HISTORICAL METALLURGY

Journal of The Historical Metallurgy Society volume 10 number 1 1976

J. Percy

VOLUME TEN NUMBER ONE 1976

Journal of the Historical Metallurgy Society

Formerly the Bulletin of the HISTORICAL METALLURGY GROUP, the name of this publication and of the Group was changed in 1974 when the merging of the Iron and Steel Institute and the Institute of Metals resulted in THE METALS SOCIETY with which THE HISTORICAL METALLURGY SOCIETY is associated. The numbering of volumes has remained unchanged.

Enquiries relating to the contents should be addressed to the Honorary Editor: Dr R F Tylecote, Department of Metallurgy, The University of Newcastle upon Tyne, Haymarket Lane, Newcastle upon Tyne NE1 7RU.

Enquiries concerning membership of the HMS, back numbers and subscriptions to the Journal, etc, should be directed to the Honorary Treasurer: Charles R Blick, 147 Whirlowdale Road, Sheffield S7 2NG.

Contents

1 **Metallographic examination of six ancient steel weapons**
C W Brewer

10 **Report on International Symposium at Eisenstadt**

11 **Bessemer and West Cumberland**
D R Wattleworth

13 **Blast furnace management on Teesside in 1908**
D Charman

15 **An examination of some Palestinian Bronzes**
K Branigan H McKerrell and R F Tylecote

24 **Slag from an ancient copper smelter at Timna, Israel**
Charles Milton Edward J Dwornik Robert B Finkelman and Priestley Toulmin III

34 **Crucibles from a Roman settlement in Germany**
H G Bachmann

36 **The minerals of south-west Scotland**
J Williams

40 **Report on Maryport ingots**
B Ashmore

42 **Book reviews**
The Assyrian Iron Age/Technical Monuments in the FDR/Essex and the Industrial Revolution

44 **Abstracts**

52 **Notes on contributors**

Published by THE HISTORICAL METALLURGY SOCIETY

Designed by Roy Day, Production Editor and set in IBM 9/10 point Press Roman type by Mary Jefferies.Printed offset-litho by THE METAL SOCIETY at 1 Carlton House Terrace, London SW1Y 5DB.

The cover illustration is of Dr John Percy FRS (1817–88) the first director of the Royal School of Mines, President of the Iron and Steel Institute 1885–87 and author of the series of books, first appearing in 1861 which have come to be known simply as 'Percy's Metallurgy'.

Metallographic examination of six ancient steel weapons

C W Brewer ©

Introduction

This paper covers the metallographic examination of portions of some steel weapons, carried out at the Institute of Archaeology, University of London, during 1975. The weapons studied were as follows:

1. A "currency bar" from pre-Roman Britain, belonging to the Dorset County Museum
2. A medieval steel arrowhead from Hadleigh Castle, Essex
3. A Saxon steel spearhead found at Clifton-on-Trent
4. A Saxon steel scramasax or sword-knife, belonging to the Dorset County Museum
5. A Saxon steel sword belonging to the Lewes Museum, Sussex
6. A broken portion of a Japanese steel sword of the 17th century AD.

As Tylecote[1] has pointed out, although a number of steel swords have been described in the archaeological literature[2,3,4], very few swords have been metallographically examined to determine their internal structure. Of course the reason for this is that where a museum curator has a complete steel sword blade, he is very reluctant to allow a piece to be cut out of the blade for metallographic examination. Ancient steel sword blades recovered after burial in the ground in Britain are usually very rusted, owing to the poor corrosion resistance of bare iron. In the present work, the scramasax belonging to the Dorset County Museum, was metallographically examined by polishing the back edge of the blade, without cutting out any of the material. The Saxon sword was very badly corroded, and the blade was in several pieces before the examination began. The Japanese sword was free of rust, but the blade had been broken, therefore it was possible to cut, mount and polish several sections of the blade.

In the present work, the currency bar, the scramasax, and the Japanese sword blade were metallographically examined by Mr B. Gilmour, (as part of his course of study at the Institute of Archaeology), under the supervision of the author.

Except for the scramasax, sections were mounted in Bakelite, and polished on wet abrasive papers to 600 grade. Fine polishing was completed on rotating diamond pads, using 6 micron and 1 micron diamond paste. The polished sections were etched in 2% nital.

1. The Currency Bar

A number of iron "currency bars" have been found in the south of England; most of them were made during the first century BC, or the first century AD. As Tylecote[1] has pointed out, there are two main types: (1) tapered sword-shaped bars, usually about 30 inches (770mm) long, and (2) parallel-sided bars having a socketed end. The first group appear to be unfinished sword blades; however a bar of either type could be forged into a sword blade by a smith.

The chemical composition of the British currency bars, which have been examined elsewhere, shows that the carbon content varied from a small trace to an average of 0.5%. i.e. The currency bars consist of either wrought iron or low to medium carbon steel.

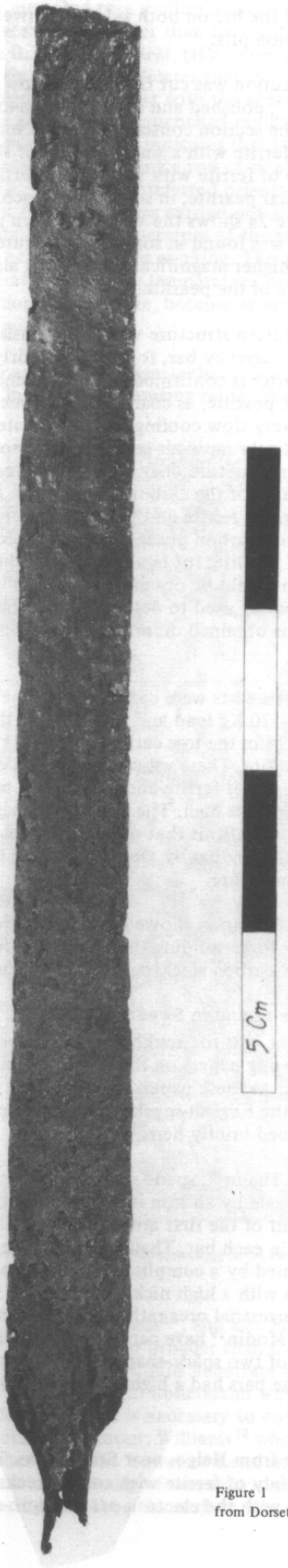


Figure 1 Iron 'currency bar', from Dorset County Museum.

The currency bar examined in the present work (Figure 1) was 475mm long, and slightly tapered, being 33mm wide at one end, and 39mm wide at the tang or handle end. The thickness of the bar was uniform, being 3mm throughout. The surface of the bar on both sides was covered with shallow corrosion pits.

A transverse section was cut from the narrow end of the "currency bar", polished and etched. Micro-examination showed that the section consisted of some very low carbon areas, mainly ferrite with a small amount of slag, and other areas made up of ferrite with various proportions of medium lamellar pearlite, in some areas reaching 100% pearlite. Figure 2a shows the Widmanstatten pattern of ferrite, which was found in some areas. Figure 2b is of the same area, at higher magnification showing also the lamellar nature of the pearlite.

The Widmanstatten structure would be consistent with hot forging of the currency bar, followed by fairly rapid air cooling. The latter is confirmed by the presence of medium lamellae in the pearlite, as coarse lamellar pearlite is only produced by very slow cooling from the austenite temperature. The relatively rapid air cooling, and also the Widmanstatten structure, make it difficult to make an accurate estimate of the carbon content of a given area, from the proportions of ferrite and pearlite present and a knowledge of the iron-carbon phase diagram. There will be a higher proportion of pearlite, (of less than equilibrium carbon content), than would be obtained under the very slow equilbrium cooling used to determine the phase diagram. A similar effect is obtained on normalising a medium carbon steel.

Vickers hardness tests were carred out on the transverse section using a 20 Kg load and showed that the hardness varied from 124 in the low carbon areas, to 194 in the areas with more pearlite. These values correspond approximately with the hardness of ferrite and low carbon mild steel respectively, but are high. The absence of martensite in the microstructure confirms that no attempt had been made to harden the currency bar by rapid quenching from the austenite temperature.

The micro-examination showed that the currency bar had been made by forge welding thin strips of wrought iron and strips of a low carbon steel together, as discussed by Gilmour[13].

Currency Bars Found in Sweden

During a recent visit to Stockholm, the author obtained copies of two interesting papers on the metallography of Swedish currency bars. As these papers may not have been widely circulated in the English-speaking metallurgical world, they will be described briefly here.

According to Thalin[18], spade-shaped iron currency bars were produced for sale by an iron industry in northern Sweden in the second half of the first millenium AD. Although layers were present in each bar, Thalin considers that these layers were not formed by a complicated welding procedure. The currency bars with a high nickel content are believed to have come from terrestrial ores rather than from meteoric iron. Hansson and Modin[19] have carried out metallographic examination of two spade-shaped iron currency bars from Sweden. These bars had a high nickel and high cobalt content.

Currency Bar from Helgo, near Stockholm. The microstructure consisted mainly of ferrite with some streaks of pearlite. Investigation with the electron probe micro-analyser showed

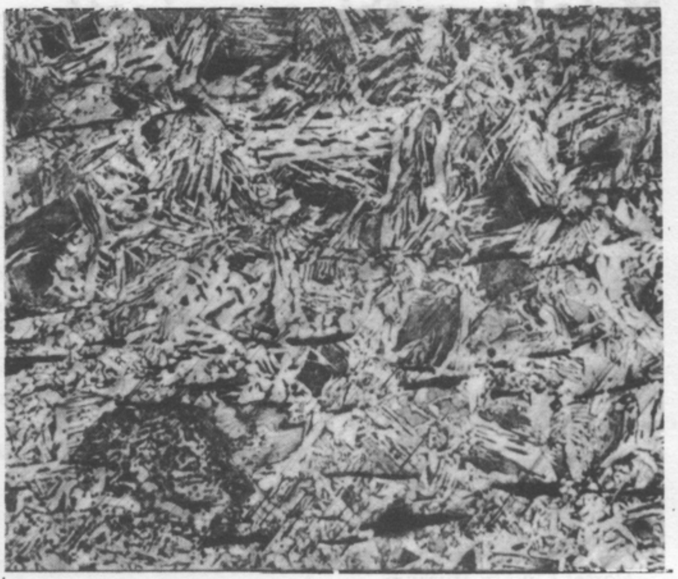


Figure 2a Microstructure of 'currency bar', showing the Widmanstatten distribution of ferrite, and slag particles. x 74. B. Gilmour).

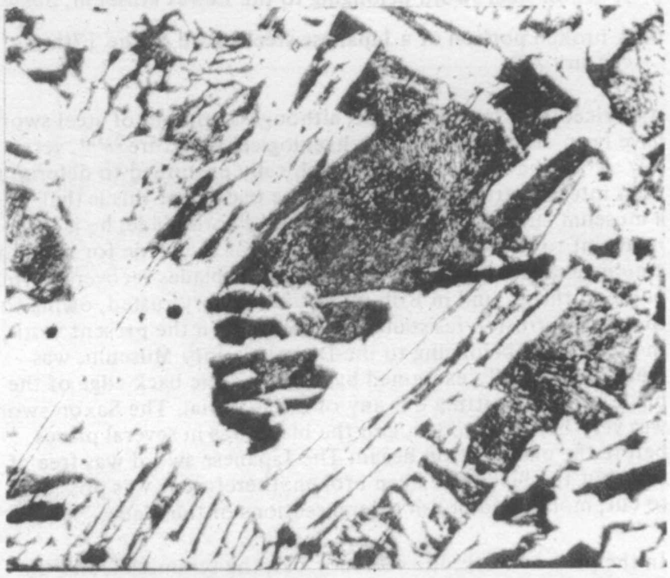


Figure 2b 'Currency bar' at higher magnification, showing Widmanstatten structure and lamellar pearlite. x 400. (B. Gilmour)

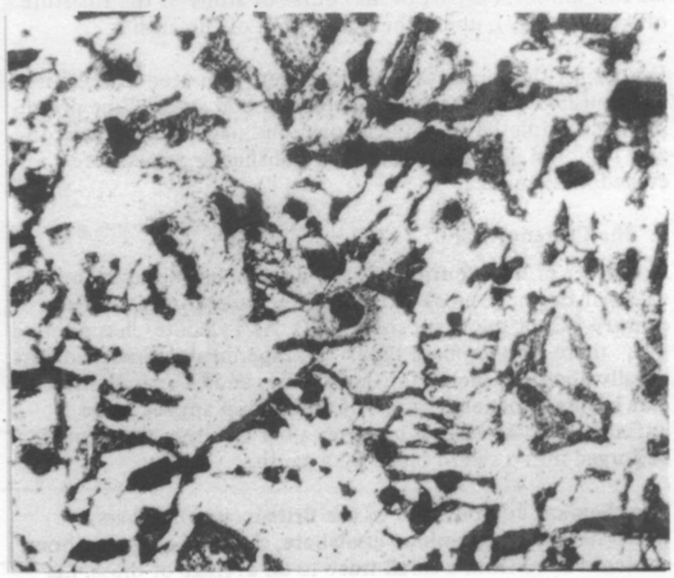


Figure 3 'Currency bar'. Region of intermediate carbon content, showing grains of ferrite (white) and lamellar pearlite (dark), and some slag. x 400 (B. Gilmour) that the matrix material contained 0.4% Ni, and 0.3% Co; whereas the streaks of pearlite contained 1.4% Ni and 0.6% Co.

Currency Bar from Hog Parish, Halsingland. Two cross-sections from another spade-shaped currency bar were examined. The microstructure consisted mainly of ferrite with some pearlite. The somewhat coarse grains were not deformed; they had recrystallized after the last deformation. The most interesting feature of the structure was some streaks of martensite, containing much higher nickel and cobalt than the surrounding matrix, viz:

	Nickel %	Cobalt %
Martensite, streak 1	25	5
Matrix	1	0.5
Martensite, streak 2	9.3	2.1
Matrix	11.2	0.3

The presence of a high nickel content in localised areas would considerably increase the hardenability of the local low carbon steel; i.e. the critical cooling rate of that area would be decreased to such an extent, that martensite would be produced at a moderate cooling rate, which would not produce martensite in the low alloy matrix, because the formation of pearlite would not be suppressed there. One section showed a distinct welded seam, where the bar had been folded.

The authors suggest that the uneven distribution of alloying elements may be due to the following explanation: Two types of raw material were probably used, one of unalloyed iron and one of nickel-iron with cobalt. The two materials were welded in a forging hearth.

2. A Medieval Steel Arrowhead

During the excavation of Hadleigh Castle, Essex, by Mr Peter Drewett[7], two steel arrowheads were found; both were very rusted. A portion of one of them was made available for metallographic examination by courtesy of the Passmore Edwards Museum of Natural History, Stratford, (London Borough of Newham). The arrowhead examined had a flat broad blade, shaped like an inverted 'V', with originally a rear fin on each side. The rear of the arrowhead consisted of a socket, into which the wooden shaft would have been fitted. See Figure 4.

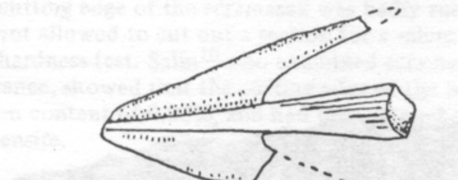


Figure 4 Medieval arrowhead from Hadleigh Castle, Essex. (4 cm long)

The arrowhead was 85mm long, and weighed 14 grams. In order to conserve it as a museum specimen, a small portion only was removed from the end of the remaining rear fin, by the Museum's archaeologist. This section was mounted in Bakelite, and the longitudinal edge was polished and etched. Although badly corroded, there was sufficient residual metal in the thin sample for micro-examination. The microstructure, (Figure 5), consisted of very small equiaxed grains of ferrite, some small grains of fine pearlite, and slag, indicating a dirty steel containing possibly 0.25 to 0.3% carbon. The fine pearlite indicates that this is not an equilibrium microstructure, and the same limitations regarding the estimation of carbon content apply, as discussed above. The Vickers hardness was measured on the mounted thin section, using a 1 Kg load; HV 245. This is somewhat harder than the hardness of annealed 0.25 to 0.3% carbon steel, (HV approximately 200). The presence of fine pearlite indicates that the steel was probably air cooled, and together with the absence of martensite confirms that the steel was not quenched rapidly. The very small grain size of the microstructure indicates that the arrowhead was probably made by hammering a rod of steel into the shape of a flat blade. The absence of preferred orientation in the grains indicates that hot hammering was carried out at a temperature above the recrystallization temperature of the steel, so that recrystallization occurred during working. The smallness of the grains suggests that the working temperature was not much above the recrystallization temperature, because appreciable grain growth has not occurred.

The shape of the arrowhead suggests that it was a flesh-piercing arrow, probably intended for hunting rather than for war.

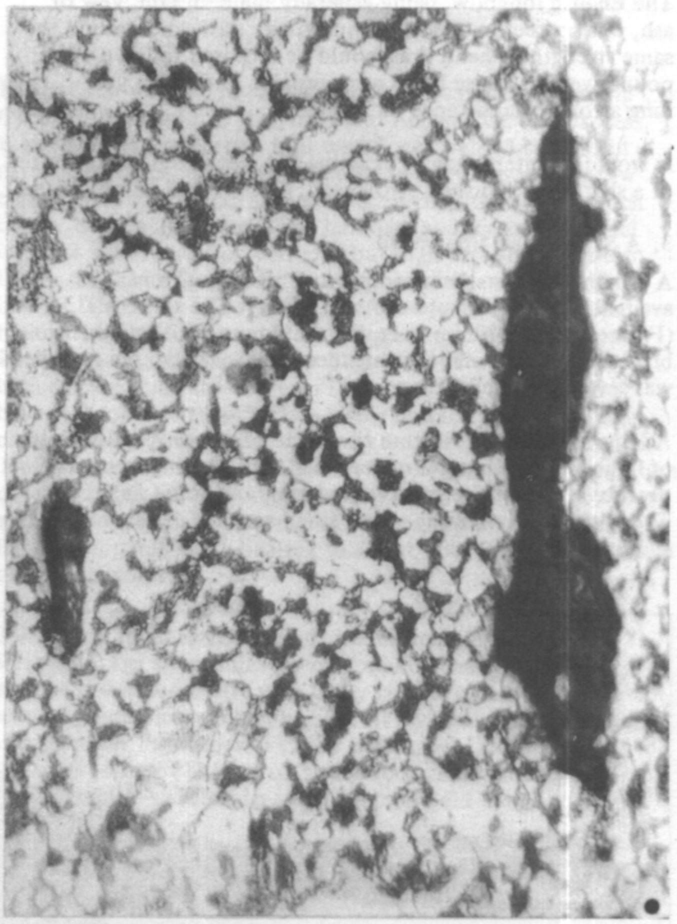


Figure 5 Microstructure of medieval arrowhead, showing ferrite (white), fine pearlite (dark) and massive slag. x 800

According to Oakeshott[4], Williams[12], and also Hall[16] arrows tipped with sharp steel points no broader than the shafts, when fired from an English longbow, could penetrate chain-mail,, but not plate armour. In order to understand why plate armour resisted steel-headed arrows, it is necessary to consider the metallurgical structure of armour. Williams[12] who has examined 16th century armour from the Tower of London, found that three samples consisted basically of wrought iron, which was shaped by hammering, and then the surface was carburised to about 0.3% carbon. The maximum Vickers hardness was 210. Henger[17] has metallographically examined six samples of plate armour. One sample of Italian armour of 1400 AD and two samples of German armour of 1500 AD, consisted mainly of wrought iron, with a lightly carburised surface consisting of ferrite and some pearlite. Another sample of Italian armour of 1480 AD consisted of highly carburised wrought iron, and had been quenched after carburising; the case contained bainite and nodular pearlite. The hardness of the bainite could be at least 400 HV. Two samples of late 15th century armour consisted of high carbon steel rather than carburised wrought iron, and was possibly made by decarburising cast iron.

Apparently the velocity of the arrow and the hardness of the steel arrowhead were not great enough for the arrow to penetrate plate armour. Nevertheless the English longbow and arrow constituted a formidible weapon in medieval warfare, as pointed out by Oakeshott[4] and Rausing[11]. According to Giraldus Cambrensis[4] at the siege of Abergavenny in 1182, arrows with sharp steel points passed through a solid oak door four inches thick. According to Oakeshott[4], the English longbow was mainly responsible for the English victories at the battles of Crecy (1346), Poitiers (1356) and Agincourt (1415). The English longbow, being generally made of elm, yew or ash, was six feet in length, astonishingly stiff, and needed the same strength to bend it as would be required to lift a 60 pound weight. These bows were capable of firing a yard-long arrow for a distance of 350 yards.

It would be interesting to examine the metallurgical structure of a sharp-pointed steel arrowhead, if one could be obtained.

3. A Saxon Steel Spearhead

A Saxon steel spearhead, found at Clifton-on-Trent, was available at the Institute of Archaeology. The spearhead, (Figure 6) was 340mm long, the maximum width of the broad blade was 50mm, and the thickness 4mm. The whole spearhead was severely corroded.

A longitudinal section from the blade edge, consisted mainly of large and small grains of ferrite, a very small amount of fine pearlite at the ferrite grain boundaries, and some slag; i.e. wrought iron containing a very small amount of carbon. (Figure 7).

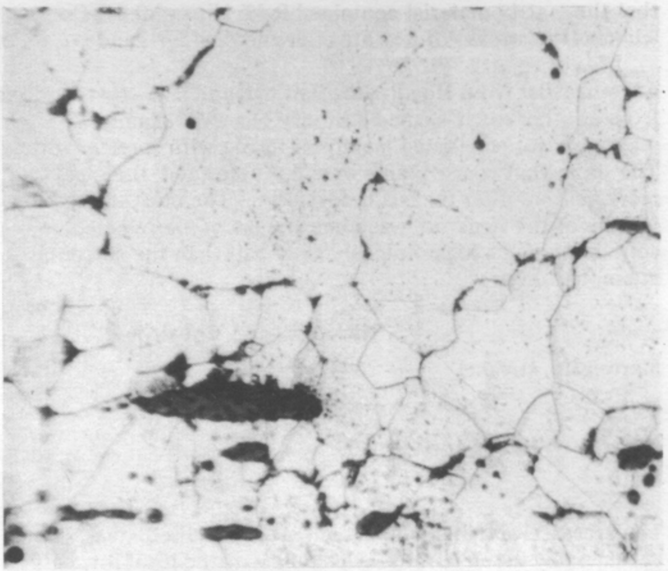


Figure 7 Saxon spearhead: longitudinal section from edge of blade, showing ferrite a small amount of pearlite and slag. x 375

The average Vickers hardness (1 Kg load) of the rear blade section was 114, which is only slightly higher than the hardness of annealed ferrite. Apparently the blade had not been cold-worked appreciably after hot forging. Hardness tests, (1 Kg load), were also carried out on fresh metal at the tip of the blade: HV 214, 178, 178; average 190. The tip of the blade may have had a slightly higher carbon content than the rear edge, or the tip may have been cold hammered a little during the final fabrication.

The transverse section from the rear socket consisted mainly of ferrite, with a carburised portion on the outside of the curved section, which consisted mainly of coarse lamellar pearlite and some ferrite; see Figure 8. The coarse lamellar pearlite indicates that the socket had been cooled slowly. The Vickers hardness in the high carbon region was 240, and in the low carbon region 175. As there is no reason why the socket should be harder than the blade, it is unlikely that the socket was deliberately carburised.

Figure 6 Saxon spearhead, found at Clifton-on-Trent.

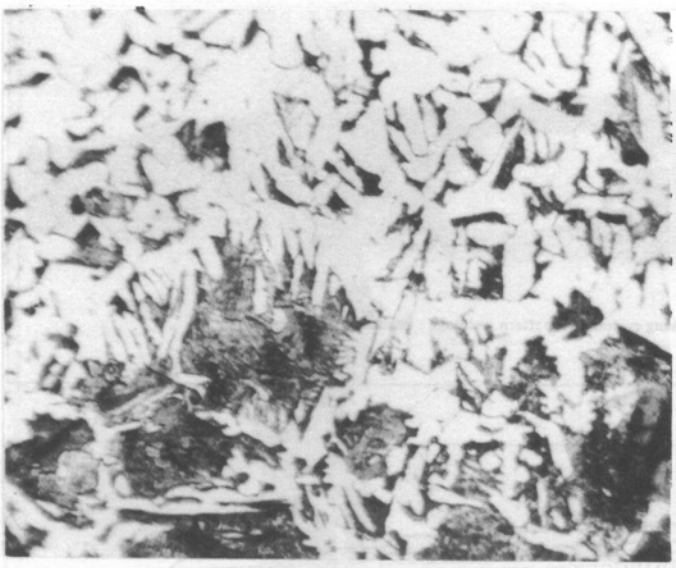


Figure 8 Saxon spearhead. Transverse section from rear socket, showing transition from low carbon area to carburised region on outside. Ferrite (white), and coarse lamellar pearlite (dark). x 375

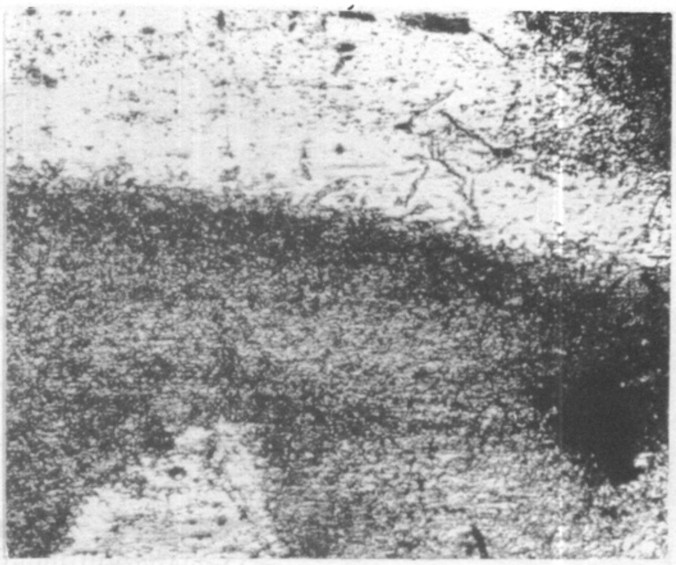


Figure 10 Saxon scramasax. Polished rear edge of blade, showing low carbon and higher carbon areas. x 75 (B. Gilmour)

4. A Steel Scramasax

A Saxon steel scramasax or sword knife, was kindly made available by the Dorset County Museum, for non-destructive examination, and was examined by B. Gilmour. The scramasax was 315mm long, the maximum width was 33mm, and the thickness was 4mm at the rear edge, tapering to a knife edge. (Figure 9). The rear or blunt edge of the blade was polished with some difficulty. The microstructure consisted of alternate layers of low carbon iron and layers made up of grains of ferrite and of fine pearlite with a carbon content of approximately 0.3%; a considerable amount of slag was present. (Figures 10 and 11). The structure showed that the blade had been pattern-welded and forged. The pattern-welded structure inside the blade was shown on an X-ray radiograph. (Figure 11). Vickers hardness tests, using a 20 Kg load, along the polished rear edge of the scramasax, showed that the hardness varied from 200 to 260. Unexpectedly the hardness of the low carbon layers (260) was somewhat higher than the higher carbon areas (200). This may have been due to the use of a wrought iron high in phosphorus for the low carbon strips. Apparently the whole blade had not been quenched from the austenite region. The cutting edge of the scramasax was badly rusted, and it was not allowed to cut out a section for a micro-examination or a hardness test. Salin[10] who examined scramasaxes found in France, showed that the cutting edge of the blade had a carbon content of 0.85%, and had been quenched to form martensite.

The pattern welding process has been discussed by Tylecote[1], Cyril Stanley Smith[5], Maryon[8], and Anstee[9]. In this process, thin layers of low carbon iron were forge welded to twisted carburised strips, producing a laminated structure. Very low carbon iron or wrought iron consists mainly of ferrite, which is soft, ductile and tough. The hardness and strength of steel increase with its carbon content; but high carbon steel is also brittle, i.e. lacks toughness, or has poor resistance to sudden impact. Therefore if a sword blade were made entirely from high carbon steel, it would lack toughness, and would break easily in battle. By making the blade of layers of low and high carbon steel, the blade will be tough and flexible, and have reasonable strength. (It is also a method for introducing carbon into an iron blade, when the iron could not be melted). The cutting edge can be made very hard by having a high carbon content there, and quenching rapidly from the austenite temperature to form hard martensite. The martensite should be lightly tempered by re-heating to about 200°C, to remove some of its brittleness.

Going back to an earlier period, a considerable number of Early Iron Age swords have been found in Britain. However most of these swords are very badly rusted, and very few have been examined metallographically. As Tylecote[1] has pointed out, there are two types of Celtic iron swords from the Early Iron Age period: (1) the iron sword (consisting mainly of ferrite), which had its edges hardened by cold hammering,

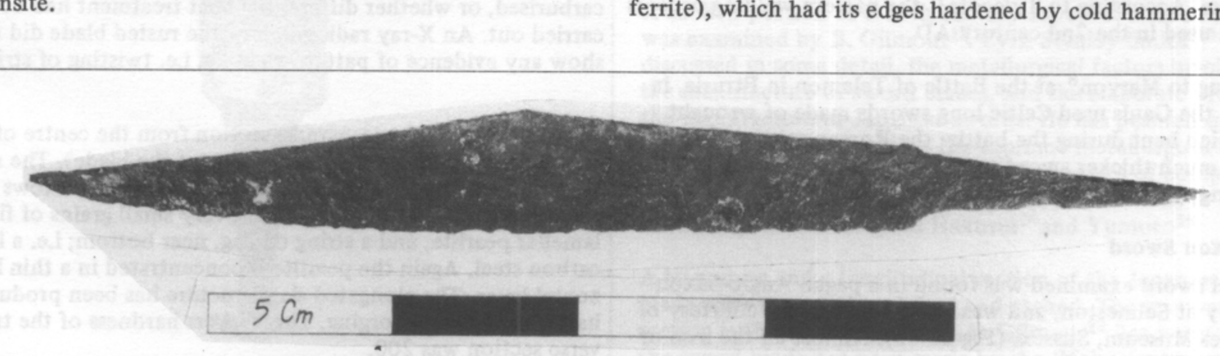


Figure 9 Saxon steel scramasax.

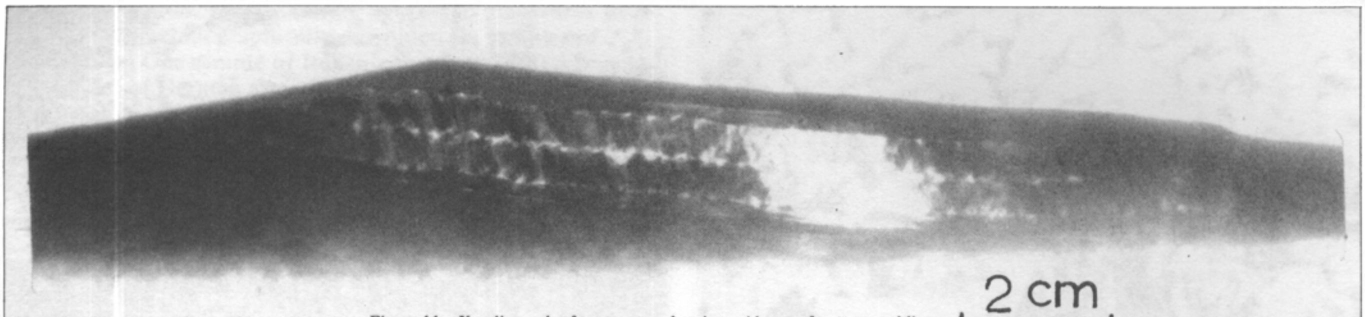


Figure 11 X-radiograph of scramasax, showing evidence of pattern welding.

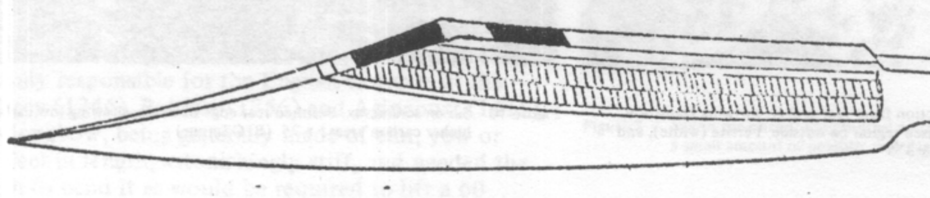


Figure 12 Diagram showing pattern-welded region of scramasax. Dark shading on rear edge indicated areas polished. (c.20cm long) (B.Gilmour).

and (2) the sword with a 'piled' structure, of alternate layers of iron of low and higher carbon content, and which may have the blade hardened by carburising. McGrath[20] has metallurgically examined four rusted Early Iron Age swords from Llyn Cerrig Bach, Anglesey. These swords have been dated archaeologically between the 2nd century BC and AD 60. Three of the iron swords had a piled structure, resulting from hot forging of layers of wrought iron, which had been carburised to different carbon contents. There was no evidence of cold working. All three blades consisted of a core of relatively low carbon steel (0.15 to 0.25% carbon by metallographic estimation), between two outer layers of higher carbon material (0.3 to 0.7% carbon). There was a considerable quantity of trapped slag. The fourth blade consisted of low and higher carbon layers of iron, but had been forged by a much more complicated procedure. The Vickers hardness in each blade ranged from 150 to 200, being somewhat higher in the third blade (175 to 265). Therefore the swords had not been quenched rapidly after the final forging.

