

CRUCIBLES FROM THE BRONZE AGE OF EGYPT AND MESOPOTAMIA

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Crucibles of the design depicted in the Old Kingdom Tomb of Mereruka at Saqqara were found at the Old Babylonian site of Tell edh-Dhiba'i in Baghdad revealing a significant geographical and chronological distribution of the crucible style and the technology they represent. It is argued that these previously unrecognized artefacts were the normal means of melting metal in the drier regions of western Asia during the Bronze Age and that crucible fragments often found in these areas are not 'bowl shaped' but are in fact Mereruka-style crucibles. Casting experiments with replicas of such crucibles have demonstrated their operational efficacy and attested to the accuracy of the tomb reliefs.

Key words: Bronze Age, Crucible, Egypt, Mesopotamia, Metallurgy.

SURVEYS of ancient Near Eastern crucibles used for metal working have almost invariably assumed that they had a bowl shape. This is well demonstrated by Tylecote who has a typology of types A to L of such crucibles (Tylecote 1976: 17–19, table 12, fig. 13). This approach reflects modern practice where deep bowl shaped crucibles are placed on top of the coals of a furnace to melt the metal charge and then manipulated with tongs to pour the contents out.

Tylecote developed his typology in *The prehistory of metallurgy in the British Isles*, where he acknowledges that British crucibles often differ from early foreign crucibles which were normally placed under the fire (1986: 97). Crucible fragments from sites such as Marsa Matruh (White 2002: 189), Qau (Davey 1985: 145), Qantir (Rehren 1995: 102; Philip 2007: 203) and el-Amarna (Eccleston & Kemp 2008) have slag on the internal surface showing that the fire was in or over the crucible.

The New Kingdom tomb paintings in the Tomb of Rekh-mi-re depict the fire over the crucible (Davies 1943: pl.17). The use of tuyeres in these depictions may raise a question about the location of the seat of the fire, however in a discussion about tuyeres, Tylecote describes how they may be configured to deliver forced air into a crucible (1981: 117). Tuyeres of the type referred to by Tylecote have also been discovered at Qantir and el-Amarna in second millennium contexts (Pusch 1990: 86ff; Eccleston & Kemp 2008). The use of green branches to carry fully charged crucibles as depicted in the Tomb of Rekh-mi-re confirms that the external surface of the crucible was comparatively cool and that the heat was concentrated inside the crucible (Rehren 1995: 103).

The crucible shape depicted in the Old Kingdom Tomb of Mereruka has not occupied much discussion although the crucible was ubiquitous enough for its silhouette to become the hieroglyphic symbol for copper (Davey 1985; Gardiner 1957: 490, 529; Ockinga 2005: 113). The discovery of such crucibles at Tell edh-Dhiba'i revealed a geographic and chronological distribution of the 'Mereruka' technology not previously appreciated (Davey 1983, 1988).

The Tell edh-Dhiba'i – Mereruka-style crucibles do not feature in any typologies and present an obvious problem, in their upright position they will not retain a liquid. This feature prompts the need for an explanation of their operation. Is it possible to melt metal in crucibles of this shape using the system depicted in the Tomb of Mereruka? The apparent absence of such crucibles from the western Asiatic archaeological record also warrants clarification.

THE MERERUKA RELIEFS

There are four metallurgical scenes found in the Tomb of Mereruka, Saqqara, depicting weighing, melting, casting and hammering of copper (Fig. 1). The melting scene shows two crucibles back to back and two teams of three people using blowpipes to ventilate the fire which is at least partly in front of the crucibles. There is something like a lid on top of the crucibles. The Old Kingdom ideogram for copper appears above the weighing scene which is to the left of the melting scene.

