Charles Dawson's cast-iron statuette: the authentication of iron antiquities and possible coal-smelting of iron in Roman Britain

Paul Craddock and Janet Lang

ABSTRACT: The scientific or technical authentication of iron artefacts has not attracted a great deal of attention although there are some notable forgeries. Scientific examination of Charles Dawson's little iron statuette and another little figure found more recently at the Roman iron smelting site at Beauport Park, Sussex, has shown both to be of coal- or coke-smelted grey cast iron. The sulphur and manganese contents of the Dawson statuette strongly suggest that it is Victorian. It had also been treated with potassium dichromate, as were all the finds from Piltdown, thereby linking the actual forgery process firmly with Dawson. The other figure is more complex but still relatively recent. Iron that does not contain evidence of smelting with fossil fuels can be very difficult to date or authenticate, and some of the problems with the direct dating of iron by radiocarbon dating, or by metallographic structure are discussed here. Other examples of grey cast iron have been reported from several Romano-British sites. Consideration of their composition and archaeological context suggests that most are probably intrusive, but some could be evidence of experiments to smelt iron using coal in the Roman period.

Introduction

This paper explores some of the scientific and technical methods of dating or authenticating iron antiquities, as well as re-examining the possibilities that the Romans may on occasion have produced cast iron and even experimented with coal to smelt iron. These questions were raised by the examination of two small iron statuettes purportedly found at the well-known Roman iron-smelting site at Beauport Park near Hastings in Sussex (Straker 1931, 330–37; Cleere and Crossley 1985, 70–2) and now both in the collections of Hastings Museum and Art Gallery.

One of the statuettes (Fig 1) was acquired and published by Charles Dawson, of Piltdown fame, and is reasonably well known from the many books dealing with Dawson and his scientific frauds (*eg*, Weiner 2003, 164–5; Walsh 1996, 170–78; Russell 2003, 61–70). However, for some reason the various scientific examinations made on it over the last century by scientists as eminent as Sir William Roberts-Austen have never been properly published. This is in spite of the controversy surrounding the statuette since its first public announcement, and its importance for the history of technology if it really was a Roman iron casting.

In 1976 a second small and heavily corroded figure standing on a base (Fig 2) was found on a spoil heap at Beauport Park by a Mr Alan Scott. It was donated to the Hastings Museum together with some Roman pottery in 1997 (accession no 997.45). The piece appeared to be a single casting beneath the deep corrosion, but radiography showed that it is more complex (Fig 4; see below). The appearance and depth of the corrosion (Fig 9) suggests that it is much more likely to have been buried than the Dawson statuette and thus is likely to be a genuine find, but not necessarily a Roman antiquity.

Together they do raise the question of how to establish the age, or at least the authenticity, of an iron artefact.

For most metals the study of the corrosion can give an indication of antiquity but iron corrodes so rapidly that this criterion is not of much use. Thus other means have to be used to try and establish the antiquity of an iron artefact; these include radiocarbon dating (Cook *et al* 2001 and 2003; Creswell 1991 and 1992; Eylon 2002; Craddock *et al* 2002, and see below). Alternatively, metallographic examination and analysis can establish the methods by which the iron was smelted, if it was alloyed and how it was worked, from which it is often possible

Figure 1: Dawson's cast-iron statuette (Hastings Museum and Art Gallery Reg. 917.4). Left: front view; right: back view, note the large hole in the left thigh (cf Fig 3).

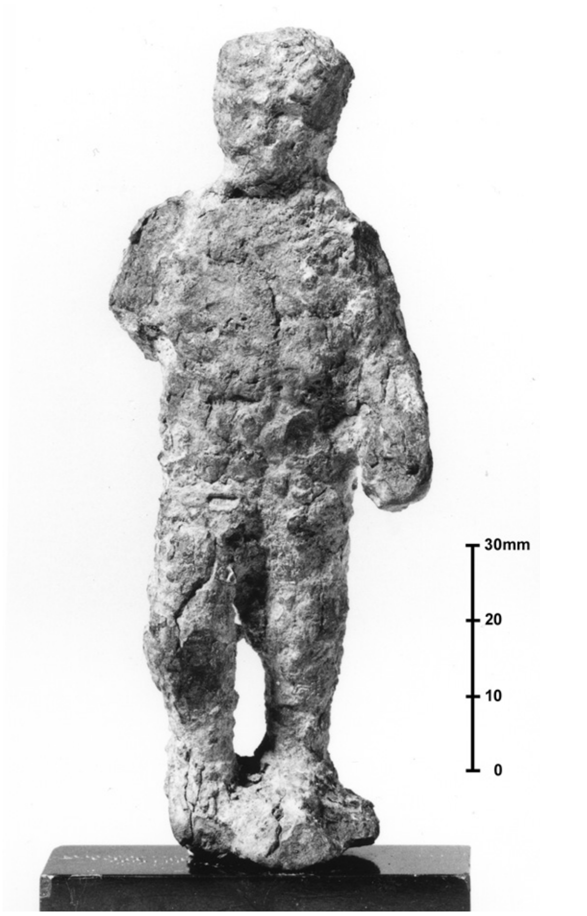

Figure 2: Cast-iron standing figure (Hastings Museum and Art Gallery Reg. 997.45).

to arrive at some idea at least of the maximum age of the artefact and whether it is likely to be of some antiquity.

The structure and composition of the two statuettes considered here were likely to be of some especial interest. Dawson claimed that his statuette was of cast iron (although even that was unsure, see below), and on superficial consideration that seems self-defeating. Either his statuette was of wrought iron and not very exciting, or it was of cast iron and therefore a modern copy. This was because the continuing popular perception has always been that the Romans did not use cast iron, which is almost certainly correct, but also that they were actually incapable of making it (*eg*, Walsh 1996, 176; Russell 2003, 62). This, as the well-documented finds of spills of cast iron on Roman iron smelting sites attest (see below) is incorrect. Thus, although it is true that few artefacts of cast iron from the Roman period have so far been recognized (Tylecote 1987, 325–6), there is no intrinsic reason why the Romans should not have tried casting this otherwise useless material that was occasionally produced. Furthermore, an iron smelting site was the obvious place for such an experiment to have taken place.

The story of Dawson's statuette

Charles Dawson, 'the Wizard of Lewes' as he was locally known, from the number and variety of his discoveries, almost always claimed that each of his many finds had been found many years before his first public announcement of them, thereby making it difficult to check his story. Most of the books written on Dawson in the half century following the exposure of the Piltdown fraud in 1953 include accounts of his other finds. Unfortunately, these accounts tend to give his concocted description of their discovery and acquisition by him, together with their later known histories, without qualification. The trouble with this approach is that Dawson's stories, which were usually total fabrications, are unconsciously given some credence by being included with the subsequent narrative that is verifiable. In this account we will largely omit Dawson's account for the good reason that it is almost certainly spurious. The story of the discovery and acquisition of the iron statuette followed the usual pattern, suffice it to say that Dawson claimed it had been dug up at Beauport Park in 1877 some 16 years before he took it to the British Museum, where its real known history begins.