A distinction should be made between the 'piling' process of sword making and the much more complicated 'pattern welding' procedure. According to Tylecote[1], the pattern welding process was first used in the 2nd century AD.

According to Maryon[8], at the Battle of Telamon in Etruria, in 255 BC, the Gauls used Celtic long swords made of wrought iron, which bent during the battle; the Roman soldiers, using a shorter, much thicker sword, probably of hardened steel, won a crushing victory, some 40,000 Gauls being killed.

5. A Saxon Sword

The steel sword examined was found in a pagan Anglo-Saxon Cemetery at Selmeston, and was made available by courtesy of the Lewes Museum, Sussex. (Figure 13). Almost all the iron or steel of the blade had been corroded; the corrosion products appeared to be hydrated ferric oxide on the outer layers, and some black magnetite, Fe_3O_4, near the centre. The dimensions of the sword in the rusted condition were: length 900mm; width 75mm; maximum thickness of sword blade, 8mm; total thickness of residual scabbard 30mm. At about 20cm from the hilt, the sword blade had rusted right through. A flat, thin layer, only 2mm thick, parallel to the blade surface, and at the centre of the thickness of the blade, was found to contain residual metal. A small sample was removed under supervision of the staff of the Conservation Department of the Institute. This sample was mounted in bakelite, and the longitudinal edge was polished, and etched in 2% nital. A transverse section from the same layer was also polished. The longitudinal section (Figure 14) showed layers of almost pure ferrite or wrought iron (white), and thin layers of low carbon steel, consisting of small grains of ferrite and of very small grains of fine pearlite, (central layer in the micrograph). The Vickers hardness of the longitudinal section was 167. At low magnification six separate layers of alternately pure iron and low carbon steel could be seen across the 2mm wide section. This structure indicates that the sword blade had been made by welding together (forging) thin flat strips of wrought iron and of low carbon steel. After the final hot forging of the blade, the centre of the blade must have been cooled relatively slowly, probably in air, because of the presence of lamellar pearlite. As the edges of the blade had rusted away,it was not possible to determine whether the edges had been carburised, or whether differential heat treatment had been carried out. An X-ray radiograph of the rusted blade did not show any evidence of pattern welding, i.e. twisting of strips.

Figure 15 shows the transverse section from the centre of the sword blade, parallel with the surface of the blade). The microstructure (at higher magnification than Figure 14) shows large grains of ferrite (white), and a few, very small grains of fine lamellar pearlite, and a string of slag, near bottom; i.e. a low carbon steel. Again the pearlite is concentrated in a thin horizontal layer. The elongated slag structure has been produced by hammering during forging. The Vickers hardness of the transverse section was 200.

In spite of Norse mythology, the Saxons never produced swords of exceptionally high quality, like the damascene blades produced in the Middle East during the Middle Ages.

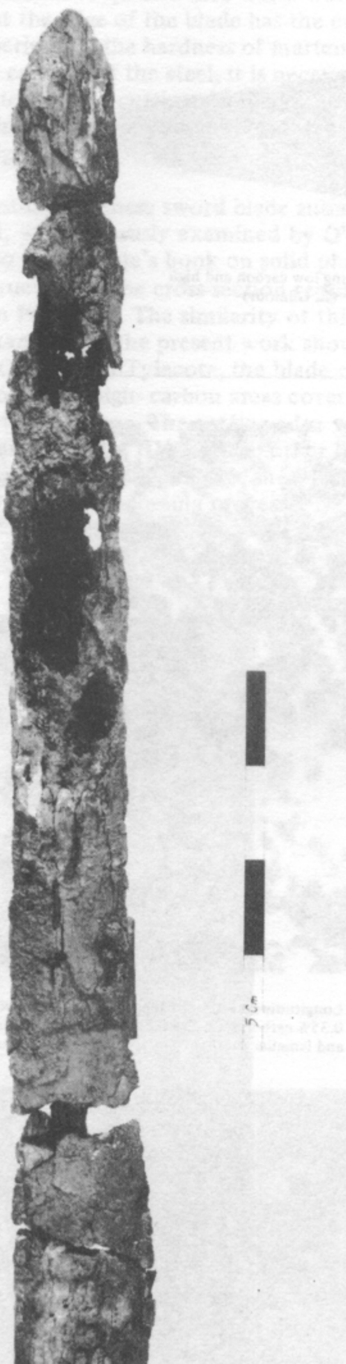


Figure 13 Steel sword from Anglo-Saxon cemetery at Selmeston.

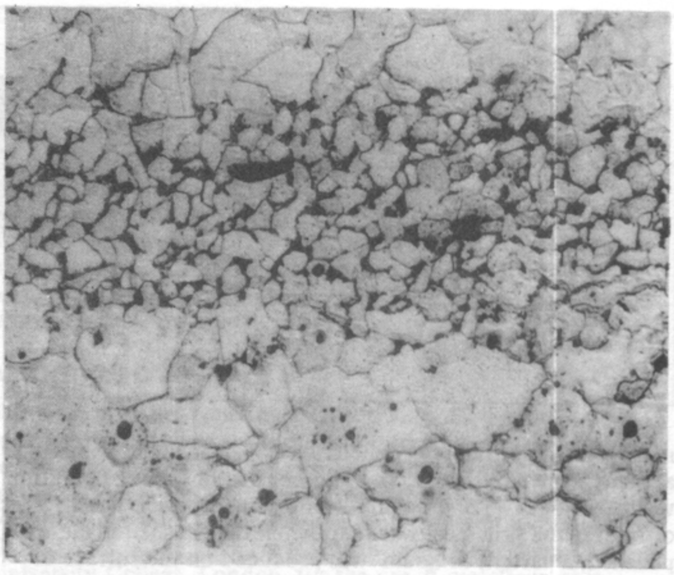


Figure 14 Saxon sword. Longitudinal section, parallel with surface of blade, showing layers of ferrite (white), and low carbon steel layer (central strip), consisting of small grains of ferrite and of lamellar pearlite. Black areas are slag particles. x 200

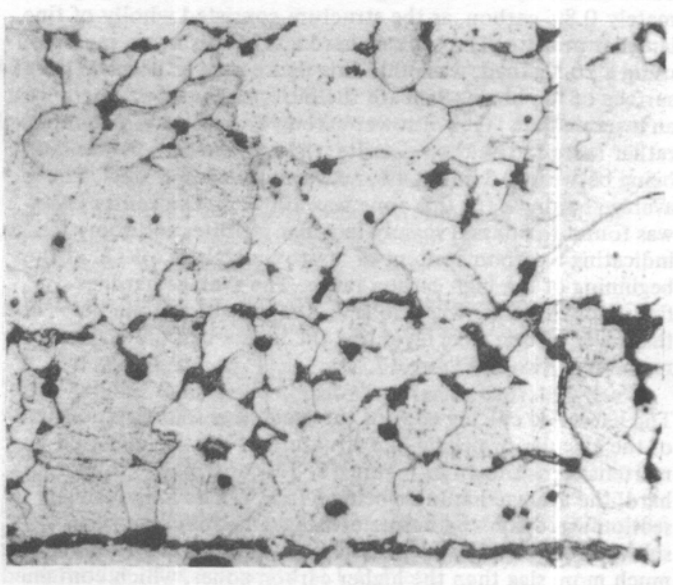


Figure 15 Saxon sword. Transverse section, parallel with surface of blade; showing large grains of ferrite (white), and very small grains of fine lamellar pearlite. x 375

6. Japanese Sword

A broken portion of a 17th century Japanese steel sword blade was examined by B. Gilmour[13]. Cyril Stanley Smith[5,6] has discussed in some detail, the metallurgical factors involved in the manufacture of sword blades, and the elaborate process for the manufacture of Japanese swords. He has pointed out that the Japanese sword blade is the supreme metallurgical art; it involves unmatched skill in forging, in control of composition, in heat treatment and in finishing. For publications in English on the Japanese sword, see Hakusui[14] and Yumoto[15].

A transverse and a longitudinal section of the Japanese sword blade were mounted, polished and etched. The transverse section is shown in Figure 16. As Gilmour[13] has pointed out, the sword blade has been made by the 'Makuri-gitae' method, in which a relatively soft low carbon steel core is surrounded by a casing of harder, higher carbon steel, and the cutting edge has a high carbon content. Before the final forging of the blade, the metal of the various portions was forged, folded,

Figure 16 Transverse section of Japanese sword blade, showing low carbon and high carbon layers, and high carbon cutting edge. x 5 (B. Gilmour)

re-forged and refolded, or 'piled' a number of times, sometimes as many as twenty times. The purpose of the folding operation was to produce a good quality, homogeneous steel. A side-effect of folding the skin steel was that, when the finished blade was polished, a pattern or 'grain' was produced on the surface of the steel.

Micro-examination of a longitudinal section showed that the outer casing layer was of high carbon steel, containing approximately 0.8% carbon, as the structure consisted wholly of fine lamellar pearlite. The Vickers hardness of this layer, measured using a 20 Kg load, was 300. This figure rose to 350 HV at the surface of the blade. Beneath the outer casing layer, there was an intermediate layer of lower carbon content, which contained rather more ferrite than pearlite, the average carbon content being between 0.3 and 0.4%, i.e. medium carbon steel. The average hardness for this zone was 200 HV. The centre layer was found to contain mainly lamellar pearlite, and some ferrite, indicating a carbon content of approximately 0.6% i.e. at the beginning of the high carbon range. The average hardness figure for this zone was 256 HV. The transition zone between the lower carbon steel layer and the higher carbon central region is shown in Figure 17.

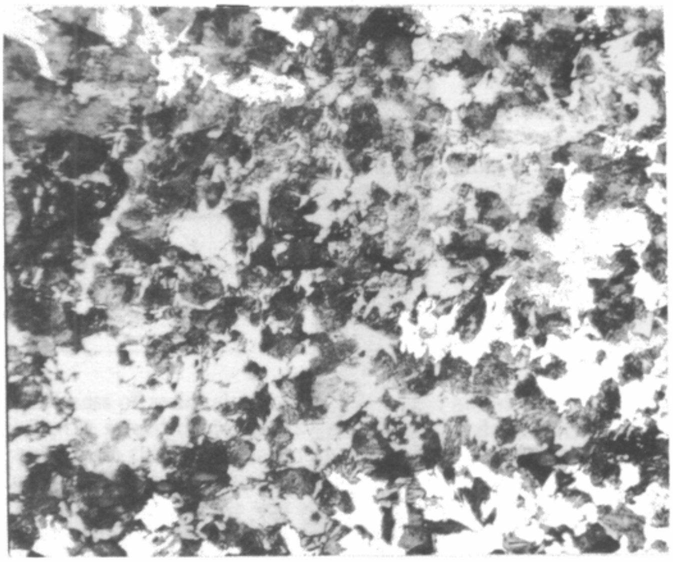


Figure 17 Longitudinal section of Japanese sword, showing transition zone, between 0.35% carbon steel and 0.6% carbon steel layers. Grains of ferrite (white), and lamellar pearlite (dark). x 400 (B. Gilmour)

The hardened cutting edge of the blade was found to consist of the acicular or needle-like structure of lightly tempered martensite; as shown in Figure 18. This area was extremely hard; the average hardness being 875 HV. The longitudinal section was examined before etching. One feature which showed very clearly was that the low carbon zone contained much more slag than the higher carbon zones, which contained only a few, very thin slag stringers.

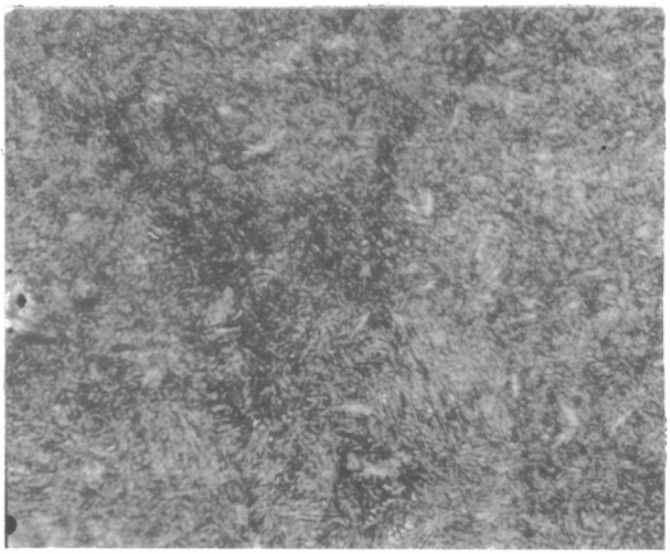


Figure 18 Japanese sword. Transverse section of cutting edge, showing tempered martensite. x 400. (B. Gilmour)

The micro-examination and hardness tests showed that the sword blade had been differentially heat treated. In making a Japanese sword, the heat-treatment was usually carried out in the following manner: Once the blade had been forged into its final form, the cutting edge was heat-treated to harden the steel. To prevent the bulk of the blade from being hardened during quenching, the whole blade was covered in a 'pack' of wet clay and powdered charcoal, and the clay was then scraped away from the edge to be hardened. The clay was allowed to dry, and then the whole was heated to about 800°C and quenched in water. This produced the extremely hard martensite in the high carbon cutting edge, and the much tougher pearlitic structure in the bulk of the blade. There, the cooling rate would be decreased by the thick layer of clay, so that the formation of lamellar pearlite was not suppressed. Martensite is extremely hard, but it is also very brittle owing to the strained body-centred tetragonal lattice of iron, caused by the presence of carbon atoms in super-saturated solid solution.

If the blade has been quenched in cold water to form martensite in the edge then, before the blade can be used in service, some of the brittleness must be removed from the martensite by tempering, which involves reheating the blade at some temperature from 200°C upwards. The tempering temperature depends upon the hardness and toughness required. The higher the tempering temperature, the lower the hardness, but the greater the toughness. According to C. S. Smith[5], one method for hardening a Japanese blade is to quench into warm water, of such a temperature that the edge of the blade has the correct hardness without tempering. As the hardness of martensite depends on the carbon content of the steel, it is necessary to have a high carbon content in the cutting edge to obtain maximum hardness; a higher carbon content also increases the hardenability of the edge region.

A portion of a 17th century Japanese sword blade submitted by Professor H. O'Neill, was previously examined by O'Neill[21] and has been referred to in Tylecote's book on solid phase welding[22]. The microstructure of the cross-section repolished by Tylecote is shown in Figure 19. The similarity of this blade with the blade examined in the present work should be noted. As reported by O'Neill and Tylecote, the blade consisted of a low carbon steel core with high- carbon areas covering the cutting edge and part of the surface. The cutting edge was martensitic, with a hardness of 724 HV, but the other high-carbon areas had a maximum hardness of 285, showing the use of a controlled gradient heating or cooling process.

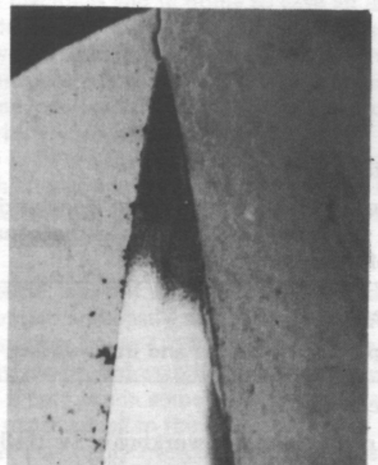


Figure 19 Cross-section of 17th century Japanese sword blade, submitted by Professor H. O'Neill, and examined by Dr R.F.Tylecote.

CONCLUSION

Owing to the high temperature required, steel was not melted commercially in appreciable quantities until the 18th century AD. Before this time, the problem involved in making a sword blade was how to get carbon into wrought iron and make a blade which would be hard, strong and also tough. This has been achieved in the 'currency bar', the Saxon scramasax, the Saxon sword and in the Japanese sword examined, by forge welding; alternate strips of low carbon wrought iron and of carburised wrought iron, i.e. by piling. In the scramasax, pattern welding was used; while in the Japanese sword a much more elaborate process was followed.

ACKNOWLEDGEMENTS

The author wishes to thank the following: Mr Brian Gilmour, for permission to use some of his photomicrographs, and to report some of the findings from his thesis; Dr Nigel Seeley, of the Conservation Department, Institute of Archaeology, for obtaining some of the samples, and for helpful discussions; Dr D. Jones of the Mechanical Engineering Department, University College, London, for the use of metallographic facilities; Miss P. Wilkinson, archaeologist at the Passmore Edwards Museum, and also the Dorset County Museum, and the Lewes Museum, Sussex.

REFERENCES

1. R.F. Tylecote, 'Metallurgy in Archaeology. A Prehistory of Metallurgy in the British Isles'. 1962, London, Edward Arnold Ltd.
2. Anthony Snodgrass, 'Early Greek Armour and Weapons, from the End of the Bronze Age to 600 B.C.' 1964, University of Edinburgh Press.
3. R.H.Ellis Davidson, 'The Sword in Anglo-Saxon England; its Archaeology and Literature'. 1962, Oxford University Press.
4. R. Ewart Oakeshott, 'The Archaeology of Weapons. Arms and Armour from Prehistory to the Age of Chivalry'. 1960, London, Lutterworth Press.
5. Cyril Stanley Smith, 'A History of Metallography'. 1960, University of Chicago Press.
6. Cyril Stanley Smith, 'The Techniques of the Luristan Smiths' in 'Science and Archaeology', (Editor: R.H.Brill), 1971, Cambridge, Massachusetts. M.I.T. Press.
7. Peter L. Drewett, 'Excavations at Hadleigh Castle, Essex', Jnl. British Archaeological Assoc., 1975, (being published).
8. Herbert Maryon, 'Pattern welding and damascening of sword blades'. Studies in Conservation, 1960, 5, 25 & 52.
9. J.W.Anstee et al, 'The technology of ancient glass and metal' Nature, 1956, 178, 1430.
10. E. Salin, 'La civilisation mérovingienne d'àpres les sepultures, les textes et le laboratoire – 3 me Partie – Les techniques'. 1957, Paris, p.331.
11. Gad Rausing, 'The Bow'. 1967. Sweden; Lunds University Historical Museum. (In English).
12. A.R.Williams, 'Metallographic Examination of 16th Century Armour'. Bull. Hist. Met. Group, 1972, 6, No.2, 15–23.
13. B. Gilmour. 'The Development of the Technology of Iron and Steel Sword Blade Making: An Outline'. Thesis, Institute of Archaeology, University of London, May 1975.
14. Inami Hakusui, 'The Japanese Sword'. 1948, Tokyo, Cosmo Publ. Co.
15. John M.Yumoto, 'The Samurai Sword'. 1958. Vermont and Tokyo, Charles E. Tuttle & Co.

16. A.R.Hall, in Singer, Holmyard, Hall and Williams, 'A History of Technology, Volume II'. 1956. Oxford University Press.

17. G.W.Henger, 'The metallography and chemical analysis of iron-base samples dating from antiquity to modern times'. Bull. Hist. Met. Group, 1970, 4, No.2, 45–52.

18. Lena Thalin, 'Notes on the ancient iron currency bars of Northern Sweden, and the nickel alloys of some archaeological objects'. Early Medieval Studies, 5, p.24. Antikvarisk Antikvarisktarkiv 50, (1973), Kungl. Vitterhets Historie och Antikvitets Akademien, Sweden. (In English).

19. Torsten Hansson and Sten Modin, 'A metallographic examination of some iron findings with a high nickel and cobalt content'. Early Medieval Studies 5, (1973), p.5. (ibid) Sweden. (In English).

20. J.N.McGrath, 'A preliminary report on the metallographic examination of four fragmentary Early Iron Age sword blades from Llyn Cerrig Bach, Anglesey'. Bull. Hist. Met. Group, 1968, 2, No.2, 78.

21. H.O'Neill. Trans. Inst. Weld. 1946, 9, 3–9.

22. R.F.Tylecote. 'The Solid Phase Welding of Metals'. London, 1968.

Report

REPORT ON THE INTERNATIONAL SYMPOSIUM HELD AT EISENSTADT, (BURGENLAND) AUSTRIA FROM 29th SEPTEMBER – 2nd OCTOBER 1975

This was held under the auspices of the Burgenlandisches Landesmuseum and the Commité pour la Siderurgie Ancienne de l'UISPP. It was the second meeting of this committee and the theme was:

Archaeological research on European Ironworking with special regard to the Burgenland.

The results of archaeological excavations of prehistoric ironworking sites within and outside Europe were discussed and papers were given by the following contributors from nine different European countries:

A.–J. Ohrenberger (Eisenstadt):

History and development of Ironworking in the Burgenland during prehistoric and early periods.

H. Schmid, (Eisenstadt):

The geological conditions for prehistoric and later ironworking in Burgenland.

K. Bielenin (Krakow):

New observations on early ironworking in the area of the Burgenland.

K. Kaus, (Eisenstadt):

The dating of prehistoric ironworking installations in Burgenland based on small finds.

E. Nosek (Krakow):

Small scraps from iron blooms from bloomery sites in the Burgenland.

J. Gomori (Sopron):

Archaeological research on Iron in West-Hungary.

G. Vastagh (Budapest):

Some peculiarities of Hungarian bloomeries.

R. Pleiner (Prague):

New contributions to the archaeology of ironworking in Czechoslovakia and the significance of the shaft-furnace in the history of iron production.

G. Sperl (Leoben):

The relationship between copper and ironworking.

W.U. Guyan (Schaffhausen):

Archaeological research on ironworking in Switzerland.

K. Bielenin (Krakow):

Survey of prehistoric bloomery types in Poland.

G. Bauhoff, (Dusseldorf):

Iron research in Germany.

I. Martens (Oslo):

Prehistoric and later ironworking in South Norway.

R.F. Tylecote (UK)

Iron working in the Sudan in the first 500 years AD.

P.L. Pelet (Lausanne):

The architecture of primitive iron furnaces, general trends and autonomous evolution.

Excursions were made to Raiding – to see late La Tène furnaces; to Unterpullendorf – to see Early medieval furnaces and orepits; and to Klostermarienberg to see three late La Tène dome-shaped furnaces.

Five different types of furnaces have so far been found in Burgenland of varying dates. Of these the dome-shaped Celtic furnaces seem to be the most developed with the greater capacity for production. The latest results have revealed a type of furnace with a slag pit half-sunk in the ground (Weppersdorf, Langenthal etc).

Bessemer and West Cumberland

Read at the 10th ANNUAL CONFERENCE SHEFFIELD – 20/22 SEPTEMBER 1974

D R Wattleworth ©

In any reference to the Industrial Revolution the names of Watt, Stephenson and Arkwright are sure to arise but seldom that of Bessemer. Admittedly he came later but his contribution to the industrial progress of this country cannot be overestimated. West Cumberland in particular benefitted enormously in the latter half of the 19th century from his work and indeed it could be claimed that the present industrial activity in that area can be traced to the influence of his invention.

Another pioneer who made a substantial contribution to industrial progress at an earlier date was Cort. His puddling process for the production of wrought iron provided the engineers of his day with a material with tensile properties needed for the production of their boilers and machines and in doing so gave an impetus to the production of pig iron without which later developments would hardly have been possible. Wrought iron served its purpose admirably but it was deficient in strength, and, particularly, hardness for the growing demands which were being made upon it. The 1830's and 1840's had seen the introduction and growth of the railways which had contributed greatly to the demand for iron, rails for the track making a particularly heavy call on the wrought iron industry.

Steel, of course, was not unknown but its production was both limited and costly and, when Bessemer filed his patent application in 1856, its implications were immediately recognised even if it was treated with a measure of scepticism in some quarters. The early difficulties experienced in the development of the process were eventually overcome but the outstanding feature was that the raw iron from which the steel was made must be comparatively free from phosphorus. Lowthian Bell in his book 'Manufacture of Iron and Steel' (1884) refers at one point to the raw iron being suitable, provided it did not contain more than one part in a thousand of the objectionable element, but, in another section, states that experience points to the possibility of very minute proportions not only being permissible but even advantageous in some cases. There does not appear to be any record of a higher limit being placed on the permissible phosphorus content by Bessemer. His experience taught him however that of all the iron produced from indigenous ores, only that made from the hematites of West Cumberland and the Furness district of Lancashire were suitable for conversion into steel by his process.

The mining of the West Cumberland hematites was already a thriving industry in 1856, output running at the rate of some 324,000 tons per annum but little of this was smelted locally, most of it going to other parts of the country. There was a small blast furnace plant at Cleator Moor which had been working since 1841, both ore and coal being available in the immediate neighbourhood. It was not until 1856 that rail transport was available for delivering the ore to the coastal area. With plentiful supplies of coal together with port facilities at Workington and a strong market in iron a group of local men financed and formed The Workington Iron Company and built two blast furnaces at what was known locally as 'Old Side', drawing their supplies of ore from the Cleator area.

It was with this company that Bessemer placed an order for iron in 1859. It turned out to be quite unsatisfactory, analyses showing it to contain an unexpected amount of phosphorus. Bessemer sought permission to visit the works where he found they were using a small amount of scale in their furnace burden. This was material which came as a return load from Staffordshire in wagons taking pig iron to that area. Satisfied that this accounted for the unsatisfactory nature of the iron he had received, Bessemer asked the management to make him 100 tons of iron from hematite ore only and to cast it into pigs with the letter 'B' moulded on them. This material proved to be quite satisfactory and made industrial history by being the first cast of 'Bessemer Iron'.

It took some little time to establish the new process of steel making. Early failures by some who had eagerly taken licences to use it, had brought it into a measure of disrepute and Bessemer had to start his own works in Sheffield to demonstrate its success. His early production was of tool steel in competition with steel made by the crucible process which he was able to undersell by as much as £30 per ton and still make a handsome profit. The business grew steadily and satisfactorily demonstrated the reliability of Bessemer steel, so much so that licences were taken up quite rapidly and by 1865 there were seventeen Bessemer steelworks in Great Britain.

The comparatively slow progress up to 1862 did not mean that there was general doubt about its ultimate success. Some ironmasters and industrialists were awake to the possible effect the wide adoption of Bessemer steel for structural purposes could have on the demand for iron. Local coalowners formed the West Cumberland Hematite Iron Company and in so doing attracted investment from farther afield. Among subscribers were J B Pease of Middlesbrough and A Albright of Birmingham both prominent in industrial circles, together with Teesside shipbuilders J Stockton and G Norton.

Work commenced on the erection of four blast furnaces and their ancillaries together with the building of workmen's houses and the first furnace was blown in during November 1862. The company did not however confine its activities to the production of sale iron. Part of its pig iron production was converted into wrought iron in 32 puddling furnaces and rolled into bars and plates. In 1872 however they installed a Bessemer steel plant and rail mill and brought their blast furnaces up to seven.

In the years following 1862 when it became evident that the Bessemer steelmaking process was making real headway, further companies were formed in West Cumberland for the making of pig iron from the local hematite ores. The dates of formation and the number of blast furnaces installed were as follows:

Harrington Hematite Iron Company	1863	4 furnaces
Cumberland Mining and Smelting Company	1865	6 furnaces

Maryport Hematite Iron Company	1867	6 furnaces
Solway Iron Company	1870	4 furnaces
Lonsdale Hematite Iron Company	1870	4 furnaces
Moss Bay Hematite Iron Company	1872	4 furnaces
Parton Iron Company	1872	2 furnaces
Derwent Hematite Iron Company	1873	5 furnaces
Kirk Brothers	1875	1 furnace
Distington Hematite Iron Company	1878	3 furnaces

All the companies with furnaces operating prior to 1874 benefitted from the steadily rising demand for iron which reached its peak in the years 1872/3/4. During those three years the price of pig iron rose from 80/– to 195/– per ton but the boom was of comparatively short duration and by the end of 1874 the price had dropped to 90/–. Prices continued to fall as competition in the steel trade increased and exports fell due to other countries becoming self sufficient. Eventually the demand for West Coast hematite iron declined for two reasons – the discovery of ores of low phosphorus content in Spain which could be imported more cheaply than the local ores could be mined and the success of Gilchrist and Thomas in the early 1880's in producing satisfactory steel in a basic lined converter.

The demand for Bessemer iron resulting in the expansion of the local industry had of course created a corresponding demand for the hematite ore. In the twenty years from 1850 to 1870 the production of ore from the local mines had increased from 100,000 tons to one million tons per annum. Peak production was reached in 1881 and 1882 with an average for those two years of 1,670,500 tons.

All this activity at both the blast furnace plants and ore mines had found the area lacking the population necessary for meeting the demands of industry. Workington for instance had a population of only 6,280 in 1851, with Maryport much the same at 6,150. Apart from coal mining, agriculture and a small fishing industry there was little else to provide employment and these left no surplus manpower such as was required by the new works. The same situation applied in the ore mining district and in both cases it was met by importing labour from elsewhere. Ireland was the principal source together with a proportion from Cornwall in the case of the ore mines.

The Workington Iron Company and the West Cumberland Hematite Iron Company both built houses adjacent to their works for both workmen and officials accommodating some 2,000 people and in the case of the latter company their house property was further expanded when they added their steelworks in 1872.

Each new ironworks that was established encountered the same problem and met it in the same way and West Cumberland gradually became a cosmopolitan area with more 'offcomers' than natives. The largest single influx of people came in 1883 when Charles Cammell and Company purchased the Derwent Iron Company at Workington and transferred their Dronfield steelworks there including almost the whole of their workforce.

By the mid 1880's the population of Workington had risen to some 25,000 and that of Maryport to 12,000. West Cumberland had acquired an industrial population which undoubtedly stemmed from its unique deposits of hematite ore and Henry Bessemer's dependence on them for the successful working of his steelmaking process. Unfortunately the monopolistic position was not maintained. Apart from the finding of suitable ores in other countries and the success of the basic converter the development of the open hearth furnace opened up an entirely new field. At the same time the expansion of the railway systems of the world, which had provided a ready market for British made rails, was slowing down and all these factors had their repercussions in West Cumberland. By the end of the 1880's business was very bad and in 1891 both the Maryport Hematite Iron Company and the West Cumberland Hematite Iron and Steel Company went into liquidation and ceased operations. The smaller companies had their troubles leading to capital reorganisations, broken time and eventually closure.

The unemployment problems can be imagined especially at a time when the Boards of Guardians of the Poor were the only official means of affording relief. Emigration to the colonies took place but made little impression on the population figures. To quote from a local newspaper of December 1891:

"empty larders, empty pockets, the long dark winter months ahead, less work available than ever and no prospect of any improvement. A truly lamentable state of affairs affecting all sections of the community."

The best the writer could say was that trade had been bad before and with no apparent chance of revival it had eventually taken an upward turn. Blind hope was all he could offer his readers.

Things did pick up a bit by the end of the century and eventually amalgamations leading to the closure of the less efficient plants and the concentration of producttion produced a more stable position.

It is quite remarkable that the population of West Cumberland remained as steady as it did. It was a heritage from the days when Bessmer's invention brought prosperity to the region and it remained to be available when new industries were brought in.

The making of steel by the Bessemer Process has continued at Workington until the present year, one hundred and two years in all. During that time West Cumberland has produced 74 million tons of pig iron and ferro alloys in its blast furnaces and 25 million tons of Bessemer steel, the latter representing 37% of all the acid Bessemer steel made in Great Britain.

The year 1956 marked the centenary of the filing of Bessemer's patent and also the founding of the Workington Iron Company which eventually became part of the Workington Iron and Steel Company. The occasion was marked by a visit to the Moss Bay works by Her Majesty the Queen who was able to see the inspiring spectacle of a 'blow' in one of their 25 ton converters. Later Her Majesty unveiled a large slate panel bearing the head of Sir Henry Bessemer in the company's apprentice training school, appropriately named after the man whose inventive genius had contributed so much, not only to West Cumberland industry but also to the progress of industrial Britain.

The last 'blow' in the Workington Acid Bessemer plant terminated at 10.30 hours, on Friday, 26th July 1974. Directly afterwards, the engineers began the task of carefully dismantling the No.1 vessel so that it could be taken, by heavy duty transporter, to a Department of the Environment depot, where it will be kept until a suitable site has been chosen for it to be displayed in a realistic works environment, complete with the machinery and drive which will allow it to simulate its operational movements. A steel ladle and other ancillary equipment will be included in the display.

This arrangement has been made between the British Steel Corporation and the Directorate of Ancient Monuments and Historic Buildings of The Department of the Environment to ensure that one of the three Workington Acid Bessemer converters is saved as an item of prime industrial archaeological interest.