The use of three blowpipes for each furnace is logical as it is possible for them to apply a steady

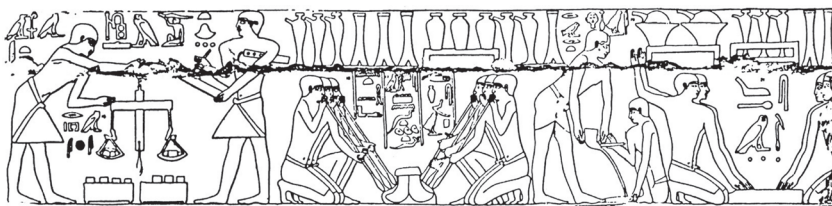


Fig. 1. Drawing of the copper weighing, melting, casting and hammering scenes in the Tomb of Mereruka, Saqqara (After Duell 1938: pl 30).

stream of air. Two people would be less efficient and four people would create a problem of over-crowding. It is worth noting that other Old Kingdom furnace depictions sometimes have one or two people with blowpipes although the material being melted is not necessarily copper or a copper alloy.

The blowpipe operators each have a hand holding the blowpipe near their mouths. This would have enabled them to cover the mouth piece of the blowpipe with the thumb preventing hot furnace gases being sucked in as the operators drew breath.

The casting scene has a person using two stones or lumps of refractory clay to hold the crucible over a mould, and a second person poking the front of the crucible with a stick as the molten metal pours out (Fig. 2). This scene reveals how the crucible was operated. The crucible was tilted only slightly forward from its upright position to pour the metal charge out. It is possible to deduce from this image that the molten metal was retained in the crucible by a barrier which could be dislodged with a stick at the time of casting.

The crucibles stand upright in the furnace image and the blowpipes are directed at the front of the crucibles indicating that heating was focused at the metal in the crucible (Fig. 3). It is therefore probable that the barrier did not completely block the hole in the front of the crucible. However the geometry of the crucibles can not be determined from the reliefs



Fig. 2. The crucible in the casting scene of the in the Tomb of Mereruka, Saqqara (Photo CJ Davey).

which depict the crucibles in profile only and awaited the discover of complete vessels at Tell edh-Dhiba'i.

The casting scene shows the crucible being held a significant distance above the mould when the metal charge is poured out. This is unrealistic because of the difficulty of aiming the pour and the danger of splashing molten metal about. This aspect of the reliefs does seem to represent some artistic license aimed at emphasising the success of the melting operation and the nature of casting procedure. That this justifies the conclusion that the rest of the scene is stylistic does beg the question as to why this would have been done. If anything was to be altered for dramatic effect, it would have been the furnace, but its portrayal is comparatively small and the fire is insignificant.

In an assessment of the Mereruka tomb decoration, Naguib Kanawati has noted that some of the scenes may depict actual events in the life of the tomb owner (Kanawati 2007: 3). There are numerous metallurgical scenes found in Egyptian Old Kingdom tombs, however no two are the same. That there was a tomb decorator's canon of stylised metallurgical scenes to inscribe on tombs has no justification at present. The suggestion that the Mereruka tomb scene is stylistic also overlooks the evidence from the Tell edh-Dhiba'i.



Fig. 3. The crucibles forming the furnace in the melting scene of the in the Tomb of Mereruka, Saqqara (Photo CJ Davey).

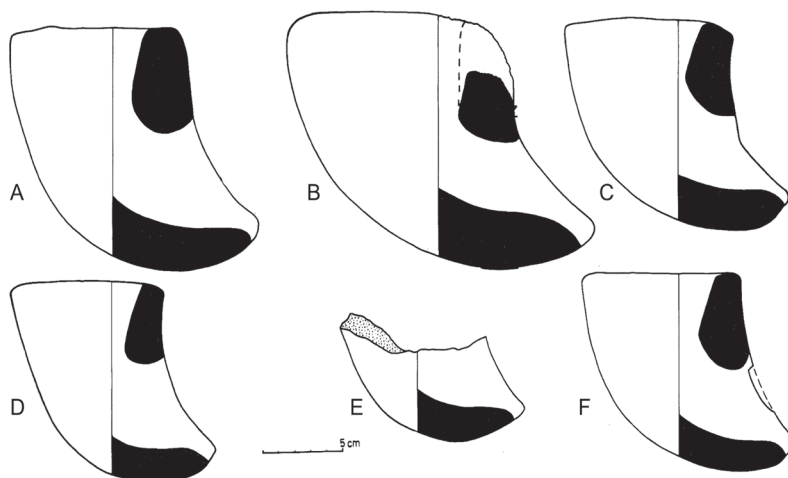


Fig. 4. Drawings of the crucibles from Tell edh-Dhiba'i; A 614/4, B 614/5, C 614/3, D 614/6, E 614/8, F 614/7.