Dawson showed it to A W Franks, Keeper of British and Medieval Antiquities at the British Museum and Charles Herbert Read, the Deputy Keeper, early in 1893, stressing from the outset that the importance of the piece was that it was of cast iron. The Museum staff were sufficiently interested to announce and display it at a meeting of the Society of Antiquaries of London on the 18th of May 1893 (Read 1893). Beforehand it was submitted to no less an authority than Professor W C Roberts-Austen for his opinion. He took a drilling of 6.77 grains (0.44g) and dissolved this in acid. On the basis of the tiny amount of carbon left he 'had no hesitation in saying that the figure was not cast iron, but was of wrought, malleable iron, a steel-like iron, such as was manufactured in early times by a direct reduction process from iron ore'. At the presentation Read gave this scientific verdict, adding that: 'I assume we may take the opinion of so high an authority as Professor Roberts-Austen as final, and the possibility of the figure being an example of iron casting by the Romans is disposed of.'. This must have been galling to Dawson, who was in the audience, but worse was to come. To what must have been his utter mortification in the discussion which followed, three of the leading antiquarians of the day got up and suggested that it was a modern copy. First A H Smith, a classical archaeologist at the British Museum, who was eventually to become Keeper of the Greek and Roman Department, suggested (almost certainly correctly as it now seems) that it was a modern miniature copy based on a life-size marble figure of a horseman from the Quirinal Palace in Rome, and probably sold there as a souvenir. The great archaeologist, Sir John Evans, agreed with this assessment. A S Murray, then Keeper of the Greek and Roman Department in the British Museum, also suggested that it was a modern copy of a genuine Roman piece. Read made a somewhat convoluted defence of the statuette, claiming that as it would have involved a great deal of work to fashion by hammering and chiselling, it was unlikely to date from a period when the casting of iron was practised, and so should be Roman.

This must have been a serious setback for Dawson, and he perhaps wisely let the matter drop at the Antiquaries, until after he had succeeded by other methods to secure his election as a Fellow. He set about filling in the details of the statuette's supposed discovery in 1877, backed up with a series of letters to local antiquaries enquiring after other material that he claimed had been found at the same time as the statuette (Russell 2003, 63–6). He later included the statuette, together with other items from his collection, in an exhibition of Sussex ironwork that he organized in 1903 at the Museum of the Sussex Archaeological Society in Lewes. Before the exhibition Dawson had submitted the statuette to Dr Kelner of the Royal Arsenal at Woolwich, who pronounced 'that there was not the slightest doubt as to its being of cast iron'. Dawson (1903) described the exhibits in some detail, making sure that the statuette's significance as 'the earliest known example of cast-iron in Europe' was not missed.

Soon after Dawson's death in 1916, his collection of local antiquities was purchased from his widow by the Hastings Museum Association and presented to the museum where it remains to this day. The base of the statuette has a paper label attached. Although this is rather torn it is still possible to read the following: 'Mounted and restored (r. calf & l. foot) by a.P. Ready British Msm 1916'. The label also bears a stamped L1199 in purple ink and a written 9174. It would seem most likely that this work was done through Arthur Woodward Smith, who as well as being Dawson's colleague and co-excavator at Piltdown, was also Keeper of Geology at what is now known as the Natural History Museum, but which at the time was usually still referred to as the British Museum.

The statuette was cited as evidence that the Romans were deliberately producing cast iron in the excavation reports of the Romano-British sites of Wilderspool (May 1904, 21) and Tiddington (Fieldhouse *et al* 1931, 14) where cast iron really had been found (see below for more on these sites). Thereafter the statuette was all but forgotten, although Straker in his classic study of the Wealden iron industry, reproduced Dawson's 1903 article almost in its entirety (Straker 1931, 35–7), but added his own comment:

> 'Notwithstanding Mr Dawson's belief in the authenticity of this find, there are some doubts on the matter. The sale of items found was a valuable source of income to the diggers, and it is possible that deception may have been practised. From the context it is obvious that similar bronze figures have been produced, and a replica in modern cast iron would not be difficult to cast and to corrode by burial.'

Perhaps understandably the statuette was not mentioned in Cleere and Crossley's more recent history of the Wealden iron industry (1985).

Following the revelation of the Piltdown fraud in 1953, Dawson's other finds were investigated (Weiner 2003, 153–71). In particular, Robert L Downes, a graduate student from Birmingham University, who was studying the Sussex iron industry at the time, examined the relevant Dawson items of iron in Hastings in the course of his work. He became suspicious and thereafter extended his investigations to Charles Dawson's other finds. Unfortunately he could not find a publisher for what would have been a very complete and informative book on Dawson's many and various frauds, and the manuscript now resides in the archive of the Sussex Archaeological Society (Downes 1956). He submitted the statuette to H Morrogh of the British Cast Iron Research Laboratory for metallographic examination and made the following comments on his report (*ibid* 1956, 174; reproduced in Russell 2003, 67):

> 'A thin slice was taken from the right leg of the statuette, just above the knee, and examined under the microscope. The research manager reported that the material was a grey cast iron. There was nothing in the structure to suggest any date, and it could have been made at any period during which the manufacture of cast iron was possible. The carbon and silicon contents were fairly high, consistent with the material being produced deliberately as cast iron, and not accidentally. Mr Morrogh said the amount of sulphur present was significant (0.05-0.1 per cent) and might indicate that the statuette was produced from a furnace using coke as a fuel. If this was the case, the statuette could not have been made before the eighteenth century and not in Sussex at any date.'

This led Russell (2003, 67–70), understandably, to conclude that the statuette was a forgery, but in fact grey cast iron with a high sulphur content has been excavated at a number of Roman sites in Britain (see below).

The statuette was mentioned in Coghlan's book on ancient iron (1956, 77), noting Straker's caution, and stating that the statuette was then currently being investigated by Downes. The statuette was also mentioned by Schubert (1957, 58, fn3), who also cast doubts on its authenticity (and stated, erroneously it seems, that it had been analysed by Coghlan). The statuette seems never to have been mentioned by Tylecote despite his having tabulated the finds of Roman cast iron from Britain (1986, 168, Table 83).

Over the years the statuette has appeared in a number of exhibitions concerned with fakes and forgeries, notably the 1990 *Fake?* Exhibition held at the British Museum (Jones 1990, 96, Cat 90) and most recently in 2003 at the Natural History Museum to 'celebrate' the 50th anniversary of the unmasking of the fraudulent nature of the Piltdown skull.

Scientific examination of the statuettes

Visual and radiographic examination

Initial examination showed that the surfaces of both statuettes are extensively corroded with little detail surviving.

Radiography demonstrated that the right leg of the Dawson statuette had been replaced from the knee down (Fig 3). A brass rod had been screwed into the thigh, and served as the internal support for the wax or resin used to simulate the missing lower leg. The end of the rod continues down below the foot and into the base and thus secures the statuette; the lower part of the left foot is also missing and now has a rod which also serves to attach the statuette to the base. There is a large cavity on the back of the left thigh which appears as an irregular oval at the surface as if it was a casting fault, but the radiograph shows that it goes right through the thigh and is in fact quite regular. This suggests it may once have housed a dowel holding the statuette to something else. No evidence for previous sampling could be seen.