Blast furnace management on Teesside in 1908

D Charman Corporation Archivist, British Steel Corporation, London. ©

Mr John Hudson of the Head Office Treasury of the British Steel Corporation recently purchased an interesting blast furnace record in a job lot of second-hand books. It is a small notebook, bound in black leather, measuring 6³/8″ x 3¼″, consisting of an index (not used), and 134 pages, of which 80 are blank. It is titled on the front cover, 'Blast Furnace Department, 12 months ending 30th September 1908. Percy Cooper Esq.'. Inside is written 'Weekly Costs'. It contains a number of tables setting out statistics relating to all aspects of blast furnace and coke oven management. The first set of tables record the blast furnace weekly costs, the second, coke, coal and water consumption, steam pressure, temperature of blast, stoppages at the furnaces and the quantity of dust collected in the dust catchers. The third and fourth tables deal with the quantities of ironstone calcined and the weekly approximate yields and makes of by-products at the coke ovens. The fifth set of tables is the Pig Iron Cost Account, and the sixth and last relates to coke costs. The book is obviously a fair copy, probably made up at the end of the year from rough notes. The writing is small, neat, and uniform, and the tables are beautifully set out and rubricated. Nowhere is the name of the works given in the book, but it is possible to identify it with a fair degree of accuracy from the information provided.

The fact that the water supply came from Darlington places the works firmly on Teesside, as does the item 'Slag to sea' in the Pig Iron Cost Account, which indicates that the slag was loaded from hoppers on the quay into vessels which dumped it out at sea. The Blast Furnace Department had four blast furnaces of which only three (Nos.1–3) were in blast throughout the year, the pages for No.4 Furnace being deliberately left blank. The hearths were also unusually large for the period, each being capable of making up to 1600 tons of iron a week. The largest make during the year was 1608 tons by No. 3 Furnace in the week ending 23rd November, 1907.

The main ingredient of the burden was calcined ironstone, presumably from the Cleveland ore mines, but the addition of tap and mill cinder gives a clue to the purpose for which the iron was being made. Cleveland ironstone had too low a phosphorus content for basic Bessemer steelmaking, and the addition of tap cinder would have been necessary to bring the pig iron up to the 2% minimum required for this process. The implication is, therefore, that the Department was producing basic Bessemer iron.

Only one works on Teesside of the period fits this description, Acklam. The manufacture of iron on that site dated from 1865 when Stephenson and Jacques operated three blast furnaces. In 1881 the works was taken over by the North Eastern Steel Company Ltd., with A.J.Dorman as Chairman and Sidney Gilchrist Thomas on the Board. Thomas had developed the basic Bessemer process, and had recognised the potential value of 'puddlers' tap' (which lay in great heaps in the wrought iron districts– for the production of Bessemer steel from Cleveland ironstone, and had formed a syndicate to buy up options on available supplies. The works began operating in 1883 with Arthur Cooper as manager, to whom Percy Cooper must, almost certainly, have been related. The Company was taken over by Dorman Long in 1902, and the Bessemer Converters were replaced by Open Hearth furnaces in 1919. (Carr & Taplin, A History of the Steel Industry, Blackwell, 1962, pp 101, 102, 265; A Technical Survey of Dorman Long (Steel) Ltd., Iron and Coal Trades Review, November 1959).

Notebooks such as this, though uncommon, were kept by production managers from time to time to record information which they considered to be important, and the purpose of this particular book may have been to record a spectacular reduction in blast furnace costs from £3.3.6.69d per ton of iron in October 1907, to £2.11.11.56d per ton in September 1908, a saving of 11/7.13d per ton, or 19%. This fall in costs must be seen against the economic background of the time. The British iron and steel industry had been in decline for some years by the beginning of the 20th century, as compared with its chief rivals, Germany and the U.S.A., and a comparatively good year in 1906 was followed by four lean years which began with a rapid fall off towards the end of 1907. 1908 was a very bad year during which many blast furnaces were blown out and some works, including Cyfarthfa and Blaenavon were closed. Forge and foundry iron was particularly badly hit with a decline in production of 440,000 tons on the North East Coast alone. The price of Cleveland No.3 GMB pig iron fell from £3-3-0 per ton in December 1906 to £2-10-3 per ton in December 1907, and to £2-9-6 in December 1908. (Carr & Taplin ibid., pp 230–239, Ch.XXIII. The Course of Trade 1906–14).

Some at least of the savings in the Acklam Blast Furnace Department were due to a drop in the price of raw materials, for example, raw ironstone which cost 8/9.59d per ton in October 1907, cost only 7/0.04d per ton in September 1908, and coke, which had cost 18/0.78d per ton, cost only 14/3.48d a year later. A great deal, however, was due to a change in the composition of the blast furnace burden by a switch from home produced to imported iron ore. Between October 1907

An examination of some Palestinian Bronzes

Keith Branigan, Hugh McKerrell, R.F. Tylecote ©

The purpose of this short paper is to publish a small group of bronze artifacts purchased in Jerusalem in 1964, and, more importantly, to publish the results of analysis and examination of these same items. Moorey and Schweizer[1] have drawn attention to the scarcity of information available about the early metallurgy of the Near East, although this situation will be partly remedied with the publication of a more extensive programme of analysis (McKerrell,[18] 1975, forthcoming). Here we have attempted not only to examine the composition of the metals employed but also to examine the artifacts in order to determine the methods of manufacture used.

THE ARTIFACTS

The six items described and studied here were all bought in an antiquity shop in the Old City of Jerusalem in August 1964 by KB, in whose possession they remain. No information is available about the provenance or context of the objects, although all of them are typologically distinctive and well-known types. All appear to be genuine antiquities, and the results of analysis and metallographic study have cast no doubts on their authenticity. It is possible that items 1–3 came from illicit digging in the several cemeteries around 'Ain-Samiya, twelve kilometres north-east of Bethel, which is known to have been going on in 1963[3] shortly before these objects appeared on the market in Jerusalem. The chronological scheme followed in the description of the artifacts is that of Kenyon, chosen here in preference to the several other schemes in use[2] since in speaking of an 'intermediate' (IE/MB) period it does seem to identify with the character of the period in question.

1. Dagger blade with broken tip. Existing length 23.2cm, maximum width 2.8cm. The blade is slightly elliptical in section but without a distinctive mid-ridge or mid-rib, and there are four rivet-holes arranged in two horizontal pairs. This type is well-known, mainly in Intermediate EB–MB contexts (Kenyon[4], Figure 70,3 and 5; Dever, Figure 5,) but also in an EB.III tomb at Jericho (Kenyon[5], Figure 66,3).

2. Dagger blade complete with one rivet still in a rivet-hole. Length 19.7, maximum width 2.4. The blade is lozenge-shaped in section, each face rising to a mid-ridge. There are six rivet-holes set in horizontal pairs. The commonest of all Intermediate EB–MB dagger types, particularly prolific at Jericho (Kenyon[6], Figure 70,11) and Jebel Qa'aqir (Dever[7], Figure 5) and found with either four or six rivets. The parallels quoted are six-rivet examples. Four rivet examples are known from EB.III contexts at Bab edh-Dhra and Lachish (Dever[8], Figure 5, 6 and 7), but apart from the absence of six-rivet examples in EB.III the length of this example also suggests that it is more likely to be of EB–MB date. The few EB.III daggers of this type which are known are substantially longer than 20 cms.

3. Dagger blade, slightly damaged at the heel. Length 23.6, maximum width 2.4. The blade is lozenge-shaped in section with a mid-ridge on each face; in addition there is a very marked rib which runs down the centre of the mid-ridge on each face. The base of the blade, from just below the rivets, has concave edges and there is a shallow V-shaped notch in the heel. Of the five rivets three are arranged in a triangle, the other two as a horizontal pair. Daggers which closely parallel this one are hard to find amongst published material, particularly the combination of five rivets and the fine central mid-rib. Examples with a notched heel, concave base edges, and a fine mid-rib have been in EB–MB tombs at Jericho (Kenyon[9], Fig 70,9; 1965, Figure 41,6) but these have six rivets each. A five-rivet example, but with no base notch was recovered from another EB–MB tomb at Jericho (Kenyon[10], Figure 41,3). The closest parallel, however, is perhaps a blade from the EB–MB cemetery at 'Ain-Samiya, which shares all of the main features of the dagger examined here. Another of the 'Ain-Samiya daggers also features the unusal five-rivet hafting system, and this observation might slightly strengthen the possibility suggested earlier that the EB–MB weapons in this group were looted from the cemetery.

4. Dagger blade, tang lost, heel damaged and edges broken. Existing length 21.9, existing maximum width 4.8. The blade has a fine decorative mid-rib and four other ribs which converge in two pairs to meet the central rib. The tip and edges of the blade are otherwise almost flat, but the central portion of the blade, outlined by the two shorter mid-ribs, is thickened into an oval section. One or more rivets would have been positioned in the short, square tang which has broken off this example. The dagger is typical example of the so-called 'Hyksos' dagger, found in Palestine in MBA II contexts. Examples from tombs at Gaza, Megiddo and Gezer were all found in association with typical piriform juglets and other MBA II pottery (Schaeffer[11], Figures 125, 143–4, 156).

5. Dagger blade, bottom half only survives, edges damaged. Existing length 11.1, existing maximum width 4.3 This dagger is identical in form to No.4, and, in this instance, the square tang survives with two rivet-holes set horizontally. The only difference between the two daggers is that the thickened centre-section on No. 5 is lozenge-shaped in contrast to the oval section of No. 4. The same comments on parallels and dating apply to both daggers.

6. Axe blade, the socket broken off and lost and the blade corroded. Existing length 6.0, existing maximum width 4.6. The blade is a thickened oval in section and is distinguished by the two oval holes cast in its base; beyond these would be the circular or slightly oval shaft-hole, now lost. This is a duck-bill axe, most commonly found in Syria and Lebanon where examples from Ugarit (Schaeffer[12] Figure 49,7; 56, 16–24), Baghouz (du Buisson[13], pl. LVI) and other sites (Schaeffer[14], Figure 75,8; 76,10) all come from contexts between c.1950–1800 BC, that is MBA I and MBA II in Palestine.

An examination of some Palestinian Bronzes

Keith Branigan, Hugh McKerrell, R.F. Tylecote ©

The purpose of this short paper is to publish a small group of bronze artifacts purchased in Jerusalem in 1964, and, more importantly, to publish the results of analysis and examination of these same items. Moorey and Schweizer[1] have drawn attention to the scarcity of information available about the early metallurgy of the Near East, although this situation will be partly remedied with the publication of a more extensive programme of analysis (McKerrell,[18] 1975, forthcoming). Here we have attempted not only to examine the composition of the metals employed but also to examine the artifacts in order to determine the methods of manufacture used.

THE ARTIFACTS

The six items described and studied here were all bought in an antiquity shop in the Old City of Jerusalem in August 1964 by KB, in whose possession they remain. No information is available about the provenance or context of the objects, although all of them are typologically distinctive and well-known types. All appear to be genuine antiquities, and the results of analysis and metallographic study have cast no doubts on their authenticity. It is possible that items 1–3 came from illicit digging in the several cemeteries around 'Ain-Samiya, twelve kilometres north-east of Bethel, which is known to have been going on in 1963[3] shortly before these objects appeared on the market in Jerusalem. The chronological scheme followed in the description of the artifacts is that of Kenyon, chosen here in preference to the several other schemes in use[2] since in speaking of an 'intermediate' (IE/MB) period it does seem to identify with the character of the period in question.

1. Dagger blade with broken tip. Existing length 23.2cm, maximum width 2.8cm. The blade is slightly elliptical in section but without a distinctive mid-ridge or mid-rib, and there are four rivet-holes arranged in two horizontal pairs. This type is well-known, mainly in Intermediate EB–MB contexts (Kenyon[4], Figure 70,3 and 5; Dever, Figure 5,) but also in an EB.III tomb at Jericho (Kenyon[5], Figure 66,3).

2. Dagger blade complete with one rivet still in a rivet-hole. Length 19.7, maximum width 2.4. The blade is lozenge-shaped in section, each face rising to a mid-ridge. There are six rivet-holes set in horizontal pairs. The commonest of all Intermediate EB–MB dagger types, particularly prolific at Jericho (Kenyon[6], Figure 70,11) and Jebel Qa'aqir (Dever[7], Figure 5) and found with either four or six rivets. The parallels quoted are six-rivet examples. Four rivet examples are known from EB.III contexts at Bab edh-Dhra and Lachish (Dever[8], Figure 5, 6 and 7), but apart from the absence of six-rivet examples in EB.III the length of this example also suggests that it is more likely to be of EB–MB date. The few EB.III daggers of this type which are known are substantially longer than 20 cms.

3. Dagger blade, slightly damaged at the heel. Length 23.6, maximum width 2.4. The blade is lozenge-shaped in section with a mid-ridge on each face; in addition there is a very marked rib which runs down the centre of the mid-ridge on each face. The base of the blade, from just below the rivets, has concave edges and there is a shallow V-shaped notch in the heel. Of the five rivets three are arranged in a triangle, the other two as a horizontal pair. Daggers which closely parallel this one are hard to find amongst published material, particularly the combination of five rivets and the fine central mid-rib. Examples with a notched heel, concave base edges, and a fine mid-rib have been in EB–MB tombs at Jericho (Kenyon[9], Fig 70,9; 1965, Figure 41,6) but these have six rivets each. A five-rivet example, but with no base notch was recovered from another EB–MB tomb at Jericho (Kenyon[10], Figure 41,3). The closest parallel, however, is perhaps a blade from the EB–MB cemetery at 'Ain-Samiya, which shares all of the main features of the dagger examined here. Another of the 'Ain-Samiya daggers also features the unusal five-rivet hafting system, and this observation might slightly strengthen the possibility suggested earlier that the EB–MB weapons in this group were looted from the cemetery.

4. Dagger blade, tang lost, heel damaged and edges broken. Existing length 21.9, existing maximum width 4.8. The blade has a fine decorative mid-rib and four other ribs which converge in two pairs to meet the central rib. The tip and edges of the blade are otherwise almost flat, but the central portion of the blade, outlined by the two shorter mid-ribs, is thickened into an oval section. One or more rivets would have been positioned in the short, square tang which has broken off this example. The dagger is typical example of the so-called 'Hyksos' dagger, found in Palestine in MBA II contexts. Examples from tombs at Gaza, Megiddo and Gezer were all found in association with typical piriform juglets and other MBA II pottery (Schaeffer[11], Figures 125, 143–4, 156).

5. Dagger blade, bottom half only survives, edges damaged. Existing length 11.1, existing maximum width 4.3 This dagger is identical in form to No.4, and, in this instance, the square tang survives with two rivet-holes set horizontally. The only difference between the two daggers is that the thickened centre-section on No. 5 is lozenge-shaped in contrast to the oval section of No. 4. The same comments on parallels and dating apply to both daggers.

6. Axe blade, the socket broken off and lost and the blade corroded. Existing length 6.0, existing maximum width 4.6. The blade is a thickened oval in section and is distinguished by the two oval holes cast in its base; beyond these would be the circular or slightly oval shaft-hole, now lost. This is a duck-bill axe, most commonly found in Syria and Lebanon where examples from Ugarit (Schaeffer[12] Figure 49,7; 56, 16–24), Baghouz (du Buisson[13], pl. LVI) and other sites (Schaeffer[14], Figure 75,8; 76,10) all come from contexts between c.1950–1800 BC, that is MBA I and MBA II in Palestine.

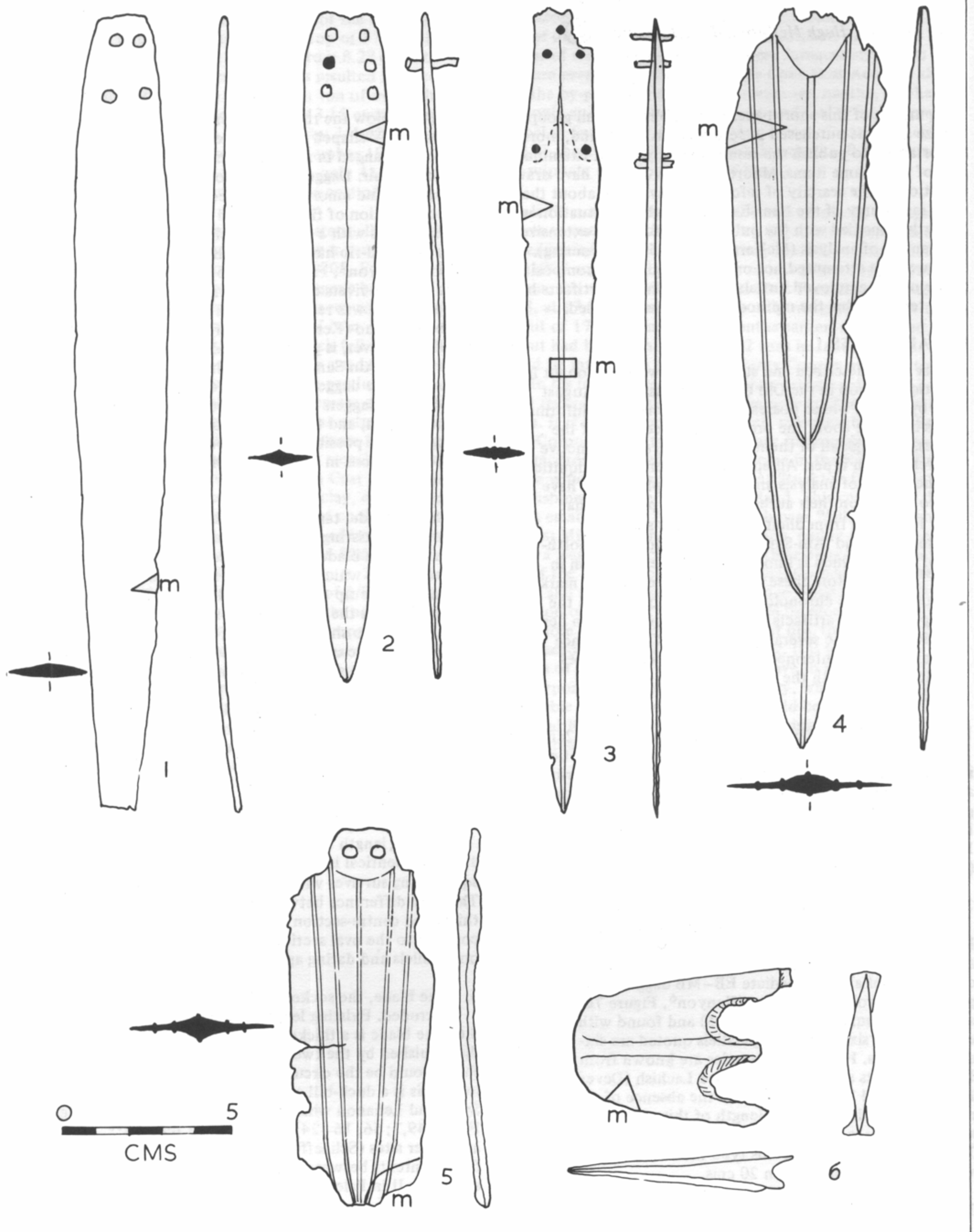


FIGURE 1 The six Palestinian bronzes examined

X–RAY FLUORESCENCE ANALYSIS

The analytical results (%) obtained on sound internal metal samples from each object were as follows:

	Cu	Ni	Zn	As	Pb	Ag	Sn	Sb
1. Dagger IE/MB	96.0	0.5	0.4	1.6	0.0	0.1	0.3	0.5
2. Dagger IE/MB	96.0	0.3	0.5	1.4	0.5	0.1	0.4	0.8
3. Dagger IE/MB	92.0	0.3	0.2	0.7	0.4	0.2	6.3	0.0
4. Dagger MB II	89.0	0.0	0.2	0.0	0.0	0.0	10.3	0.0
5. Dagger MB II	89.0	0.0	0.2	0.3	0.8	0.0	9.8	0.0
6. Axe MBI–II	89.0	0.4	0.1	0.6	1.3	0.0	8.6	0.0

Daggers 1 and 2 would be termed arsenical coppers, the remainder are all tin bronzes.

The results may be compared with all other reliable alloying data known from Palestine, over the EB to MB, details of which are listed in the Appendix. Only the results of Macalister[15] seem of such doubtful value as to require omission, but, by no means are the various analysts involved consistent in the alloying elements sought. Even so, a fair picture of alloying practices in Palestine from ca. 3000–1600 BC emerges and the main features are brought together in the table below. This shows the proportion of all analysed artifacts which may be classed as arsenical copper and tin bronze, as a function of the three main chronological periods involved.

	EB	IE/MB	MB
Tin bronze >5% Sn			
No. of analyses	36	44	86
No. of bronzes	0	3	26
% of total	0%	7%	30%

	EB	IE/MB	MB
Arsenical copper >1% As			
No. of analyses	25	39	85
No. of arsenical coppers	6	16	22
% of total	24%	41%	26%

The new analyses thus fit well with the patterns from other work and occasion no surprises. For the IE/MB two of the daggers are arsenical copper and the third tin bronze. The arsenic content of the single bronze is markedly the lowest of the early blades, a consistent alloying pattern paralleled throughout the ancient world and suggestive of deliberate rather than adventitious control of arsenic contents. Antimony levels for both of the arsenical coppers are significantly higher than for any of the tin bronzes, a reasonable situation in view of the close chemical similarity of arsenic and antimony, and an indication, perhaps, of the smelting of arsenic/antimony-rich copper ores. The IE/MB bronze dagger (No. 3 in our list) is only the third tin bronze known from this period in Palestine, both of the other examples are daggers also. There is a clear indication that daggers from this period were preferentially prepared from alloyed metal, mostly arsenic copper, occasionally tin bronze; in all about two-thirds of such blades were produced from good metal during the IE/MB period.

With the inclusion of the new results, about a half of all analysed artifacts from both the IE/MB would be classed as alloyed metal. For the earlier period the predominant material is arsenical copper, whilst during the MB there is an increased use of tin bronze and a corresponding decrease in the proportion of arsenical copper. No tin bronze at all is known from the Palestinian EB, during the IE/MB some 7% of all analysed artifacts are bronze, and for the MB the corresponding figure is 30%. These figures reflect increasing availability of tin supplies, and, although detailed discussion is beyond the scope of this short paper, it is nonetheless interesting to note that it is the areas most directly accessible to the Mediterranean (Palestine, Egypt, Syria and Crete) that demonstrate such marked increases in bronze usage. For Western Europe it is Britain, during the Step 5 Beaker Period of Lanting and van der Waals[17], perhaps as early as ca.2200 BC, which first achieves full use of tin bronze. Whether the Palestinian situation reflects early far-flung contact with Western European tin suppliers is hard to say; certainly Muhly[16] details a forceful case for such activity by the mid-second millenium, and within the Near East no substantial tin ore locations have ever been located. Yet positive use of bronze is clearly demonstrated for many areas during the EB (Particularly Central Anatolia, the Troad, Northwestern Iran and the Cyclades) long before any Western supplies could be feasibly available. However, it is precisely these locations which show either zero, or at most slight, increase in proportional bronze useage from the EB through to the MB. Palestine particularly, as well as Egypt, Syria and Crete, are the most striking exceptions to this pattern.

The apparent peak in arsenical copper usage during the IE/MB is well reflected in the new analyses. And the situation in Palestine, in turn, reflects a striking (ancient) world-wide interest in this metal at the same point in time. Although conscious use of arsenic copper goes back (at least) to the fourth millennium, it is only from the end of the third millennium that the most marked usage takes place. Not only was there then the obvious alloying application, but new work[18] demonstrates also a positive interest in arsenic enriched surface coatings for many artifacts, producing a striking silver-coloured appearance. Mirrors from Middle Kingdom Egypt, halberds from Iberia, C. Europe and Britain, daggers from Amorgos, and many non-utilitatian items from Anatolia and Caucasia – all fall into this same category. And with two IE/MB daggers from Ajjul also having surface levels of arsenic consistent with such embellishment, Palestinian metallurgists quite clearly kept up with the then current international practices.

METALLOGRAPHIC EXAMINATION

1. Dagger IE–MB. Contains short small inclusions parallel with the surfaces and elongated towards the edge of the blade. Hardness in the centre is 117 HV1, and near the edge, 117. Upon etching the blade shows heavy, coarse longitudinal (i.e. towards the edge) coring. The inclusions are now blue to blue-grey. The etched section shows that the extreme tip of the edge has been bent over probably by accident. There is evidence of considerable cold work on the edge and at the centre.

2. Dagger IE–MB. Contains many more and larger inclusions than No.1. Some are elongated and all are blue to blue-grey, and may be cuprous oxide. They are present in the same amount near both surfaces which suggests that the blank was not cast in an open mould. The hardness near the centre of the blade is 96 HV1, and that near the edge is 140. Etching showed even heavier and darker coring than No.1. The grains

at the edge showed slip markings but no twins, so that the edge has been hammered but not annealed.

3. Dagger IE–MB. The surface contains detached equiaxed grains with corroded slip markings. There is slight evidence of residual coring but the structure is much more homogenous than Nos. 1 and 2. There are some primary inclusions but these now seem to have little relation to the direction of coring. The hardness of the area nearest the centre of the blade was 113 HV1, and that near the edge was 168. The etched structure is very fine-grained, with twins and slip-markings.

A second section was made from the centre of this dagger to see how the grooves on either side of the fine mid-rib were made. As they are at the moment, there is little doubt that they have been worked like the rest of the weapon. It is very much to be doubted whether they were cast into the original blank. If so, any sign of this has now been obscured by final working. The structure around the grooves is the same as the rest of the section. The hardness is 110 HV1 which agrees with the 113 in the other section. Again, the structure was the alpha solid solution, equiaxed, with twins and slip markings. There were some blue-grey oxide particles. The intergranular corrosion seemed to be particularly well-developed near the grooves which is probably due to extra cold-work during the working-in of the grooves.

4. Dagger MB.II. This has large corrosion cavities near the surface. The fine grains are twinned and appear to be deformed. The hardness of the centre of the blade was 72 while that of the edge was 135. This tin-bronze is a solid solution, i.e. it has been homogenised by heating so that the tin has been completely dissolved. The bent twins suggest that it has been worked and annealed several times or hot-worked.

5. Dagger MB.II. There are some large cavities near the centre of the blade formed during casting. The grains are equiaxed and there is little evidence of coring suggesting that the casting has been well-homogenised. The slag or oxide inclusions are not directional showing that there has been little work done on the blade, but there are fine elongated grains near the surface which show signs of a final grinding or sharpening. One rib has been cast-in while another shows signs of working; this consists of fine, slightly distorted but mainly equiaxed grains with slip markings. The hardness is 99 in the centre and 125 at the edge of the blade.

6. Axe MB.I–II. This is a casting with equiaxed grains and little evidence of deformation. On etching it shows evidence of coring. The hardness is 78 in the centre, and 100 HVI at the edge. This increase may be due to local cold-work or a faster cooling rate.

In many ways the structure of the first three daggers resembles that of the objects from Tal y Yahya[19], which turned out to be arsenical coppers or hybrids. After casting a certain amount of homogenisation treatment has been carried out, but not taken to completion. The difference in hardness between the centres and the edges shows that the edges have had some final hammer hardening. It would appear that the blanks have been cast in two-part moulds, possibly vertically.

On the fourth and fifth daggers the edge has again been hammer hardened. The ribs have been cast-in but this was not everywhere perfect and the missing parts have been cut-in and the surrounding areas evened out.

As far as production techniques are concerned, our brief investigation is breaking new ground and much work needs to be done on many more samples before any firm conclusions can be drawn. The daggers identified as IE–MB weapons all appear to have been cast in two-part moulds and to have subsequently been cold-worked. The grooves which delineate the mid-rib on No.3 were also worked-in after casting. In contrast the two 'Hyksos' daggers had their ribs cast-in, and although we cannot be sure, the fineness of the ribbing must at least allow the possibility that cire-perdue moulds were used for this process. The same conclusion has been drawn for daggers with equally fine ribbing from the Aegean[20], where a **cire-perdue** mould has fortunately survived from the period c.2800 BC. Apart from cold-working, one of the 'Hyksos' daggers also shows evidence of annealing, and this is found also on the IE–MB dagger No. 3 but not on either of the other IE–MB weapons. In view of dagger No.3's quite different composition to daggers 1 and 2 (tin-bronze as opposed to low-arsenic bronze or arsenical copper), it is possible that the different working techniques are also significant. There is the possibility of a chronological distinction between dagger 3 and daggers 1 and 2, which might explain the different compositions and working techniques. We noted that daggers 1 and 2 both have a few parallels in EB.III as well as EB–MB, whereas dagger 3 does not, and indeed its closest parallels come from a cemetery, 'Ain Samiya, which is considered by Dever[2] to be MB.I in his terminology, and therefore relatively late in Kenyon's EB/MB period[4].

A second similar dagger, though with six rivets, was found in a late EB–MB context at Lachish[21] and subsequent examination showed that this dagger had been annealed[22] like our example. The possibility must, therefore, be borne in mind that tin-bronze and annealing were introduced **during** the EB–MB period in Palestine, rather than either at the beginning of it or after. However, as emphasised above, this is amongst the first metallographic studies of Palestinian metal of this period and the sample is so small that it can really do no more than hint at some of the problems and questions which a further, much larger, programme of study might usefully examine. Previous work with Palestinian material (Tufnell[23] and Kelso[24]) has been very limited.

REFERENCES

1. P. Moorey and F. Schweizer, **Archaeometry** *1972*, **14**, *177–98.*
2. W. Dever, **Bulletin American School Oriental Res.** *1973*, **210**, *69.*
3. W. Dever, **Israel Exploration Journal**, *1972*, **22**, *83.*
4. K. Kenyon, **Jericho I**, *1960, London, British School of Archaeol. Jerusalem, Fig. 70,3,5.*
5. K. Kenyon, **op. cit.** *n.4, Fig. 66,3.*
6. K. Kenyon, **op. cit.** *n.4, Fig. 70,11.*
7. W. Dever, **op. cit.** *n.3, Fig. 5.*
8. W. Dever, **op. cit.** *n.3, Fig. 5, 6 and 7.*
9. K. Kenyon, **op. cit.** *n.4, Fig. 70,9;* **Jericho II**, *1965, London, British School of Archaeol. Jerusalem, Fig. 41,6.*
10. K. Kenyon, **op.cit** *n.9, Fig. 41,3.*
11. C. Schaeffer, **Stratigraphie comparée et chronologie de l'Asie occidentale**, *1948, Oxford, Clarendon Press. Figs. 125, 143–4, 156.*
12. C. Schaeffer, **op. cit** *n.11, Fig. 49,7; 56, 16–24.*
13. R. du Mesnil du Buisson, **Baghouz**, *1948, Leiden, pl. LVI*
14. C. Schaeffer, **op. cit** *n.11, Fig. 75,8; 76, 10.*

15. R.A.S. Macalister. **The Excavation of Gezer.** *London, 1912, Vol. II.*

16. J.D. Muhly. Copper and Tin. **Trans. Connecticut Acad. Arts Sci.** *1973,* **43,** *155–533.*

17. J.N. Lanting and J.D. van der Walls. **Helinium,** *1972,* **12,** *20–46.*

18. E.R. Eaton and H. McKerrell. **World Arch.** *1975* (forthcoming).

19. R.F. Tylecote and H. McKerrell. **Bull. HMG** *1971,* **5,** *(1), 37–38.*

20. K. Branigan. **Aegean Metalwork of the Early and Middle Bronze Age,** *Oxford, 1974, p.72–82.*

21. O. Tufnell. **Lachish IV,** *O.U.P. London, 1958, pl.22,5.*

22. O. Tufnell. **op. cit** *331.*

23. O. Tufnell. **op. cit** *p. 328–331.*

24. J L. Kelso. **BASOR.** *1943,* **91,** *28.*

APPENDIX – PARTIAL BIBLIOGRAPHY

H.G. Buchholz, 'Analysen Prahistorischer Metallfunde aus Zypern und den Nachbarlandern'. **Berliner Jahrbuch fur Vor-und Frühgeschichte:** *1967,* **7** *: 189.*

C.H. Desch, 'Sumerian Copper. Sixth Interim Report'. **British Association for Advances in Science:** *1935, 340.*

C.H. Desch, 'Sumerian Copper. Seventh Interim Report'. **British Association for Advances in Science** : *1936, 308.*

E.R. Eaton and Hugh McKerrell, 'Near Eastern alloying and some textual evidence for the early use of arsenical copper'. **World Archaeology:** *1975* (forthcoming).

J. Garstang, 'Jericho : City and Necropolis'. **L.A.A.A.** *1935,* **22** *: 143.*

J.H. Gladstone, 'Ancient Metals from Tell-el-Hesy'. **Proc. Soc. Bibl. Arch.** *1894:* **16:** *95.*

P.L.O. Guy and R.M. Engberg, **Megiddo Tombs.** *1938, Chicago.*

J.L. Kelso, 'Some Sixteenth-Century Copper Objects from Tell Beit Mirsim'. **B.A.S.O.R.** *1943:* **91:** *28.*

C.A. Key, 'Note on the Trace-Element Content of the Artifacts of the Kfar-Monash Hoard'. **I.E.J.** *1963:* **13:** *289.*

J.N. Lanting and J.D. van der Waals, British Beakers as seen from the Continent. **Helinium.** *1972,* **12:** *20–46.*

R.A.S. Macalister, **The Excavation of Gezer.** *1912, Vol. II, 1912. London.*

C.C. McCown, **Tell En-Nasbeth.** *Vol. I. 1947.* Berkeley.