TELL EDH-DHIBA'I

Tell edh-Dhiba'i is located in the suburbs of Baghdad and was excavated by the Directorate of Antiquities, Iraq, in 1965 under the direction of Lamia al-Gailani (al-Gailani 1965). The material at the site belonged to the Isin-Larsa and Old Babylonian periods of the early second millennium BC (al-Gailani 1965: 33, 35).

A coppersmiths' workshop was found in the course of the excavation dating to the Old Babylonian period, which is about 1800 BC. A personal report from Dr al-Gailani indicated that during the excavation of the workshop it began to rain and as some of the items were sun-dried clay, it was necessary to remove objects hastily. Excavation records were therefore less than ideal.

The preliminary report of the excavation contained comments by W. Winton of Science Museum, London, who studied photographs of the finds and identified the objects under discussion as crucibles. However he was not aware of the Egyptian depictions and proposed a system of tilting to contain and pour molten metal (al-Gailani 1965: 36).

In 1977 with the support of the British School of Archaeology in Iraq, Christopher Davey was able to study the Tell edh-Dhiba'i collection in the course of which a number of discoveries were made (Davey 1983). These included the identification of a lost-wax mould, a pattern and core for an axe head providing the earliest evidence for sand casting and complete crucibles of the shape depicted in the

Egyptian Old Kingdom Tomb of Mereruka. Moorey describes and discusses the material in detail acknowledging its importance (1999: 265–272).

Much of the collection, including all the crucibles, was on display at the time of the study in 1977. The display was dismantled and reassembled in stages allowing the collection to be studied in groups making it impossible to study all the crucibles together or to revisit issues associated with an object once it had been returned to the display. Analysis was largely limited to visual inspection.

There were five crucibles and one fragment (Fig. 4). There is a certain standardisation of size and shape. The crucibles are 90–130 mm diameter and 110–150 mm in height. Crucibles 614/7 and 614/3 are the same size and shape, as are 614/6 and the fragment 614/8. The two larger crucibles are not identical, however, an inspection of them reveals that their internal dimensions and shapes are consistent with the smaller crucibles, 614/5 with the first two and 614/4 with the latter crucible and the fragment. The size difference is the result of a thicker body. This consistency was not appreciated until replicas of the crucibles were made as described below and the drawings made in Baghdad were compared.

Insert Fig. 4 near here.

The crucibles were all made from local clay tempered with grog and chopped straw or grass. The grog was probably ground up pottery such as used crucibles and the straw was evident from the imprints it left. The fabric was therefore not particularly strong, but it was a good insulator.

Crucible 614/6 was unused. Its surface was a pinkish colour, but less than 2mm under the surface the colour of the fabric was blackish. This would indicate a short heating of the crucible, maybe in an oven. The straw itself was not apparent indicating that the crucible had been heated to a temperature of at least 600°C. The presence of a lost wax mould at the site reveals that there were other ceramics used by the metal-smiths that required such heating prior to use.

Crucible 614/5 had a fabric thickness of over 3cm, twice that of Crucible 614/6. It had been used and was in a poor state of repair with the external surface layers flaking off in an onion effect. This behaviour has prompted speculation that the crucible may have been sun-dried prior to use, rather than heated in an oven; this may explain the use of a thicker body. The pot-bellows found at the site also appeared to be sun-dried.