The radiograph of the second figure shows a distinct break on the right side, just above the buttock (Fig 4) which can also be seen on the surface as a deep depression in the lower back at the right side. The radiograph also suggests that the right leg is attached by means of a pin through to the left buttock. A distinct circular area can be seen on the side of the right buttock which is probably one end of the pin but the other end is not visible.

The surface appearances of the two statuettes differ markedly. The second figure is covered with reddish brown stained soil with red-orange iron oxide and darker brown-black areas where the surface layer has spalled off, typical of corroded iron objects.

Figure 3: Radiograph of Dawson's statuette. Note the lower part of the right leg is missing (see text), and also the regular round hole in the left thigh which corresponds to the irregular hole seen in Figure 1. Scale: 1:1

Figure 4: Radiograph of the standing figure. This shows that the right leg is separate from the torso and would seem to be held by a single peg which would possibly have allowed the leg to swing. Scale: 1:1

The Dawson statuette is a much darker brown, a feature found on many of Dawson's later forged antiquities, and this is almost certainly due to treatment with potassium dichromate (see below). There are traces of what appears to be wood on the surface which has a slightly waxy appearance. The left arm is vestigial, either because it was damaged or possibly because it was a faulty casting. The right arm is missing at the shoulder and it is evident from the broken surface that it had snapped off.

Semi-quantitative analysis

Semi-quantitative analyses on the uncleaned surfaces and polished taper sections of the two statuettes were made by energy dispersive X-ray fluorescence (XRF). The taper section of the Dawson statuette contained iron with a manganese content estimated at about 0.5-1.0%. Small amounts of chromium of the order of 0.1–0.5% were detected in the corrosion of the statuette but not in the uncorroded body metal. The chromium almost certainly originates from the application of potassium dichromate (see below). The taper section of the second figure was of iron with a manganese content estimated at about 0.3-0.7%. Traces of titanium and vanadium were also detected but could not be quantified.

Metallography

Both statuettes appeared to be metallic under the corrosion and respond strongly to a magnet. Taper sections were made on the edge of the arm where the arm snapped off the Dawson statuette and on the heel of the second figure. In both cases the statuettes were clamped so that the area to be polished was in contact with the surface of a polishing wheel while the object itself was secured so that it could not move about during polishing and examination. The statuettes were protected by neoprene strips at the jaws of the wooden clamp. Small areas were polished and examined before and after etching with nital.

The Dawson statuette is a grey cast iron; graphite is visible in the unetched section (Fig 5). The carbon content is estimated to be in the region of 3.0–3.5%. The coarseness of the graphite is variable, with areas of fine eutectic graphite and some larger flakes. The metal

Figure 5: Unetched polished section on the right arm of Dawson's statuette with fine graphite flakes distributed interdendritically.

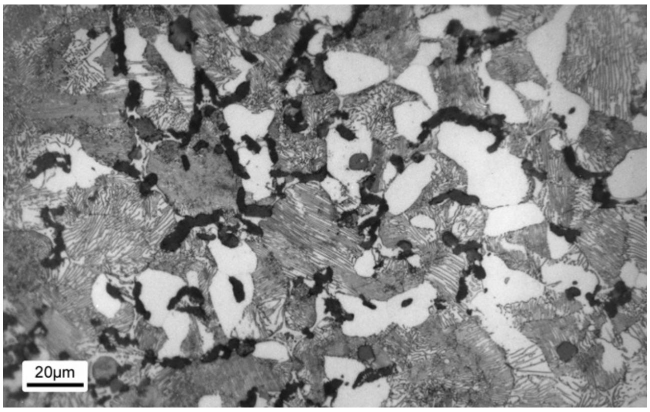

Figure 6: Polished section on the stub of the right arm of Dawson's statuette etched with nital, showing graphite flakes in a pearlite matrix, associated with ferrite; a typical grey cast iron structure.

contains some phosphorus and manganese as well as carbon and, as previously determined by Morrogh, it also contains an appreciable amount of silicon, which tends to promote graphite formation, and 0.05-0.1% sulphur. By itself, sulphur favours the formation of white cast iron, however this would be nullified by the presence of manganese in the metal, and thus a grey cast iron is the expected structure. With this composition solidification would have begun below 1300°C.

Etching revealed the matrix as pearlite with ferrite mainly associated with the eutectic graphite (Fig 6). The pearlite-stabilizing elements (arsenic, chromium, copper, nickel and tin) were not present at the detection limit of the XRF analysis (about 0.05% in the metal). A few small areas of iron phosphide eutectic were present.

It was not possible to examine and analyse the Dawson statuette within the scanning electron microscope (SEM). This was because it was too large to put into the microscope sample chamber with its plinth, and the poor condition of the restoration on the right leg rendered it impracticable to dismount the statuette.

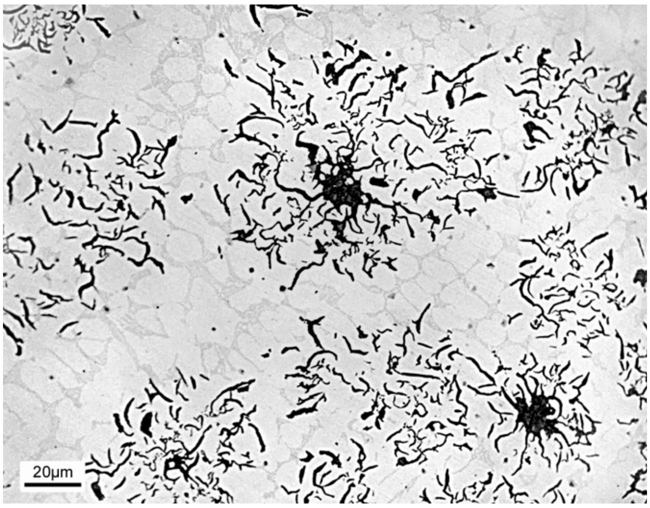

Figure 7: Unetched polished taper section on the second figure, showing graphite flakes aggregated in cells; iron phosphide eutectic shows faintly.

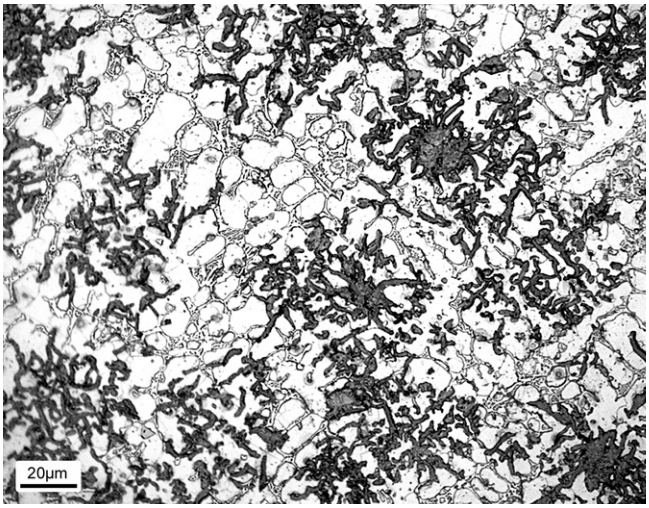

Figure 8: Polished taper section on the second figure etched with nital showing graphite flakes in cells with iron phosphide in ferrite. The structure is clearly that of grey cast iron.