H. McKerrell, **The Alloys of the Early Bronze Age in Scotland.** (Edinburgh) *1975.*

P.R.S. Moorey and F. Schweizer, 'Copper and Copper Alloys in Ancient Iraq, Syria and Palestine: Some New Analyses'. **Archaeometry:** *1972,* **14:** *177.*

J.D. Muhly, 'Copper and Tin. The Distribution of Mineral Resources and the Nature of the Metals Trade on the Bronze Age'. **Trans. Connecticut Acad. Arts and Sciences:** *1973.* **43:** *155.*

E.D. Oren, 'A Middle Bronze Age I Warrior Tomb at Beth-Shan'. **Zeitschrift des Deutschen Palastina-Vereins:** *1971,* **87:** *109.*

J. Perrot, 'The Excavations at Tell Abu Matar, near Beersheba'. **I.E.J.** *1955,* **5:** *73.*

O. Tufnell, 'The Shihan Warrior'. **Iraq:** *1953,* **15!** *161.*

O. Tufnell, **Lachish.** *Vol. IV. 1958. London.*

O. Tufnell, 'The Courtyard Cemetery at Tell El–'Ajjul, Palestine'. **Bull Inst. Arch.** *1962.* **3:** *1.*

APPENDIX

Reliable analyses, published elsewhere, of EB, IE/MB and MB material from Palestine. Main alloying elements, As, Sn, Pb and Zn only.

PALESTINE EB

		%Sn	%As	%Pb	%Zn	
Tell Ajjul	Javelin	0	0	0	0	McKerrell, 1975
Tell Ajjul	Javelin	0	1–5	0	0	McKerrell, 1975
Tell Hesi	Knife	0		Tr		Gladstone, 1894
Tell Hesi	Adze	Tr		0.68		Gladstone, 1894
Tell Hesi	Crescentic axe	0	0.5	0.5	0	McKerrell, 1975
Tell Hesi	Spearhead	0	0.5	0	0	McKerrell, 1975
Tell Hesi	Flat axe	0	0	0.5	0	McKerrell, 1975
Tell Hesi	Adze	0	0.5	0	0	McKerrell, 1975
Jericho	Fragment	0.24	Tr	0.1		Garstang, 1935
Jericho	Flat axe	0.	2.18	0.54		Buchholz, 1967
Lachish 1500	Blade	0	0	2.32		Desch, 1935
Lachish 1513	Dagger	0	Tr	0		Desch, 1935
Lachish 1523	Pin		Tr	0		Tufnell, 1958
Lachish 1556	Dagger	0	0	0		Desch, 1936
Megiddo	Pin	0				Guy & Engberg,1938
Megiddo	Spatula	0				Guy & Engberg,1938
Megiddo 1101B	Spearhead	Tr				Guy & Engberg,1938
Megiddo 1101B	Spearhead	0				Guy & Engberg,1938
Megiddo 1101B	Dagger	0				Guy & Engberg,1938
Megiddo 1101B	Ring	0				Guy & Engberg,1938
Megiddo 1101B	Kohl stick	0				Guy & Engberg,1938
Megiddo 1101B	Toggle pin	0				Guy & Engberg,1938
Kfar-Monash	Saw	0	0	0	0	Key, 1963
Kfar-Monash	Macehead	0	0	0	0	Key, 1963
Kfar-Monash	Flat axe	0	0	0	0	Key, 1963
Kfar-Monash	Flat axe	0	0	0	0	Key, 1963
Kfar-Monash	Knife	0	0	0.49	0	Key, 1963
Kfar-Monash	Adze	0	4.07	0.05	0	Key, 1963
Kfar-Monash	Adze	0	1.15	0.06	0	Key, 1963
Kfar-Monash	Adze	0	0	0	0	Key, 1963
Kfar-Monash	Crescentic axe	0		0	0	Perrot, 1955
Kfar-Monash	Crescent	0	0	0	0	Key, 1963
Kfar-Monash	Chisel	0	3.55	0	0	Key, 1963
Kfar-Monash	Dagger	0	0	0	0	Key, 1963
Kfar-Monash	Spearhead	0	2.2	0.06	0	Key, 1963
Tell en Nasbeh	Dagger	0		0	0	McCown, 1947
Tell Fara	Dagger	0	0.5	0.5	0	McKerrell, 1975

PALESTINE IE/MB

		%Sn	%As	%Pb	%Zn	
Tell Ajjul 1552	Dagger	0	Tr	0		Desch, 1935
Tell Ajjul 1552	Dagger	0	Tr	0		Desch, 1935
Tell Ajjul 1517	Dagger	0	11.5			Moorey & Schweizer,1972
Tell Ajjul 1517	Rivet to above	0	3.5			Moorey & Schweizer,1972
Tell Ajjul 1565	Dagger	0				Tufnell, 1953
Tell Ajjul 1570	Dagger	0				Tufnell, 1953
Tell Ajjul 1152	Dagger	0	1–5	0	0	McKerrell, 1975
Tell Ajjul 1539	Dagger	0	0.5	0	0	McKerrell, 1975
Tell Ajjul 1539	Dagger	0	5–10	0	0	McKerrell, 1975
Tell Ajjul 1542	Dagger	0	0	0	0	McKerrell, 1975
Tell Ajjul 1565	Dagger	0	5–10	0	0	McKerrell, 1975
Tell Ajjul 1569	Dagger	0	>10	0	0	McKerrell, 1975
Tell Ajjul 1570	Dagger	0	0.5	0	0	McKerrell, 1975
Ascalon (BM129419)	Dagger	0	5–10	0.5	0	McKerrell, 1975
Beth Shan	Javelin	0	0.08	0.21	0.01	Oren, 1971
Gaza (BM 1937·5·5·38)	Spearhead	0.5	0	0.5	0	McKerrell, 1975
Gezer (BM 1937·5·5·59)	Spearhead	0.5	0.5	0	0	McKerrell, 1975
Jericho A62	Dagger	1.0	0			Moorey & Schweizer,1972
Jericho A111	Dagger	0	1.9			Moorey & Schweizer,1972
Jericho M16	Dagger	0	0			Moorey & Schweizer,1972
Jericho G83a	Dagger	ca14	<0.2			Moorey & Schweizer,1972
Jericho M16	Spearhead	0	1.1			Moorey & Schweizer,1972
Jericho G83	Spearhead	0.5	3.4			Moorey & Schweizer,1972
Jerusalem (BM 1937·5·5·41)	Spearhead	0.5	1–5	0	0	McKerrell, 1975
Jerusalem (BM 1937·5·5·42)	Spearhead	0	0.5	0	0	McKerrell, 1975
Near Jerusalem (BM 1937·5·5·78)	Dagger	>10	1–5	0	0	McKerrell, 1975
Lachish 2009	Pike	0	Tr	0		Desch, 1935
Lachish 2032	Javelin	0	Tr	0		Desch, 1935
Lachish 2111	Javelin	0	Tr	0		Desch, 1935
Lachish 2049	Dart	0	Tr	0		Desch, 1935
Lachish 2111	Dagger	0	Tr	0		Desch, 1935
Megiddo 884A	Pin	0				Guy & Engberg,1938
Megiddo 9124A	Dagger	0.85	0	0	0	Guy & Engberg,1938
Megiddo 912A2	Pin	0.69	0	0.49	0	Guy & Engberg,1938
Megiddo 1014B	Pin	0				Guy & Engberg,1938
Megiddo 1014B	Pin	0				Guy & Engberg,1938
Megiddo 1014B	Borer	0				Guy & Engberg,1938
Megiddo 1120B	Borer	0	0	0	0	Guy & Engberg,1938
Palestine	Dagger	0.	0.5	0	0	McKerrell, 1975
Palestine	Pin	0	1–5	0	0	McKerrell, 1975
Tiberias (BM 1937·5·5·4T)	Dagger	0	1–5	0	0	McKerrell, 1975

PALESTINE MB

		%Sn	%As	%Pb	%Zn	
Tell Ajjul	Adze	0	0.86	0		Desch, 1936
Tell Ajjul 1417	Dagger	1.0	0.5	0.7	0.01	Tufnell, 1962
Tell Ajjul	Dagger	0.5	1–5	0.5	0	McKerrell, 1975
Tell Ajjul	Dagger	0	0	0	0	McKerrell, 1975
Tell Ajjul(BM 132049)	Pin	>10	0	0	0	McKerrell, 1975
Ascalon(BM 129418)	Dagger	0.5	0	0.5	0	McKerrell, 1975
Ascalon(BM 126977)	Duck-bill axe	5–10	0	0.5	0	McKerrell, 1975
Ascalon	Shaft-hole axe	12.5	<0.2			Moorey & Schweizer, 1972
Ascalon	Shaft-hole axe	16.0	0.2			Moorey & Schweizer, 1972
Ascalon	Duck-bill axe	7.23		0.19		Oren, 1971
Tell Beit Mirsin	Macehead	0			0	Kelso, 1943
Tell Fara 550	Dagger	0	1–5	0.5	0	McKerrell, 1975
Tell Fara 554	Dagger	1–5	0	0	0	McKerrell, 1975
Tell Fara 556	Dagger	0	1–5	0	0	McKerrell, 1975
Tell Fara 551	Dagger	>10	0	0.5	0	McKerrell, 1975
Tell Fara 1021	Dagger	1–5	1–5	0	0	McKerrell, 1975
Tell Fara 555	Awl	1–5	0.5	0	0	McKerrell, 1975
Tell Fara 550	Awl	0	0	0	0	McKerrell, 1975
Tell Fara 556	Awl	0	0	0	0	McKerrell, 1975
Tell Fara 556	Awl	0	0	0	0	McKerrell, 1975
Tell Fara 551	Awl	5–10	0	0	0	McKerrell, 1975
Tell Fara 551	Awl	0	0	0.5	0	McKerrell, 1975
Tell Fara 555	Awl	0	0	0	0	McKerrell, 1975
Tell Fara 555	Awl	0.5	0	0	0	McKerrell, 1975
Tell Fara 556	Awl	1–5	0	0	0	McKerrell, 1975
Tell Fara 556	Awl	5–10	0	0	0	McKerrell, 1975
Tell Fara 555	Awl	5–10	0	0.5	0	McKerrell, 1975
Tell Fara 556	Awl	0	1–5	0	0	McKerrell, 1975
Tell Fara 550	Awl	0	1–5	0	0	McKerrell, 1975
Tell Fara 558	Awl	1–5	1–5	0.5	0	McKerrell, 1975
Tell Fara 567	Awl	5–10	0	0	0	McKerrell, 1975
Tell Fara 555	Awl	5–10	0	0	0	McKerrell, 1975
Tell Fara 556	Awl	0.5	5–10	0	0	McKerrell, 1975
Tell Fara 545	Awl	0	0	0	0	McKerrell, 1975
Tell Fara 545	Awl	0	0.5	0	0	McKerrell, 1975
Tell Fara 556	Awl	1–5	0.5	0	0	McKerrell, 1975
Tell Fara 551	Awl	0	1–5	0	0	McKerrell, 1975
Tell Fara 551	Awl	0	0	0	0	McKerrell, 1975
Tell Fara 545	Nail	0	0	0	0	McKerrell, 1975
Tell Fara 551	Nail	1–5	0	0.5	0	McKerrell, 1975
Tell Fara 556	Nail	0	1–5	0	0	McKerrell, 1975
Tell Fara 556	Nail	1–5	0	0	0	McKerrell, 1975
Tell Fara 556	Nail	0	1–5	0	0	McKerrell, 1975
Tell Fara 556	Needle	0	1–5	0	0	McKerrell, 1975
Tell Fara 545	Needle	1–5	0	0	0	McKerrell, 1975
Tell Fara 556	Pin	0.5	0	0	0	McKerrell, 1975

		%Sn	%As	%Pb	%Zn	
Tell Fara 551	Wire	0	1–5	0	0	McKerrell, 1975
Tell Fara 556	Wire	0	1–5	0	0	McKerrell, 1975
Tell Fara 551	Cross	0	1–5	0	0	McKerrell, 1975
Tell Fara 551	Ring	5–10	5–10	0	0	McKerrell, 1975
Gaza(BM 135632)	Dagger	1–5	0.5	0	0	McKerrell, 1975
Gaza(BM 135633)	Dagger	0.5	1–5	0	0	McKerrell, 1975
Gaza(BM 135631)	Dagger	1–5	0.5	0	0	McKerrell, 1975
Gaza	Adze	0	0.5	0	0	McKerrell, 1975
Gaza(BM 135637)	Arrowhead	1–5	0	0	0	McKerrell, 1975
Gaza(BM 135634)	Arrowhead	0	0	0	0	McKerrell, 1975
Gaza(BM 135635)	Arrowhead	0.5	0.5	0	0	McKerrell, 1975
Gaza(BM 135643)	Needle	0.5	0	0	0	McKerrell, 1975
Gaza(BM 135644)	Needle	0	0.5	0	0	McKerrell, 1975
Gaza(BM 135645)	Needle	0	1–5	0	0	McKerrell, 1975
Gezer(BM 129408)	Spearhead	1–5	0	0	0	McKerrell, 1975
Jericho G37	Dagger	0	8.6			Moorey & Schweizer,1972
Jericho G37	Rivet to above	0	0.2			Moorey & Schweizer,1972
Jericho G37	Pin	11.0	0			Moorey & Schweizer,1972
Jericho G37	Pin	17.5	0			Moorey & Schweizer,1972
Jericho	Flat Axe	>10	0	0	0	McKerrell, 1975
Jericho	Flat Axe	1–5	1–5	0	0	McKerrell, 1975
Jerusalem(BM 129404)	Dagger	0.5	0.5	0	0	McKerrell, 1975
Lebanon ?	Dagger	0.01	1.5	0.7	0.5	Tufnell, 1962
Megiddo 911D	Axe	9.2	0	2.2	0	Guy & Engberg,1938
Megiddo 911D	Axe	10.8	0	0.9	0	Guy & Engberg,1938
Megiddo 911C	Spearhead	0.8	0	1.3	0	Guy & Engberg,1938
Megiddo 911D	Spearhead	5.7	0	0.8	0	Guy & Engberg,1938
Megiddo 911D	Spearhead	7.7	0	0.4	0	Guy & Engberg,1938
Megiddo 911D	Spearhead	10.7	0	0.4	0	Guy & Engberg,1938
Megiddo 911D	Dagger	1.4	0	0.8	0	Guy & Engberg,1938
Megiddo 911D	Dagger	8.7	0	3.1	0	Guy & Engberg,1938
Megiddo 911D	Dagger	1.2	0	3.4	0	Guy & Engberg,1938
Megiddo 911D	Dagger	9.4	0	0.4	0	Guy & Engberg,1938
Palestine	Duck-bill axe	1–5	0	>10	0	McKerrell, 1975
Samieh	Dagger	12.8	2.3			Moorey & Schweizer,1972
Samieh	Dagger	0.8	0.6			Moorey & Schweizer,1972
Zorah (BM 1937·5·5·49)	Spearhead	0.5	0	0	0	McKerrell, 1975
Zorah (BM 1937·5·5·50)	Spearhead	1–5	0.5	1–8	0	McKerrell, 1975

Slag from an ancient copper smelter at Timna, Israel

Charles Milton, Edward J. Dwornik, Robert B Finkelman and Priestley Toulmin III

ABSTRACT

Slag from ancient copper-smelting near Timna, Israel, consists essentially of skeletal fayalitic olivine crystals, near $(Fe_{1.64}Mg_{.09}Ca_{.04}Mn_{.22})SiO_4$, in a matrix consisting mainly of feathery (also skeletal) ferro-hedenbergite crystals, near $(Fe_{.54}Ca_{.36}Mn_{.09})SiO_3$, with minor glass. Computation of analytical data, supported by visual evidence of thin sections, indicates the olivine content of the slag is near 20 percent, ferro-hedenbergite near 55 percent; not discernible optically and probably occluded in a glassy matrix, is about 25 percent of mainly anorthite-rich feldspar and minor magnetite, with perhaps disordered silica, SiO_2. Also probably present, but only to be inferred from chemical data, are very minor quantities of iron-titanium oxides (magnetite-ilmenite?) and calcium phosphate (apatite?). Oxyhydroxides of iron – indicated by X-ray evidence, as well as by chemical analysis – represent the effects of exposure of the slag to weathering on the desert floor for millennia.

The texture of the slag resembles the 'spinifex' or 'crystalline' quench' structure described in Archean ultra-mafic flows in Africa, Australia and Canada[1,2] . The slag contains metallic copper pellets with a high (20%) iron content, much of which has exsolved as tiny blebs of magnetic α-iron. The compositions of both the silicate and metal phases of the slag are consistent with fusion temperatures in the range of 1350–1400°C. It is not believed that the copper ingots produced here contain nearly as much iron as the pellets but if they did, then secondary refining, as proposed by Rothenberg[3] and later denied by Lupu and Rothenberg[4], becomes a tenable hypothesis. If contemporary copper artifacts do contain so much iron, and later ones do not, a refining stage must be considered. We ascribe the high-iron copper pellets in the slag to the quenching (ie. pouring) of the slag at high temperature (~1350–1400°C) whereas ingot copper allowed to cool slowly under a slag blanket would permit separation of dissolved iron into the slag, leaving a copper with but a few percent iron. The slag copper also contains appreciable (~1 percent) lead; with zinc and cobalt (both~0.5 percent). All three may be related to the local occurrence of mottramite, a hydrous lead zinc copper vanadate and of possibly cobaltiferous, manganese oxides, and oxy-hydroxides.

Consideration of the smelting process as indicated by the slag study is consistent with the conclusions of Beno Rothenberg (from archaeological study of the smelter sites) that the operations were small-scale, conducted in small furnaces in the sand, rather than in large furnaces as previously held by Nelson Glueck; the small size of the molten slag batches would rapidly chill and favour skeletal crystallization of olivine and pyroxene. On the other hand, the relatively high temperatures indicated by our data may suggest more elaborate smelting apparatus.

INTRODUCTION AND ACKNOWLEDGMENTS

Near the present copper mining operations at Timna in Southern Israel (Negev) are the ruins of a recently-discovered copper smelter originally thought to have been worked around 1000BC[3] one of the many popularly ascribed to the biblical King Solomon[5] Later, Lupu and Rothenberg[4] state that 'The ancient copper industries in the Arabah were Royal Egyptian enterprises', terminating in the reign of Ramses V, in the year 1156 BC.

We now know that there were at least three important periods of copper production at Timna:– a Chalcolithic one dated to about the end of the 4th millennium, the main Egyptian one mentioned above and a Romano–Byzantine one. These periods seem to be correlated with the availability of the local acacia wood for charcoal.

Reports[6] mention extensive underground workings at Timna and credit Nelson Glueck with first realising the nature of the slag strewn on the desert floor. Until recently, the earliest date of mining has been in doubt, However, Giles and Kuijpers[7] report copper mining in Northern Anatolia, Turkey, assigned on the basis of radiocarbon dating of probable mine timber, to an age of 2800 years BC; and Wertime[8] records copper artifacts, crucible fragments, some with adhering copper slag, and a small copper smelting pit, from Tal-i-Iblis in southwestern Asia (Iran), dated as early as 4100–4000 BC. However, such findings do not necessarily imply underground mining, nor does copper production necessarily require prior mining – ore or native copper lying on the ground would suffice for smelting or melting operations. Timbering, however, does imply underground mining operations. Strewn about the desert surrounding the now-fenced-in ruins at Timna is black stone, in masses up to a kilogram or two, which is the slag from the Egyptian period copper smelting operations. Similar copper mining and smelting continued in the region in Roman and Byzantine times. (Tylecote, Lupu and Rothenberg[3], 1967[9]) describes piles of large flat pieces of slag, and much smaller crushed fragments strewn about the smelting sites; the crushing was to release copper pellets embedded in the slag. Present-day copper production at Timna is from a different type of ore by a leaching process in which no slag is made.

There are no contemporary written records describing the ancient copper metallurgy, and therefore not unnaturally there is some uncertainty and controversy as to how the metal was extracted from the ore. It is therefore important that available evidence – in this case the slag with its adherent metallic copper – be examined carefully for whatever information it may reveal. This requires an understanding, first, of the nature, origin, and geological features of the ore itself, and of the materials used in its reduction to metal; and second, the physical-chemical processes used in extraction of copper from such ore. The first is fairly well understood and has been well described by numerous writers; some citations are given below. The second requires rather detailed investigation using modern analytical techniques – petrographic-microscopical, chemical analysis employing conventional 'wet' methods, emission spectrography, electron probe, and X-ray diffraction.

Furthermore, the analytical data must be considered in the light of related phase-equilibrium systems: available diagrams of relevant systems therefore are of interest, and are cited below. Because such methods of studying a slag may not be familiar to many archaeologists, the experimental and interpretative data have been given in some detail.

Although the material studied – the slag with its included copper – is rather variable and heterogeneous, so that, strictly speaking, the results of precise analytical techniques would apply only to the particular specimens studied, it is reasonable to assume that these specimens are sufficiently representative so that broad conclusions can be drawn.

Unlike most archaeological artifacts, whose external aspects provide an adequate base for their interpretation, the nature, origin and history of ancient slags can be determined only by advanced modern methods of material analysis; it is hoped that the present study will demonstrate both the applicability and the necessity for employing such procedures.

We are indebted to Dr Uri Wurzburger, Dr Yuki Bartura, and Mr Joseph Mart, of the staff of the Timna Copper Mines, under whose guidance the site of the ancient smelter was visited in 1970 and specimens collected. Professors Arnulf Muan and Joseph W Greig of the Pennsylvania State University; Professor Alexandru Lupu of the Technion, Israel Institute of Technology, Haifa, and Professor Robert Maddin of the University of Pennsylvania, commented helpfully during this study, and Dr Michael Fleischer of the United States Geological Survey critically and most instructively reviewed earlier drafts of this paper. Dr Strathmore R B Cooke and Professor George Rapp, of the University of Minnesota, kindly gave us access, prior to publication, to their extensive data on ancient copper-slags from Mediterranean and Middle Eastern localities, other than Israel.

However, responsibility for the contents of this report is solely the authors.

CHARACTER OF ORE AT TIMNA, ANCIENT AND MODERN

On a practical, as well as scientific basis, two distinct types of copper ore are found in the Rift Valley of southern Israel – one is the anciently-worked, weathered sulfide ore, associated with much iron and manganese, disseminated in Upper Nubian sandstones; the other, non-sulfide, mostly copper silicate with little, if any, iron and manganese, replacing carbonate beds in Cambrian dolomitic sandstones; this is the ore being worked today. Although this ore crops out in the Timna area, it could not be worked by the metallurgical processes that were effective for the sulfide type ore. Both types of ore also exist on the eastern (Jordanian) side of the Rift Valley (Wadi Araba) in the vicinity of the Wadi Abu Khusheiba, a few kilometers southwest of the ruined city of Petra, and some fifty kilometers north of Timna[10] There is no record, however, of any ancient mining at these localities.

This note, therefore, related to the anciently-mined nodular ore disseminated in the surficial 'Upper Nubian Sandstone' around Timna, described by Slatkine[11], and to the slag produced from it in ancient times. Slatkine describes this ore as mostly sulfides, chalcocite with covellite, rarely native copper, and minor cuprite, malachite and azurite, atacamite, chrysocolla, and dioptase; limonite is abundant. Slatkine interprets the origin of the ore as follows:

'La plupart des nodules cuprifères du 'White Nubian Sandstone' sont des plantes fossiles. Les tissus de ces plantes ont été substitués initialement par de la pyrite, (qui peut être d'origine biochimique). Les formes intactes des structures ligneuses laissent supposer que la matière végétale, au moins dans certains des tissue les plus résistants, n'a subi ni ecrasement, nii putrefaction. Les végétaux pyritisés ont ultérieurement été remplacés totalement ou en partie par de la chalcosine, precipitee à partir de solutions acides diluées, suivant un processus de réduction bien connu. Les concrétions cuprifères d'origine non végétale se sont formés probablement par un processus identique. Il n'y a pas d'indication que de la chalcosine aie ete precipitée directement par de la matière organique en decomposition; mais il est possible que dans certains cas de la chalcosine aie été précipitée directement par de la matière organique déjà carbonifiée. Un abaissement ultérieur du niveau hydrostatique a provoqué l'oxidation partielle ou totalle des minéraux cuprifères at ferrifères. Dans l'etat de nos connaissances actuelles la source du cuivre doit être attribuée au lessivage des niveaux cuprifères plus anciens.'

METALLURGY OF ANCIENT ORE

A comprehensive account by Beno Rothenberg[3] of the archaeology of copper mining and smelting in Israel reviews previous work, and goes into detail as to procedures and materials employed. He stresses that because of its low copper content (a few percent) the ore now mined could not be used in any known ancient smelting process; and that the actual ancient mining sites discovered by him contain copper in the form of nodules with some 40–50 percent copper. He took issue with Glueck holding that the copper production did not involve construction of stone furnaces or clay crucibles. However, later Tylecote, Lupu and Rothenberg[4], show a fairly elaborate 'Reconstruction of a 12th Century BC furnace'; and Lupu[12] refers to a 'Chalcolithic smelting process . . . stone-built furnace . . . the first furnace discovered . . . '.

Rothenberg's 1962 paper[3] detailed the procedures thus: a mixture of hand-separated ore and quartz was crushed and winnowed in the strong prevailing northerly winds. This was done in shallow depressions in the sandstone, 1–1/2 meters in diameter. The mixture, thus enriched by removal of much of the quartz, was further ground and crushed, and limonite, acacia charcoal, and limestone were added. The charge was smelted using charcoal in open fires in a shallow cavity in the ground (actually, as shown later, in open furnaces); the molten copper sank into a conical hole or concave cavity at the bottom. Air blown by bellows through clay tuyeres supplied oxygen for the combustion of the charcoal; temperatures considerably higher than the melting point of copper, 1083°C, where thus attained. (Our studies indicate that temperatures around 1400°C were attained). The oval crude copper ingots, weighing 5–10 kg, were later re-melted and refined and cast in northern Israel, in the Jordan Valley[3].

Rothenberg[3] does not describe the copper produced at Timna, other than that it was 'rough', and required further processing before it could be used. Lupu and Rothenberg[4] refer to a 'high content of iron in the copper', and give three analyses of copper pellets from the slag, with compositions Cu 89–92 percent, Fe 3.71–6.37 percent, and Pb 0.7–1.2 percent; they also show a polished section of the copper, 'showing much oxides'. Referring to the chemical composition and micro-structure of the copper they state 'there are large quantities of copper oxide, some lead and inclusions of silicates'.

We have examined copper pellets from the slag, and find a micro-structure similar to that shown in Lupu and Rothenberg's[4] Figure 24, and corroborate their iron and lead values. However, we were surprised to find that the pellets showed a very strong magnetism, and we have further identified the abundant gray-blue (in reflected light) component of the pellets as not copper oxide, but metallic iron (Table 4). The copper pellets are malleable, and possibly could have been used without further processing, as Lupu and Rothenberg[4] emphatically state 'Metallic copper . . . was produced . . . and no further smelting process was required for the products of the 'Arabah sites' '. However, previously Rothenberg[3] held that 'The Iron Age smelters of Wadi Timna and Wadi Amram produced ingots of rough copper which must have been taken to an industrial centre for melting, refining, and ultimately casting into copper implements'.

Certainly, if further examination of copper pellets from these slags, or of copper ingots from the ite, should show magnetism to be a general character of the ancient Timna copper, then the contemporary copper artifacts made from this copper should also be examined for magnetism. If they too are magnetic, then Lupu and Rothenberg's statement may be accepted. Should they be non-magnetic, then some kind of secondary refining of the copper must have occurred. No such artifacts are available to the writers; but a collection of a hundred or more ancient Graeco-Roman copper and bronze coins was tested for magnetism; none was found. However, the Timna copper is many (perhaps ten) centuries older than these coins, and may represent a much more primitive state of metallurgical art.

In this connection, it might be of interest to note the magnetism of certain ancient bronzes (R J Gettens, personal communication, 1973); and the magnetism of many ancient (possibly Bronze Age) coppers from India and the Mediterranean region, caused by substantial iron (at least 1 percent) formed by reduction or iron oxide during the copper smelting (Strathmore R B Cooke and Stanley Aschenbrenner, personal communication, April 14, 1975).

CHARACTER OF THE SLAG

The slag specimens studied are black, heavy, and porous, with many gas-holes up to two or three centimeters in diameter, evidence of marked fluidity in the liquid state. Broad glistening areas suggest a platy crystalline development; and in the vugs, platy lighter coloured crystals are occasionally seen.

McLeod (1962) observes that the slag is very variable, sometimes glassy, sometimes partly unfused sandstone. Some of the specimens examined by us appear to have been uniformly well fused, though now partially crystallized or devitrified, while others contained unassimilated fragments of rock.

The finely crushed slag (presumably free from metallic copper-iron) is in part attracted by a magnet, hence the presence of magnetite (Fe_3O_4) is assumed. There are also physico-chemical reasons for expecting some magnetite to be present in the slag, because iron-rich silicate melts as a rule are not wholly reduced. Also, the chemical analysis of the slag (Table 2) indicates enough ferric iron to form some 5 percent magnetite (some probably oxidized to lepidocrocite and akaganeite).

In thin section the slag appears as shown in Figures 1 and 2. About a fourth of the slag consists of a skeletal growth of almost colourless olivine crystals in a brownish, generally isotropic matrix, much of which shows obscure feathery anisotropic crystallization (ferro-hedenbergite). A similar texture has been described by Naldrett[1] in fayalitic smelter slags, and by Pyke, Naldrett, and Eckstrand[2] in ultra-mafic Archean flows from Ontario.

Tylecote, Lupu, and Rothenberg[9] suggest that the Chacolithic smelting at Timna may have been of such a primitive character as not to have produced ingots, but rather beads (prills) disseminated in the slag, which was then broken up to release the beads which were then melted together in a crucible. But they show the construction of a "12th Century BC" furnace, with a sophisticated tuyere-bellows system, and slag overlying a 'plano-convex ingot'.

CHEMISTRY OF THE SLAG

A representative sample of the slag was analyzed using the 'rapid' procedures developed by Shapiro and Brannock[13]. The results are presented in Table 1. Electron microprobe analysis of thin polished sections of the slag olivine and matrix (Table 3), and X-ray diffraction patterns of the analyzed slag, gave data from which it was possible to identify the major crystalline phases observed in the slag

TABLE 1
Chemistry of the slag – chemical analysis

Chemical Analysis of Slag	
SiO_2	42.4%
Al_2O_3	4.6
Fe_2O_3	3.5
FeO	31.0
MgO	1.5
CaO	8.6
Na_2O	.59
K_2O	1.1
H_2O^+	.40
H_2O^-	.08
TiO_2	.22
P_2O_5	.71
MnO	4.5
CO_2	.05
Cl	.08
Cu	.56
	99.89
O = 2Cl	.02
	99.9

Notes on chemical analysis

Methods used in analysis (except for Cl and Cu) are those described in USGS Bulletin 1144–A, supplemented by atomic absorption.

Chlorine was determined spectrophotometrically after a Na_2CO_3 fusion by complexing with mercury derived from mercuric thiocyanate and then determining the released thiocyanate with ferric ion derived from ferric ammonium sulphate. The sample size was 500 mg. Copper was determined by atomic absorption spectrometry after decomposition with HF, HNO_3 and $HClO_4$. The sample size was 500 mg.

Analysts:

G Chloe, P Elmore, J Glenn, J Kelsey; and H Smith and E Lillie (Cl and Cu), US Geological Survey.

TABLE 1A
Computation of chemical analysis of slags

A 'norm' calculation of the chemical analysis of the slag, Table 1, gives the following:

	wt. percent			
$CaO{\cdot}SiO_2$ wollastonite	13.3			
$MgO{\cdot}SiO_2$ enstatite	3.8			
$FeO{\cdot}SiO_2$ ferrosilite	29.3			
$MnO{\cdot}SiO_2$ rhodonite	8.4			
ferro-hedenbergite		54.8		$(Ca_{.26}Mg_{.09}Fe_{.51}Mn_{.15})SiO_3$
$2FeO{\cdot}SiO_2$ fayalite		19.6		
			74.4	
$Na_2O{\cdot}Al_2O_3{\cdot}6SiO_2$ albite	5.1			
$CaO{\cdot}Al_2O_3{\cdot}2SiO_2$ anorthite	6.7			
$K_2O{\cdot}Al_2O_3{\cdot}6SiO_2$ orthoclase	6.6			
feldspar			18.4	
$FeO{\cdot}TiO_2$ ilmenite	0.4			
$3CaO{\cdot}P_2O_5$ 'apatite'	1.7			
$FeO{\cdot}Fe_2O_3$ magnetite	5.1			
			7.2	
			100.0	

– olivine, ferro-hedenbergite, possibly silica. A calculated 'norm' (Table 1A) helped to infer the probable presence of minor phases such as feldspar and iron oxide, and served as a control on calculation of the chemical composition and quantity of glassy matrix. The norm is an idealized assemblage of phases that would result from the equilibrium crystallization of the slag; discrepancies between it and the actual assemblage or mode, arise principally from failure to equilibrate, due to rapid crystallization. Thus, for example, we know that with the 19.6 percent normative fayalite there is Ca_2SiO_4, Mg_2SiO_4, and Mn_2SiO_4 in the olivine, increasing the olivine content of the slag and correspondingly reducing the calculated amount of ferro-hedenbergite somewhat. However, it appears safe to conclude from these data that the slag consists of olivine near fayalite in composition and pyroxene near ferro-hedenbergite; with some 25 percent of glassy or irresolvable matrix material.

