Yutz, Lorraine (PRB 1929-2-11.2), decorated with cast animals, showing that the spout was assembled with pins. The solder at the neck is a recent repair. 10 mA, 10 min, 120 kV.*

Figure 3.13. *Ewer (Waddesdon Collection 57.1997) enamelled in the Renaissance style, attributed to the Limoges workshops (courtesy of Waddesdon Collection).*

hold the face plates in position were corroded or not. To show the condition of the pins, the watch was viewed in real time, which made it possible to determine the optimum angle for showing the pins unobscured by other components. In this position, the pins were successfully radiographed using film, allowing a detailed examination; this suggested that it would be possible to take the plates apart (Meehan *et al.* 1996). The details of an unprovenanced 1st century AD Graeco-Roman pen were revealed by the radiographs which showed that it was a cleverly devised multipurpose writing implement (Figure 3.15). It has a stylus for scribing on wax at one end with an eraser/burnisher to remove mistakes at the other. Inside is a split-nibbed pen for writing on bark or parchment with ink.

Crimped and folded joins are not commonly found, but can be identified by radiography. The top and bottom plates of the so-called 'bean can' from Wetwang (see p. 52, Figure 3.3) were crimped on to the cylindrical sides. Radiographic examination revealed, surprisingly, that the Sea City dish from Kaiser Augst (Cahn and Kaufmann-Heinemann 1984) had a footring which was made from a folded join between the outer and inner sections of the dish. Another type of mechanical join on the sides of South American jaguar figures, made by inserting a series of tabs cut out of one edge into slots cut close to the other edge, was also recognized by radiography (Tushingham *et al.* 1979).

Finally, in this section, mention might be made of screw joins found in a few late Roman brooches where the screw threads can be seen very clearly by radiography. Published examples include a Roman fibula from Kaiser Augst and another from Pistoja, Florence (Deppert-Lippitz *et al.* 1995). In the

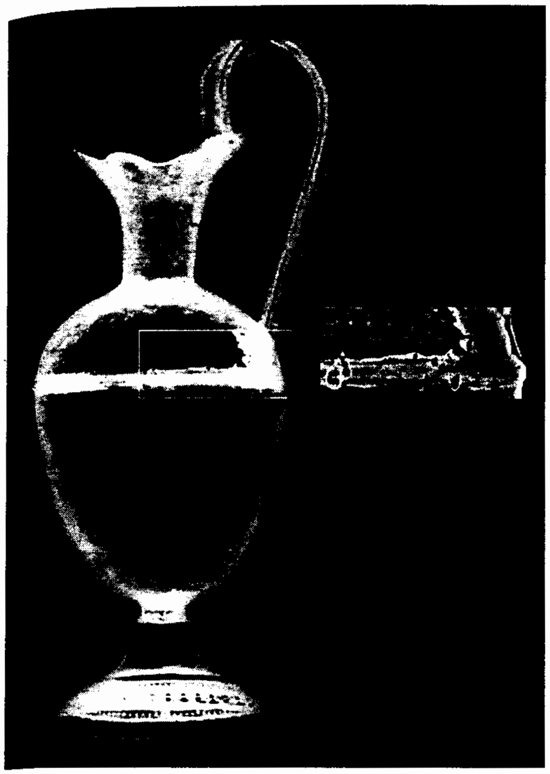


Figure 3.14. *Radiograph of the enamelled ewer no. 57.1997 showing the wires securing the top and bottom sections, the brazed joins, soft soldered repairs, the construction of the handle from rolled sheet. Variations in the enamel thickness on the side of the vessel are visible where the handle is attached. The enlarged detail has been processed to show the wire loops and variations in the enamel layer at the join.*

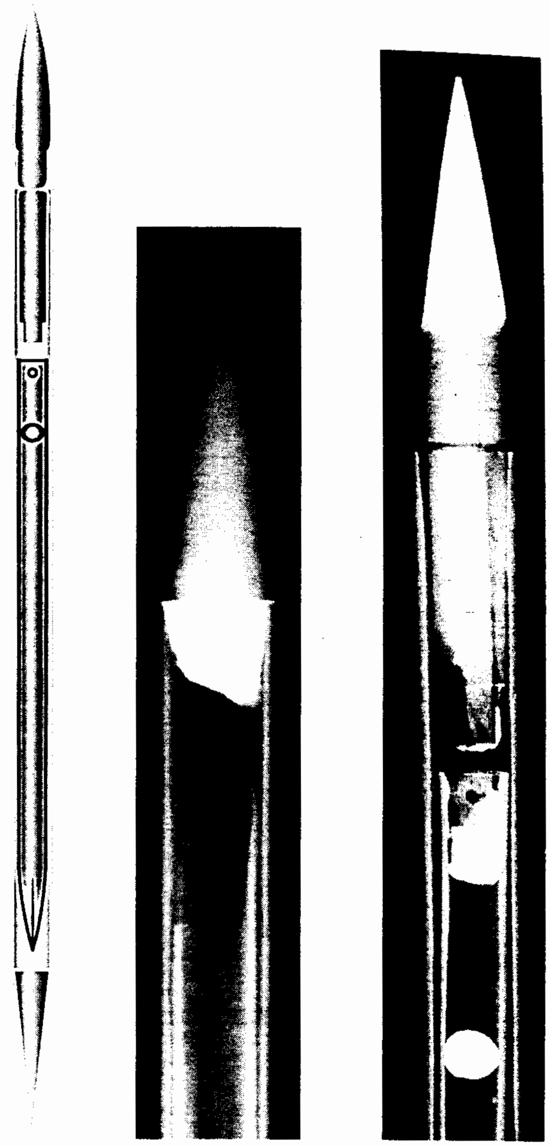


Figure 3.15. *Unprovenanced 1st century AD Graeco-Roman pen, 13 cm in length; 4.6 mm maximum diameter, brass casing. (a) Drawing of the pen and its components. (b) Enlargement of the radiograph showing the stylus point, with the split nib inside. (c) Wedge shaped scraper or eraser, originally held in place with soft solder and a rivet.*

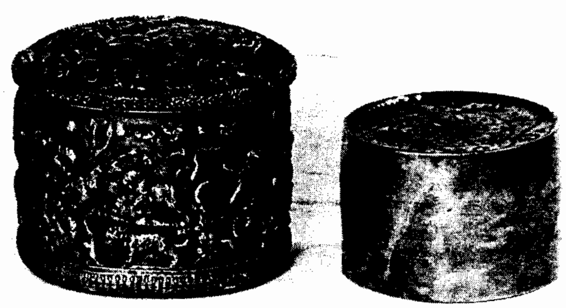
recent past, screws were often used in restoration work because the screw threads provide a key for other materials (Chapter 8).