The second figure is also a grey cast iron. The graphite is visible in the unetched section in the form of fine flakes concentrated in cells, and has become slightly nodular in the centres of some of the cells (Fig 7). Etching showed that the matrix consists of ferrite with an extensive interdendritic network of iron phosphide eutectic (mp *c*960°C) (Figs 8 and 9). The figure was examined in the SEM (Fig 10), which revealed a number of cuboidal inclusions, associated with the graphite or the phosphide eutectic. These inclusions were analysed together with the ferritic matrix and the phosphide eutectic (see Table 1).

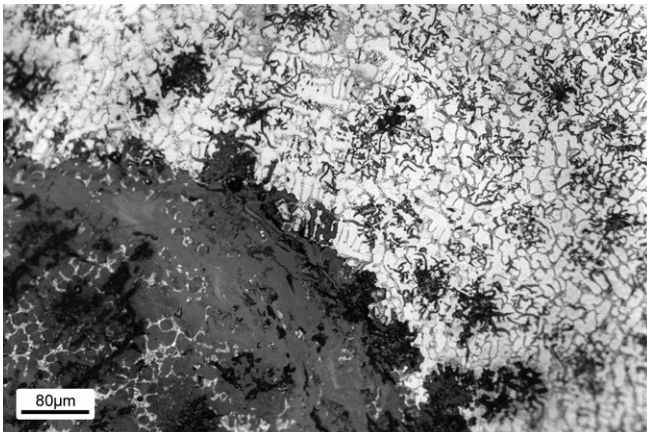

Figure 9: Polished section on the second figure towards the edge of the taper section etched with nital, with darker corroded surface layers on the left. This shows intergranular penetration of corrosion into the body metal.

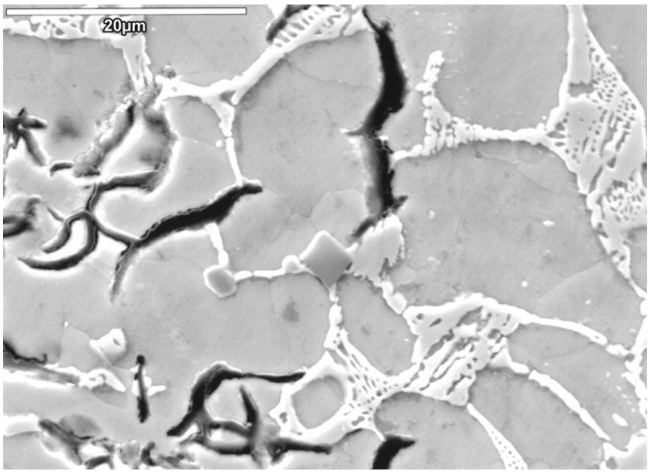

Figure 10: Backscattered electron micrograph of the polished section on the second figure etched with nital, showing iron phosphide eutectic (white), graphite (black) and titanium-rich inclusions (grey cube and rhombus) in ferrite matrix.

The results show that the matrix contains silicon, which is normal in a grey cast iron, but also some manganese. This suggests that the smelting temperature was high enough for manganese to enter the metal. Manganese is not found dissolved in iron (or steel) made by the bloomery process as the temperature attained is normally too low. When sulphur is found in bloomery iron it is in the slag rather than in the metallic components and probably comes from the ore rather than the fuel. Here it appears to be associated with some of the inclusions and some parts of the eutectic, but not the ferrite, and is probably mainly present as manganese sulphide or (FeMn)S, as exemplified by analysis 6. Phosphorus is dissolved in the ferrite as well as the eutectic. Some of the cubic grains are closely associated with the iron phosphide second phase (analysis 9 and Fig 8). The inclusions contain high proportions of titanium with some vanadium, about 1% silicon and traces of niobium. This possibly suggests an igneous mineral source; titanomagnetite spinels containing vanadium are known, for example. This mineral is likely to have come from the ore or, possibly, the furnace lining, but such minerals do not occur in the ores or clays of south east England. The microstructure suggests that the titanium-rich particles acted as nuclei for the formation of graphite and the phosphide eutectic. A similar structure is illustrated by Morrogh (1941, fig 36).

Discussion

Dawson must have gone away from the 1893 Society of Antiquaries meeting both mortified and bemused. Things had never gone wrong with his schemes before. It was his practice only to allow the object, whatever it might be, to be independently examined and analysed where he was reasonably certain that the result would support his claims. As he had in all probability acquired the

Table 1: SEM-EDX analyses of areas on the taper section on the second figure (wt%)

Analysis no	Area	Al	Si	P	S	Ti	V	Cr	Mn	Fe	Co	Nb
1	steadite	0	0.8	7.3	0	0.3	3	0.2	0.7	90.4	0.2	0
2	ferrite	0	3	0.4	0	0	tr	0.1	0.2	96.1	0	0
3	square inclusion	0	1.2	0.1	0	57.4	3.5	0	0	38.1	0	tr
4	ferrite	0	3.4	0.4	0	0	0	0	0.3	95.8	0	0
5	ferrite	0	2.9	0.5	0	0	0	0	0.3	96.1	0	0
6	inclusion	0	1.2	0.6	11.6	14.2	6.7	0.2	19	46.5	0	tr
7	steadite	0	1.2	0.7	0	0.1	0.1	0.1	0.6	87.2	0.2	0
8	?steadite	0	2.6	0.7	0	0	0	0.1	0.2	96.2	0.3	0
9	square inclusion	0.6	0.8	0	0	55.6	16.2	0.4	0.2	26.0	0	tr
10	ferrite	0	3.1	0.5	0	0	0	0.1	0.2	95.9	0.3	0
11	steadite	0	2.2	4.1	0.2	0.5	0.2	0.1	0.8	91.8	0	0
12	square inclusion	0.7	0.7	0	0	55.1	15.0	0.4	0.2	28.3	0	tr

Key: tr = trace

statuette in an undamaged and uncorroded condition he very likely knew that it was cast iron. Thus the intended scenario would have been for Roberts-Austen to confirm this, and then for the Antiquaries' meeting to accept it as a genuine Roman artefact of cast iron. Instead Roberts-Austen got it wrong, but the Antiquaries got it right, and even worse with Read defending it on grounds that were not only wrong but which went directly against Dawson's claims for its importance! A less driven man than Charles Dawson might have been tempted to give up fakery altogether, but instead he ensured that henceforth his creations had unchallengeable provenances.