All the used crucibles had numerous stress cracks indicating severe differential heating. The internal surfaces of the crucibles and the fragment were blackened at the bottom inside the lip and some had traces of copper. However, slag or vitrified material in this area was not significant indicating that the clay had only limited amounts of fluxing agents, such as iron, and that heating had not been prolonged. The evidence is therefore for the concentration of heat and the melting of copper in the bottom of the crucibles.

The exterior surface of Crucible 614/7 was white and friable around the front opening indicating that there had been repeated applications of heat in that region (Fig. 5). The rest of the outside surface of the crucible retained its pinkish hue showing no signs of significant protracted heating. This confirms the furnace configuration depicted in the Mereruka reliefs which show the fire against the front of the crucible and inside it.

Inside Crucible 614/7 were some corroded metal fragments, insufficient for a quantitative analysis, but adequate for X-ray fluorescence which detected the presence of copper, tin, arsenic and traces of iron and nickel.

The fragmentary crucible 614/8 is significant. A logical reconstruction in the light of current typologies would have it formed into a bowl shape, but it is clearly the base of a crucible with the same shape as the other Tell edh Dhiba'i crucibles. An inspection of archaeological site reports, some of which are mentioned below, reveals numerous such fragments.

The crucibles found at Tell edh-Dhiba'i reveal a consistency with the scenes depicted in the Tomb of Mereruka. The crucibles were used in a near upright



Fig. 5. Picture of Crucible 614/7 showing the white colouring at the front and stress fractures (Photo CJ Davey).

position with forced air applied through the hole in the front (Fig. 6). There must have been a barrier covering much of the opening at the base to help retain the molten metal in the crucible. The air forced into the crucible was heated as it passed through burning charcoal placed against the front of the crucible and was directed at the metal to be melted above which was more charcoal fuel. This technique did not significantly heat the external surface of the crucible except immediately around the side opening.

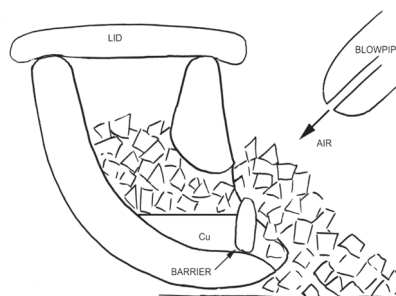


Fig. 6. Cross-section of the proposed crucible metal melting operation.

EXPERIMENTS –FIRST SERIES

The geometry of the Tell edh-Dhiba'i crucibles is asymmetrical and quite complex so that normal pottery forming techniques were not appropriate. Instead it was found convenient to form the replica crucibles over a pattern shaped like a bull's horn (Fig. 7). The uniformity of internal shape of the Tell edh-Dhiba'i crucibles described above would support this approach and indicates that they were formed using two different horn-shaped patterns.

First series of experiments were undertaken at the Royal Melbourne Institute of Technology in 1985. The crucibles were made from Melbourne's Merri Creek clay which contains iron oxide, a fluxing agent.

The crucible was buried in a bed of charcoal after a barrier of clay was placed over the spout of the crucible. A thermocouple was located inside the crucible to monitor temperature. A stream of air was aimed at the front of the crucible over the top of the clay barrier.

The temperature was sluggish to increase until a refractory brick was placed on top of the crucible producing an immediate rise in temperature. However it remained difficult to exceed 1000°C.

After pulling down the furnace it was discovered that the barrier was secured to the crucible by slag and attempts to dislodge it resulted in breaking the crucible. This demonstrated the failure pattern of the crucibles. The fragment so created was similar in shape to Tell edh-Dhiba'i crucible fragment 614/8 and the others reported in the literature.

While the trial was a failure it highlighted a number of important aspects. The refractory nature of the original crucibles, and more particularly the barrier, was important as vitrification of them would prevent the removal of the barrier. The Tell edh-



Fig. 7. Making a replica crucible over a horn-shaped pattern (Photo CJ Davey).

Dhiba'i crucibles in some cases were well used but there was little evidence of vitrification. The lid on the crucible was important for elevating the temperature. This feature is clear on the Mereruka reliefs, but had not previously been commented upon.