Soldered Joins

Soft Soldered Joins

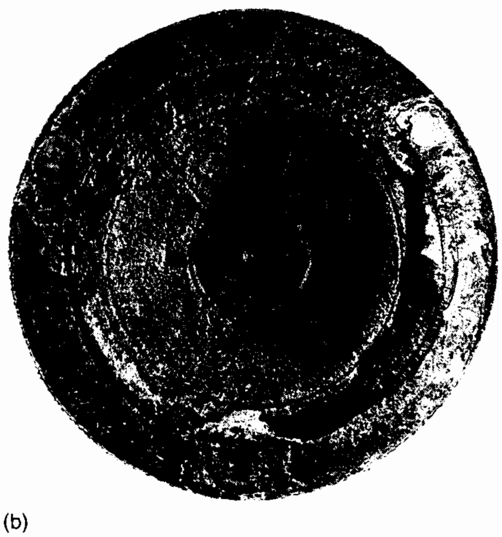
Soft solder is an alloy of tin and lead and has a low melting point (below 300°C). A soft soldered join shows very clearly on radiographs of bronze or silver vessels because tin and lead are radiographically denser than either bronze or silver. On the surface, soft solder can be identified visually and confirmed by X-ray fluorescence (XRF) analysis, but even if the join is internal, inaccessible or buried under corrosion or soil, it is visible on a radiograph as a denser area, sometimes exhibiting an uneven bubbly texture. A radiograph of a copper Islamic ewer, which is constructed from a number of plates and has also been repaired with soft solder, is shown in Figure 9.3. In a development of the soft soldered join, known as a coppersmith's join, the edges of the sheets have interlocking teeth which are soldered together, making it stronger than a simple butt joint. Early examples of coppersmith's joins were identified by radiography on vessels dating to about AD 800, from the Ummayyid *qasr* of Umm el Walid in Jordan (Schweizer 1994).

Handles were soldered onto Roman silver plate using soft solder because of its low melting point. If an object is assembled and decorated in a sequence of operations using heat, one of the last tasks might be to attach the handles, so a low melting point solder is essential in order to avoid earlier joins melting and the object falling apart. In the case of the silver canister from the Walbrook Mithraeum in London, radiographs revealed not only the presence of the soft solder by which the feet were originally attached, but also repairs in the base which have been made with high melting point solders. Subsequent analysis showed that these are of a composition consistent with being original repairs (Figure 3.16). Soft solder was also used in 19th or early 20th century restoration or conservation, but because some modern solders have compositions which differ from those used in antiquity, compositional analysis can sometimes determine if a join or repair was carried out in antiquity. The radiograph of the silver dish which bears the designs of the Risley Park Lanx is illustrated in Figure 9.5.

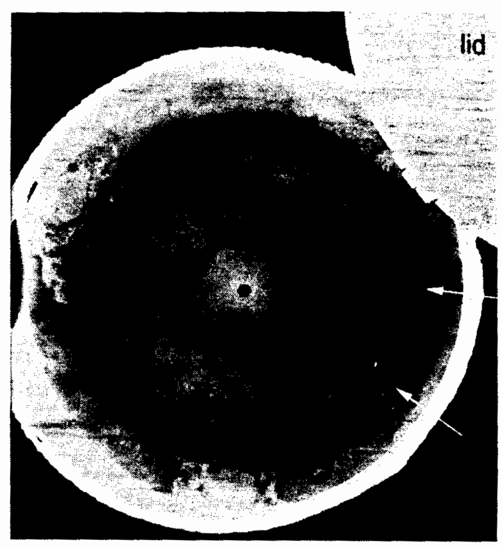


(a)

Figure 3.16. *(a) 2nd century AD Roman silver canister from the Walbrook Mithraeum, London, (b) base of canister showing patches of soft solder where feet were probably attached, and an attempt to repair one of the gaps. (c) The radiograph shows the soft soldered patches for the feet and two patches of hard solder used in an attempt to fill the gap (arrowed).*



(b)



(c)

This shows that the dish is made of fragments soldered together, using two types of solder, that is, soft solder (light in the xeroradiograph) and hard solder (dark). The authenticity of the dish is discussed in Chapter 9.

The presence of solder joins at the rims of double skin or shell vessels can be detected by radiography, which helps distinguish them from cast vessels. The Romans used this double skin technique of manufacture, especially for cups. The thin external, decorated surface is raised with a repoussée design, while the internal section is usually plain and thicker. The two are joined at the rim either by soldering them together or folding over the edges. Normally, in a cast or wrought vessel, areas of a design which are in high relief appear on a film radiograph as lighter in shade, whereas on a double skin vessel these areas appear dark, indicating that they are at least partly hollow although the intervening space is sometimes partly filled with solder (Meyers 1978).

Hard Soldered Joins

The higher melting point, hard solders or brazing alloys usually contain silver and copper and are used to join silver or copper alloys. As there is little difference between the composition of the hard solders and the metal to which they are applied, it is not easy to distinguish the soldered areas. Sometimes porosity indicates the presence of hard solder, but not always. If the join between components is not completely filled with solder a gap may be visible on the radiograph (e.g. Figure 9.5). With smaller objects, such as jewellery, hard soldered joins are sometimes more easily located using the imaging and analytical facilities and elemental mapping programmes of the scanning electron microscope (SEM), although microfocus X-radiography is also very suitable for examining small objects. Reiter *et al.* (1994) examined ferrous metal dress pins with oval heads from the Hallstatt necropolis at Rubenheim in Saarland. They found that the heads of the pins were made in two halves, soldered together with a bronze solder (brazing alloy). The microradiographs show the filets of solder inside the pinhead and small globules of unfused solder; the composition of the solder was determined subsequently by metallography and XRF analysis.

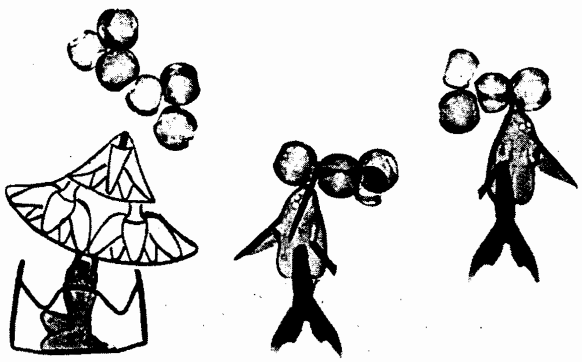
Many bowls have footrings to allow them to stand firmly on a flat surface. Most commonly, the footring consists of a ring of metal soldered on to the base of the bowl, usually with hard solder. The soldered joins at the footrings on Sasanian bowls are very obvious to the eye, but joins made in the Roman period are much more difficult to detect, either visually or radiographically. This is probably because a hard solder was used with a composition close to that of the body metal. Another problem which footrings present to the radiographer is their location: it is usually extremely difficult, if not impossible, to position the film immediately next to the join.