Shortly after the Antiquaries debacle Dawson was invited to excavate a supposed flint mine in Sussex, which he seems to have thoroughly salted with an odd miscellany of artefacts dating from the Neolithic to the post-medieval periods (Russell 1999 and 2003, 33–41). This time the finds were accepted without question, apparently emanating from a real archaeological context (although the site was never properly published). It is likely that this experience suggested to Dawson that an archaeological context would provide an ideal venue for his future fraudulent creations. Thus in 1906 he somehow managed to introduce forged fragments of tiles bearing enigmatic traces of lettering onto the excavations directed by Salzman at the Roman Shore fort at Pevensey in Sussex (Salzman 1908; Russell 2003, 97–107). Shortly afterwards Dawson produced a similar tile bearing a complete inscription, giving not only the Roman name for the fort, but also the name of the Emperor Honorius. This in turn suggested that the fort had been repaired in the early 5th century. These finds were also accepted, and were quoted in the standard works on Roman Britain as the evidence for the latest refurbishment of the Roman defences in Britain, up until their exposure as forgeries in the 1970s (Peacock 1973). However, Dawson had now set his sights on becoming a Fellow of the Royal Society, and for this his antiquities would have to be more palaeontological than archaeological. In 1907 the discovery of a primitive jaw bone at Heidelberg was announced, and gave Dawson his inspiration. He would create a site producing not only a jawbone but the skull as well and in 1912 Piltdown duly burst upon the world.

The presence of chromium in the corrosion of the Dawson statuette suggests that the corrosion was induced, or at least stained with potassium dichromate. This is not without a wider interest. An important part of the evidence that the Piltdown finds were forged was that the flints as well the bones had been treated with potassium dichromate to make them appear old. Dawson actually admitted that he had treated the bones, saying that he did so in order to harden them. Thus there should be no problem, but in the seemingly never-ending attempts over the last half century since the Piltdown fraud was unmasked to involve others in the conspiracy, chromates have been cited as evidence. Thus both the eminent palaeontologist, William Sollas (Walsh 1996, 98) and the zoologist, Martin Hinton (Gardiner 2003) have been accused of complicity on not much stronger evidence than being in possession of a bottle of potassium dichromate. Here we have Dawson using potassium dichromate to create an artificially corroded appearance over twenty years before Piltdown and long before he can have had any association with his purported (and almost certainly non-existent) co-conspirators.

The authentication of iron artefacts

Although the Dawson statuette is perhaps the best known iron forgery, it is certainly not the only one, fakes and forgeries being especially prevalent amongst collections of antique arms and armour (Allan and Gilmour 2000, 105–9; Watts 1992, and see below) and instruments of torture (North 1992). Even so, authentication studies on ferrous artefacts are less common than those on copper alloys and precious metals.

Corrosion studies

For most metals the condition of the corrosion is perhaps the most useful indicator of age, but corrosion studies are less useful on iron. This is partly because most iron collectables are in a clean and uncorroded state, there not being much of a market for rusty iron, but it is also because of the nature of iron corrosion (Cronyn 1990). Iron corrodes relatively easily, as noted above, but the corrosion is extremely dependent on the environment. Some Iron Age and Roman artefacts from anaerobic, usually waterlogged conditions, can emerge with little or no corrosion, as exemplified by the Iron Age sword from the Thames at Syon Reach (Craddock *et al* 2003a). However, exposed to a damp and oxidizing atmosphere the corrosion of iron proceeds rapidly, resulting in the familiar loose and flaking rusty surface. It is common experience that a piece of wrought iron or mild steel buried in the garden can become totally mineralized well inside a decade, and cast iron is not much more durable. The chemical attack proceeds most rapidly along the grain boundaries where the atoms tend to be more energetic and thus more susceptible to attack than atoms in the regular crystalline arrays in the grains themselves. The penetration of the corrosion into the metal along the grain boundaries is a reliable indication of age in most metals, but in iron this can also proceed rapidly, as exemplified by the second figure (Fig 9).

AMS radiocarbon dating

Another approach to the authentication of iron has been the radiocarbon dating of the carbon contained within it. This was first suggested by van der Merwe back in 1969, but it remained impracticable because of the size of sample required until the advent of dating by accelerator mass spectrometry (Cresswell 1991 and 1992; Cook *et al* 2001 and 2003). It is necessary to assume that all of the carbon in the iron derives from the fuel, and in the case of charcoal-smelted iron, that the timber from which the charcoal was made will have been growing only a relatively short time previously (but see Eylon 2002 for evidence of the use of mature timber). Where fossil fuel has been used a geological age can be expected. This would obviously be no use for dating the iron, but for authenticity purposes would be indicative that the iron was not ancient, as iron was usually smelted with charcoal until the 18th century AD virtually everywhere, except for China and Korea. Thus, for example, an artefact purporting to be Anglo-Saxon, but with a geological age carbon date, would be unlikely to be genuine. However the potential sources of carbon in the production of iron are not simple (Eylon 2002; Craddock *et al* 2002). Perhaps the original ore was a carbonate, as was certainly the case with the Wealden iron ores of siderite, and if these were used without roasting them, the ore could easily introduce a proportion of carbon of geological age into the iron, along with the carbon from the charcoal. A much more serious and prevalent source of geological age carbonates would be from the limestone that was regularly added as a flux in the blast furnace process of smelting, which produced cast iron.

Cresswell (1992) recognised this as a potential problem and suggested that cast iron with calcium-rich slag inclusions should not be considered for dating. The problem here is that most cast iron does not contain slag inclusions; being much lighter than the molten iron, the slag separates almost completely from the iron in the smelting. Even rejecting all cast-iron artefacts for AMS dating would not remove the danger. Cast iron is usually easily recognizable (although not always, as Dawson's statuette showed) and thus where the artefact to be dated is actually made of cast iron then one can be aware of the potential problems of mixing of carbon sources, but most cast iron was converted to wrought iron, originally by fining and then by other processes. The iron produced is metallurgically indistinguishable from the wrought iron produced from iron made by the bloomery process, such that it is impossible to determine that the feedstock was cast iron, much less that its smelting had been fluxed with limestone. Thus a situation could easily arise in which charcoal-smelted and limestone-fluxed cast iron was converted to wrought iron that would have an apparent radiocarbon age of several thousand years depending on the proportions of geological-age and recent charcoal carbon in the iron. This situation could arise even more simply where a mixture of scrap irons containing both charcoal-smelted and fossil fuel-smelted irons was used. The potential problems caused by intermixing are especially acute for China where charcoal, coke and anthracite have all been regularly used in the bulk production of iron for over a thousand years.

The problems are not too serious for dating archaeological iron artefacts where the context gives some idea as to the technical possibilities of the iron production. The real problems are with authenticity determinations on antiquities with no firm provenances, such as the Dawson statuette, where the object may be ancient or a more recent copy or forgery. Where mixing of carbon from charcoal and from material of geological age had taken place a fortuitous and spurious early radio carbon date could easily be produced. If the iron had been converted to wrought iron then it would be very difficult to establish if the date was potentially erroneous.