Lupu and Rothenberg[4] give nine partial analyses of Timna slag; of these, four are of the poured slag and five are of slag solidified in the furnace. Of the four, two are very high in MnO (32.3 and 40.4 per cent, respectively), and quite different from the material we have examined; they will not be considered further.* The other two are more comparable with the Timna slag of this report. Table 2 gives these compositions.

Table 3 gives the electron probe analysis of olivine and of the matrix, which is mostly ferro-hedenbergite.

The analysis was performed using an energy-dispersive system of a MAC electron probe. Analyzed reference standards used included GSE glass, synthetic tektite, augite, olivine and pyroxene as well as quartz, corundum, and periclase. The system was operated at 15kV and 10^{-9} amps with a Li-drifted silicon detector with resolution of about 190 e V. Counting interval was 50 seconds.

Because of the intimate intergrowth of prismatic olivine crystals and matrix phases, raw intensity data for constituent elements showed some variation. Visually distinguishable matrix phases (light tan to dark brown in colour; clear, feathery and ropey in texture) could not be related to compositional variation. The analyses listed below are averages for twelve carefully selected analysis sites and are good to within ± 10 per cent.

Because of the relative diameter of the electron beam some of the matrix, adjacent to the olivine, is included within the actual volume.

*The surprisingly high MnO in the two slags reported by Lupu and Rothenberg[4] implies a variation in the metallurgy from that considered in this report; we understand that this is now being investigated further.

with the actual volume of sample excited. This was substantiated by the detection of Al and K (neither of which is present in the olivine structure) during analysis of the olivine. Results for Mg in the matrix were erratic and low; although some magnesian component is doubtless present in the ferro-hedenbergite, the probable presence of erratically distributed small olivine grains makes a quantitative estimate impossible.

Because of inherent uncertainties – variability of sample, and analytical difficulties – it is not practicable to compute relative proportions of olivine, pyroxene, silica, etc., in the slag, a rather heterogeneous assemblage of phases in imperfect equilibrium. However, a good idea of the relative proportions of the dominant olivine and pyroxene can be obtained from Figures 1 and 2.

TABLE 2
Comparison of three analyses of Timna slag

	Lupu and Rothenberg[4] 4	8	*This report* (Table 1)
SiO_2	40.2	34.2	42.4
Al_2O_3	2.2	9.6	4.6
Fe_2O_3	–	–	3.5
FeO	43.3	36.5	31.0
MnO	1.7	7.6	4.5
CaO	9.3	5.2	8.6
MgO	0.5	1.6	1.5
Cu	0.61	0.28	0.56
S	0.10	0.17	–
	97.––	95.––	96.––

TABLE 3
Electron Probe Analysis of Olivine and Matrix

	OLIVINE Weight percent	Corrected for 1/8 matrix	Atoms per atom Si	*MATRIX* Measured
SiO_2	32.8	30.2	1.0	49.3
Al_2O_3	–	–	–	6.1
FeO	50.7	54.4	1.51	21.6
MgO	1.4	1.6	.08	–
CaO	2.9	1.3	.05	13.8
K_2O	–	–	–	1.4
MnO	6.8	7.1	.20	3.7
	94.6	94.6		95.9

Olivine components normalized to 100%:
$(Fe_{1.64}Mg_{.08}Ca_{.06}Mn_{.22})SiO_4$

Fe_2SiO_4	82 mol %
Mg_2SiO_4	4 mol %
Ca_2SiO_4	3 mol %
Mn_2SiO_4	11 mol %

The matrix composition corresponds to:

K–feldspar	8.4 wt %
Ca–feldspar	13.3 wt %
Pyroxene $(Ca_{.36}Fe_{.54}Mn_{.09})SiO_3$	72.8 wt %
SiO_2	5.5
	100.0

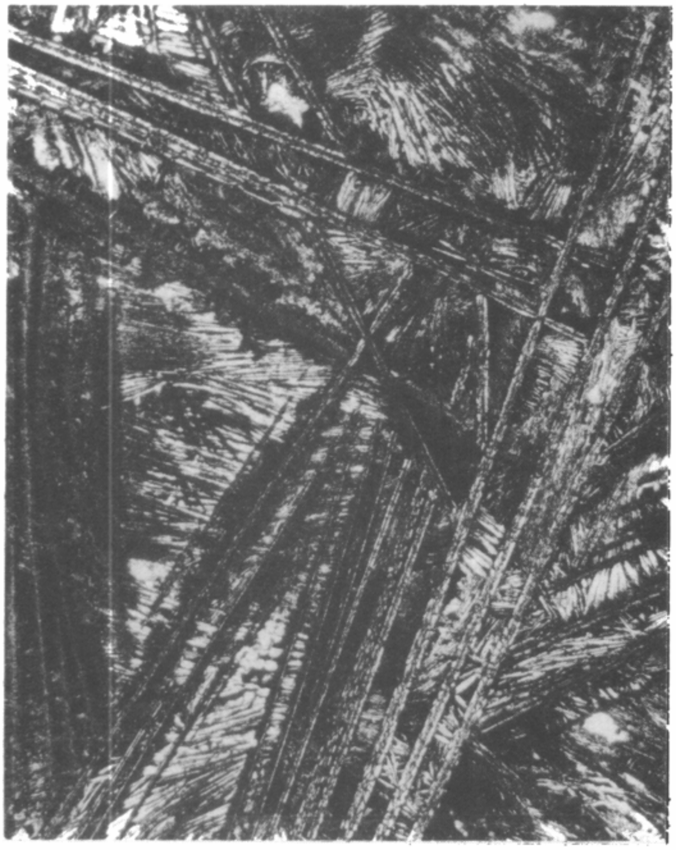


Fig.1 Slag, Timna, Israel

Crossed nicols x 12. The slag consists largely of prismatic skeletal crystals of approximately $Fe_{1.64}Mg_{0.09}Ca_{0.05}Mn_{0.22}SiO_4$ (olivine near fayalite) in a glassy matrix, part of which crystallized to ferrohedenbergite.

X–RAY DIFFRACTION DATA FROM THE SLAG

X-Ray patterns from multicomponent systems such as a slag are, not surprisingly, very complex.

However, with information available from other analytical techniques an attempt can be made to interpret these patterns. Diffractometer tracings obtained on the powdered slag samples gave more than 50 peaks with d-spacings greater than 1.54A. Comparison with X-Ray patterns of mineral standards confirms that the slag contains major fayalitic olivine and hedenbergite, and suggests the presence of several other phases, including a calcium-rich feldspar, iron oxyhydroxides (lepidocrocite and akaganéite) and a discordered silica phase, perhaps similar to that described by Roy[14]. The presence of trace amounts of certain other phases, likely to be present, such as magnetite and calcium phosphate, may be obscured by peaks from the major phases. Also, a very few relatively weak lines were not identified. These results are in reasonable agreement with the petrographic data (Figures 1 and 2) and the chemical analyses.

SMELTING OPERATIONS INFERRED FROM STUDY OF SLAG – THE SILICATE PHASES

An interpretation of the slag and the smelting process may be based on the phase-equilibrium relations in the ternary system CaO–'FeO'–SiO_2.

The components SiO_2, CaO, FeO, and Fe_2O_3 make up some 85.5% of the slag; with MnO, which behaves chemically very much like FeO in this system, 90% is accounted for. Consideration of the phase-equilibrium relations in the system CaO–FeO–SiO_2, taking into consideration the probable effects of additional components, suggests that **if crystallized slowly and at equilibrium**, the completely molten slag would begin to crystallize about 1350–1400°C with the separation of tridymite, a form of SiO_2, followed at slightly above 1100°C by a ferro-hedenbergite-like phase (actually an iron-rich wollastonite solid solution, which on further cooling inverts to ferro-hedenbergite), and fayalitic olivine. These three phases would be the final products of crystallization at a temperature probably somewhat below 1100°C. Rapid chilling of a melt of the composition of the slag, however, would probably suppress nucleation of the tridymite, ie., the melt would supercool, and the more readily nucleated ferromagnesian silicates would be the first major crystalline phases to form.

Residual melt would be enriched in SiO_2, and a poorly crystallized, partly glassy, SiO_2–rich residuum would be expected to fill the interstices between the larger pyroxene and olivine crystals, in agreement with the observed relations. Indeed, despite the clear textural (and archeological!) evidence of very rapid crystallization, it is interesting to note that Fe+Mg distribution between the pyroxene and olivine (see Figure 3) is very close to that between the analogous phases in the final stages of equilibrium crystallization of the simple system CaO–FeO–SiO_2.

It thus appears that the slag behaved qualitatively very much like a similar composition in the simpler ternary system, and we may use the phase relations in that system, with due caution, in interpreting the origin of the slag. Because of its rapid cooling, the slag most likely did not begin to crystallize until well below its liquidus temperature of 1350–1400°C; on the other hand, it must have been heated to that temperature or above if it was ever completely liquid, as it appears to have been.

It may be noted that the experimental data of Wones and Gilbert[15] requires that the partial pressure of oxygen at the magnetite-fayalite-quartz equilibrium (∼1100°C at the liquidus in this system) be only $10^{-9.75}$ atm. Thus, rather strongly reducing conditions were required.

Because of the smallness of the furnace charge and the relatively small temperature interval between 1125°C and the maximum heating of the charge, the time of crystallization of the olivine was brief, resulting in skeletal crystals (Figures 1 and 2) and not the equant or euhedral crystals found in igneous rocks that have cooled slowly over long periods of time. Similar considerations apply to the pyroxene of this slag.

Although Nurse and Midgely[16] observe that 'iron-akermanite' ($Ca_2Fe^{II}Si_2O_7$, an end-member of the melilite group) is not stable at liquidus temperatures in the system CaO–'FeO'–SiO_2, the addition of relatively minor amounts of alumina apparently does stabilize melilites at the liquidus (Muan and Osborn[17]). The absence of such a phase in the Timna slag is doubtless due in large part to rapid cooling and further supports the interpretation of crystallization history in terms of the 'simple' system CaO–'FeO'–SiO_2.

Tylecote, Lupu and Rothenberg[9] describe the slags as consisting of fayalite glass with crystals of melilite. They also report that the iron in the copper prills is not present as metal, but is in 'entrapped fayalite slag' or 'FeO'. Lupu[12] reports that the copper 'drops' in the slag contained some

(a) Skeletal olivine, showing inclusions of matrix material within crystals; and obscurely crystalline matrix.

(b) Single skeletal olivine crystal. The upper left field is dark, indicating non-crystallization of the matrix. Incipient crystallization is shown lower right.

(c) Twinning (?) in olivine. A possibly similar 'penetration twin' was described in a New Zealand alkali basalt (Brothers,[21]). Note glassy matrix.

(d) Olivine, showing characteristic terminations, indicative of abrupt termination of olivine crystallization; ie., solidification of molten slag to glass.

Fig.2 All x 230, crossed nicols.

cuprous oxide and lead. The papers here cited give no evidence for fayalite glass, melilite, 'Fe0', or cuprus oxide in these slags, and we have found none in the specimens examined by us.

COPPER–IRON PELLETS IN THE SLAG

The metal pellets occur as rare, randomly dispersed, irregularly shaped, rounded grains ranging in size from 1mm to 2mm in diameter in this specimen. On weathered surfaces of the slag, they appear as green knobby protrusions with red nuclei. A polished surface reveals an internal structure consisting of irregular subspherical 'blebs' of highly reflective metallic iron (diameter 20–100μm) heterogeneously dispersed in the copper matrix (Figure 4). Rare anhedral silicate inclusions also occur. Modally, they are composed of 70 percent copper, 29 percent iron, and 1 percent other phases.

Some of the results of our study of the iron-bearing copper pellets of the Timna slag are summarized in Tables 4 and 5. It is clear that the inclusions in the copper pellets examined here are indeed iron and are different from those examined by Lupu and Rothenberg[4], furthermore, this iron itself contains some copper. Table 5 gives the gross composition of the iron-bearing copper pellet, determined spectroscopically: the Fe content of 10 or more percent is confirmed by visual inspection (cf. Figure 4) and also by X-Ray fluorescence analysis of a copper pellet about 5mm in diameter, which gave a bulk composition of approximately 80% Cu, 20% Fe. Further, microprobe analyses of the Fe-rich phase in the pellet show a composition of approximatley 4% Cu, 96% Fe.

It is also of interest to note the unusually high Co content of the metal pellets (Table 5), which considerably exceeds those mentioned as anomalously high (0.2%) by Maddin and Muhly[18]. The substantial lead, zinc, cobalt and nickel, as noted by Talbot[19] have marked effects on the solubility relations in the copper-iron system.

Examined in the light of the known phase-equilibrium relationships in the system Cu-Fe (Figure 5), these textural and compositional relations suggest the following history. The lowest temperature at which a mass with bulk composition 20% Fe, 80% Cu can exist as a completely melted liquid is about 1400°C. Allowing for imprecision in sampling and analysis, and the possible effects on the liquidus of minor and mixed elements, it seems reasonable to postulate that the belbs were heated to 1350–1400°C. From this temperature down to 1094°C (in the pure Cu–Fe case) the composition of crystalline metal phase with which the liquid would be saturated is around 9% Cu, 91% Fe. No such phase has been seen by us, and it is probable that the copper-rich liquid metallic droplets were not saturated with an iron-rich metallic phase when the slag was poured and quenched. These droplets, on being cooled rapidly below 1094°C (again, for discussion purposes, in the pure system Cu–Fe), would crystallize to an aggregate of crystalline copper and γ–iron, the latter containing in solid solution some 4–6% Cu, decreasing with temperature.

If equilibrium were maintained, the γ–Fe would invert to α–Fe at about 850°C, expelling most of its dissolved Cu in the process. This inversion, however, is very sluggish, in a matrix of copper, whose crystal structure is the same as that of γ—Fe. Cold-working is generally required to force the transition in metallurgical experiments[20]. The Cu-rich composition of the exsolved iron blebs in the Timna copper pellets suggests that inversion to α–Fe took place at a temperature well below that at which diffusion could effectively remove this excess Cu. Neither the resolution of our microprobe nor the precision of our diffraction measurements is sufficient to determine whether the iron phase is metastably Cu-rich or has further sub-microscopic particles of metallic Cu.

TABLE 4
X–Ray powder patterns for iron in Timna slag copper pellet, and for pure α–iron

Iron in Timna slag copper pellet*		*α– iron (Shannon et al, 1955, XRPD 6–0696)*		
I	d	I	d	hkl
Weak	2.10 (strongest Cu line is 2.09)			
Strong	2.03	100	2.0268	100
Weak	1.45	19	1.4332	200
Medium	1.195	30	1.1702	211
Med., broad	1.02	9	1.0134	220
		12	0.9065	310
		6	0.8275	222

*Analysis of this iron gave Fe 96.1± 0.3 percent, Cu 3.8± 0.3 percent. The analysis was made with an MAC microprobe operating at 15kV and 4 x 10^{-9} amperes. A LiF crystal and pure metal standards were used. Several 30 second counts were taken on a number of individual grains. Corrections were made for background and absorption. Also, see Table 5.

TABLE 5
Semiquantitative spectroscopic analysis of copper pellet from Timna slag

Cu, Fe	>10 percent	Mo	500 ppm
Pb	1 percent	Ge	300 ppm
Zn, Co	0.5 per cent	Ag	200 ppm
Ni	0.3 percent	Mn	50 ppm
Si, Ca	0.15 percent	Ba	30 ppm
Na	0.05 percent	V	15 ppm

not detected: Mg, Ti, As, Au, B, Be, Bi, Dc, La, Nb, Pb, Pt, Sb, Sc, Sn, Sr, Te, U, W, Y Zr, A1, K, P, Ce, Ga, Hf, Li, Re, Ta, T1, Yb

Detected, but only trace: Cr

Norma Rait, US Geological Survey, Analyst

Tylecote, Lupu and Rothenberg[9] give four analyses of 'copper prills and drops', with copper (89–92 percent), iron (5.0–9.7), and lead (0.2–1.2) present in all four, and one with 0.01–01 percent sulfur.

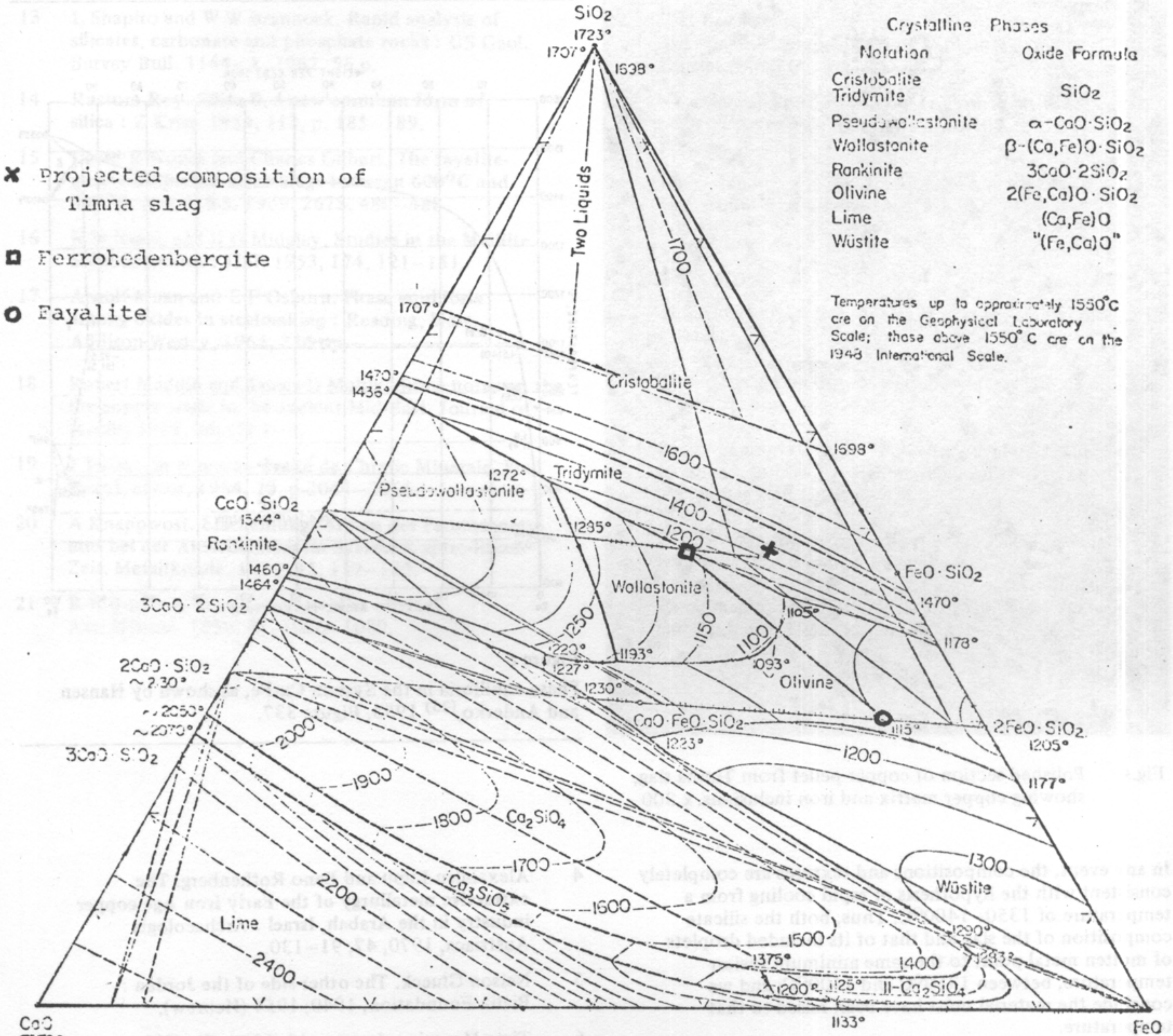


Fig.3 Phase equilibria in the System CaO–'FeO'–SiO_2 in equilibrium with metallic iron. The light triangle connecting SiO_2, an iron-rich pseudowollastonite and an iron-rich olivine represents the phases in equilibrium with melt at the 1105°C reaction point. Because the Timna slag (X) plots within this triangle, the corners of the triangle represent the phases to which it would have crystallized under equilibrium conditions. The actual compositions of the pyroxene (□) and olivine (O) in the slag reflect disequilibrium, principally failure of tridymite to nucleate, but the fact that the line joining the actual phases is so nearly parallel to the equilibrium line strongly suggests equilibration with respect to Fe-Mg distribution between melt and both crystalline phases. The phase diagram is simplified from that of Levin et al,[22] Figure 586.

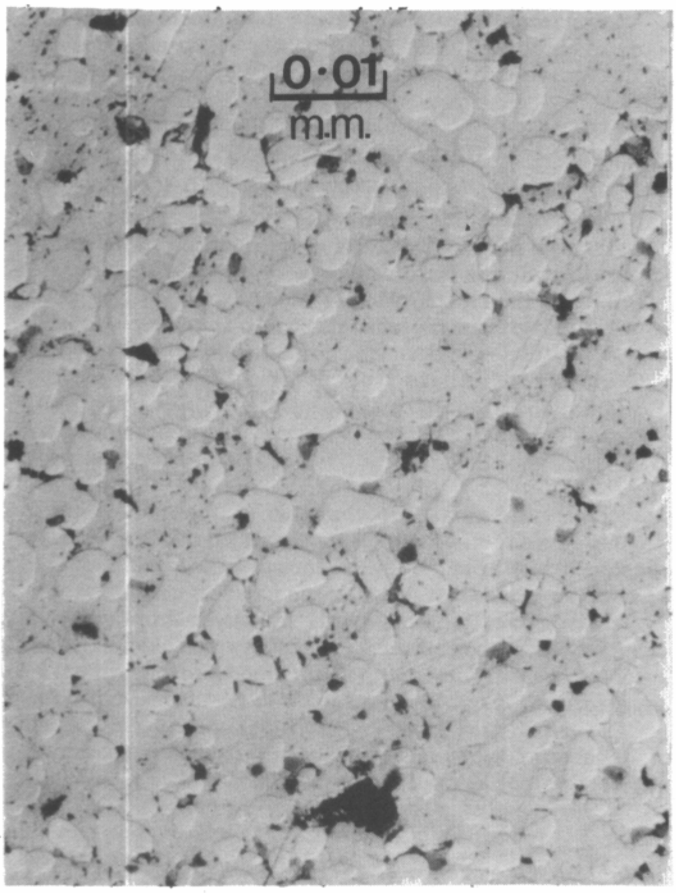


Fig.4 Polished section of copper pellet from Timna slag, showing copper matrix and iron inclusions. x 300

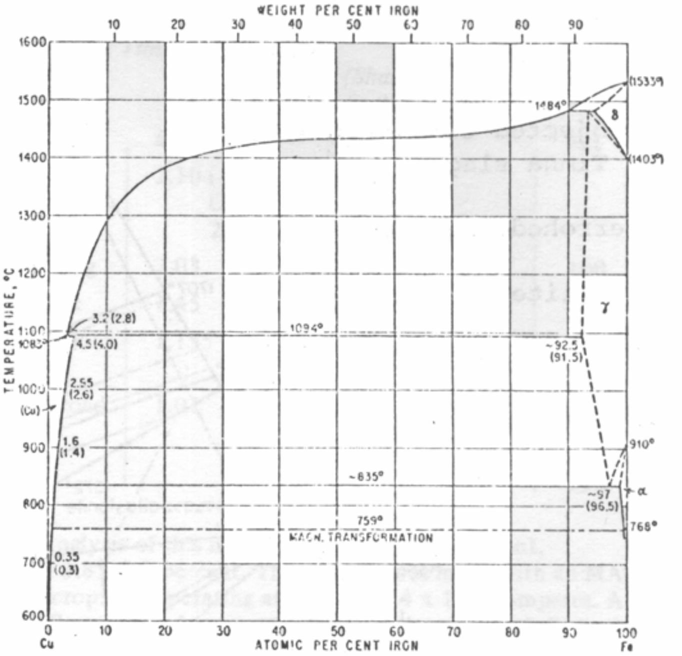


Figure 5

Phase equilibria in the System Cu-Fe, as shown by Hansen and Anderko,[23] 1958, Figure 337.

In any event, the compositions and textures are completely consistent with the hypothesis of rapid cooling from a temperature of 1350–1400°C. Thus, both the silicate composition of the slag and that of its included droplets of molten metal point to the same minimum fusion temperature, between 1350°C and 1400°C; and we conclude the material must have been raised to that temperature.

This reconstruction of the ancient metallurgy supports the conclusions of Rothenberg[3] rather than those of Glueck, as summarized in Rothenberg's paper[3]: the copper smelting was on such a small scale as to rule out elaborate furnace construction. Simple reduction in open depressions in the sandstone surface as proposed by Rothenberg would account for the features of the slag here described, although special care may have been required to maintain the very reducing conditions required.

REFERENCES

1 A J Naldrett. **Archean ultramafic rocks: Canadian Contributions**, No. 10 to the Geodynamics Project, 1972, p.141–151.

2 D R Pyke, A J Naldrett and O R Eckstrand, **Archaen Ultramafic Flows in Monro Township**, Ont. : Geol. Soc. America Bull. No 84, 1973, p 955–978.

3 Beno Rothenberg. **Ancient copper industries in the western Arabah** : Palestine Exploration Quarterly, 1962, **94**, 5–71.

4 Alexandru Lupu and Beno Rothenberg. **The extractive metallurgy of the Early Iron Age copper industry in the Arabah, Israel** : Archaeologia Austriaca, 1970, **47**, 91–130.

5 Nelson Glueck. **The other side of the Jordan** : Bialik Foundation, 1940; 1954 (Hebrew).

6 Time Magazine, January 13, 1975, **The Oldest Mine?** p.65.

7 D L Giles and E P Kuijpers. **Stratiform copper deposit in Northern Anatolia, Turkey : Evidence for Early Bronze I (2800 BC) Mining Activity** : Science, 1974, **186**, 823–825.

8 Theodore A Wertime. **The beginnings of metallurgy; a new look.** *Science,* 1973, **182**, 875–887.

9 R F Tylecote, A Lupu and B Rothenberg. **A Study of Early Copper Smelting and Working Sites in Israel.** JIM, 1967, **95**, 235–243.

10 F W Prokop and Schmidt–Eisenlohr, **Erfahrung bei der Untersuchung von Kupfervorkommen in Wadi Araba, Jordanien** : Erzmetall, 1966, **19**, 111–120.

11 A Slatkine. **Nodules cuprifères du Neguev Meridional (Israel)** : Bull. Research Council of Israel, Section G, Geosciences, 1961, **10G**, 292–301.

12 Alexandru Lupu. **Metallurgical aspects of Chalcolithic copper working at Timna, Israel** : Bull. HMG 1970, **4**, 21–23.

13 L Shapiro and W W Brannock. **Rapid analysis of silicates, carbonate and phosphate rocks** : US Geol. Survey Bull. 1144–A, 1962, 56 p.

14 Rustum Roy. **Silica 0, a new common form of silica** : Z Krist, 1959, **111**, p. 185–189.

15 David R Wones and Charles Gilbert. **The fayalite-quartz-magnetite assemblage between 600°C and 800°C.** Am. J. Sci. 1969. **267S**, 480–488.

16 R W Nurse and H G Midgley. **Studies in the Melilite Solid Solutions** : JISI, 1953, **174**, 121–131.

17 Arnulf Muan and E F Osborn. **Phase equilibria among oxides in steelmaking** : Reading, Mass., Addison-Wesley, 1965, 236 pp.

18 Robert Maddin and James D Muhly. **Some notes on the the copper trade in the ancient Mid-East,** Journal of Metals, 1974, **26**, (5) 1–7.

19 J Talbot. in Nouveau Traité de Chimie Minerale, Paul Pascal, editor, 1964, **20**, p 2064–2066.

20 A Knappwost. **Erscheinungsformen des Paramagnetismus bei der Ausscheidung im System Kupfer-Eisen:** Zeit. Metallkunde, 1954, **45**, 137–142.

21 R N Brothers. **Penetration twin in olivine:** Am. Mineral. 1959, **44**, 1086–1089.

22 E M Levin, C R Robbins and H F McMurdie. **Phase diagrams for ceramists:** 1964, Columbus, Amer-Ceramic **Soc.**, 601 pp.

23 Max Hansen and Kurt Anderko. **Constitution of binary alloys:** New York, McGraw-Hill, 1958, 1302pp.

24 Th. G Sahama and Kai Hytonen. **Calcium-bearing Magnesium-iron olivine:** Am. Mineral 1958, **43**, 862–871.

ILLUSTRATIONS

1 Thin polished section of slag, showing skeletal olivine crystals.

2 Thin polished section of slag showing details of olivine crystallization.

3 Phase diagram of CaO–'FeO'–SiO_2 system (oxide phase in equilibrium with metallic iron) in relation to Timna slag composition.

4 Polished section of copper pellet from slag showing copper matrix and iron inclusions.

5 Phase diagram of Fe-Cu system as shown by Hansen and Anderko, 1958, Figure 337.

Crucibles from a Roman settlement in Germany

H G Bachmann ©

Material Investigated

During excavations at Nida-Heddernheim near Frankfurt-on-Main in 1961 by the city's museum for prehistory, a large number of crucibles and crucible fragments was found in the basement of a workshop building *(Figure 1)*. Pottery finds place the metallurgical material into the 2nd century AD; related relics, like furnaces or moulds were missing[1]. To find out what metals or alloys had been melted in the crucibles, the author was asked to analyse a selection of the material.

The following samples (inventory no.: alpha 20 221) were chosen for this study (colour classifications after MUNSELL SOIL COLOR CHARTS[2]):

Sample 1 : crucible sherd, convex-concave, 65 x 40 x 10 mm, outer side: 5 YR 6/1 to 6/2 = light grey to pinkish grey; inner side: vitrified and slagged, brown to green.

Sample 2:: crucible sherd, 50 x 45 x 13 mm, outer side like sample 1; inner side: 7.5 YR 6/2 = pinkish grey; slightly slagged.

Sample 3 : crucible sherd, 70 x 55 x 17 mm, outer side same as samples 1 and 2; inner side like sample 2.

Sample 4 : crucible sherd, 63 x 63 x 13 mm, outer side like samples 1, 2 and 3; inner side like samples 2 and 3.

Sample 5 : "earth" filling from large lidded crucible (cf. Figure 1, centre).

Sample 6 : crucible with circular cross-section, pear-shaped (cf. Figure 1, right background), volume ca. 80 cc; outer side like sample 1, partly glazed and vitrified; inner side: dark brown with traces of adhering slag.

Methods of Investigation

From all samples (except no. 5) fractions of the slag crusts were removed. The powdered material was submitted to semi-quantitative x-ray fluorescence analysis (XFA). Registration was limited to elements of atomic order above 22 (ie. XFA in air). The "earth"-sample no. 5 was analysed as found. All the samples were more or less contaminated with top soil. Quantitative analyses were, therefore, thought unnecessary. The results obtained are summarized in Table 1.