The most delicate joining techniques (reduction or colloidal soldering) involve the use of very finely divided metal or mineral, such as malachite (Littledale 1934), probably mixed with glue which holds the pieces in position. On heating, the glue chars, reducing any mineral to metal, and the minute particles of metal melt and fuse the parts to be joined together. The use of this type of joining technique on jewellery is illustrated in Figure 3.17, which shows two Egyptian necklaces containing beads with reduction-soldered joins. The construction of the bottle-shaped beads in Figure 3.17(b) shows clearly on the radiograph: the closed part of the bottle was made in two parts, with a reduction-solder join, the neck was pushed through a hole in the bottle, and then a flared top was added to the neck.

The stems on wrought cups are usually attached by solder but it is difficult to radiograph the joins satisfactorily because of their geometry. Side and vertical views are usually taken. If a cup, perhaps made of bronze or silver, is in sound condition, it is possible to hold the film (in a flexible cassette) in position close to the surface by strapping it with masking tape over a strong paper or card strip. Soft pads of paper, polyurethane foam or pieces of polystyrene can be used to hold the film in contact with the walls of the vessel. Shaped lead sheet shields and bags of lead shot placed around the outside of the object help to reduce scatter. Real-time radiography is excellent for this type of subject, because of the facility to move the object in the X-ray beam whilst observing the real-time image.

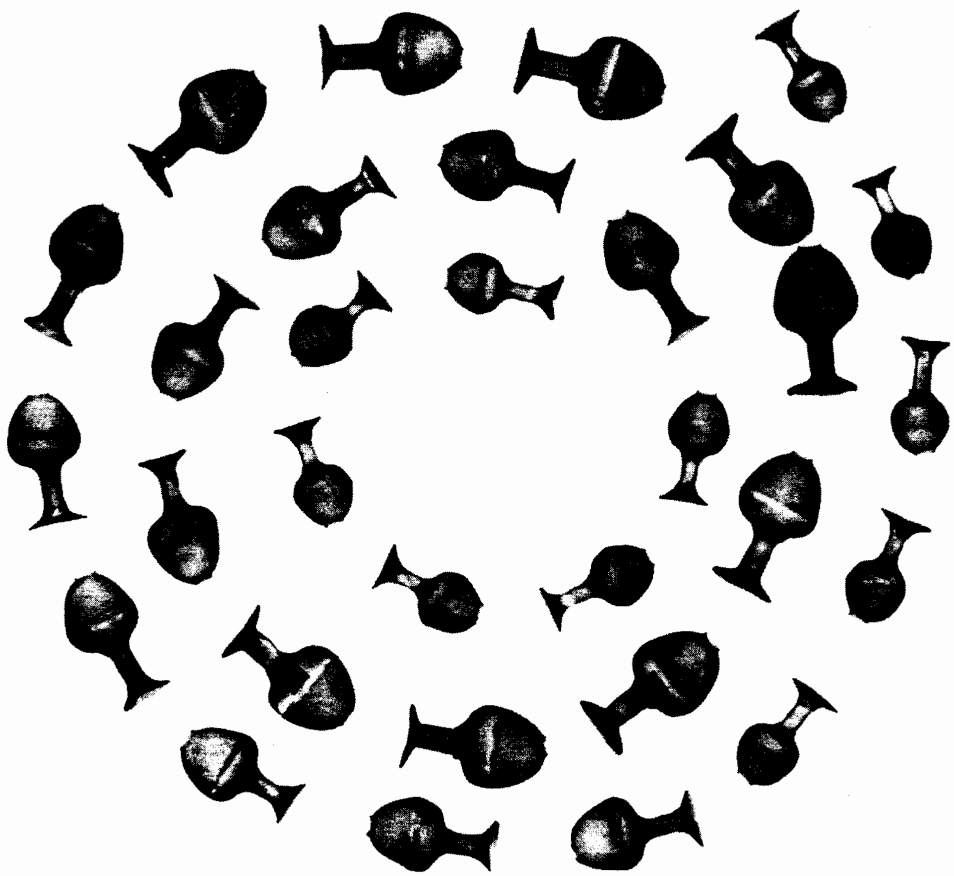
Welding

Welding, for the purpose of this book, is considered to be the joining of two pieces of metal (normally ferrous), using an elevated temperature and/or pressure; both are required for the majority of welds on ferrous items such as tools and weapons. In modern fusion welding a filler metal is used and a very high temperature (>1500°C) is required to melt it; this



(a)

Figure 3.17. *(a) Beads from an amuletic string with pendants, Middle Kingdom (EA 3077). The beads have soldered joins (dark). The fish pendants were made with separate tails, fins and suspending loops added to the body. Enlarged print from radiograph. (b) Amuletic string, Middle Kingdom (EA 14695). The bottle-shaped beads have soldered joins at their maximum diameter: a hole made at one end allows the neck to be made by pushing through a tube of rolled sheet. Open flared ends were added to the free end of the neck. Enlarged print from radiograph.*



(b)

was not achievable in the past so welding in the modern sense was not used. Some non-ferrous items have welded joins achieved by using pressure (Tylecote 1962, pp. 152, 154) rather than elevated temperatures.

Medieval coin dies can be considered as a good example of the use of welding and have been studied by McDonnell (1992) and Lang (Archibald *et al.* 1995). The dies are usually thick rods of iron or steel, 10–25 mm in diameter and may have a separate

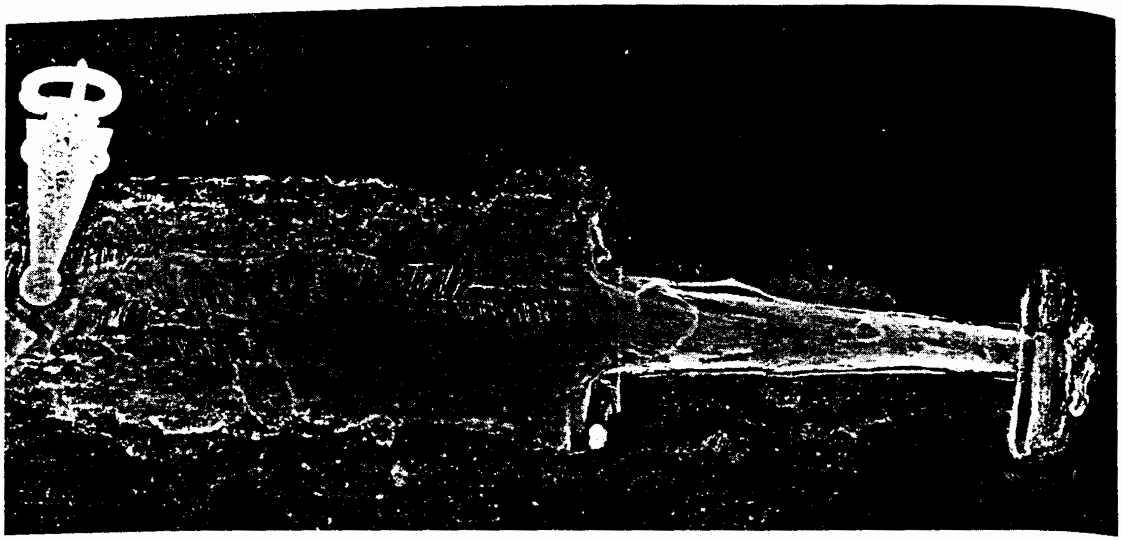


Figure 3.18. *Sword from Sutton Hoo, Suffolk, mound 17, excavated in 1991, straight from the site, before cleaning. The pattern of the sword, the gold and garnet belt fittings, traces of the organic grip, a silver ring for suspension and a break in the tang, presumably sustained during manufacture, all show on the negative xeroradiograph. The post-excavation packaging also showed, indicating that had organics such as wood or cloth been present they would have been visible.*