Lest it be thought that this is just a theoretical problem, a recent publication on the AMS dating of iron (Cook *et al* 2003) included AMS radiocarbon dates on six pieces of steel body armour that typologically should have been from Germany and Italy and dated between the 15th and 16th century AD. Only one produced a date that was commensurate with the typology, the rest had dates ranging from 570 BP to 4350 BP. The proportion of carbon coming from geological age carbon necessary to shift the radiocarbon date significantly is quite large, such that, realistically, fossil fuel in part must have been used to smelt the iron. Cook *et al* 2003 suggested that this meant that use of fossil fuels in European iron smelting must be much earlier than previously believed. There is, of course, a much more prosaic explanation that does not require rewriting the history of metallurgy, namely that at least five of the pieces are 19th-century forgeries. It is sobering to consider that if instead of being late medieval armour, the pieces had purported to be antiquities of similar age to the Dawson statuette, then the AMS radiocarbon dates could have quite erroneously produced powerful evidence that they were genuine.

Composition

The trace and minor element content of the iron can provide useful indications of age, but as with the AMS radiocarbon dating, the data needs to be interpreted with caution.

Nickel is invariably found in meteoritic iron and sometimes found in trace or minor quantities in early smelted iron, but the presence of other metals can usually be taken as evidence that the iron post-dates the mid 19th century when alloy steels began to be made. However there are exceptions.

Chromium in small quantities, typically of the order of 0.5–1%, began to be added to tool steel in Europe and North America from the mid 19th century, and as such supposed iron antiquities with this quantity of chromium would normally be regarded as suspect. Gilmour (Allan and Gilmour 2000, 484–5), for example, published a Persian steel and flint strike-a-light typologically dated to the 13th century AD, which contained 1.2% chromium, 1.2% nickel, 0.3% manganese, 0.1% sulphur, 0.08% phosphorus, 0.05% vanadium and 0.03% silicon. The strike–a-light had not come from controlled excavation, and its authenticity would normally and quite correctly have come under some doubt. However, steel armour excavated from a context dated to the 14th–15th century AD from a burial at Samarkand has been found to contain about 0.8% of chromium in the form of the carbide located in the cementite phase (Papachristou 1996). This demonstrates that on occasion chromium can become incorporated in the iron alloy, probably during the crucible steel process.

Manganese can be a more informative indicator of the likely age of an iron artefact (Craddock and Wayman 2000, 26–7), although its presence has to be interpreted with care. In the blast furnace and in the production of crucible steel small amounts of manganese oxides present in the iron ore could be reduced and dissolved in the forming iron metal; the manganese content is typically below 1%. Some of the early recipes for crucible steel specify that manganese oxides were to be added to the charge, and although the main purpose for this will have been to encourage the absorption of carbon, inevitably some manganese will have dissolved in the forming steel (Craddock and Lang 2004).

In the post-medieval period in Europe there was a huge expansion in the demand for iron, but this was severely constrained by the availability of charcoal. Experiments were carried out with coal and latterly coke as the smelting fuel, but this left the resulting iron with an appreciable sulphur content. It could not be used for wrought iron because the sulphur occurred in the metal as iron sulphides, which melt at the high temperatures necessary for the ordinary forging of iron. The long thin stringers of molten sulphides in the metal behaved like incipient cracks that spread catastrophically on hammering, thereby effectively making it impossible to hot work iron that had been smelted with fossil fuel. In 1839 Joseph Heath patented his 'carburet of manganese', added to ameliorate the effects of sulphur present in iron that had been smelted with fossil fuel. The active component in the carburet was metallic manganese which on addition dissolved in the iron and preferentially reacted with sulphur, forming manganese sulphide as exemplified by the inclusion, specimen 6 (Table 1). In contrast to the iron sulphides, manganese sulphide remained solid during the subsequent hot-forging processes. This offered a cheap and easy solution to the problems caused by sulphides in iron and was rapidly and widely adopted as an addition to bulk iron production. Thus most wrought iron produced after the 1840s will contain 0.1–1% manganese.

Conversely, the conditions in the old solid-state bloomery process of making iron were generally not reducing enough to reduce any manganese which might be present in the ore, and instead it went into the slag. Thus suspect antiquities of wrought iron with more than about 0.1% of manganese dissolved in the iron are unlikely to predate the 1840s. The manganese content of about 0.5–1% in the Dawson statuette is rather high even for a cast iron, and may in part represent a deliberate addition.

Sulphur is perhaps the most interesting and technologically diagnostic element in iron. It can enter the iron during the smelting and fining processes from a variety of sources and may or may not still be present in the metal after smelting. Although Tylecote and Clough (1983) speculated that nodules of iron pyrites from the chalk might have been used as ore in southern Britain in antiquity, it seems that in general only thoroughly oxidized iron minerals were used in the past. When these were smelted with charcoal the resulting iron would have contained little or no sulphur. The problems of smelting iron ores with coal, thereby introducing sulphur into the metal, were appreciated in post-medieval Europe. The well-known innovation of using coke as the fuel at Coalbrookdale in the early 18th century allowed iron to be smelted but the sulphur content of the iron was still high and meant it could only be used for castings. Only with the introduction of powerful steam-driven blowing engines from the mid 18th century, followed by other innovations, notably the hot blast in the 1820s, was the temperature in the smelting furnace raised high enough to remove the majority of the sulphur from the iron. As stated above, the effects of any sulphur that remained could be dealt with by the addition of manganese. In China coke and anthracite began to be used to smelt iron from the mid first millennium AD and until recently the temperatures attained were rarely hot enough to enable the sulphur to be removed (Craddock *et al* 2003b; Wayman *et al* 2004).

Thus, the iron smelted with fossil fuel from Europe before the 19th century, and all the iron smelted with fossil fuel from China, can have quite high sulphur contents, typically between 0.1–1%, but in iron smelted in Europe from the early 19th century at the latest, the sulphur content for coke-smelted irons came down to the order of 0.01–0.1%. In practical terms this means that for authenticity purposes, iron artefacts with sulphur contents in this range may be modern, although alternatively they may be the result of inadvertently smelting an iron ore containing a little pyrite. Iron containing more than about 0.1% sulphur is unusual in the modern world, and thus high sulphur contents may in certain circumstances be an indication of authenticity. The converse does not hold, absence of sulphur need not indicate authenticity. Thus many coke-smelted modern irons have only minute traces of sulphur, and of course charcoal continued as a fuel for the bulk smelting of iron all over the world well into the 20th century.

This discussion of the sulphur content of iron brings us back to the significance of sulphur content as an indication of how, and thus indirectly when, the iron used to make the two statuettes was likely to have been smelted.

Dawson's statuette is a grey cast iron and was found to contain 0.05-0.1% sulphur, which as Morrogh (1941) commented 'might indicate that the statuette was produced from a furnace using coke as a fuel. If this was the case the statuette could not have been made before the 18th century and not in Sussex at any date'. The latter statement is correct and based on the fact that the Wealden iron industry only used charcoal right up to its demise in the late 18th to early 19th century. However, the former statement that the statuette could not have been made before the 18th century is not necessarily true as examination of some of the iron found on Romano-British iron-smelting sites has demonstrated.