The ventilation of the furnace was significant. It was clear that the accuracy of the air blast and the air velocity itself rather than volume were the main contributors to high furnace temperatures. Blowpipes with a substantial choke in the nozzle may achieve these characteristics more effectively than bellows and tuyeres. Interestingly, an object that defied identification in the Tell edh-Dhiba'i collection, No. 614/10, may have been a blowpipe nozzle that was made incorrectly – the small hole not being completed. Above all, the barrier mechanism needed more attention along with the rest of the ceramics.

EXPERIMENTS –SECOND SERIES

A second series of experiments were conducted in 2006 under the auspices of the Australian Institute of Archaeology. New crucibles were made over the same pattern used for the earlier experiments using clay with no fluxing agents. The crucible was fired prior to use to a temperature of about 800°C.

The barrier was shaped from a piece of refractory brick and stuck to the crucible using low-iron oxide clay mixed with dung. The metal used was brass with a melting point of 1040°C. The proposed configuration was based on the images in the Tomb of Mereruka (Fig. 6).

The use of blowpipes operated by people was considered an occupational safety risk because of the possibility of drawing back hot furnace gases. Instead compressed air was applied at a pressure 1 atmosphere through a nozzle choked down to 4 mm diameter. The nozzle was aimed at the front opening of the crucible and over the top of the barrier in a manner similar to the depiction in the Tomb of Mereruka.

Steady air flow rather than pulsed flow has been used in other pyro-technological experiments (Pryce et al. 2007: 546). The approach is considered conservative as a pulsed flow would achieve greater air velocity and higher furnace temperatures.

The crucible was charged with charcoal and a pile of charcoal was placed in front of it (Fig. 8). During each firing the temperature rose to 750–800°C in 8 minutes where it remained for almost twenty minutes, before rising to 1100–1200°C where

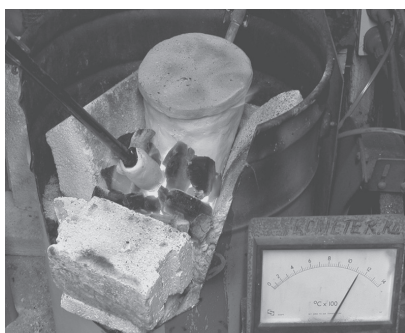


Fig. 8. Crucible set up and operating at a temperature of 1140°C (Photo CJ Davey).

it stayed until the conclusion of the firing 10 minutes later (Fig. 9). The barrier was dislodged and it was found necessary to hold the crucible steady when doing this. The metal flowed out of the crucible assisted by a little tilting.

The heating profile was repeated more than once. The reason for the plateauing of the temperature after 8 minutes remains a mystery. The amount of charcoal used was 350gm and the amount of brass melted was 70gm. The efficiency of the melting operation could be greatly improved with practice and it is considered that the amount of metal that could have been melted with this weight of charcoal was much larger.

It was found that a sharp knock would dislodge the gate. Cleaning the charcoal away from the molten metal was difficult and hazardous. The Mereruka

scene sequence showing that the crucible was lifted from the fire and the gate was dislodged so that the molten metal flowed underneath it skimming off of any floating charcoal, would address this problem.

REVIEW OF CRUCIBLE FRAGMENTS

Crucible fragments from the Bronze Age Levant and Mesopotamia have been reported in the literature. Hazor and Serabit el-Khadim are two cases in point (Yadin 1958: pl. 98; Beit-Arieh 1985) and it is normally assumed that the fragments once formed bowl-shaped crucibles. The drawings of the crucible fragments from both locations, however, are indicative of the fragments from Tell edh-Dhiba'i and the fragment created during the first experiment.

Indeed if the crucibles were bowl shaped, there would be little reason for them to break. The fact that there are numerous fragments of similar shape strengthens the argument that these are the remnants of Mereruka-style crucibles. It may reasonably be concluded that Mereruka-style crucibles were common in the Bronze Age of the Ancient Near East, but have not generally been recognised.