Figure 3.19. *Xeroradiograph of a late 9th century* AD *pattern welded Anglo-Saxon sword from Hurbuck, Durham (ML1912-7-23.1). The pattern was made by welding together three twisted rods, side-by-side. The blade has been constructed from two pattern layers (the arrow shows where the two patterns can be seen, superimposed) welded together with a thin cutting edge around the outside.*

strip sandwiched between two patterned strips and completed by a plain cutting edge welded around the outside. Using conventional radiographic techniques (including stereo pairs) it is virtually impossible to show the existence of the plain metal strip between the two pattern-welded strips. However, by taking a succession of cross sectional 'slices', CT shows the surface layers, the edges and the core very clearly, without having to resort to cutting a small slice from the blade for a metallographic cross section (Wessel *et al.* 1994).

The use of Stereoradiography (see Chapter 2) allows the patterned layers to be separated visually. This technique is particularly valuable when trying to distinguish pattern-welded inscriptions which were made by inlaying small letters shaped from pattern-welded strips. These blades were popular in the 10th century AD, when the pattern-welded sword became less common, possibly for economic reasons. The inscriptions are frequently invisible under the corrosion layers, but they can be revealed by radiography and stereo pairs enable inscriptions which are superimposed to be separated (Figure 3.20) (Lang and Ager 1989).

FINISHING

Finishing processes include filing and grinding, polishing, turning on a lathe and fitting the object for its function. Generally the traces of these activities are to be found only on the surface layers and they may not show up on radiographs. Many items of late Roman silver plate were finished by turning on a lathe, removing surface roughness but leaving a crude, almost faceted surface. The radiograph of the ladles from the Carthage Treasure (see Figure 3.10) die face welded on. Radiography can be used to locate the weld, which is usually parallel to the die face. If the weld is at an angle to the face or is not accurately positioned relative to the beam, it is difficult to pick up on the radiograph because the X-ray absorption at the weld is so little different to that on either side of the weld (Chapter 1). It appears that sometimes the asperities on the surface of the shaft in the area of the join were forged over the join, possibly to make for easier handling; this obscures the weld for visual examination and even on a radiograph (Archibald *et al.* 1995). Evidence that the shafts were sometimes made by folding over a bar or strip to give the necessary bulk can also be seen on the radiographs.

To radiograph the dies, a relatively high kilovoltage (*c.* 220 kV) and a long exposure is necessary, together with lead screens, some filtration and masking because the circular cross section increases the propensity to scatter radiation. McDonnell (1992) cut profiles in lead sheet to outline the dies, while Lang (Archibald *et al.* 1995) used lead sheet and bags of lead shot. Barium putty can also be used, but it needs to be wrapped in plastic as it is an unpleasant and sticky material to handle and might adhere to the objects.

Other examples of welding are to be found in larger tools, such as a Romano-British adze from Waltham Abbey, where the heel and the cutting edge had been welded into the blade. Radiography at the British Museum enabled the welds to be located so that the component sections could be studied metallographically. The excavated material from York provided two examples of welding revealed by radiography. The first was a repair to the tip of the sword beater, which had broken off and been welded back into place (Tweddle 1992, p. 882–8). Microradiographs of the mail showed both riveted and welded rings and careful examination indicated that the welded rings were made from a different stock of better, cleaner, more homogeneous metal than the riveted rings, presumably to assist welding (Tweddle 1992, p. 1006).

South American metallurgy provides some examples of non-ferrous joins which appear to have been welded. Lechtman *et al.* (1975, p. 46) used radio-graphy to show the joins on seven hollow jaguars from Peru, which she described as being 'sweat-welded' because a thin strip of metal was interposed between the two edges to be joined. Heating (sweating) causes the strip to fuse with the two edges, albeit somewhat irregularly. Tushingham *et al.* (1979) examined a number of Peruvian nose ornaments by radiography and showed that the joins between silver and gold were made by welding.

Flow Welding

Flow welding was used in constructing Classical statuary from sections which had been cast separately. Molten bronze (lead was used occasionally) was poured into the juncture between the components (Mattusch 1996). The joins can be identified on radiographs, usually as bands of increased radiographic density and thickness.

Pattern Welding

Amongst antiquities, probably the best known use of welding is in pattern welding. This was a method of blade-making practised mainly by the Anglo-Saxons, although it first appeared in the Iron Age. Iron strips or rods were twisted, laid side-by-side and then welded together, by forging. Whatever the purpose of this operation, the finished blade would have shown a patterned surface. After burial for a millennium, an iron sword usually appears to be a rusty strip of metal, recognizable only by its length and thickness. The tang, if it remains, often shows clearly on radiographs (Figures 3.18, 3.19). Striations can be observed on the radiographs of non-pattern welded swords, weapons and tools: these appear to arise at least partly from elongated slag stringers, which are of different radiographic density to the metal. In pattern welding, forging the strips or rods also results in an uneven, striated structure (fibring) which responds unevenly to corrosive attack. At the same time inclusions, such as oxides and other impurities, also tend to be concentrated in the welds between the strips, encouraging preferential corrosion to take place at the joins during burial; this makes the pattern visible on a radiograph. The sword from the Anglo-Saxon ship burial at Sutton Hoo found in 1939 was completely corroded, but radiography provided sufficient information about the pattern for a replica to be made (Bowman 1991, figure 5.13). As the swords are usually corroded, a low kilovoltage is used (e.g. $<$90 kV), and in order to allow the maximum contrast, lead screens are not used between the object and the film.