Cast iron and the possible use of coal to smelt iron in Roman Britain

It is reasonably well established that it is not difficult to produce small quantities of cast iron in a bloomery smelting operation (*eg*, Crew 2004). However, with the exception of the Chinese, no one in antiquity seems to have realised the potential of the material and so there was no effort to encourage its formation. Quite the reverse in fact, for example some traditional Indian iron smelters even offered up special prayers to prevent this happening (Craddock 2003)! There is a continuing debate over the existence of cast-iron artefacts in the Roman world, and the references in the classical literature to liquid iron are equivocal to say the least (*ibid*, 249). Tylecote (1987, 325–6) however, cited examples of fragments of vessels of grey cast iron found in Romano-British deposits, and suggested that they could have been imported from China (although the possibility exists that they are intrusive).

Additionally, small spills and non-artefactual fragments of cast iron have been found on a number of early smelting sites in Britain and elsewhere. Some that have been examined and analysed have been collected (Tylecote 1976, 167–8 and 1986, 167–8, Table 83). The product of iron ore smelted with charcoal, having a low silicon content and cooled relatively rapidly, would be expected to be white cast iron. However, some of the pieces examined from Romano-British sites are of grey cast iron, with appreciable silicon and sulphur contents. The presence of silicon favours the formation of grey cast iron, but sulphur favours the formation of white cast irons, unless manganese is present which effectively removes it from the iron (see above), as is the case with these pieces from Romano-British sites.

The relatively high sulphur content suggests smelting with coal which is generally not believed to have been used before the 18th century in Britain. However, Tylecote (1986, 167) remained equivocal over the possibility of the use of coal to smelt iron in Roman Britain, and coal does seem to have been used quite extensively in Roman Britain (Webster 1955). Clearly these reports of early occurrences need to be examined in a little more detail.

One site was at Tiddington in Warwickshire (Fieldhouse *et al* 1931). This was interpreted as being an industrial site, where along with other activities, iron was smelted. Amongst the finds was a bar of grey cast iron 6 inches (150mm) in length, and which weighed 20 oz (567g). On analysis it was found to contain 3.52% carbon, 1.92% silicon, 0.765% phosphorus, 0.63% manganese and 0.049% sulphur (*ibid*, 33) (NB: sulphur misquoted as 0.77% in Tylecote 1987). The iron has a structure (Fieldhouse *et al* 1931, plate XIII) and composition typical of modern grey cast iron, with quite a low sulphur content, as was noted in the report. Furthermore the bar was described as having 'only superficial lamination' (*ie* corrosion; *ibid*, 32). Fieldhouse *et al* explored the idea that the Romans were deliberately making cast iron, citing the Dawson statuette as part of the evidence (*ibid*, 17), and concluded that cast iron was likely to have been produced at Tiddington. However, a more recent re-assessment of the site suggests it was only a minor rural settlement with no appreciable industry (Webster 1974, 53). In particular the evidence interpreted as iron smelting is more likely to have been come from blacksmithing operations, which would have been carried out at almost every settlement. There were no reports of coal from the site, nor any readily accessible deposits in the vicinity, and thus on balance it seems likely that the cast iron bar was intrusive.

The cast iron excavated from Wilderspool, near Warrington in Cheshire (May 1904) is rather different. The small 'squarish' piece, 2 x 1½ x 1 inch (55 x 40 x 25mm), was of grey cast iron, and described as being 'covered with scale'. It was found to contain 3.2% carbon, 1.05% silicon, 0.756% phosphorus, 0.485% sulphur, and 0.4% manganese (*ibid*, 26). The analyst in 1904 noted 'the remarkably high sulphur content', much higher than found in contemporary irons, and as discussed above, a good indication that the smelting process was operating at a relatively low temperature compared to those of the 19th and 20th centuries. The results are a little puzzling in that the manganese content would seem to be too low to counteract the very high sulphur content, and a white cast iron would be expected.

In contrast to Tiddington, coal was recovered from the archaeological deposits, and more recent investigations have confirmed that iron-smelting really was taking place in the vicinity (Hinchcliffe *et al* 1992). May was clearly a keen archaeometallurgist and even had slag analyses carried out, perhaps a first for archaeometallurgy. One of the slag pieces was found to contain 59.6% silica, 13% alumina and only 22% iron oxides (and 1.48% pyrite). One would naturally expect the slag to contain sulphur if coal had indeed been used to smelt the ore, and the rather high silica content and low iron content is suggestive of smelting under highly reducing conditions such that much of the iron oxide that would otherwise have gone into the slag was reduced to iron. In the traditional post-medieval blast furnace processes limestone was added as a flux, but calcium is noticeably absent from the Wilderspool slags, and they must have been very viscous and difficult to manipulate. The high aluminium is suggestive of clay minerals acting as a flux; if so then this probably came from the furnace lining.

As was to be the case with the Tiddington report, May considered the question of whether the Romans were deliberately producing cast iron, and Dawson's statuette was cited as positive evidence (*ibid*, 21) (this is probably the earliest instance of archaeologists being misled by Dawson's frauds, being three years before the inscribed Pevensey tile was published and a full eight years before Piltdown).

Taken together, the evidence from the site and from the piece of cast iron itself suggest that this was the result of an experiment to smelt iron using coal, and thus as May (1904, 30) claimed, forms the earliest evidence for the use of coal to smelt iron in Britain and probably one of the earliest examples from anywhere. It is likely that the main products of these experiments were the familiar blooms of iron which because of the sulphur content (the manganese notwithstanding), would have broken up on hammering. Cast iron was an unfamiliar material which the Romans did not know how to exploit. If they had persevered with their experiments the history of metallurgy in Europe could have been very different.

Conclusions

The re-examination of Charles Dawson's little statuette of cast iron, and its more recently discovered companion, has led to a more wide-ranging discussion on related topics beyond the authenticity or otherwise of the figures themselves. Briefly, neither is likely to be of any great age, although the corrosion on the more recent discovery suggests that at least it is likely to be a genuine find.

A number of finds of grey cast iron, some also containing small amounts of sulphur, have been reported from Romano-British sites. Such a metal should have been made by smelting the iron ore with fossil fuel, a practice not normally associated with the Romans. Where there is no supporting evidence for the use of coal, such as at Tiddington, it is likely that the iron was intrusive. Similarly, the second standing figure from Beauport Park is likely to be intrusive, and Dawson's statuette was a forgery that almost certainly never went near the site. In contrast, the small piece of grey cast iron from Wilderspool was from an iron smelting site where both coal and slag containing sulphur was found, and together this strongly suggests that some experimentation had been made to smelt iron with coal.

Acknowledgements

The authors are very grateful to Victoria Williams, curator of the Hastings Museum and Art Gallery, for allowing us to study these two statuettes and for helpful discussions, and to Mike Wayman of the University of Alberta for useful discussions on the metallographic structures. The photographs in Figures 1 and 2 are by T Springett. The radiographs in Figures 3 and 4 are by J Ambers.