In addition to XFA, samples 3 and 4 were investigated by x-ray diffraction (Guinier technique). The phase composition of the two samples is very similar. They consist of quartz, SiO_2, lead carbonate, $PbCO_3$, and oxides of the spinel type

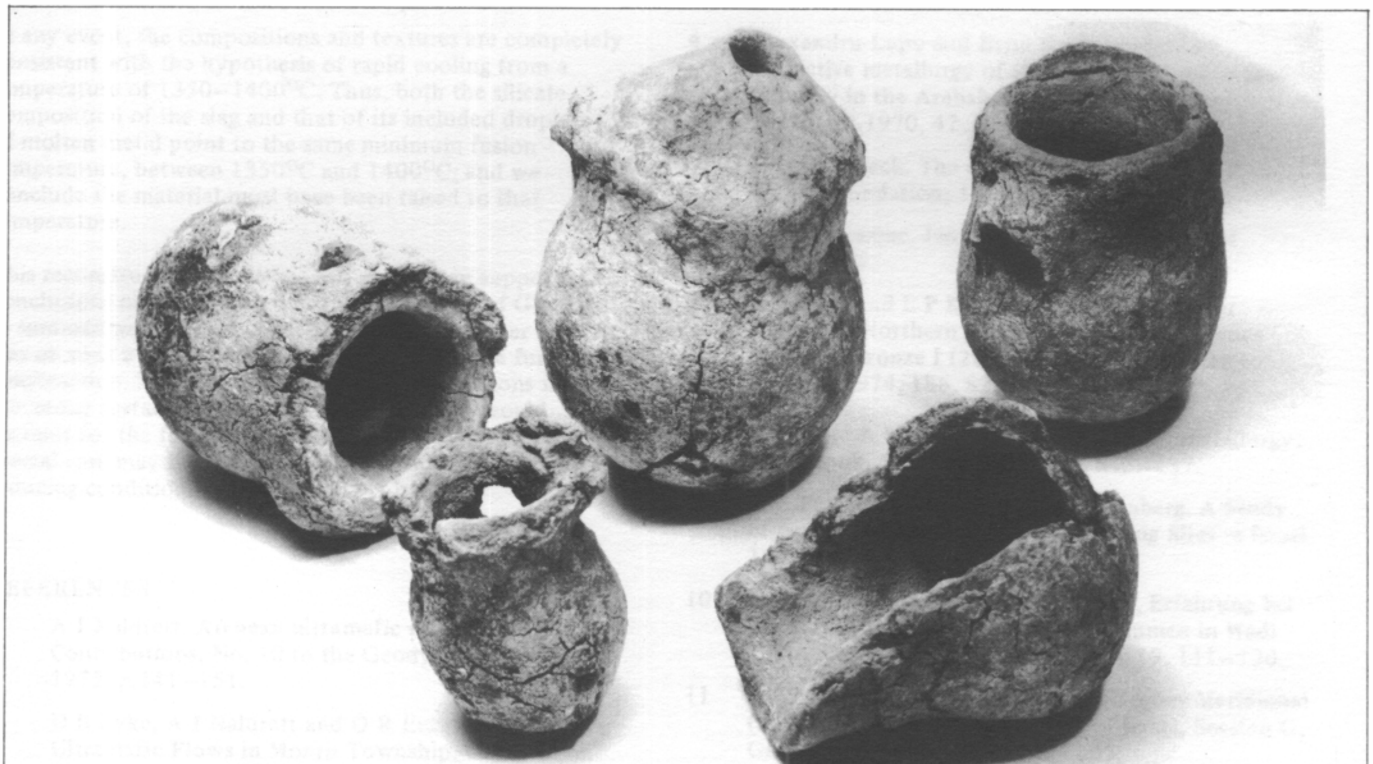


Figure 1

Crucibles from Nida-Heddernheim near Frankfurt-on-Main; scale 1 : 2.2

(Fe_3O_4 and isomorphous compounds with slightly varying lattice constants). Admixture of small amounts of copper oxides, Cu_2O, and CuO, is probable. Silicates could not be identified with certainty, they may, however, be present in small amounts.

Results

Though it has been shown by Tylecote[3], that certain copper ores can be smelted in crucibles, the occurrence of the material and its composition point to melting rather than smelting. The elements present in the samples: lead, copper, tin and zinc indicate the types of alloys melted. The foundry-workshop in which the crucibles were used and discarded probably specialized in the manufacture of small objects, votive figures, applications or the like. Perhaps, scrap metals and/or pre-melted alloys provided the basic raw materials. A lead bar, also found in the excavated area, fits well into this picture. In the four slags analysed, lead is the dominant metal.

The other elements noticed, like iron, manganese, nickel etc. are certainly not intentional additions to the alloys produced. They are impurities either present in the metals used for melting or they are introduced into the slags from the refractory material of the crucibles The elements strontium, zircon, rubidium etc. are associated elements typical of sediments. Iron in small amounts is omnipresent in most non-ferrous metals as well as ceramic raw materials.

Prior to melting, the crucibles were probably not completely filled with pieces of metal. To prevent excessive oxidation during heating and melting, the metal charge had to be covered with charcoal powder (burning to carbon monoxide), sand (slagging the impurities) or similar agents. Slagged inner linings of the crucibles indicate that oxidation was not prevented altogether. The slag layer of low specific weight formed on top of the heavier alloy. The viscosity of the slag could vary, but a slag layer floating on top of the molten metal was normally encountered. Construction of the crucibles had to take this into account.

The pear-shaped vessels (the German excavators coined the phrase "melting pears" for these crucibles) have no milk-pitcher's spout for pouring the molten metal like many of the crucibles shown in the compilations by Tylecote[4] and Coghlan[5]. All the specimens from this site which are still intact, have a circular hole pierced into the upper third of the vessels (with the exception of the lidded type, cf. below). This constructional feature must have helped to hold back slag layers or crusts when emptying the molten metal into the moulds. The highly viscous or even solid slag layer (phase analysis: free silica and spinels) could not pass through the narrow pouring hole and remained inside the crucible. A very similar type of crucible was found at the Roman castellum of Rheingonheim near Ludwigshafen-on-Rhine[6]. It was used for the same purpose and contained fragments of "bronze".

One of the crucibles from Nida-Heddernheim was lidded and had a slightly protruding spout at the join of lid and the actual crucible. The lid is firmly attached to the crucible, though there is little doubt that the vessel was first filled with the melting charge and after that the lid with its circular hole in the centre was put on and joined to the crucible with wet clay. This lidded type somewhat resembles a lidded crucible from Dinas Powys, Glamorgan, dating from the 7th century AD; cf. Tylecote[4]. The hole in the lid was perhaps used to insert a rod for stirring the contents during heating and melting or to help retain slag crusts. If this type of crucible was meant to be used for more than one melt, the lid had to be removed after cooling for cleaning and refilling. Despite this shortcoming, the lidded type had the advantage of keeping the heat in better than the open type and at the same time reduce surface oxidation.

Table 1

Sample No.	Main Elements	Minor Elements	Traces
1	Pb, Cu	Sn, Fe, Zn	Sr, Ni, Mn
2	Pb, Cu	Fe, Zn, Sn	Mn, Sr
3	Pb, Cu	Fe, Zn, Sn	Sr, Mn
4	Pb, Cu	Fe, Zn, Sn	Sr, Ni
5	Fe, Cu	Pb, Sn, Zn,	Mn, Ni, Zr, Rb, Co
6	Cu, Fe	Sn, Zn, Pb	Mn, Ni, Zr, Sr

References

1. Fundberichte aus Hessen, 2, 1962, 212.
2. Munsell Soil Color Charts, 1971 ed., Munsell Color Div., Kollmorgen Corp., Baltimore.
3. R F Tylecote, JHMS 8, 1974, 54.
4. R F Tylecote, Metallurgy in Archaeology, 1962, 130-135.
5. H H Coghlan, Notes on the Prehistoric Metallurgy of Copper and Bronze in the Old World. Pitt Rivers Museum Occasional Papers in Technology No.4, 1951, 70-73.
6. O Roller, Pfalzer Heimat 8, 1957, 60-61.

The minerals of south-west Scotland

James Williams © **ADDRESS GIVEN AT 11th ANNUAL CONFERENCE AT DUMFRIES IN SEPTEMBER 1975**

The area I shall consider in the present discussion is that more or less covered by the three South-western Scottish counties of Dumfries, Kirkcudbright and Wigtownshire – the 'modern' Region of Dumfries and Galloway. The boundaries of this region are mainly natural ones: on the west the North Channel and on the south the Solway Firth. The eastern boundry is merely that between the counties of Dumfries and Roxburgh.

The basic geology of the area is Ordovician and Silurian sediments. Into these sediments granitic batholiths have been injected – mainly in Devonian times. The main granitic masses include those known as Loch Doon, Cairnsmore of Fleet and Criffel. Subsidiary intrusions occur at Cairnsmore of Carsphairn the Spange Water, Afton Water and the Knipes on the borders of Ayrshire, Kirkcowan and Glenluce and finally the Portencorkrie mass near the Mull of Galloway.

Most of the valleys are filled with Carboniferous and Permian sediments – some sediments of Triassic age are to be found between Annan and Canonbie.

The south-west of Scotland has, in the past, been concerned with Geological research. For example Sir James Hall, a friend and co-worker of Hutton, carried out much original work on the theory of granitic intrusion – especially on the contact zone between the Cairnsmore of Fleet granite and the sediments near to New Galloway. On the side of paleontology it was at Dobb's Linn near Moffat that Lapworth commenced his extensive studies in stratigraphy. At an earlier period Dr Henry Duncan, founder of the Savings Bank Scheme, uncovered numerous animal footprints from the Permian/Triassic sandstones at Corncockle near Lochmaben. In more general terms Patrick Dudgeon of Cargen (1817–95) influenced much 19th century work in the area. As a young man, aged 16, he went out to China and ultimately retired some 16 years later. While in China he acquired a considerable knowledge of mineralogy and this knowledge he exploited during the remainder of a long life. He was a very close friend of Prof. Heddle of St Andrews University and each summer they used to depart on geological excursions in the grand style. Yachts were used extensively and carters and quarrymen employed in large numbers. These trips lasted for several months and many of the fine specimens they recovered may be seen in the Royal Scottish Museum in Edinburgh. Both Heddle and Dudgeon left their extensive collections to this Museum. Although most of these trips were to the Highland and Islands of Scotland some considerable work was carried out on a local basis and geologists were frequent guests at his home near Dumfries. We have already mentioned Heddle as a particularly close friend but people like Harness, Boney and Geikie were frequent guests.

You will have already heard from another speaker of the mineral wealth of the Wanlockhead/Leadhills area. These deposits are mainly of lead, zinc and copper ores. I hope to deal with the occurrence of these and other elements encountered within our area and perhaps give some indication of the richness and variety which exists. However, before we commence on the ores and their extraction, I feel we should mention briefly the abundance of structural materials at one time extracted and exported from this area.

The granites were widely exploited in the past at Dalbeattie and Aird's Point in the Criffel mass and at the small isolated intrusion at Freetown. Much of the material extracted in Victorian times was of a high quality and much in demand as a building and monumental stone. It was used extensively in the London Embankment and the Liverpool Docks – indeed it was the enterprise of the Liverpool Dock Trustees in 1826 which opened the quarries at Craignair near Dalbeattie. Apart from its use as a building stone the granite was much used in the preparation of kerbstones and perhaps even more extensively as setts – the granite setts were distributed very widely and were even sent as far afield as the Argentine and Russia.

The Permian/Triassic sandstones of Dumfries and more particularly those at Corncockle Muir near Lochmaben were very widely used as building stones. At the peak of the industry in the late 19th century perhaps some 190,000 tons were being extracted annually. Although much material was used locally very considerable quantities of stone were sent out of the area, e.g. much of the late Victorian expansion of Glasgow and Edinburgh was built in Dumfriesshire sandstone. This export trade was not confined to Great Britain – the well-known 'Brownstones' of Brooklyn in New York are built, to some extent, with Dumfriesshire sandstone.

Commencing more properly with the mineral wealth of the area I feel we must mention in passing that most precious of metals – **GOLD**. You may have already heard of the mid 16th century extraction of gold at Leadhills and Wanlockhead. This perhaps reached its peak in the reign of James V when something of the order of £100,000 per annum was being extracted: several hundred workers were employed and the search was reputedly halted when wages reached four pence per day!! Much of this 16th century gold was used in the coinage of the day – it has been estimated that perhaps two thirds of the bonnet pieces of James V were minted in Scottish gold: The Scottish regalia is also of Scottish gold.

Our first documentary evidence for gold in this area only carries us back into the medieval period but from archaeological finds it would seem likely that this gold was being utilised by the people of the Early Bronze Age. (A particularly fine gold Lunula of this period was found during last century at Auchentaggart not many miles from Wanlockhead and, although employing decoration and workmanship of an Irish type, is possibly made of local gold.)

Apart from a single 16th century reference to the working of, an auriferous quartz vein in Longcleugh by Bevis Bulmer all the gold extracted was from alluvial deposits. As well as in the Wanlockhead/Leadhills alluvial gold has been recovered from the River Tweed, near St Mary's Loch, close to the Garyhorn Lead Mines at Carsphairn and also in Kirkmaiden Parish in Wigtownshire.

Surface deposits of copper ores, suitable for extraction by Bronze Age man exist in the South-west of Scotland but since no tin deposits exist we cannot be sure that they were utilised in the production of Bronze. Certainly from the presence of moulds for axes and a certain number of hoards of scrap bronze we know that some founding was carried out. In all probability the bronze was imported in ingot form from southern Britain – possibly pure tin was imported and used with local ores to produce bronze but once again we cannot be sure.

Moving into historical times we have a brief mention of mining for copper at Wanlockhead/Leadhills in the mid-16th century. After this we hear little or nothing until the 18th century when there appears to have been something of a boom in exploration work; this applied especially to copper and lead ores. The rapid rise of the Industrial Revolution at this time acted as a strong stimulus but unfortunately not much was achieved in terms of high grade ores in considerable quantities. Much of the material went to be mixed with higher grade ores at the major smelting sites. For example the copper ores from Hestan Island and Balcary in Rerrick Parish went by sea to Swansea. As far as we know, no smelting, on a commercial scale, took place locally. The main mineral encountered was chalcopyrites: This was frequently found in the unoxidised state but the oxidation products, when present, included malachite, azurite, cuprite and chrysocolla. The copper ores are frequently foundl intimately mixed with those of lead and zinc. Mines which have yielded copper ores include Wanlockhead/Leadhills, Garyhorn, Black Craig, Pibble, Lackentyre, Kingslaggan, Balcary, Hestan, Glenstocking, Craigencallie, Culcronchie, Drumruck and Torbeckhill. We have little or no mention of who carried out this work except a fleeting mention to a 'German Company' at Torbeckhill in Annandale during the 18th century.

IRON MINERALS have been extracted in this area for upwards of two thousand years. Our knowledge of prehistoric working of iron is very limited – tap slag and cinder have been recovered, as surface finds, from some of the Iron Age forts in the area (some of these sites saw occupation into the Early Medieval and Medieval times). By the start of the medieval period proper we have more substantial evidence in the results of a small excavation carried out at Millhill near New Abbey in Kirkcudbrightshire. The excavations were carried out in 1965 and the site proved to consist of a low heap some 30m in length x 11m in breadth lying next to the March burn about a mile to the north of New Abbey. A single trench was carried into the side of the heap and showed it to consist mainly of tap-slag with a heavy admixture of ash and charcoal – the charcoal being of hazel and oak.

Although the trench was quite small, by good fortune it exposed a small smelting hearth which measured, approximately, 0.6m in diameter and about 23 to 28cm in depth. The hearth was surrounded by a structure of set stones; the stones of the hearth proper had been lined with clay which, when found, showed a fine yellow-green glaze not unlike that found on medieval lead-glazed pottery and this at least indicates that reasonably high temperatures were achieved.

About 30m to the north a freshly ploughed field yielded a scatter of medieval pottery, probably associated with the habitation site of the iron-workers, which could be dated to the period AD 1200–1300. The report of the excavations was published in 1965 and at that time it was felt that the site possibly represented a small rural (?) family unit which was probably only worked occasionally as the need for a supply of iron arose.

No samples of ore were recovered during the excavations but several veins of low grade haematite are known in the immediate vicinity (Craigend and Mabie). The alternative source of ore would have been bog iron ore or limonite which was much used and readily available in many localities.

Very considerable numbers of possibly similar sites are known to exist in Dumfriesshire and Galloway but a great deal of exploratory work requires to be done before we can assign definite dates to them. At the time of writing the Millhill article the following numbers of sites were known:–

Dumfriesshire	10
Kirkcudbrightshire	10
Wigtownshire	4

As far as iron minerals and their extraction locally is concerned by far the most important mineral is haematite. Iron pyrites, although a common vein mineral, is nowhere abundant enough to warrant extraction and in any case is a much more undesirable ore.

The earliest mine and perhaps the most interesting as far as specimen material is concerned is that at Auchenleck, Auchencairn. The mine was already open in 1843 when Hay Cunningham contributed his 'Geognostical Account of the Stewartry of Kirkcudbright' to the Highland Society's Transactions (Vol.8). He described the mine as being worked by a horizontal adit. In 1845 the New Statistical Account recorded that some 50-70 tons of ore were being obtained weekly from this mine and were being sent chiefly to the Birmingham district. A mining engineer visited the mine in 1863, when it was working, and noted that the ore-bearing ground was some 18m in width – it is perhaps to this great width that the high incidence of subsidence is due. The date of closure is not known but it was certainly abandoned by 1896 when the Geological Survey produced its Explanation of Sheet 5. The spoil-heaps still yield fine small specimens of botryoidal haematite – rarely banded with yellow limonite. A little specular haematite is to be had in cavities. The gangue minerals are barytes and quartz. The barytes is common and is usually an orange-pink in colour. The quartz is mainly of the ferruginous variety but some smoky quartz, and more rarely, amethyst is to be encountered.

The so-called Carsphairn Iron Ore vein is situated high on the ridge to the south of Loch Doon in northern Kirkcudbrightshire. It is a lonely situation some 3½ miles from Carsphairn and the nearest road is at the Garyhorn Lead Mines some 2½ miles distant. Many of the spoil-heaps are at or about 600m above sea-level. The vein has been traced for a length of 2½ miles but it has never been worked on a commercial scale and no ore has been taken from it and smelted. On two occasions extensive trials were made but neither of these led to any development mainly due to the inaccessability of the site.

About 1869 and again in 1876 the Dalmellington Iron Company opened the vein by a series of cross-cuts and small mines and in this way took out some 400 tons of good quality haematite but it was left on the ground as it could not profitably be carried to Dalmellington for smelting.

In 1901 the vein was examined by Colville's of Motherwell and they reported that the Dalmellington Iron Company had driven their mines to a maximum depth of 21m. The haematite was noted as being deposited in a fissure running in a north/south direction – at the southern end the country-rocks are Silurian shales and greywackes but for about a mile at its northern end the vein intersects the Loch Doon granites. In 1901 some drilling trials were carried out and although on some occasions the bore passed through eight foot masses of haematite this was found to be by no means solid. In Colville's opinion much of the fissure is barren and that the masses which occur are small and local in their distribution.

Specimens of haematite – mainly dense and massive in form but sometimes showing the botryoidal habit – may be collected from the old spoil-heaps.

Although only very loosely connected with iron minerals the iron-rich variety of silica known as jasper might be mentioned briefly as it did see some commercial exploitation in the past. The Ayrshire jaspers are well-known but some material from Barlocco Bay near Auchencairn in Rerrick Parish was also used in the manufacture of snuff-boxes in the earlier years of last century.

LEAD MINERALS Perhaps our earliest indications of the industrial extraction of lead in this area were given by the remains of a lead melting furnace found during the excavations at Dalswinton Roman Fort in Nithsdale during the mid-1950's. During these excavations no galena or other lead ores were found and in all probability the furnace was merely used to remelt lead pigs and prepare sheeting for water-tanks etc. It is however just possible that the Romans were using local sources of ore but we shall probably never know exactly. In the medieval period we are on firmer ground and know that in 1239 Sir David Lindsay made a grant of lands in Crawford Muir to the monks at Newbattle Abbey – in this grant mention is made of a mine on the Glengonar Water. That mine had been sunk for lead as appears from a suit raised before the Lord Auditors in Parliament. This was at the instance of Patrick, Abbot of Newbattle, against James, Lord Hamilton, for the spoilation of 1000 stones of lead ore, which he had carried off from the Abbey lands of Friar or Crawford Muir. Lord Hamilton was ordered to restore that quantity of lead ore. During the medieval period much galena was used as 'potter's ore' in the production of lead-glazed pottery.

An intriguing site connected with the medieval extraction of lead is that recorded in 1882 by Patrick Dudgeon of Cargen. At Martingirth near New Abbey Dudgeon had come on a lead smelting site and in examining the slag he found the lead/copper oxidation product linarite. In describing the site he made reference to 'Roman Pottery' but with the confused terminology of mid-Victorian archaeology this can probably be equated with material from the medieval period. The exact position of this smelting site is presently unknown but on the farm of Martingirth a small knoll is still known by the name 'Silver Hill' – could this site therefore have been used to desilver lead? The abbey of Sweetheart is near at hand and before its foundation the lands belonged to Holm Cultram Abbey in Cumberland. Another similar site is known to exist at the neighbouring farm of Woodside but our knowledge of this is even more fragmentary. (The iron smelting site at Millhill is only about ¼ of a mile from the Silver Hill of Martingirth.).

Apart from Wanlockhead/Leadhills no other sites of any size appear to have been utilised until we come to the mid 18th century. The major sites we will touch on are as follows:–

Woodhead (Garyhorn), Carsphairn
East and Black Craig Mines, Newton-Stewart
Pibble Mine
Lackentyre and Kingslaggan, Anwoth
Knockibae, New Luce
Glendinning or Louisa Mine, Westerkirk

WOODHEAD, CARSPHAIRN PARISH. The leadmines at Garyhorn or Woodhead are situated in a lonely stretch of upland a few miles from Carsphairn. They were opened in 1839 by Colonel M Cathcart the landowner of the time. It is possible that they were opened in order to give some form of employment to the tenants on the estate. The most modern equipment was installed: A 10m water wheel drove a crusher and the smelting furnaces were 'on the most approved plan'. Facilities for desilverising the lead were also available. The associated village for the population of 300 was based, to a great extent, on the facilities and practices available at places like Wanlockhead and Leadhills. e.g. a school, school-house and a library were provided. The mine apparently closed down in 1873.

The main ore was galena – associated with zinc blend. Very little in the way of oxidation products were met with. The smelting and desilverisation utilised coal, brought by road, from Dalmellington.

EAST AND WEST BLACK–CRAIG, MINNIGAFF PARISH These mines are situated at the East and West ends of a lead zinc vein which is said to have been discovered by a soldier in 1763. They saw extensive exploitation in the late 18th century and also during the 19th century. Many hundreds of tons of lead were raised annually and apparently the workings extended to 150m in depth. The main lead ore was galena – often intimately associated with zinc blende or sphalerite. The gangue minerals included quartz, calcite and considerable quantities of barytes. In the spoil-heaps, especially those at the east end it is possible to obtain speciments, and these include traces of nickel and cobalt oxidation products.

PIBBLE MINE, KIRKMABRECK PARISH. The mine is situated on the north-west slope of Pibble Hill not far from the now disused Gatehouse Station. Few details of the mine are known in respect to the periods of working. The principal minerals were galena and sphalerites – some copper ores were also present. Some quite interesting secondary minerals have been recorded and these include pyromorphite, anglesite, cerussite, linarite and lanarkite. Minerals of a similar type were recorded at the two nearby mines of **LACKENTYRE** and **KINGSLAGGEN in ANWOTH PARISH.** These mines were both quite small but did produce an interesting suite of minerals: oxidation products of lead and copper – perhaps the most interesting record is that of lead molybdate or wulfenite.

KNOCKIBAE IN NEW LUCE PARISH is one of the few metalliferous mines in Wigtownshire and unfortunately I must admit that I am completely ignorant as to the minerals found and the periods of working.

Finally we must make brief mention here of the **GLENDINNING OR LOUISA MINE IN WESTERKIRK PARISH.** This mine is primarily known as a source of antimony minerals and these we shall detail later. Zinc and lead minerals however do occur and during the 19th and 20th centuries saw some considerable extraction – as far as can be determined far in excess of the weight of antimony produced.

ZINC MINERALS occur locally intimately associated with lead minerals and no mines were ever opened expressly for the extraction of zinc ores. In early days the zinc minerals were regarded as waste and discarded on the spoil-heaps: when, towards the end of the 19th century, there arose a demand for zinc it was mined at places like Wanlockhead, Leadhills, Glendinning, East and West Black-Craig. Many of the old spoil-heaps were reworked and considerable quantities of zinc minerals recovered in that way.

ARSENIC MINERALS have never been commercially extracted in this area although a vein of mispickel is known at Talnotry near the Palnure Burn. The lode is said to occur along the junction of the Cairnsmore granite with the Silurian slages and greywackes. It runs in a North-east direction and is about 1.2m in width; it consists mainly of vein-quartz with scattered strings and patches of mispickel up to 5 cm in width. An analysis of the ore proved about 22% of arsenic and the vein was opened up about 1900 when a shaft about 20m deep was sunk and a level driven a short distance. A few tons of ore were raised but none was taken away and the mine was soon abandoned.

NICKEL MINERALS. Some of the oxidation products of nickel, occasionally accompanied by cobalt oxidation minerals, are known at Cassencarrie, Pibble, Southwick, Wanlockhead/ Leadhills and at Talnotry. At Talnotry, as well as mispickel, there is an occurence of nickeliferous pyrrhotite mixed with some niccolite. Although the vein has been sampled no ore has ever been raised.

MOLYBDENUM MINERALS occur with some rarity in this area: they have been recorded at Almorness, Screel, Lotus Hill, Lower Porterbelly, Lackentyre and Pibble. The occurrence at Almorness is as the sulphide molybdenite – indeed perhaps some of the very finest Scottish specimens have been obtained from this locality. However, although the vein is marked on the Institute of Geological Science's MS 6" to the mile Geological maps, it has not been located in the field in recent years. This is mainly due to the very difficult terrain and the heavy undergrowth which exists on the Almorness peninsula. On the above mentioned map the vein is mistakenly marked 'Graphite' – there is some evidence to suggest that this molybdenite was mined sometime in the 18th century under the impression that it was in fact graphite.

ANTIMONY MINERALS were occasionally encountered in earlier days during prospect work for lead and other metal ores. They have been recorded at the Glenshanna Burn in Westerkirk Parish, the Knipes (Hare Hill) near New Cumnock, Wanlockhead and at Crawthwaite in Tundergarth parish. The specimens from Wanlockhead were of the lead/antimony mineral jamesonite – they were recovered during normal mining operations last century at the Glen Crieff vein. At Crawthwaite we have some documentary evidence suggesting a trial for antimony sometime prior to 1834 but little is known of the site.

The Knipes or Harehill Antimony Mine gives us something much more substantial to work on although it was only opened as a trial in the 1850's. The vein is near the small Knipes/Harehill granite mass and is 30 to 45 cm in breadth, runs north-south, and is nearly vertical. The vein consists mainly of quartz with strings and masses of ore (stibnite) up to 20cm in thickness. The oxidation products stibiconite, valentinite and kermesite are recorded. Much of the material formerly recorded as cervantite has proved to be stibiconite. No ore has ever been removed from the site – no doubt due to the difficulties of transport (The mine is at 520m above sea-level and approximately 300 feet above the nearest road, Good specimens can be readily obtained.

Lastly we must mention in some detail the Glendinning or Louisa Antimony Mine which is situated at the head of the Glenshanna Burn, a tributary of the Meggot Water, in Westerkirk parish. This mine, which we have already mentioned briefly in connection with lead minerals, deserves more than passing mention as it was the first mine expressly worked for antimony ores in Great Britain.

The vein is at about 80 degrees to the vertical and the walls are horizontally slickensided and about 1.2m apart. The infilling consists mainly of breccia of the country-rock (silurian shales and greywackes) cemented together with calcite and quartz with occasional strings of ore up to 5 cm in width. The primary antimony mineral is stibnite and this occurs in masses and strings. It also occurs intimately mixed with galena and sphalerite – a little iron pyrites and some chalcopyrites also exist. Some poor specimens may be had from the spoil-heaps.

History records that the vein was discovered in 1788. The mine was opened in 1793 by the Westerhall Mining Company which consisted of four shares held thus. – Sir James Johnstone 2, Captain Cochrane 1 and Mr Tait 1. (Could this be Tait of Wanlockhead's 'Tait's Level'?). The mine was worked between 1793 and 1798 when about 100 tons of antimony were raised worth, at that time, £8400. No records of working for the period 1798–1888 are known although a plan prepared in 1868 has been preserved. In 1888 the mine was reopened by Sir Frederick Johnstone but closed again by 1891: during this time some 88½ tons of antimony were produced. Uneconomic transportation being given as the reason for closure. In 1919 a new company was formed, the Westerhall estates having been broken up in the meantime, and they worked the mine up to 1922 and from that time to the present nothing further has been done.

Sir John Sinclair's Statistical Account of 1794 gives a fairly detailed description of the method used to purify and smelt the ore – at this time the antimony was sold either as 'Sulphurated antimony' (purified stibnite) at £42 per ton or else as 'Regulus of Antimony' i.e. the pure metal at £80 per ton.

To produce the sulphurated antimony, the ore was first crushed and washed and then placed in a pot with a perforated base. This pot was then placed inside a second vessel and heated in a furnace. The stibnite having a very low melting point flowed into the lower vessel leaving lead, zinc and other ores behind.

To prepare the 'Regulus' the ore was first crushed and washed and then placed in a crucible together with iron and an alkaline flux – not named in the Account but probably lime. The iron combined withthe sulphur leaving free antimony. The fluid metal was poured into a mould and when cool was removed and again crushed. It was then placed in a second crucible; this time with pure antimony and alkaline flux. After heating in the furnace the molten metal was cast in conical moulds. When cool this procedure resulted in casts of 'Regulus of Antimony' "having the form of a large sugar loaf and a fine starry surface".

During the period 1888–91 the ore was probably dispatched from Langholm to Carlisle using the new railway which had been opened in 1864. The same transportation appears to have applied in 1919–22.

The same Account gives an interesting description of the working conditions prevailing at the time. About 40 men were employed in the mining and smelting and they were accommodated in a new village called Jamestown. For access the company constructed some 3½ miles of road and four stone bridges. A school was built and following the example of Wanlockhead and Leadhills a library was started with a gift of £15 worth of books. By the time the Account was written the total number of volumes had risen to 120. On the closure of the mine the books were moved in 1800 to Kirktonhill and in 1841 they were moved again. On this occasion to the new schoolhouse at Old Bentpath. Finally in 1862 a new building was erected, financed by public subscription, to house the library and this building remains today.

The initial gift of books included, as might be expected, a number of volumes on morals and history but also present were 'Fourcroys Chemestry, Comstead's Mineralogy, Lavoisier's Chemestry and Henkel on Pyrites'.

Returning to the conditions of employment the miners worked a six-hour day and were paid between £23 and £26 per annum. The company contributed £10 per year and the miners 1/– each per quarter to a Welfare Fund for the relief of miners unable to work because of ill-health or old age.

Each miner was allowed to graze a cow at £1 per annum and supply it with hay during the winter at 10/– per annum. He could also cultivate as much land as he required at a rent of 10/– per acre for growing potatoes and cabbages. The company also built a storehouse in which it was intended to keep grain which was bought when cheap during the summer and resold to the miners during periods of scarcity 'at the rate at which it was purchased'.

APPENDIX
(in order of reference in the text)

near New Galloway [Knocknairling] NX614773
Dobb's Linn NT196 157
Corncockle NY086 870
Dalbeathie NX820 607
Aird's Point NX989 660
Creetown NX480 565
Leadhills NS885 153
Wanlockhead NS873 130
Auchentaggart NS813 089
St Mary's Loch NT24/22
Garyhorn Lead Mines NX535 937
Hestan Island NX839503
Balcary NX813 483
Blackcraig NX445 643
Pibble NX 525 607
Lackentyre NX554 574
Kings Laggan NX563 578
Glenstocking NX868 528
Craignecollie NX503 780
Culcronchie NX505 613
Drumruck NX575 628
Torbeckhill NY235 793
Millhill, New Abbey NX963 679
Craigend NX920 695
Mabie NX950 700
Auckenleck, Auchencairn NX773 525
Carsphairn Iron Mine NX505 927
Garryhorn Lead Mines NX535 937
Barlocco Bay NX795 469
Dalswinton Roman Fort NX933 853
Martingirth, New Abbey NX967 681
Woodside NX975 687
Woodhead, Carsphairn NX535 937
East Black Craig NX448 644
West Black Craig NX443 640
Pibble Mine, Kirkmabreck NX525 607
Lackentyre NX554 574
Kingslaggan NX563 578
Knockibae NX192 665
Louisa Mine, Westerkirk NY313 967
Talnotry NX489 715
Cassencarrie NX480 575
Southwick NX915 562
Talnotry NX477 703
Almorness NX835 517
Screel NX797 547
Lotus Hill NX900 683
Lower Porterbelly NX858 657
Lackentyre NX554 574
Pibble NX525 607
Knipes/Harehill NS659 103
Louisa Antimony Mine NY313 967

Report

PIG IRON INGOTS FROM MARYPORT BLAST FURNACE

by Brian Ashmore ©

This report refers to the three cast iron pigs which were the subject of C. R. Blick's letter, 'Maryport Revisited' which was published in the Bulletin for 1973, Volume 7, Part I, pages 43–44.

A. CHEMICAL ANALYSIS

%	NH 1755	NH 1757	NH 1769
Total Carbon	4.20	2.51	3.98
Silicon	0.85	1.65	0.55
Manganese	0.20	0.22	0.18
Sulphur	0.040	0.52	0.046
Phosphorus	0.116	0.163	0.146
Nickel	0.025	0.025	0.020
Titanium	0.017	0.034	0.015
Chromium	0.010	0.010	0.010
Molybdenum	0.006	0.005	0.005
Aluminium	0.004	0.005	0.003
Magnesium	0.01	0.01	0.01
Copper	0.020	0.020	0.018
Arsenic	0.010	0.010	0.010
Tin	0.002	0.002	0.002
Cobalt	0.005	0.005	0.005
Vanadium	0.025	0.025	0.025
Antimony	0.005	0.005	0.005
Lead	0.0002	0.0002	0.0002

Points of note:–

1. High level of phosphorus for local hematite iron shown in all 3 ingots (normally hematite iron contains 0.06% phosphorus maximum).
2. Low carbon and high sulphur contents of sample NH 1757 (c.f. present day blast furnaces where furnace operating problems can result in low carbon associated with high sulphur contents).
3. Residual element levels typical of local hematite iron.