Metallographic examination (Tylecote and Gilmour 1982) of this type of sword has revealed that the blades are formed by a long, pattern welded central section, often consisting of a plain ferrous

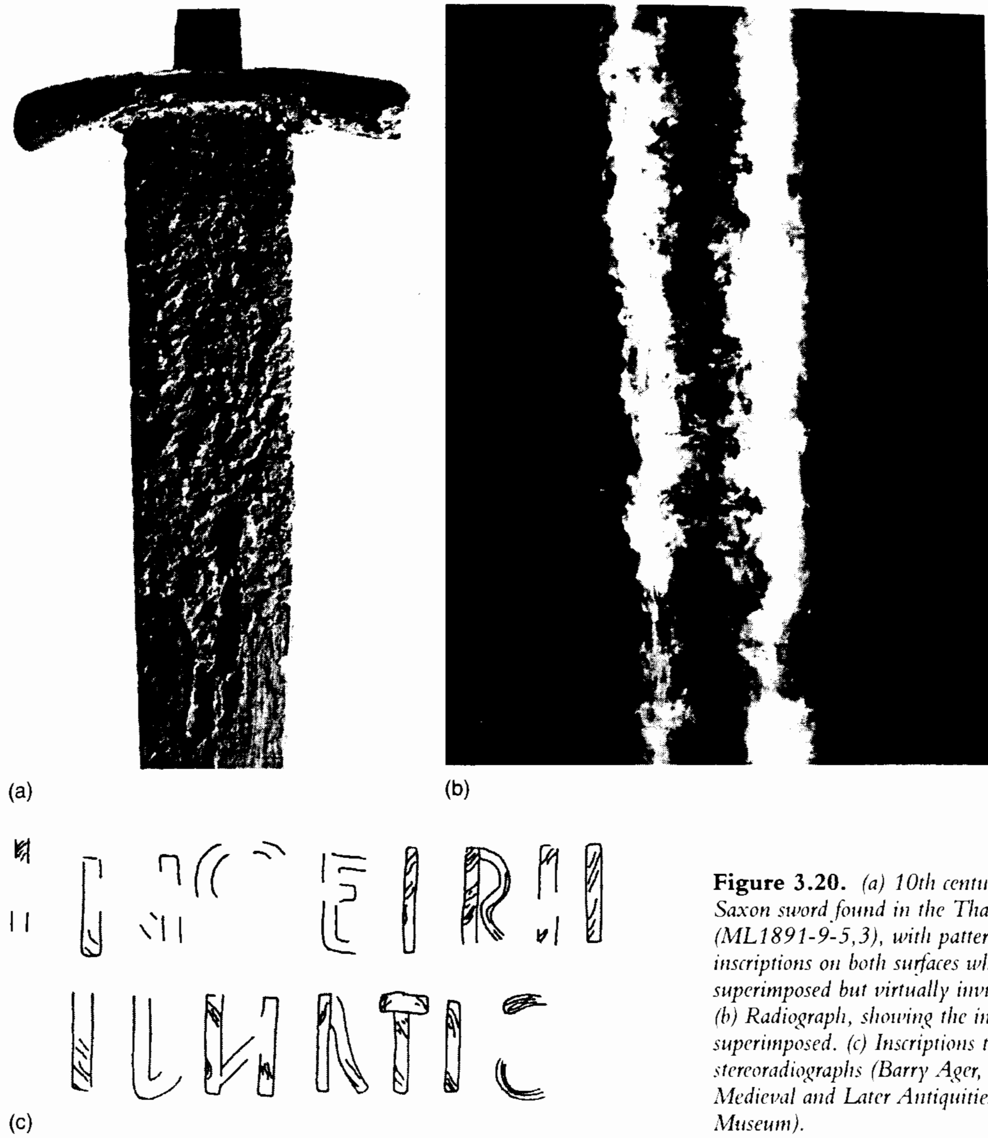


Figure 3.20. *(a) 10th century* AD *Anglo-Saxon sword found in the Thames at Kew (ML1891-9-5,3), with pattern-welded inscriptions on both surfaces which are superimposed but virtually invisible to the eye. (b) Radiograph, showing the inscriptions superimposed. (c) Inscriptions transcribed from stereoradiographs (Barry Ager, Department of Medieval and Later Antiquities, British Museum).*

shows an uneven density due to raising and, superimposed on top, the regular concentric variations due to finishing on a lathe. By the Roman period, lathes were used extensively to finish silverware by holding a bladed tool against the surface to cut or scrape away the irregularities as the object rotated (Craddock and Lang 1983). Concentric variations in thickness are introduced as the tool moves outwards towards the rim. This type of banding can be seen on the radiographs of vessels where the evidence of turning is visible on the surface (e.g. the ladles from Carthage, Figure 3.10).

Sometimes the finishing has a functional purpose. Files, for example, have been studied by Fell (1985). One of the final processes in finishing these ferrous tools is to cut the teeth, before the final hardening heat treatment. As they are made from ferrous alloys, files are frequently heavily corroded. Radiography is extremely useful in their identification, as it is not always possible to clean such objects, either because

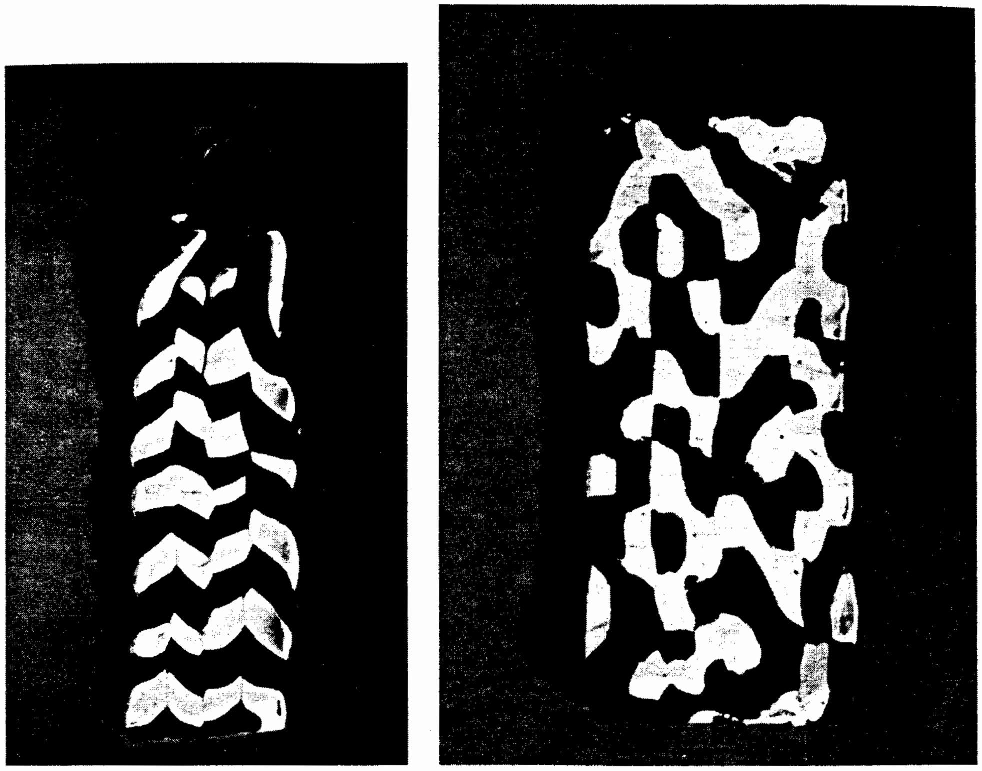


Figure 3.21. *Schematic models of pattern welding made in plasticene after Ypey (1973). (a) Replica of hammered surface and (b) after surface removal (by cutting), curving patterns are revealed.*

they are in a fragile condition or because it is not economic. It should be possible to detect traces of precious metal (gold) if they remain in the fine teeth of jewellery files.