References

Allan J and Gilmour B 2000, *Persian Steel: The Tanavoli Collection* (Oxford).

Cleere H and Crossley D 1985, *The Iron Industry of the Weald* (Leicester).

Coghlan H H 1956, *Notes on Prehistoric and Early Iron in the Old World* (Oxford).
Cook A C, Wadsworth J and Southon J R 2001, 'AMS radiocarbon dating of ancient iron artifacts: A new carbon extraction method in use at LLNL', in I Carmi and E Boaretto (eds), Proceedings of the 17th International Radiocarbon Conference, *Radiocarbon* 43(2A), 221–27.
Cook A C, Wadsworth J, Southon J R and van der Merwe N J 2003, 'AMS radiocarbon dating of rusty iron', *Journal of Archaeological Science* 30(1), 95–101.
Craddock P T 2003, 'Cast iron, fined iron, crucible steel: liquid iron in the ancient world', in P T Craddock and J Lang (eds), *Mining and Metal Production Through the Ages* (London), 231–57.
Craddock P T and Lang J 2004, 'Crucible steel – bright steel', *Historical Metallurgy* 38(1), 35–47.
Craddock P T and Wayman M L 2000, 'The development of ferrous metallurgical technology', in M L Wayman (ed), *The Ferrous Metallurgy of Early Clocks and Watches: Studies in Post Medieval Steel* (London), 13–27, and see also 74–5.
Craddock P T, Wayman M L and Jull T 2002, 'The radiocarbon dating and authentication of iron artefacts', *Radiocarbon* 44(3), 717–32.
Craddock P T, Cowell M R and Stead I 2003a, 'Europe's earliest brasses?' *HMS News* No54, 3–4.
Craddock P T, Wayman M L, Wang H and Michaelson C 2003b, 'Chinese cast iron through twenty five hundred years', in P Jett (ed), *Scientific Research in the Field of Asian Art: Proceedings of the First Forbes Symposium at the Freer Gallery of Art* (London), 36–46.
Cresswell R G 1991, 'The radiocarbon dating of iron artefacts using accelerator mass spectrometry', *Historical Metallurgy* 25(2), 78–85.
Cresswell R G 1992, 'Radiocarbon dating of iron artifacts', in A Long and R S Kra (eds), Proceedings of the 14th International Radiocarbon Conference, *Radiocarbon* 34(3), 898–905.
Crew P 2004, 'Cast Iron from a Bloomery Furnace', *HMS News* No57, 1–2.
Cronyn J M 1990, *Elements of Archaeological Conservation* (London).
Dawson C 1903, 'Sussex ironwork and pottery', *Sussex Archaeological Collections* 46, 1–62.
Downes R L 1956, Charles Dawson on trial (A study in archaeology), unpublished manuscript in the collections of the Sussex Archaeology Society at its library at the Barbican House Museum in Lewes.
Eylon D 2002, 'On the radiocarbon dating of charcoal-reduced iron and steel' in Gyu-Ho Kim, Kyung-Woo Yi and Hyung-Tai Kang (eds),*BUMA-V Proceedings of the Fifth International Conference on The Beginnings of the Use of Metals and Alloys* (Seoul),161–8.
Fieldhouse W J, May T and Wellstood F C 1931, *A Romano-British Industrial Settlement near Tiddington Stratford-upon-Avon* (Birmingham).
Gardiner B G 2003, 'The Piltdown forgery: a re-statement of the case against Hinton' *Zoological Journal of the Linnaean Society* 139(3), 15–35.
Hinchcliffe J, Williams J H and Williams F 1992, *Roman Warrington: Excavations at Wilderspool 1966-9 and 1976* (Lancaster: Brigantia Monograph 2).
Jones M (ed) 1990, *Fake? The Art of Deception* (London).
May T 1904, *Warrington's Roman Remains* (Warrington).
Morrogh H 1941, 'The metallography of inclusions of cast irons and pig irons', *Journal of the Iron and Steel Institute* 143, 207–86.
North A R E 1992, 'Instruments of torture', in M Jones (ed), *Why Fakes Matter* (London), 93–9.
Papachristou O 1996, 'Armour of a warrior from the Amir Temur citadel', *Obshchestvennye nauki y Uzbekistane* 7–10, 148–53 [in Russian].
Peacock D P S 1973, 'Forged brick-stamps from Pevensey', *Antiquity* 47 (No186), 138–40.
Read C H 1893, 'Comments on Charles Dawson's iron statuette', *Proceedings of the Society of Antiquaries* 14, 359–61.
Russell M 1999, 'Of flint mines and fossil men: The Lavant Cave deception', *Oxford Journal of Archaeology* 19, 497–500.
Russell M 2003, *Piltdown Man* (Stroud).
Salzman L F 1908, 'Excavations at Pevensey, 1906–7', *Sussex Archaeological Collections* 51, 99–114.
Schubert H R 1957, *History of the British Iron and Steel Industry* (London).
Straker E 1931, *Wealden Iron* (London).
Tylecote R F 1976, *A History of Metallurgy* (London)
Tylecote R F 1986, *The Prehistory of Metals in the British Isles* 2nd edn (London).
Tylecote R F 1987, *The Early History of Metallurgy in Europe* (London).
Tylecote R F and Clough R 1983, 'Recent bog iron ore analyses and the smelting of pyrite nodules', *Offa* 40, 115–8.
van der Merwe N J 1969, *The Carbon-14 Dating of Iron* (Chicago).
Walsh J 1996, *Unravelling Piltdown* (New York).
Watts K N 1992, 'Samuel Pratt and armour faking', in M Jones (ed), *Why Fakes Matter* (London), 100–7.
Wayman M L, Lang J and Michaelson C 2004, 'The metallurgy of Chinese cast-iron statuary', *Historical Metallurgy* 38(1), 10–23.
Webster G 1974, 'The West Midlands in the Roman Period', *Transactions of the Birmingham and Warwickshire Archaeological Society* 86, 49–58.
Webster G 1955, 'A note on the use of coal in Roman Britain', *Antiquaries Journal* 35(3–4), 199–217.
Weiner J S 2003, *The Piltdown Forgery*, reissue of the 1955 original (London).

The authors

Paul Craddock and Janet Lang both researched early metallurgy for many years at the British Museum, and, having retired, Janet now continues this work at Reading University. One of Paul's especial interests has been in the scientific detection of fakes and forgeries, out of which developed an especial interest in the 'Wizard of Lewes' and his many fabrications. Janet has specialised in metallographic structure and ironwork generally. This is a combination of interests that has proved useful in the study of these statuettes.

Addresses: Paul Craddock, Department of Scientific Research, British Museum, London WC1B 3DG.
e-mail: pcraddock@thebritishmuseum.ac.uk
Janet Lang, Department of Archaeology, University of Reading, Whiteknights, PO Box 218, Reading RG6 2AA.
e-mail: j.r.s.lang@btinternet.com