B. METALLURGICAL STRUCTURES

Sample NH 1755

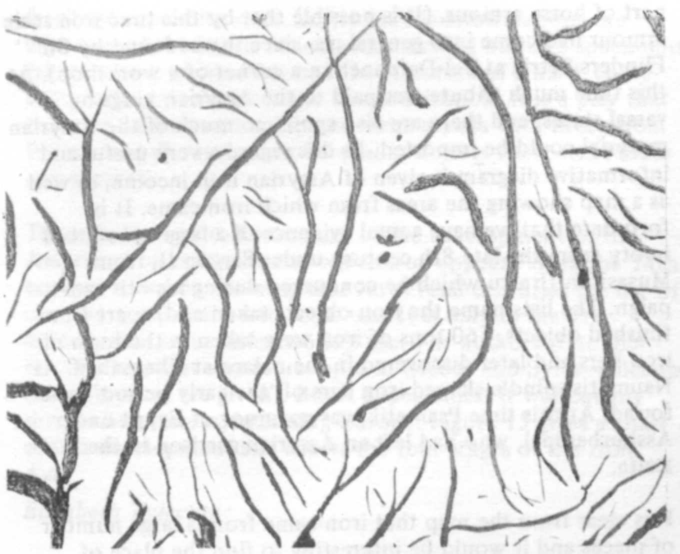
Flakes of graphite in a pearlitic matrix containing phosphide eutectic associated with cementite.

Sample NH 1769

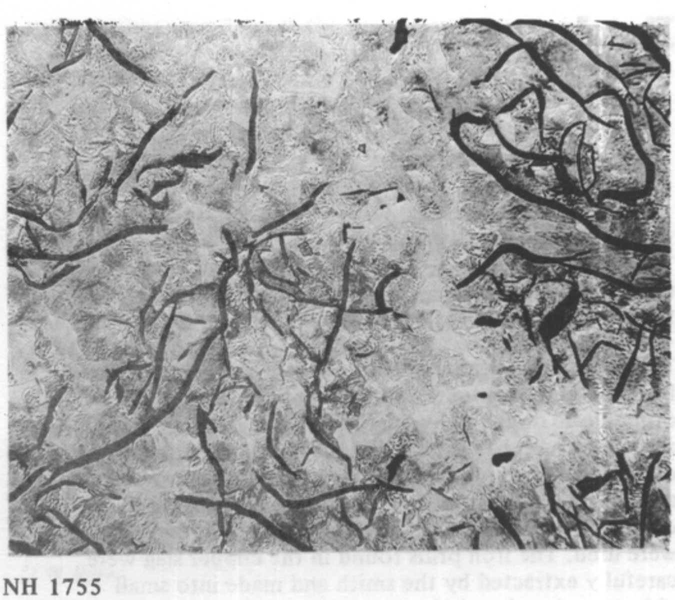
Structure similar to above but containing higher proportion of phosphide eutectic/carbide phase. This would result from the lower carbon and silicon contents of the metal.

Sample NH 1757

White iron structure i.e. cementite and pearlite. This structure would result from the low carbon and high sulphur contents of the metal. The material was porous in nature.

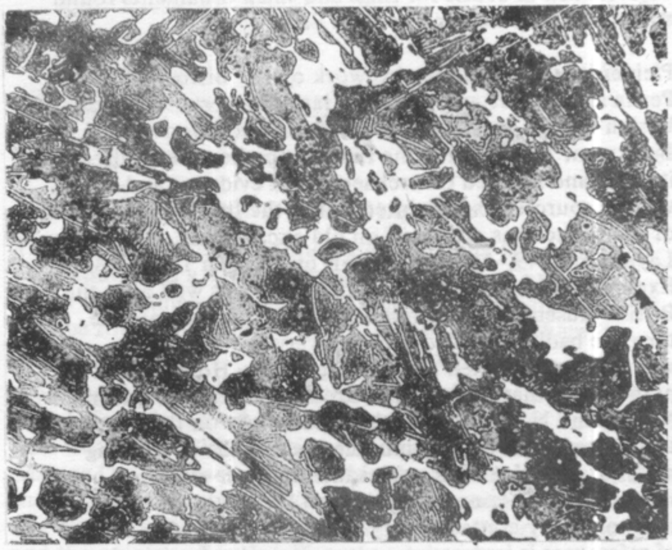


NH.1755



NH 1755

NH 1757



NH.1757

NH 1769

X100 *Unetched*

NH.1769

X100 *Nital*

PIG IRON SAMPLES EX MARYPORT BLAST FURNACE

Book reviews

R Pleiner and Judith K Bjorkman
The Assyrian Iron Age: The History of Iron in the Assyrian Civilization. Proceedings of the American Philosophical Society, Vol. 118, No.3, June 1974, pages 283–313.

The beginning of the use of iron is still very obscure. Iron found in early contexts has hitherto been thought to be of meteoric origin and whilst this is true in many cases, recent research has shown that many of the early iron objects found were made of iron smelted from ore by the accidental discovery of small iron particles during the course of copper smelting in which fluxes containing iron were used. The iron prills found in the copper slag were carefully extracted by the smith and made into small objects such as bezels for rings and small ornaments found sporadically on sites in the Near East.

Pleiner is well known for his work on the history of iron in Persia and Greece and this is his latest important contribution on the Assyrian iron age in collaboration with Bjorkman. This paper is the first comprehensive study of its kind and is based on archaeological evidence and written sources. As is pointed out in the introduction, many of the collections are based on old excavations, the first by Layard in 1849–1859 and, later, by Place in 1867–1870. Examples of these are kept in the Louvre as well as in the British Museum and are not always easy to evaluate, i.e. they are badly corroded iron and very few have been analysed or examined metallographically. Hopefully, it is pointed out that more recent excavations carried out in N. Iraq and N–W Iran will shed more light on the iron technology. However, admirable use is made of existing material even if, alas, it comes mainly from written sources. Pleiner laments the general lack of interest in technology by contemporary scribes and officials. The list of references is impressive and use is made of original sources wherever possible.

Since iron was a new material, it was expensive to produce and mainly reserved for kings and potentates. The authors make the most of the snippets of information available and are able to build up a picture of the slow emergence of the use of iron in Assyria in the late second millennium. We hear of foundation deposits of iron for temples and palaces, ceremonial daggers and the occasional iron-tipped arrowhead. It is suggested that more iron must have been produced than can be gleaned from the administrative texts since at least one Middle Assyrian king employed a blacksmith in his palace. The mention in a single document of twenty blacksmiths in a provincial town is significant, but we are not given a date and this might refer to a much later period.

The next subject is iron in warfare. But it is not until around 700 BC, or later, that mention is made of 97 iron daggers out of a total of 280 of both bronze and iron. Several flange-shaped daggers come from excavations at Nimrud, Fort Shalmaneser and Carchemish, all dated to the very end of the seventh century. There is, however, a greater variety such as lanceheads, arrowheads and battle axes. From the mid-ninth century there is a record by Shalmaneser III of an Urartian campaign which mentions scale armour for horses, and at Nimrud Mallowan records iron plates 7 x 9 cm, claimed to be part of horse armour. (It is possible that by this time iron scale armour had come into general use since it was found by Sir Flinders Petrie at Tel-Defenneh in a corner of a workshop). At this time much tribute was paid to the Assyrian kings by vassal states, and there are also spoils, so much of the Assyrian material could be imported. In this regard a very useful and informative diagram is given of Assyrian iron income, as well as a map showing the areas from which iron came. It is fortunate that we have actual evidence of a large amount of booty from the late 8th century under Sargon II, from Musasir in Urartu which he conquered during his 8th campaign. The lists name the iron objects taken and, apart from finished objects, 160 tons of iron were taken in the form of iron bars and later discovered in the palace at Khorsabad. At Naucratis spindle-shaped iron bars of 'the early period' were found. At this time Psamatik was governor of Egypt under Asshurbanipal, who had left an Assyrian garrison in the Delta.

It is clear from the map that iron came from a large number of places and it would be interesting to find the place of manufacture of the spindle-shaped iron bars. The authors point out that, although evidence of local iron smelting is so far lacking, iron ore deposits are to be found not far from Nineveh and Khorsabad in the northern mountains.

Tools and implements have been found in several excavated sites such as Nimrud and Carchemish. Iron picks and saws are depicted in the palace at Nineveh, carried by workmen; and iron plough shares have been found in the store at Khorsabad. By this time some curved knives, blades and chisels were coming into use.

The use of iron fetters, cuffs and rings is further discussed and Table 1 shows the various rulers who mentioned them in their annals and records. This starts with Tiglath-Pileser after the middle of the 8th century and their number increases under Sargon's reign. This throws an interesting light on the warlike and conquering rulers of Assyria. But we get no information of quantities in the records and none seem to have been recorded from excavations. Figure 11 shows a drawing of fetters after Layard, although it is not clear whether he found such objects. At the end of the 8th century, smaller objects came into general use, such as iron clappers for bronze bells; 80 of these were found at Nimrud. Also found were tripods with bronze legs and joints, bridle-bits, tongs and tweezers. At Khorsabad, several iron wheels with bronze naves, hooks and chains, nails and door hinges were found, thus indicating that the Iron Age was now well under way. We also find iron being used for structural purposes.

By the 8th and 7th centuries, blacksmiths are mentioned in the texts, to distinguish them from coppersmiths, but there were smiths who worked both copper and iron. Palace smiths are mentioned from the 12th century onwards. And by the 7th century there is evidence of a provincial town having 22 blacksmiths, but only 7 coppersmiths.

Iron in medicine is discussed briefly, and also the symbolism of iron; the authors certainly do not leave a stone unturned although they must be aware that information of this kind does not throw much light on iron technology.

There follows a short paragraph on iron production in which it is stated that nothing is known of iron smelting sites. There is documentary evidence on iron ores, such as hematite and magnetite, and various technical details indicate that iron was being produced in Assyria itself. Two implements from Khorsabad have been metallurgically examined in Prague. Both were made of a very pure but soft wrought iron or very mild ferrite-plus-pearlite steel. So far little is known about the structure of the ingots found at Khorsabad but two specimens taken from a pointed bar had the structure of a hard, eutectoid, carbon steel with some decarburization. It is a pity that the authors have not compared these results with those from French and German work on similar objects from other areas and periods.

There follows a short summary of the development of the Assyrian iron civilisation in which iron appears from the 14th century onwards, showing that for several centuries the use of iron remained limited to royal use. It is only in the 7th century that iron came into full use. The authors state that the development was more rapid in Greece and Syria–Palestine (no references are given). But it appears that it was equally slow in other areas, including Europe. Figure 15 gives a chart of this development and shows the four stages of the Iron Age.

Elizabeth Tylecote

Rainer Slotta. **Technical Monuments in the Federal Republic of Germany (in German).** Bergbau-Museum Bochum, *1975; Special publication no.7, 648 pp. 407 photographs. numerous maps. Price DM 48 (about £8.00) (cloth bound).*

This is the first comprehensive summary and survey of the present status of important technical monuments in West Germany.The book,compiled by a young art historian under the auspices of the renowned Mining Museum at Bochum, was issued on the occasion of the Second International Congress for the Conservation of Technical Monuments, held at the said museum in September 1975.

Objects are grouped into the following chapters: mining (34 objects); salt works (18 objects); quarries and lime kilns (11 objects); smelters (51 objects); factories and storage buildings (9 objects); railways (including mountain and suspension railways as well as station buildings) (18 objects); mail and other traffic stations (21 objects); bridges, ferries and river tunnels (25 objects); channels, sluices and locks (25 objects); cranes, light-houses, beacons and sea-marks (33 objects); gas and water reservoirs (20 objects); mills (15 objects). Each chapter is accompanied by a map with entries for all the objects described. Nearly every building or relic is illustrated. The descriptive text and the relevant bibliography are admirably authorative.

The book or rather catalogue is likely to be the standard reference source for anybody interested in German industrial archaeology from Roman times until the beginning of this century. Of course, inspite of the ambitious aims set by the author and his sponsors, the book is not yet a complete coverage of ancient or old industrial monuments still in existence, but it is likely going to be that, if it will be amended in future editions.

Apart from giving the 'status quo', the book will most certainly aid in making people and authorities aware of the value and importance of irretrievable industrial monuments of our past, which have been and still are deplorably neglected and destroyed.

H G Bachmann

John Booker. **Essex and the Industrial Revolution.** Essex Record Office Publications, *No.66 1974. £3.50.*

The first twenty-three pages are devoted to 'The Foundries', as the author sees them as the precursors of the industrial revolution in the county. The earliest Essex foundry was established in Colchester in 1792, and the development of this and the others which followed is described in consderable detail. Two maps show the location of the foundries in 1820 and 1850, with the approximate dates of setting up. Consideration is given to the sources of raw materials, and how they reached their destinations. In this, and succeeding chapters, the products are noted, with their impact on the agricultural, transport, public services, and traditional industries. The illustrations include a nice little plan and elevation of the first Essex foundry, dated 1794, and a woodcut of the Archimedean iron works of William Cottis & Sons, Epping, dated 1893 (their cupola, recently rebuilt, still functions behind the smart shops of Epping High Street, where the Cottis foundry turns out sophisticated castings). The references to particular establishments are somewhat scattered, due to the work being concerned with many aspects of the industrial scene; a good index is provided, and sources are quoted throughout.

H W Parr.

Note

PREHISTORIC MINING IN ANGLESEY

The following account of the Paris and Mona Mines is taken from **Journal of a Tour in Wales, 1796**, by Sir Christopher Sykes of Sledmere, Yorkshire. A copy of the original journal is to be found in the National Library of Wales, where it is NLW Ms 2258C;

p 63 'It is a curious fact that this mine has been worked, not only before the use of gunpowder was known, but also before Iron was used in this Kingdom. I saw several places from whence Ore had been taken within the rock of the Mountain they followed the inclination of the rock and no mark of any tools is to be seen. They are very smooth but discoloured and the opinion of an Intelligent workman here was that fire had been applied to soften it. I cannot say I saw anything to induce me to think so, but all around there was laid parts of oval cobbles split from the ends as they would be if used as hammers, and most of them battered at both ends, these cobbles are not found nearer than the Sea Shore, and were all about 9 in. by 5 by 3 thick, varying a little, they are supposed to have been held on withers as the Blacksmith's hammers are now. It is to be lamented that these old shafts or drifts, if they can be called so, and all the rubbish of these curious split cobbles will all soon be destroyed or buried, only one small corner of the rock is now left, where they are to be found. Possibly this mine may have been opened when the Phoenicians traded to Cornwall for Tin, they can not be of a later date.'

As Sir Christopher predicted, the Parys Mine appears to have swallowed up these early workings. His account, short though it is, does however make a useful addition to the small number of early mining sites so far described from Wales.

*C S Briggs. National Monument Record (Wales)
Aberystwyth.*

Acknowledgement. This tour was kindly drawn to the writer's attention by Miss C. R. Kerkham of University College, Aberystwyth. Miss Kerkham is engaged in a study of manuscript tourist journal literature of the period.

Abstracts

GENERAL

D. Krug. **Metallic coinage materials.** Chemie in unserer Zeit, *1973. 7 (3), 65–74* (In German).

An historical review of the materials used and methods of fabrication includes a table showing copper contents of some coins dating back to 2000 BC.

K.C. Barraclough. **Development of the Cementation Process for Steel Production.** Metals & Materials, *March 1975*, 9 *(2), 51–52.*

This is an extensive summary of a paper given to a Local Section Meeting tracing the evolution of the process over the centuries from Roman times until 1951.

Cyril Stanley Smith. **Metallurgy as a Human Experience.** Met. Trans. A.I.M.E. *1975.* 6A *(4), 603–623.*

The entire history of materials is examined with emphasis upon the structural differences at stages of discovery, development and mature adjustment in analogy with the S–curve of a phase change. The earliest discovery of almost all useful materials or techniques occurred in making decorative objects. Alloying, shaping and welding techniques began in jewellery and sculpture; crystallization, spinodal transformation, and interface energy equilibrium were sensitively used in ceramic glazes, oriental lacquer and celluloid trinkets are precursors of the plastic industry. Far from being an applied science, practice in materials was far in advance of physical and chemical theory until less than a century ago, and even today intuitive understanding cannot be disregarded. The alchemists built their mystic concepts upon the colouring techniques of ancient artisans. Chemistry came from dying, pot making and particularly the quantitative separatory reactions of the assayer. But, once developed, science became highly effective in controlling and improving industrial practice. The discovery of electricity gave a new type of property to be studied, and the richness of today's approach to materials came from the subsequent joining of the physicist's approach with the other threads that had been maturing through the ages. Technological change alters the patterns of human interaction and it underlies most social upheavals. Technology is a rich part of the human experience and it deserves far more attention than it has hitherto received by historians.

BRITISH ISLES

A.E. Werner, P.T. Craddock and J.W.S. Megaw. **A group of later Iron Age collars from W. Britain : an analytical footnote.** British Museum Quarterly, *1973,* 37 *(1–2), 70–71.*

The analysis, by polarography and atomic absorption, of a collar from Dorchester is listed and discussed with respect to other Iron Age collars which have been examined scientifically.

M.R.C.

R. and Z. Cowan and P. Marsden. **The Dutch East Indiaman *Hollandia* wrecked on the Isles of Scilly in 1743.** J. Naut. Arch. *1975,* 4 *(2), 267–300.*

Contained bronze guns, mortars (military and chemical), lead ingots as ballast, silver coins and plate, pewter table-ware, iron cannon, barrels of iron nails, iron anchors and a bronze musket-ball mould. There is an appendix by R. Cowan on the trade in, and packaging of, mercury.

W.H. Manning. **The Method of Manufacture of Romano-British Wool Combs.** The Antiquaries Journal, *1972.* 52 *(2), 333–335.*

The radiographic investigation revealed individually inserted teeth welded-in into chiselled slots in a forged frame.

P. McBridge, R. Larn and R. Davies. **A mid-17th century merchant ship (wrecked near Mullion Cove in 1667).** J. Naut. Arch. *1975,* 4 *(2), 237–252.*

Finds include boat-shaped lead ingots (one weighing 134.5 kg = one ship-pound); copper ingots or cakes which comprised mainly two types; large circular plates about 0.52 m diameter, and smaller discs 0.17 and 0.2 m diameter, 0.2 to 0.04m thick. These seem to be of blister copper although the larger type are smoother as though hammered flat. Rose copper was purchased by the English E.I.C. from Hungary and Sweden. The authors cite Agricola for the process used.

P.T. Craddock, J. Lang and K.D. Painter. **Roman horse-trappings from Fremington Hagg, Reeth, Yorshire, N.R.** The British Museum Quarterly, *1973,* 37 *(1–2), 9–17.*

Trappings from the British Museum collection and the Yorkshire Museum collection, suspected of coming from the same hoard, were subjected to scientific examination. Specimens from Xanten were included for comparison. Both groups of Fremington specimens had very similar compositions: 10 elements were determined in the body metal of each by atomic absorption. The inlaid and overlaid decorations were analyzed by emission spectrography and found to be essentially silver overlay with inlaid copper and niello. Metallurgical examination revealed details of the method of manufacture of the trappings.

M.R.C.

Robert M. Organ. **Examination of the Ardagh chalice – a case history.** Book. *Application of science in examination of works of art,* Museum of Fine Arts, Boston, William J. Young, ed., *pp. 238–271, 1973,* $25.00. Illus.

This silver two-handled bowl, joined to a silver foot through a gilt-bronze neck, was found at Ardagh, County Limerick, Ireland in 1868. It evidently dates to the 8th–9th centuries. The materials and methods of construction are described in detail and extensively illustrated. A discussion is included of repairs made at the time the chalice was found. Examination methods include hardness testing, metallographic study, spectrographic and X-Ray diffraction analysis.

E.W.F.

I.M. Allen, D. Britton and H.H. Coghlan. **Metallurgical reports on British and Irish Bronze Age implements and weapons in the Pitt Rivers Museum.** Occasional Papers on Technology, No. 10, *pp. 1–283, (1970). 28 plates, 134 drawings, 8 tables, 200 refs.*

Metallographic, chemical and morphological data are presented on 128 later Neolithic and Early, Middle and Bronze Age artefacts, especially bronze axes, mainly from England and Ireland. The main chemical elements determined were Cu, Su, Pb, As, Sb, Ni, Bi, Fe, Zn, Ag, and Mg; analyses were performed by spectrographic and/or traditional chemical methods. Metallographic studies were made on both etched and unetched specimens. Most of the artefacts were made of normal tin bronze, although a few were of arsenical copper. A.H.L.

K.C. Barraclough. **The Origins of the British Steel Industry.** The Metallurgist and Materials Technologist. *Part I, Dec. 1973,* 5 *(12) 623–624. Part II, Feb/March 1974,* 6 *(2), 71–79.*

These two articles are the result of an attempt to piece together the background to the growth of the early steel industry in Britain and the rise of Sheffield to its position of pre-eminence which it held prior to the mid-nineteenth century. In Part I, the evolution of iron and steel making from the middle of the sixteenth century is traced, with special reference to the progress of the cementation process for producing blister steel. Attempts to replace imported steel by home-produced materials were generally unsuccessful until Sir Basil Brooke began to operate the cementation process in the Forest of Dean sometime between 1620 and 1635. The value of Spanish and particularly Swedish iron as high quality raw material came to be recognised, and towards the end of the seventeenth century there was a rise of cementation steelmaking in the Tyne basin. The earliest reference to cementation steelmaking in Sheffield itself is in 1709: the last cementation operation was carried out in the works of Daniel Doncaster and Sons 1951. The furnace concerned is now preserved within the B.S.C. Inter Group Laboratories at Hoyle Street. After summarising the 1843 report by Le Play (see H.M.G. Bulletin, *1973,* 7, *7–22 and 27–43:* Historical Metallurgy, *1974,* 8, *35–49*) brief reference is made to chemical and metallographic examinations of the metal. The origin of the term 'shear steel' is briefly discussed.

In Part II, the author first discusses the origin of crucible steel manufacture but finds it impossible to decide whether Huntsman or Walker first successfully developed the process. The importance of high-grade raw materials in making a high quality product is emphasised. After outlining the rise and fall of the process in terms of number of furnaces and types of product made, a detailed description of operations published in 1901 is quoted. Variations on this practice are discussed, and Le Play is quoted on costs in 1842.

K. C. Barraclough. **Cementation Furnace Uncovered.** Metals and Materials. *Nov. 1974,* 6 *(11), 504.*

Part of a cementation furnace discovered in Russell Street, Sheffield has been excavated, enabling a ground plan to be produced (illustrated). The furnace would have been capable of producing 700 tons of steel per annum.

Guy Beresford. **The Medieval Clay-land village; excavations at Goltho and Barton Blount.** Soc. Med. Arch. Monograph Series No 6, *1975, 106 pp. (£4.50).*

Both are deserted medieval villages occupied from the Saxon period up to the 15th century AD. A blacksmith's shop found at Goltho (late 14th– early 15th century) had ground-level hearths, and iron and bronze objects were found on the site. A number of knives from both sites were metallographically examined and found to consist of four types; a sandwich with a core of steel, wrought iron with a welded-on steel edge, homogeneous piled steel and iron, and steel-surfaced iron-cored. The 19 from Goltho were more or less evenly divided between the four types, while those from Barton Blount were mostly steel-edged. Hardness as high as 701 HV were achieved. Some padlock cores and other artifacts were similarly examined.

B.V. Cave. **Mill sites on the Longhope, Flaxley and Westbury streams.** J. Glos. Soc. Ind. Arch. *1974,* **10**, *9–31.*

Gives the history of the mill-sites in the Forest of Dean on the streams which powered the blast furnaces at Guns Mills and Flaxley. Discusses their later conversion to other uses. Flaxley seems to have been blown-in between 1600 and 1680 and blown-out in 1812. Guns Mills furnace was probably in blast by 1629 but was converted to a paper mill in 1742. Full drawings and some photos are given of Guns Mill furnace.

D.M.Tomlin. **Bessemer Converter tuyeres at Eston. Cleveland.** Ind. Arch. *1974, (1), 9–14.*

These have come from the Eston works and according to the author represent early tests on the Bessemer process applied to the high phosphorus ores of Cleveland,i.e.the Thomas-Gilchrist or basic process. The actual experiments are described in Thomas and Gilchrist's paper in JISI, *1879,* where is also described the work done at Blaenavon.

K. Jane Evans. **Excavations on a Romano-British site, Wiggonholt, 1964.** Sussex Arch. Coll. *1974,* **112**, *1–56.*

Amongst the finds were iron smelting and forge slag and a partially forged wrought iron billet containing 40% slag and measuring 20 x 40 x 150 mm.

H.R. Cleere. **The Roman iron industry of the Weald and its connections with the *Classis Britannica.*** Arch. J. *1974,* **131**, *171–199.*

Surveys the state of knowledge of the iron industry in the Weald of Kent and evaluates possible connections between the iron industry of the area and the Roman fleet by a study of the land and sea communications and the distribution of stamped tiles.

Cleere sees two chronological phases; an earlier non-*Classis* one and a later one worked on behalf of the fleet. Finally, this phase came to an end due to Saxon shore incursions and was possibly followed by operations in the Forest of Dean.

C. McCombe. **Pioneers in Foundry Melting – Morganite Crucible Ltd.** Foundry Trade Journal, *1975,* **139** *(3061), 165–172.*

Briefly outlines the origins and development of the small factory established at Battersea in 1856 by the five Morgan brothers for the manufacture of crucibles before describing the present factory at Norton, Worcestershire.

Anon. **A Century of Progress; Cattons as Pioneers of Steel-castings Production.** Foundry Trade Journal, *1975,* **139** *(3062), 193–195.*

Outlines the development of the business started in 1875 in Dewsbury Road, Leeds, apparently with a small crucible melting shop, through the move to Black Bull Street (Chadwick Street), to the present newly constructed foundry at Knowsthorpe.

Wendy Slemen (editor). **Lord Grimthorpe and the Bell Foundries – A Cautionary Tale from Victorian Times.** Foundry Trade Journal, *1975*, **139** *(3065), 344–347.*

Outlines the story of the Westminster Bells as told by the referee and eventual designer of the clock, Edmund Beckett, Lord Grimthorpe (1816–1905) in a book recently republished in facsimile. The emphasis of this article is on foundry aspects of the matter, with special reference to the difficulties and arguments over the famous 'Big Ben'. The first casting made came out two tons heavier than intended, and contained such a large concealed flaw that after being rung occasionally for some weeks, it one day cracked so badly that the casting had to be scrapped. The second casting also partially cracked after a few months striking, but despite a report by Dr. Percy that it was a defective casting, porous and unhomogeneous and, at the place where it was cracked, not of the prescribed composition, the bell was turned in its frame and fitted with a lighter hammer striking in a different place. By this means it was kept in service and is still in service today.

M. Le Guillou. **Freight Rates and their Influence on the Black Country Iron Trade in a Period of Growing Domestic and Foreign Competition 1850–1914.** Journal Transport History. *September 1975*, **3** *(2), 108–118.*

Considers raw materials and finished products, and makes comparison between the Black Country and the North East and S. Wales particularly.

Anon. **Early Cast Iron Beams.** Foundry Trade Journal, *1975*, **138** *(3041), 365–366.*

The beams installed over 100 years ago, were discovered at the Wylie Lockhead/McDonald's building in Buchanan Street Glasgow during alterations. Negligible rusting had occurred, but tests indicated that no special anti-rusting treatment had been used. The basic unit in each of the beams was an iron casting approximately one foot square overall, bolted onto a bottom steel plate. Two methods of stressing the beam to form a camber to the soffit before loading are described, one for beams having a span approximately 30ft. and the other for beams having a span approximately 15ft.

S.B. Smith. **Canine Cast Iron.** Foundry Trade Journal, *1975*, **138** *(3045), 521.*

A short illustrated account is given of a 6 ft. long, 4 ft.6 in. wide cast iron table whose 1 inch thick top is supported by four lifesize deerhounds. It was made by the Coalbrookdale Company for the 1855 Paris exhibition, and is now in a private collection in this country.

C. McCombe. **An Early Telford Masterpiece.** Foundry Trade Journal, *1975*, **138** *(3053), 788–789.*

Thomas Telford designed and built the cast iron aqueduct carrying the Shrewsbury canal over the River Tern in 1795–96, the castings being supplied by William Reynolds and Company, of Ketley, Shropshire. Despite the virtual disappearance of the canal in the vicinity, the structure, which is illustrated, is still in almost perfect condition. An interesting feature is the considerable distortion of some parts of the cast-iron trough, the plates having bowed out by some three inches in places without cracking. Some details of design and foundry techniques are discussed.

C. McCombe. **Shropshire Bridge Spans Three Centuries.** Foundry Trade Journal, *1975*, **139** *(3056), 15.*

Cound Bridge, near Shrewsbury, cast in iron by the Coalbrookdale Company in 1797, is thought to be the oldest iron road bridge in the world still open to vehicular traffic. Illustrations show the bridge and some design details.

Anon. **Appleby and Frodingham from the 1860's to the 1970's.** Steel Times, *1975*, **203** *(6), 470–473.*

A very brief sketch of the works from green fields in the 1850's, the finding of usable iron ores in 1859, and the development of smelting there to the present. It is merely an introduction to an extended account of the modern works.

G.R. Morton. **The Wrought Iron Trade of the West Midlands.** J.I.S.I. *1973*, **211** *(2), 93–105.*

The text of the 5th John Wilkinson Memorial Lecture delivered to the Staffordshire Iron and Steel Institute on 26th January 1972. Taking Thomas Turner's definition of wrought iron as commercially pure iron, which having been produced in a pasty condition, is always associated with more or less intermingled slag, the author shows how the growing shortage of charcoal in the 18th century led to a search for alternatives to the finery and chafery forges for refining pig iron. The puddling process followed by shingling and rolling, due to Cort, was introduced into the area in 1790, and by 1830 virtually the entire output of bar iron was produced in this manner. Hall in Staffordshire introduced the important improvement of using basic oxides and silicates of iron to fettle the hearth in about 1811. Details are given of typical works equipment and processes in the mid nineteenth century. Some of the attempts which were made to improve the process by reducing fuel, labour and repair costs are outlined, but the combined impact of the mass-production of steel by the Bessemer and open-hearth processes, and the exhaustion of the coal and iron reserves of the area led to a rapid decline of puddling after about 1873.

C. Humphries. **Forged Ironware from an Early 17th Century House.** Metals and Materials. *1973, 7 (4) 498–500.*

A thatched cottage at Whittlesford, Cambridge, built 1610, burned down in 1967, and its outbuildings provided the material which was examined. The components generally showed a very high standard of workmanship. Careful conservation of iron was evident. Over two hundred items for doors, gates, fireplace items, window fittings etc were recovered, plus 670 nails of all sizes, 1½" to 18" long, but no screws were found.

Anon. **Reconstruction of a 16th Century Tilt Hammer.** Metals and Materials. *November 1973, 7 (11), 500–501.*

Pieces of the hammer found during road widening and draining near East Grinstead are being re-erected at the Weald and Downland Museum, Singleton, Near Chichester. The hammer is to be driven by a water sheel incorporating parts found in 1970 at a furnace site at Chingley, Kent.

W.G. Aitken. **Excavations of Bloomeries in Rannoch, Perthshire, and elsewhere.** Proc. Soc. of Antiq. Scotland *1973*, **102**, *188–203.*

About 25 iron smelting sites in the vicinity of the Loch Rannoch, Scotland. Bowl hearths, forced draught, dating probably from the High Middle Ages (13th–15th century). Plans and profiles (Bridge of Gaur, Upper Dall, Grunidd nan Darachan, etc). See Bull. HMG. *1971*, **5**, *15–23.*

EUROPE

Josef Riederer. **Roman needles.** Technikgeschichte, *1974*, **4** *(2), 153–172.* (In German).

While dredging the Tiber, a number of Roman bronze objects were found. About 1000 needles were examined to deduce metallographically the method of manufacture. It was found that there are both cast and forged needles. Metal analysis revealed that pure copper, bronze (1–9% Sn) and rarely brass (21% Zn) were used. Three types of forms were distinguished: needles with two round eyes, with one round eye, and with one oblong eye.

J.R. (A.A.)

W.A. Oddy. **Analysis of the gold coinage of Beneventum.** Numismatic Chronicle, (7th series) *1974*, **14**, *78–109*.

This paper discusses the analytical results for gold content of 108 **solidi** and **tremisses** of the Duchy of Beneventum in the period 689–849 AD. The coins were analyzed by the specific gravity method. In one or two places in the series the analytical results assist in establishing a chronology for the various types, but their main use is to provide information about the gradual debasement of the gold coinage from 80% of gold in the early eighth century to 10% by the mid ninth. The steps by which this debasement took place are postulated.

W.A.O. (A.A.)

A. Mazur, M. Mazur and E. Nosek. **Metallographic investigations of iron objects from Lisów, district of Opatów.** Sprawozdania Archeologiczne, *1973*, **25**, *193–203*. (In Polish).

The eight iron objects submitted to metallographic and chemical investigations included 3 knives, 1 sword, a pair of shears and 3 spearheads. All objects were found in a cremation burial. Five objects were made of iron which contained from 0.10 to 0.12% phosphorus and from 0.02 to 0.05% copper. Shears and knife No. 3 were made of iron with greater phosphorus content (0.2% and 0.40% respectively). All objects showed high carbon content, reaching up to 0.8% C. The metal bore traces of overheating due to the fact that the objects under discussion laid for a time in the funerary pyre.