Finishing may have a decorative purpose. Anglo-Saxon swords sometimes have depressions or fullers running down the blade, (sometimes known as 'blood channels'). These channels can be made either by forging with a drift punch or by grinding with abrasives. The method used to produce the channels can be determined by radiography because forging compresses part of the blade without much change to the design, but if part of the blade is ground away the surface (and radiographic) pattern changes characteristically. Ypey (1973) produced a series of drawings demonstrating the changes which occurred in a simple twist design as the blade surface was ground away, based on experiments and radiographs of pattern-welded blades (Figure 3.21). Radiography showed that grinding the channels rather than forging them was more common in continental Europe while the opposite was true in England (Lang and Ager 1989).

Relief Decoration, Plating and Inlays

Decoration includes introducing a design on the surface of an object by punching and chasing from the front, repoussée (working from the back), carving (removal of metal from the front) and engraving (cutting a design by removing metal with a sharp tool). It also includes adding materials to the surface, such as metallic or non-metallic inlays, enamels or stones and also plating layers of a different metal, such as gold, silver or tin, onto the surface.

Not surprisingly, locating decoration is one of the tasks which archaeological radiographers frequently find themselves undertaking; the ease with which decoration can be found depends upon the difference in absorption between the design or inlay and the substrate. The difficulties presented by chased, punched and engraved designs are discussed in the next section, as they are the same as those experienced in trying to record inscriptions. Repoussée work can be identified easily because the metal is thin and details can be seen very clearly on radiographs, especially the cracks and holes which occur when the metal is over-stretched and splits. If the concavities are filled with lead, however, most of the detail is lost because of the high radiographic density of lead. Backings made of wood, plaster or bitumen do not obscure the image of a metal repoussée covering.

Some Sasanian bowls have small panels of 'let in' silver on the front, to increase the relief of features such as heads (Gibbons *et al.* 1979; Gunter and Jett 1992). The technique was to cut a small channel at an angle around the edge of the feature in the surface of the bowl, and then spring a small, convexly curved, decorated plate representing the head into the groove. The silver from the dish was smoothed over the join with a burnishing type of tool. Radiography shows these added areas very clearly and also the deep depression at the groove (Figure 3.22). Carving was also used by the Sasanian silversmiths to emphasize low relief features (Gibbons *et al.* 1979; Meyers 1981) and is recognized by abrupt changes in thickness at the edge of the feature. A similar effect can be produced by the lateral raising method described by Maryon (1948). In this technique, features are raised from the front by punching with the tool held at a very low angle: this tends to produce hollowing on the back surface, which distinguishes lateral raising from carving. Scott (1991) used both microscopy and radiography to determine that carving rather than lateral raising was used on the *Philosopher and Fisherman* plates in the J. Paul Getty Museum, which he concluded may be Byzantine.

Inlays of different metals often show up well on radiographs. Silver and, to a lesser extent, copper and gold, were used in the form of inlays by the Merovingians to decorate iron buckles, straps and other items (Figure 3.23). As excavated, these objects were covered with a layer of iron corrosion so that the silver was completely obscured; radiography readily revealed the inlay. Radiographs of the Anglo-Saxon single-edged seax blade from Sittingbourne illustrated in Plate 3.2 show plaited wires, lettering and small silver and brass decorative plates (Figure 3.24). A comparison of the radiograph and photographs of the golden-yellow metal inlaid plates on the seax shows that they are less dense than the silver ones, suggesting that they are unlikely to be gold: this was confirmed by XRF analysis. The radiographs of the Veneto-Saracenic brass tray illustrated in Figure 3.11 reveal traces of the silver inlay which remains only in the dotted keying. These brass vessels were often decorated with gold, traces of which still remain but are difficult to detect against the yellow-coloured brass: they show up distinctly on radiographs.

Figure 3.22. *4th century* AD *Sasanian silver dish (WA 124093) with 'let in' panels increasing the relief of the figures. A groove was cut into the surface at angle and a curved pre-shaped piece of silver was pushed into it. The groove can be seen where the relief panel is missing, and also traces of gilding.*

A wide variety of materials other than metals is used as inlays to decorate metal objects. The radiographic density of stones and enamels depends upon their composition and is further discussed in Chapter 9. Like metal inlays, they will often show up on a radiograph depending on the differences in density, even when they are invisible beneath surface corrosion. The knot design in enamel on the Dark Age brooch shown in Figure 3.25 can only be seen on the radiograph. Inlays like enamel or niello, a

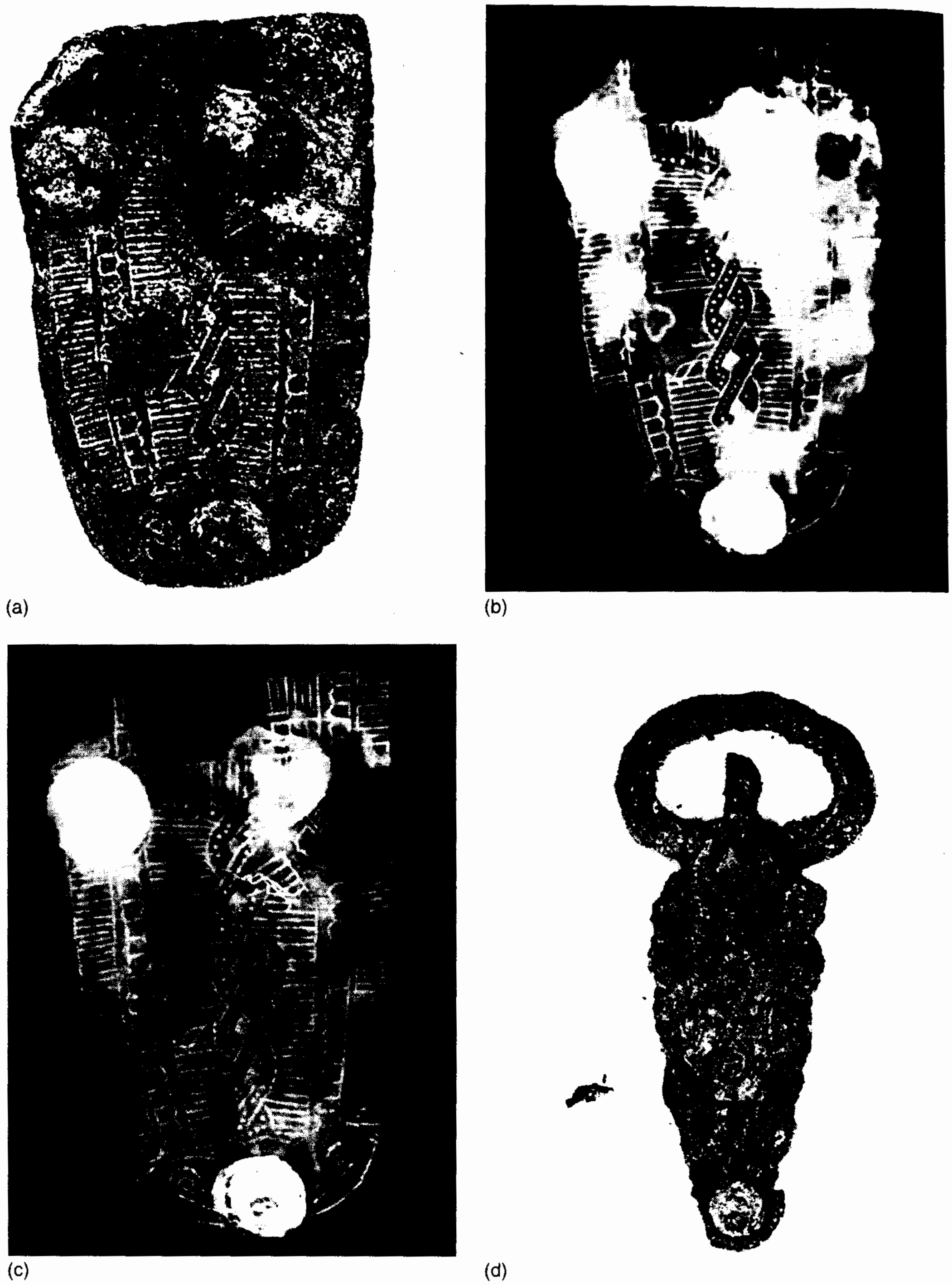


Figure 3.23. *(a) Merovingian buckle counter plate from Northern France, early- to mid-7th century* AD *(ML 1893-12-29.291), (b) photograph of the radiograph of (a). Not all the information which can be seen on the radiograph can be reproduced in a single print, (c) image scanned from the radiograph (b). Localized contrast adjustments enable all the information in the radiograph to be seen, (d) Merovingian buckle from France, mid- to late-7th century* AD *(ML 1905-5-29.291).*

black mixture of metal sulphides applied to silver in the form of a hot paste, required the metal to be keyed or roughened to hold them in place. While the inlay is still *in situ*, the keying can be seen only by radiography. Enamel inlays can be applied in a number of ways. Two widely used techniques are cloisonné, where the fields of enamel are separated by metal strips set on edge on the base plate, and champlevé enamelling, where the channels and fields for the enamel are cut into the metal. Radiography can be useful in determining the method of enamelling, estimating the depth of the enamel, and revealing the original marking-out of the design under the enamel (Stratford 1993). Enamels are fairly transparent to X-rays, unless they contain heavy metals such as lead.

(e)

Figure 3.23. *(e) scanned image of part of the radiograph of (d), with localized contrast adjustment used to reveal details in contrasty areas of the radiograph.*

Traces of surface coatings are not easily captured on radiographs, usually because they are very thin. Gilding can be seen as lighter (i.e. radiographically denser) areas on conventional radiographs, and some of the identifying characteristics of foil and fire- (mercury) gilding enumerated by Oddy (1984) can be recognized. Features such as a bubbly surface, gilding spreading beyond its allotted area, splashes of gold outwith the gilded areas and thicker gold deposits in engraved lines on the surface, which indicate the use of fire-gilding, can be discerned on radiographs which makes the technique a useful adjunct to microscopy and XRF analysis in identifying the method of gilding.

Inscriptions, Chased and Engraved Decoration

The elucidation of inscriptions on metal objects is a frequent source of enquiry and some of the difficulties

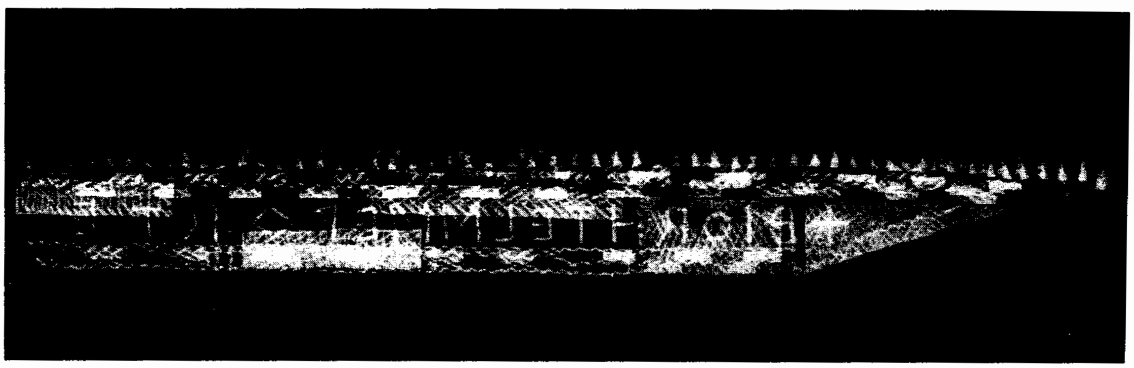
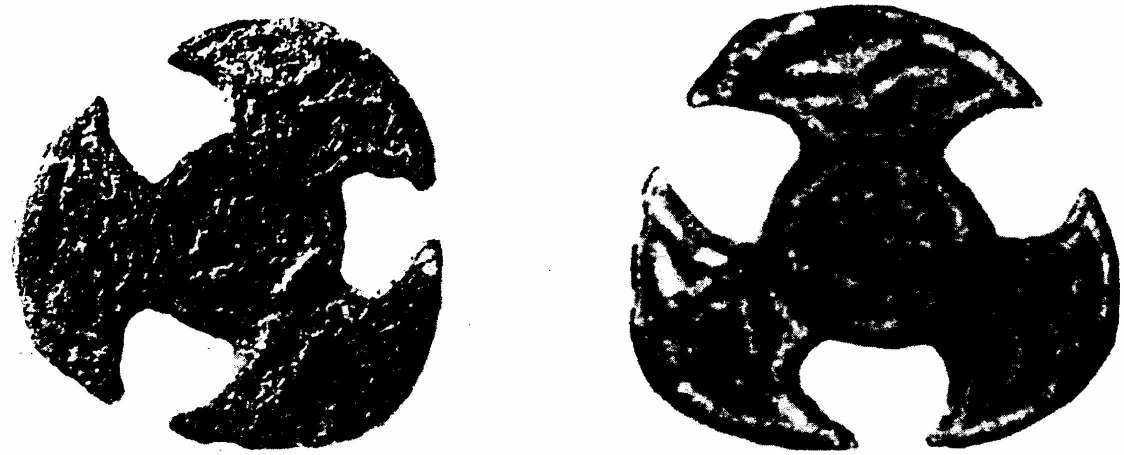


Figure 3.24. *9th to 10th century* AD *Anglo-Saxon seax (ML 1881-6-23.1) from Sittingbourne, Kent. The scanned radiograph shows the two designs superimposed. The engraved pattern (Plate 3.2(left)) is so shallow that it is not visible on the silver panels, but the cross-hatched keying underneath is revealed. The yellow panels are not as dense as the silver and are brass not gold.*



(a) (b)

Figure 3.25. *Unprovenanced Dark Age enamelled disc, 6th to 7th century* AD *(ML 1907-6-12.1). (a) Photograph shows little of the design but the radiograph (b), obtained using an image intensifier and enhanced with sharpening filters, shows the design clearly.*

have been outlined in Chapter 2. Inscriptions are frequently difficult to radiograph because the depth of the inscription is insignificant in comparison with the total thickness. This means that the conditions must be arranged so that maximum contrast is achieved by using low kVs with higher currents and longer exposures if necessary. Image processing may help to increase the contrast.