The sword which was probably imported shows a particularly high craftsmanship. In its production, welding and faggoting were employed. An analysis of nonmetallic inclusions in the sword was additionally made by means of an electron micro-probe. This analysis revealed considerable amounts of iron, silicon and calcium, and smaller amounts of aluminium and manganese. In the inclusions, iron silicates dominated; their composition is complicated by the probable presence of calcium with a certain amount of aluminium and manganese oxide.

A.A.

Alfred Mutz. **Roman bronze threads.** Wire, *1973*, **23** *(4)*, *183–186*.

Threaded shafts found in Pompeii and Athens are illustrated, with speculations as to their methods of manufacture.

M.G.

Gary W. Carriveau. **Dating of 'Phoenician' slag from Iberia using thermoluminescence techniques.** MASCA Newsletter, *July 1974*, **10** *(1)*, *two pp. 5 refs.*

The dating of metal working activities by applying the thermoluminescence method to slags is proposed. Material from Calle Pulos, Huelva, Spain, believed to be a 'Phoenician' slag from silver smelting, was subjected to a similar thermoluminescence technique to that used for pottery. The thermoluminescence date was 401 ± 280 BC. The archaeological date was 800–700 BC. The agreement is considered satisfactory.

J.W.

Roberto Cesareo and Friedrich W. Von Hase. **Nondestructive radioisotope XRF (x-ray fluorescence) analysis of early Etruscan gold objects.** Kerntechnick, *1973*, **15** *(12)*, *565–9*. (In English and German).

For the investigation of archaeological objects, XRF has the advantage of being non-destructive but is limited by the variable penetration of rays into the material to be analyzed. XRF equipment having a 200 mCi^{147}Pm/Al source and a proportional counter filled with Xe–10% CH_4 was used to determine Ag, Cu and hence Au in about 100 specimens of Etruscan grave-goods of the 8th and 7th centuries BC and of some 19th century copies by Castellani. Ag can be determined with high accuracy, but results for Cu are about 20% below those obtained by an alternative spectrographic method; it appears that the variable penetration of the radiation does not lead to serious errors. The significance of the results is discussed.

R. Boni. **Leonardo da Vinci and foundry practice.** Fonderia Italiana, *1973*, **22** *(11–12)*, *289–298; 325–335. 90 refs.* (In Italian).

Leonardo da Vinci's evolution as a bronze founder is traced starting with details of cast statuary produced in 1470–1480 in the workshop where he was a pupil and from his notes and sketches relating to the moulding and casting of cannon and his projects for cast statues.

Notes and sketches by Leonardo for the casting of an equestrian statue 7.14m high are reproduced and described. Although the project was probably never carried out, the notes give a clear indication of the state of foundry art, with suggestions for innovations in foundry technique. The stages described include the construction of the pattern, preparations of the earth and sand, and preparation and assembly of the mold and core, with details of feeding techniques, melting in crucible or reverberatory furnace, casting, cooling and solidification, knocking-out and finishing the statue.

M.G.

Anon. **Tin ingots at Port Vendres, France.** J. Naut. Arch. *1975*, **4** *(2)*, *273–4*.

A reference to a forthcoming report in **Gallia**, *1975*, *(2)* to the finding by D. Colls in 1972 of 14 tin ingots with stamps weighing 8.75 kg each. These are from Spain and the wreck is dated to the reign of Claudius (AD 41–54). They are rectangular with semi-circular handles and measure 27 x 19 x 4 cm.

M.A. Martin Bueno and J.R. Salis. **The anchorage of El Cabo de Higuer (Funterrabia, Guipuzcoa, Spain).** J. Naut. Arch. *1975*, **4** *(2)*, *331–3*.

The wreck of a small Roman boat off the Biscay coast was found to contain a mound of iron ore "25m long x 15m wide' dated to the 1st–2nd century AD. The ore is probably from the mines of Arditurri which show signs of Roman working. It has a very high iron content. This is the first indication that iron ore was moved by sea in Roman times.

V.S. Patruchev. **Akozo-Melarian axes on the territory of Marys (Volga Region).** Sov. Ark. *1975 (3)*, *28–43* (in Russian).

Describes socketed bronze axes mostly short, of Anau type; the rest are of Akazo-Melarian type. These were is use during the 8–7th century BC. The pure Malarian type is also known in Scandinavia. It continued to devleop and is found in local burials of the 7th and 6th century BC together with iron spearheads, arrowheads and daggers. No analyses are given.

E.A. Symonovich. **A category of objects discovered in monuments of the Cherniakovo culture.** Sov. Ark. *1975*, *(3)*, *213–217* (In Russian).

These are skewer-like 'pins'. Five analyses show them to be impure coppers; one with 1.1% Sn and another with 18% Sn. They were found between the Dnieper and the Don and date to the 3rd to 5th centuries AD.

J. Piaskowski. **Metallographic investigations of metal objects from an Early Medieval earthwork at Szczaworyz, District of Busko. (In Polish).** Sprawozdania Arch. *1974,* 26, *223–239.*

Thirteen iron objects from the early medieval earthwork at Szczaworyz were submitted to metallographic investigations. Eleven objects date from the 7th to mid-9th century and two (fragments Nos. 1 and 2) from the close of the 9th to the 1st half of the 11th century. In the investigations, metallographic observations, the microhardness measurements of the structural components by Hannemann method and the hardness measurements by Vickers method were employed. Quantitative and qualitative chemical analyses were also carried out. The majority of the objects examined showed a purely ferritic iron structure (arrowhead No. 3, fragment No. 2, blade and butt of the axe, mountings Nos. 1, 2 and 3). Slight primary or accidental carburization, which did not affect the properties of the metal, was noted in a few objects (arrowhead No.2, fragments 3 and 4). In fragment No.5 the carburization was stronger, though limited to a small part of the object only, whereas arrowhead No.1 and fragment No. 1 were made of strongly though unevenly carburized steel. Fragment No. 5 and possibly fragment No. 1 showed traces of heat treatment. All objects showed high phosphorus content (0.170 – 0.85% P).

It seems that most, if not all, objects examined were made by the local smith who supplied the tribe with iron objects.

Lucien Basch and Honor Frost. **Another Punic wreck in Sicily; its ram.** J. Naut. Arch. *1975,* 4, *(2), 201–228.*

The notes to this paper contain the results of analyses by Mr. G. Jones of the British Museum Natural History on the bronze nails used in its construction. Although badly corroded, the results indicate highly leaded tin bronzes with 0.2–0.6% Zn, and As less than 0.05%. These figures are very interesting since the high lead content (7.3–17.3) would militate against working and suggest that they had been cast. This contrasts with cold worked copper nails from another wreck of this period, from Kyrenia, Cyprus.

A. Johansen. **Iron Production as a Factor in the Settlement History of the Mountain Valleys Surrounding Hardangervidda.** Norwegian Archaeological Review, *1973,* 6 *(2), 84–101.*

Iron production played an important role in the transition from nomadism to the settled mode of living in conditions of isolated valley units. Data on charcoal pits and slag heaps.

J. Piaskowski. **Iron metallurgy in West Pomerania in antiquity (2nd century BC to 2nd century AD).** Wiadomosci Hutnicze, *1973, (7–8) 260–265.* (In Polish).

Iron technology in West and West-of-Oder Pomerania is described on the basis of metallographic examinations of 80 objects from 21 archaeological sites and several samples of ancient slag from the region. Local metallurgists produced low-quality iron in primitive hearths using high-phosphorus bog ore and used the iron to make various tools and utensils. Weapons were generally produced from low-phosphorus (less than 0.22% P) iron or steel which was apparently imported from other sources, possibly Celtic. The results of metallographic studies were used to explain certain customs of storing weapons by Sujonic tribe which inhabited this region in the antiquity and the disappearance of the custom of putting weapons in to the graves.

E.N. Chernik. **Ai-bonnar; a Balkan copper mine of the 4th millennium BC.** Sov. Ark. *1975* **(4),** *132–153* (In Russian).

The mine is in Bulgaria and consists of long galleries 20–100 m with a depth of 10–20 m and a width of 1–10 m. The total length os 400–500 m. The pottery is dated to the Karanova IV – Goumelnitsa culture. In the galleries were found sherds and fragments of mining tools including two copper tools of which one was an axe-hammer and the other an axe-pick. Both of these are of relatively pure copper, but the pick contains 0.25% As.

A.D. Priakhin and V.I. Sagaidak. **A metallurgical workshop in a site dated to the Timber Grave Culture (In Russian).** Sov. Ark. *1975 (2), 176–187.*

The site was at Mossolov on the left bank of the Don. The workshop measured 8.5 x 19.5 m; inside this was a hearth with moulds and large crucibles (hemispherical) with lids surrounding it. Also found were stone pounders, hammers, small anvils, splashes of metal and pieces of bronze plate. The stone moulds could be divided into open and two-part moulds. One of these was for axes cast with the shaft hole vertical and another for bill-hooks. Others were for knives, spearheads etc. The site dates to the end of the third to the last quarter of the 2nd millennium BC.

T. Dziekoński. **Investigation of raw materials and fabrication of bridle-bits from Central-Poland during the period of Roman influence.** Archeologia Polski, *1973,* 18 *(2), 479–49.*

Technology of bridle bits made of brass or wrought iron rods dipped into brass, with analysis.

V. Maly. **Investigation of a medieval axe-head. Study a zpravy Okresniho muzea Praha-vychod, Brandys n.L. – Stara Boleslav (spolecnost),** *1972 (Praha), 33–41.*

Investigation of a medieval axehead with a welded-on steel edge, quenched. Length of time of manufacture estimated.

A. Kolling. **An early bloomery in the Saarkohlenwald. (In German).** Bericht der Staatlichen Denkmalpflege im Saarland. *1973, 51–59.*

A well preserved domed clay furnace in a stone-walled construction, operated by a single tuyere of an unusual shape. Undated.

P. Piaskowski. **Metallographic examination of iron objects from Poiana and Popesti of the La Tène period.** Materiale si cercetari archeologice. *1973,* 10, *87–95.*

Iron fragments of the 2nd–1st century BC investigated. One bar from Popesti was of hard pearlitic steel.

P. Piaskowski. **Metallographic investigation of iron objects from Sobocisko, Nowa Cerekwia and Koscieliska.** Sprawozdania Archeologiczne, *1973,* 25, *151–172.*

A La Tène knife and four sickles were examined – all were carburized.

M.V. Menabde (Mrs). **Trialeti in the Late Bronze and Early Iron Ages (14th – 6th century BC). (In Russian).** A dissertation, Tbilisi *1973.*

An attempt at the chronology of Trialeti cemeteries (S. Georgia) according to which iron was slowly penetrating into the material culture of the region, about 1200 BC. The frequency of iron artifacts in the graves increases after 1000 BC.

B. Arrhenius. **On the typology of knives.** Fornvannen, *1974, 69, 105–110.*

Typology of knives and metallographic examination.

L.D. Fomin. **Technology of iron working in Olbia and Tyres.** (In Russian). Archeologiya (Kyyiv), *1974,* 13, *25–31.*

Iron working installations of the 7th – 4th century BC. Among 200 objects only 4 suitable for analyses. Wrought iron of bad quality.

G. Jacobi. **Tools and other objects from the oppidum at Manching.** Römisch-Germanische Kommission, Wiesbaden *1974.*

More than 90 different iron objects discovered at Manching which represent a cross section of Late La Tène iron working in Celtic Europe. No analyses.

J. Piaskowski. **Metallographic investigations of iron objects from the cemetery of Környe.** Act. Arch. Acad. Scient. Hung., *1974,* 26, *117–129.*

Weapons of the Migration period (AD 6th century). Among various steel or wrought iron objects there are three pattern welded blades with iron edges.

ASIA

Hoang Van Khoan. **The technology of the fabrication of iron and steel tools from Southern Siberia. (7th century BC to 12th century AD).** Sov. Ark. *1974 (4), 110–124.* (In Russian).

More than 100 iron and steel tools have been metallographically analysed. Carbon steel was used after the 5th century BC. From the 1st century BC, the majority of the tools are carbon steel but of variable quality. As early as the 5th century BC the smiths used complicated processes such as cementation of the edge, welding-on of the edge and welding by piling of alternate layers of iron and steel. The heat treatment of steel is known from the 1st century BC, and 50% of the objects show signs of this. The smiths used rapid and slow quenching. The similarity and uniformity of the forging techniques over the whole of the area studied shows close historic relationships between the tribes and peoples of Southern Siberia in the iron age.

H–G Bachmann. **The metallurgical composition of Hasmonaean coins.** Museum Haaretz Year book, *1972/73, (15/16), 81–90.*

Gives the analyses of 22 coins from the Hasmonaean dynasty of Palestine (135–37 BC) and shows that they were leaded bronzes mostly with traces of Fe, Zn and Ni. The flans were cast, perhaps in open moulds, and cold struck to give a hardness of 118 HV1.

Cheng Te–K'un. **New Light on Shang China.** Antiquity, *1975,* 49, *25–32.*

The Shang people were a mongoloid people with a ruling group with advanced metallurgy that appeared during the period 5000–2000 BC. Their pottery kilns were capable of reaching temperatures of 1400°C. The moulding was in the hands of the potter and the metallurgy was founded on ceramic traditions. Bronze vessels were found at Anyang in burials dated to the Middle Shang period (before 1384 BC). One axe had a bronze hilt or tang with the remains of a wrought iron blade within. It is possible that this is meteoric, but, with the recent discoveries of unusually early iron from other LBA sites, this is getting less likely. Some of the axes were made from 16% tin bronze in two-piece moulds.

V.V. Efdokimov. **New excavations on the site of Alexeyevo on the River Tobol.** Sov. Ark. *1975 (4), 163–172.* (In Russian).

The site dates from the 10th–8th century BC. A double mould for a gouge and some pieces of stone moulds for 4-lobed pins were found. No analyses of metal are given and the hearths found appear to be domestic of several types.

Cyril Stanley Smith. **An examination of the arsenic-rich coating on a bronze bull from Horoztepe.** Book. *Application of science in examination of works of art,* Museum of Fine Arts, Boston, William J. Young, ed., *pp 96–102, 1973, $25.00. Illus. metallographs, refs.*

A local white metal plating on a bronze bull from Anatolia, ca. 2100 BC was Cu_2As. The arsenic was evidently applied by some kind of cementation process involving arsenic vapor. This was reproduced in the laboratory. Copper-arsenic metallurgy is discussed.

E.W.F.

F.E. Treloar. **The use of mercury in metal ritual objects or a symbol of Siva.** Arbutis Asiae, *1972,* 24 *(2/3), 232–240.*

Mercury and gold-mercury amalgams were used in the foundation deposits of an 8–9th century AD temple in Kedah, Malaysia. Mercury source was apparently Sarawak. Interesting embrittlement and crystallization in the mercury and gold objects (Au 55%, Ag 30%, Hg 15%). Table of analysis, historical conclusions, and useful references on historical uses of mercury are included.

W.T.C.

William J. Young. **The fabulous gold of the Pactolus Valley.** Boston Museum Bulletin, *1972,* 70 *(359), 4–13.*

The gold from the Pactolus Valley contains platinum-iridium inclusions (65% Pt, 30% Ir, a little Os) analyzed by laser microprobe. These only occur in a few gold sources (Pactolus, Urals, Mandalay) and are used to characterize gold in a 5th century Achaemenian earring, a stamp seal, and some of the gold in the famous Bronze Age funerary hoard as coming from the Pactolus. The Achaemenian earring also contains 168 solder joints, inlay in carnelian, turquoise, and lapis lazuli, and cinnabar backing up the carnelian. Ur gold also has these inclusions.

W.T.C.

H.C. Bharadwaj and S. Misra. **A metallurgical note on Gupta period coins from Rajghat (Varanasi) excavations.** Journal of the Numismatic Society of India, *1971,* 33 *(II), 123–127.*

Four gold coins of the Gupta Period obtained from excavations at Rajghat (Varanasi) were examined for their gold content and one of the coins was studied metallographically. The gold content was determined through specific gravity measurements; it varied from 74 to 77.5%, the other predominant metal being silver. On the basis of metallographic examination, it was concluded that the coins were 'die-struck' rather than 'cast'.

N.H.

Sabri M. Farroha and Earle R. Caley. **The Chemical compostiion of some ancient Arabic coins.** Bulletin of the College of Sciences. *1965,* 8, *61–65. 3 tables, Arabic abstract.*

Arabic silver dirhems, minted between 704 and 804 AD, were analyzed by traditional wet methods. Specific gravity measurements before and after electrolytic reduction were in the range, for the cleaned coins, of 10.33–10.62. The coins were dissolved in concentrated HNO_3; the weight of Au in the insoluble residue was measured separately. Ag was precipitated as AgC1 by addition of HC1; Pb was determined partly by precipitation as $PbSO_4$ and partly electrolytically as PbO_2 (simultaneously with Cu, deposited as the metal). Fe was determined as Fe_2O_3, obtained by igniting the precipitate obtained on adding aqueous NH_3, Zn and Ni were not detected. The Ag content was 91.17–99.24%, the major trace elements being Cu (0.22–6.35%), Pb (0.42–1.84%) and Au (0.04–1.35%); the Sn and Fe contents were 0.01–0.12% and 0.04–0.18% respectively.

A.H.L.

E. Loubo-Lesnitchenko. **Imported mirrors in the Minusinsk Basin.** Artibus Asiae, *1973,* 35 *(1/2), 25–61.*

Bronze mirrors from the 4th century BC up to the 14th century AD imported into the Minusinsk Basin (north of the Altai Mountains) are studied along with their locally-made counterparts. Spectrographic analysis is used as one means of differentiation of period and place of manufacture. No analyses are given.

W.T.C.

Robert Maddin and James D. Muhley. **Some notes on the copper trade in the ancient Mid–East.** Journal of Metals, *1974,* **26** *(5), 24–30. 9 figs. 7 tables, 5 refs.*

A report of analyses of a single ox-hide copper ingot from the Cape Gelidonya (s.w. Turkey) wreck, dated ca. 1200 BC. Analysis by emission spectroscopy gave 10% iron, 0.5% tin, and 0.2% cobalt. Metallography revealed large sulphide inclusions, confirmed by energy dispersive x-ray spectrometry, and a lack of dendrites or coring.

The authors conclude that the ingot had been improperly smelted from a sulphide ore using a haematite flux at insufficient temperatures, and poured while not fully molten. Since the Co-levels of known Cypriot ores are far lower than that of the ingot, the deposits of Ergani-Maden, s.e. Turkey, are suggested as the source. Reference is made to various research programs in progress.

M.G.

A.M. Velenickij et al. **Medieval Towns in Central Asia.** Leningrad, *1973.* (In Russian).

Two sections of this book are devoted to iron working. Examples of hearths, V-shaped tuyeres from smithies of the 6th – mid 8th centuries AD. *(pp. 69–80).*

AFRICA

J. Gordon Parr. **The sinking of the Ma Robert. An excursion into mid-19th century steelmaking.** Technology and Culture, *1972,* **13**, *209–225.*

The boat, built for Robert Livingstone's use on the Zambesi on his return to Africa in 1858, had a short life. Possibly the first use of steel in shipbuilding, its plates were of 'Howell's homogeneous metal', a newly-patented crucible-cast low carbon iron. The paper contains a description of the confusing variety of steel-making processes at the time, and concludes that the failure was mainly a result of the fact that the plates were only 1/16 inch thick, with inadequately maintained paint.

C.S.S.

J.H.F. Notton. **Ancient Egyptian gold refining.** Gold Bulletin, *1974,* 7 *(2), 50–56.*

The technique of smelting mined gold ore concentrates reported as being used in Egypt in the Second Century BC has been simulated in the laboratory. A considerable degree of refining was found, comparable with that yielded by the medieval process of cementation with salt, and with a negligible loss of gold.

A.A.

AMERICA

Earle R. Caley. **Chemical composition of ancient copper objects of South America,** *in* **Application of science in examination of works of art,** ed. William J. Young. Proceedings of the seminar, *June 15–19 1970. Book. Museum of Fine Arts, Boston, pp 53–61. 1973, S25.00. Tables refs.*

Previously published analyses of copper objects from Argentina (18), Bolivia (4), and Peru (16) are critically examined. New analyses, made by gravimetric and spectrographic methods, are given for 14 objects from Peru. It is concluded that 1) native copper was used in only a small proportion of ancient South American copper objects, 2) a variety of ores was used, 3) most objects are arsenical copper, some of which were probably manufactured intentionally. Although some 575 analyses of ancient copper and bronze objects from South America have been published, most of them are inadequate for various reasons.

E.W.F.

J.F. Hanlan and R. Meyers. **Technical studies of Canadian silver at C.C.I.** Canadian Conservation Institute, *1974 (3), 5–6.* Newsletter. In French and English.

Over 40 objects in the National Gallery of Canada collections of church silver were analyzed by x-ray spectroscopy with an energy dispersive detector (EDX). Church silver has certain advantages for this study because in general the silversmith used the best grade of silver available and the pieces are in good condition, positively identified and well polished. The items covered the period 1760 to 1864 in Canada. The analyses demonstrated that there was a definite downward trend in the quality of the silver with time. At the beginning of the period studied, 80% of the silver was above the 95% French standard. At the end of the period cited all items tested were well below the standard.

M.R.

Heather Lechtman. **The gilding of metals in pre-Columbian Peru** In book App. sci. in exam. works of art, Research Laboratory, Boston Museum, *pp. 37–52, 1973, S25.00 Illus. Metallographs, Refs.*

Depletion gilding was evidently used during the Chimu period (ca. AD 1000–1470) in Peru on copper-silver-gold alloys. Analyses were made by wet chemical methods, and with the electron microbeam probe. Depletion gilding is accomplished by packing the object with a reactive powder (cementation mixture) and heating it; chlorides form from all metals except the gold, leaving the gold unattacked on the surface. This process was reproduced in the laboratory using various cementation mixtures. The difference between these alloys and tumbaga, the gold-copper alloy used in Columbia, is pointed out.

E.W.F.

TECHNIQUES

A. Van Dalen, H.A. Das and J. Zonderhuis. **Nondestructive examination of Roman Silver coins by neutron activation analysis. J. Radioanal. Chem.** *1973,* **15** *(1), 143–9.*

The detection of plated specimens (ancient falsifications consisting of a Cu core with a Ag outer layer) among a collection of Ag coins was performed by non-destructive neutron analysis. The plating can be detected by measuring the Ag/Cu ratio. It is more convenient to determine the Au/Cu ratio which is proportional to it. A short activation in a low thermal neutron flux is sufficient for this purpose. The induced activity of the long-lived ^{110}Ag is small. The necessary correction for self-absorption on the measured ratio is small. A series of 2000 coins was analysed in this way.

K. Randel, R. Wellum and J.E. Whitley. **Radiochemical determination of trace noble metals in silver artefacts.** J. Radioanal. Chem. *1973,* **16** *(1), 205–14.*

Radiochemical separations are essential for the determination of trace elements in Ag artifacts by neutron activation analysis due to the high levels of both short and long-lived activities produced by the matrix, but the sensitivity of the technique permits the examination of small samples. The noble metals are considered most significant from a diagnostic standpoint, and radiochemical techniques have been developed for their determination in samples of a few milligrams. Methods have been investigated for the determination of Pd, Rh, Ir and Pt in samples removed from museum specimens of known provenance.

E. Sangmeister and H. Otto (with reply by E.A. Slater and J.A. Charles). **Archaeology and metal analysis.** Antiquity, *1973,* **47**, *217–221. Fig.*

The first two authors defend the use of bismuth and antimony as distinguishing trace elements by means of their archaeological and statistical observations, with particular reference to bismuth content. In rebuttal, Slater and Charles maintain their earlier views. B.A.A. and P.T.C.

Carolyn Cappello, Sidney A. Katz, Lynn Padilla and Charlene Williams. **Determination of gold, copper and silver in ancient and rare coins by neutron activation analysis with californium-252.** Bulletin, N.J. Acad. Sci. *1973,* **18** *(2), 30–2.*

With a neutron flux of only $3.28 \pm 0.16 \times 10^3$ n/cm^2 sec obtained from 1 µg of ^{252}Cf, major components, gold copper and silver rather than traces were radioactivated. The apparent activity of a given coin was corrected for self-shielding from the ratio of the activity of an unshielded monitor foil to the activity of the monitor foil shielded by that coin. A careful control of the activation times and the cooling periods (Ag-10 min, 1 min; Cu-24 hr, 1 hr; Au-5 days, 2 days) enabled a high degree of selectivity in the measurement of Ag, Cu and Au. Ag, Cu and Au contents determined by non-destructive neutron activation analysis of 5 modern coins and 12 coins having historical and (or) numismatic value are reported.

Robert H. Brill, William R. Shields and J.M. Wampler. **New directions in lead isotope research. In** ***Application of science in examination of works of art.*** ed. William J. Young Proceedings of the seminar, *June 15–19, 1970.* *Book, Museum of Fine Arts, Boston, pp 73–85, 1973, $25.00 Illustrated.*

Isotopic ratios of lead extracted from ancient objects may reveal geographical origin and hence possibly provenance. Lead ore samples are in the process of being analyzed. To illustrate the versatility of lead isotope studies 5 groups of objects are reported on: (1) 3 early classical bronzes ranging from 3rd century BC to 2nd century AD; (2) White lead in paintings; (3) Lead camings in medieval stained glass windows; (4) Ancient red, yellow and green opaque glass which can contain 3 – 30% lead oxide; and (5) Lead in silver coins and gold and other objects. E.W.F.

Florence E. Whitmore and William J. Young. **Application of the laser microprobe and electron microprobe in the analysis of platiniridium inclusions on gold.** Book. Application of science in examination of works of art. Museum of Fine Arts, Boston, William J. Young, ed. *pp. 88–95, 1973, $25.00. Illus. tables refs.*

Analysis of standard and 13 objects is reported; the latter are Lydian, Achaemenian, Near Easter Bronze Age, and Egyptian. Microscopic examination of gold objects from Ur is described, and also of a 125-piece Near Eastern funerary hoard of gold objects recently given to the Museum of Fine Arts, Boston. E.W.F.

Janet Lang and A.R. Williams. **The hardening of iron swords.** J. Arch. Sci. *1975,* **2**, *199–207.*

Discusses the metallography and hardness of three swords from Canwick Common, Lincs., Waltham Abbey and Solingen. Three different methods have been used. The first (Frankish), is made of a composite structure quenched to give ferrite and martensite with a hardness of 630 HV. The second is late pre-Roman or Roman and was made by piling pure iron and carburized iron. The maximum hardness is 250 HV and it had not been quenched. The composition is (ppm); Mn 35; Ni, 1250; Co, 300 and P, 750. The Solingen blade was 15–16th Century. It is a surface carburized iron blade with a hardness of 620 HV in the martensite surface and 215 in the core. The composition is (ppm); Mn, 550; Ni, 400; Co, 300 and P, 400.

Sidney A. Katz. **An application of neutron activation analysis with 252- Californium to the measurement of silver in ancient coins.** Laboratory Practice, *1974,* **23** *(3), 112–113, 1 table, 2 references.*

The silver contents of 9 Greek and Roman coins, containing 0–98.5% silver, were determined. A small (1 mg) low flux 252 Cf source was used; the coins and silver monitor foils were irradiated for 10 minutes, allowed to 'cool' for one minute, and then counted on a 2-inch square sodium iodide crystal shielded by 1 cm of plastic and connected to a 'Baird Atomic Model 530' spectrometer. Selfshielding effects were measured using silver monitor foils and these effects were taken into consideration in the calculations. Experiments conducted with modern United States silver coins of known composition show that the error of the method is about 5%. A.H.L.

P. Meyers, L. Van Zelst and E.V. Sayre. **Determination of major components and trace elements in ancient silver by thermal neutron activation analysis.** J. Radioanal. Chem. *1973,* **16** *(1), 67–78.*

Thermal neutron activation of minute samples of ancient Ag objects has provided useful information concerning their Ag, Cu and Au contents. The results of such analysis of 18 Sasanian Ag objects are discussed together with consideration of the sampling problems involved. In order to extend these measurements to include other elements, an isotopic exchange system has been developed to separate other activities present in irradiated Ag specimens quantitatively from the Ag, Cu and Au activities. Following exchange with CuI and AgI it has been possible to count quantitatively the activity of 14 additional elements: As, Br, Co, Cr, Fe, Hg, Ir, K, Mn, Na, Sb, Sc, Se and Zn.

Madeleine Hours and F. Michel. **Scientific methods in the study of the metallurgy of antiquity at the Louvre.** In *book App. sci. in exam. works of art, Research Laboratory Laboratory, Boston Museum, pp 67–72, 1973, $25.00. Tables.*

Spectrographic analyses are reported of a series of 27 Egyptian bronze objects dating from the Old through the New Kingdom, from the Louvre. Examination made preliminary to sampling is described. The earliest objects are copper; New Kingdom objects are mostly bronze, with tin 10% or more; the absence of zinc is characteristic of Egyptian metallurgy; arsenic content varies greatly. E.W.F.

B. Arrhenius. **Archaeology in the laboratory.** Svensk Naturvetenskap, *1974, 230–236.*

Soils with elevated phosphorus content attack buried irons much less than other soils. Application of metallography.

The Editor would like to acknowledge the help he is now receiving with the abstracts. He is very grateful to the following who are now actively participating: – D.R. Howard, J.W. Butler, P.S. Richards, T.Daff, H.F.Cleere, H.W. Paar, N.Mutton, E. Raub, A.P. Greenough, J.K. Harrison, W.A. Oddy, J. Piaskowski and P. Poplawska. Some of the abstracts are taken from the periodical 'Art and Archaeology Technical Abstracts' and we are grateful to the International Institute for the Conservation of Historic and Artistic Works, London, for allowing us to reproduce them.

Notes on contributors

B G Ashmore has been employed at the Distington Foundry and Engineering Works, Workington, since 1951. In 1965 he rescued the Senhouse Romano-British collection at Netherhall, Maryport, from destruction and became its honorary custodian. Twice Chairman of Maryport Urban District Council, archaeology and local history are chief among his many interests in West Cumberland.

Dr H–G Bachmann is an industrial chemist and physical analyst. He was brought up with a mineralogical background which has been of great help to archaeological expeditions in Europe and the Near-East.

Keith Branigan is currently lecturer in Classics at Bristol University and Professor-elect in Archaeology in the University of Sheffield. He has taken a keen interest in the early history of metallurgy in the Aegean and is the author of several books on this subject. He has been in charge of excavations at Butcombe, Gatcombe and several other sites in the Bristol area.

Colin Brewer is a senior lecturer in metallurgy in the University of Queensland at Brisbane. He was recently awarded his PhD for work on the physical metallurgy of lead. He has been interested in archaeo-metallurgical problems for many years and has accompanied expeditions in Palestine. He has just completed a period of sabbatical leave in Europe where he has been working on the physical metallurgy of early artifacts.

D Charman became corporation archivist of the British Steel Corporation in 1970. For 20 years prior to this he was joint archivist, Ipswich Borough and East Suffolk County Council. In 1955 he was seconded to the Nigerian Government to set up their national archives and in 1963 went to Nairobi to set up the Kenyan national archives.

Edward J Dwornik was born in Buffalo, NY and obtained both his BA and MA in geology from the University of Buffalo. He has been with the US Geological Survey since 1948 having devoted his efforts to the study of ultra fine grained mineralogic phases related to uranium, lunar, environmental and coal research programs.

Robert B Finkelman was born in New York City and educated at the City College of New York, George Washington University and the University of Maryland. A former Principal Investigator on the lunar Apollo program for NASA, he has been with the US Geological Survey since 1965 specializing in micromineralogical research in energy related programs.

Charles Milton was born in New York City in 1896; and received a PhD degree in geology from the Johns Hopkins University in 1929. Following several years in Venezuela and Angola as oil company geologist, he has served in the US Geological Survey since 1931, as analytical chemist, mineralogist, and geologist. He is Quondam Research Professor at George Washington University, and Visiting Research Geologist at the University of California, Berkeley.

Dr Hugh McKerrell is head of the research laboratory for the Scottish Museums in Edinburgh. He has been active in carrying out XRF analyses on metal artifacts in many museums throughout the world and has recently been involved in a re-examination of the evidence regarding the so-called forgeries at Glozel in France.

Priestley Toulmin, III was born in Birmingham, Alabama, and educated at Harvard College, the University of Colorado, and Harvard University. He has been with the US Geological Survey since 1954, serving as Chief of the Branch of Experimental Geochemistry and Mineralogy from 1966 to 1972. His chief research interests are genetic mineralogy and petrology.

D R Wattleworth retired in December 1957 from the position of General Works Manager, Workington Iron & Steel Company with which company he had been associated for 50 years. During this time he had experience in all departments, from raw materials to finished products. He took an active interest in local affairs and received the OBE in 1955 for his work as Chairman, Local Employment Committee. He has made a special study of the history of the iron and steel industry in West Cumberland.

James Williams is an industrial chemist who has made a speciality of the geology of south-western Scotland. He has been involved in local excavations and is a much sought-after extra-mural lecturer.