The radiographic work carried out on the Balawat Gates from Mesopotamia, now on display in the British Museum, revealed a number of the inscriptions which were otherwise obscure, and helped to provide evidence which enabled broken parts to be pieced together (Barnett and Werner 1967). Inscriptions are sometimes of crucial importance in assessing the significance of an object. An inscription on a bronze Elamite bowl was partly obscured by corrosion and wear. With the help of radiography it was possible to decipher that the bowl was owned by Tempti-Agun I, King of the Elamites in 1575 BC, and had been given to him by his son.

The five swan necked spoons from the Romano-British site at Hoxne, Suffolk (Figure 3.26(a); see also Plate 3.3), have inscriptions on the bowls which could only be fully deciphered with the assistance of radiographs (Hassell and Tomlin 1993). These show (Figure 3.26(b)) that alterations had been made to the text: in one (0046), the craftsman had started to engrave the name PEREGRINVS, starting at the handle end and then, presumably realizing a mistake, started again from the other end simply engraving over the first six letters. On another spoon (0008), the inscription (visible on the radiograph) appears to have been deliberately abraded and polished and, as it stands, makes no sense, reading QVISSVNTVIVAT: Hassell and Tomlin suggest that it should be QUINTVSVIVAT.

Sometimes the design remains within the corroded metal only as a discontinuity, which can be recorded clearly on a radiograph although the metal has corroded completely. The decoration on a Phoenician bronze bowl from Nimrud (WA 91420) was revealed in this way, despite the bowl being completely mineralized and any attempt to reveal it by any other method would probably have been unsuccessful (Barnett and Werner 1967).

In a museum or archaeological context, metal objects are probably radiographed more frequently than objects made from other materials: it is hoped that this chapter has indicated why this non-destructive technique is so widely used and how versatile and illuminating it can be in the study of metal objects.

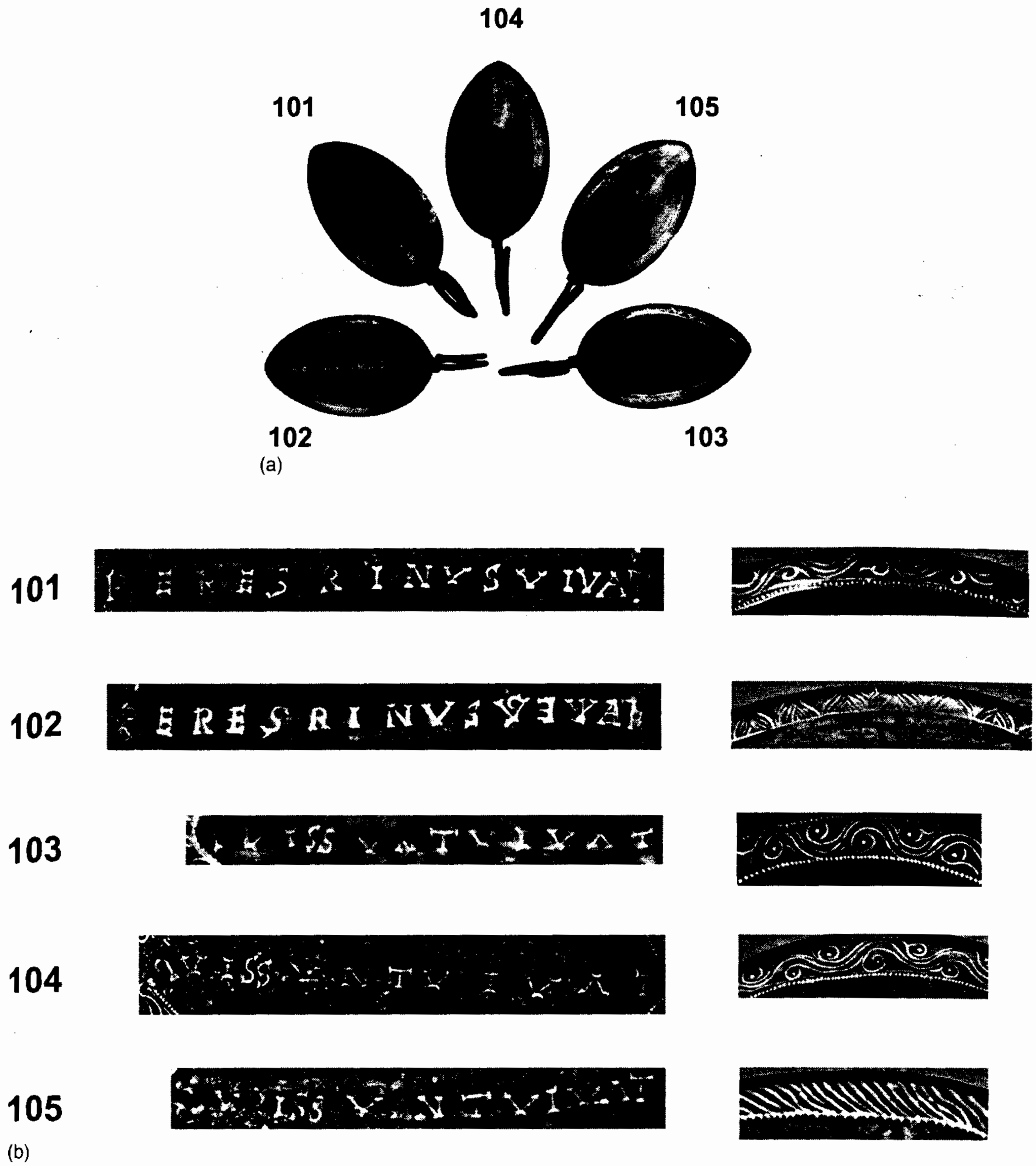


Figure 3.26. *(a) Five late Roman swan necked spoons from the Romano-British site at Hoxne, Hertfordshire, have inscriptions punched in the bowls (see also Plate 3.3). The alterations to the inscriptions are only revealed on the radiographs. 7 mA, 10 min, 100 kV, lead screens, 0.6 mm copper filter, AX Kodak film. (b) The images of the inscriptions and the designs around the rims have been processed digitally to show the details more clearly.*

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