By comparison, large numbers of crucibles were discovered at Byblos on the coast of Lebanon. Although Byblos was a city in constant contact with Egypt, none of the reported crucibles have the shape of those from Tell edh-Dhiba'i. Byblos was in a locality where fuel for firing furnaces would not have

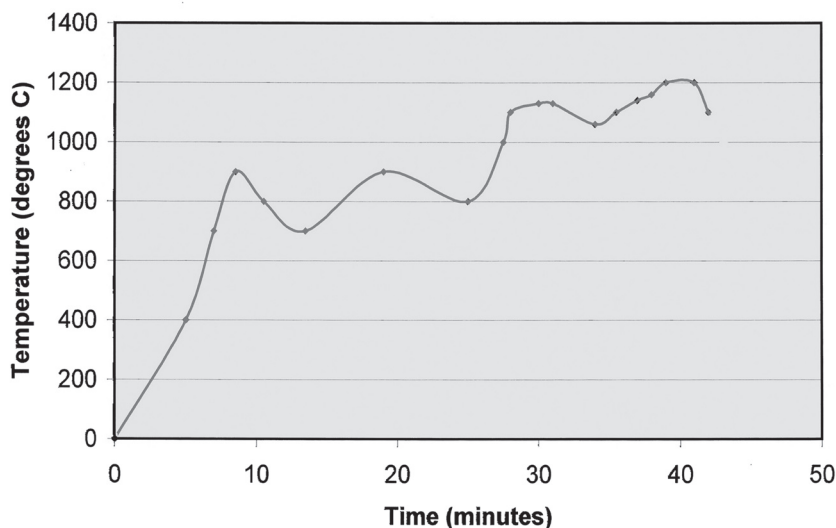


Fig. 9. A graph of the temperature in the crucible during firing.

been scarce and so if the argument below is correct, Tell edh-Dhiba'i shaped crucibles may not have been appropriate.

DISCUSSION

The propensity of these crucibles to break may raise the question of their use. Indeed, why not use the simpler form and straightforward technology of a bowl crucible.

The earlier publication of the crucibles suggested that the Mereruka shape was used in arid regions where charcoal fuel for the furnace was scarce or had to be imported (Davey 1983, 1988). The story of charcoal has not received much comment by historians and yet it is one of the more important aspects of metal working (de Jesus 1980: 37–39). Rehder (2000: 76) has argued that one adult male using a blowpipe should be able to achieve a temperature of over 1100°C in a fuel bed of charcoal. Charcoal is the most efficient fuel in the ancient world to achieve high temperatures.

The vegetation that could be made into charcoal was scarce in arid regions, and so its use would have been restricted. The quality of charcoal available may also have been variable. Charcoal may even have been imported into such areas and while it is not heavy, it is bulky. Metal could have been recycled by its owners, making tools in times of peace and weapons in time of war, charcoal however was an expendable resource. If it was not locally available, it would have been a significant cost to metal smiths in Mesopotamia, Egypt and the interior of the Levant because of the distance it had to be brought, its bulky nature and the cost and risks of production. Anything that reduced the usage of charcoal would have been important.

Craddock has questioned the use of blowpipes after the introduction of bellows and has claimed that their depiction in Old Kingdom tomb metal melting scenes 'represents artistic conservatism' (1995: 178). He does however concede that blowpipes offer accuracy in directing the blast of air. His comments are made in the context of a discussion of smelting rather than melting. Melting operations required far less ventilation unless large amounts of metal were involved, and so his comments about the tomb scenes such as those of Mereruka where comparatively small amounts of metal were melted are of doubtful validity. Compounding the problem is the fact that the date for the introduction of bellows is hard to de-

termine as the earliest types were almost certainly made from materials that have not survived.

The depictions of the Tomb of Mereruka and the crucibles found at Tell edh-Dhiba'i both reveal accuracy with respect to the application of heat. The crucibles were subjected to significant temperature differentials as the air blast was focussed into the crucible to concentrate the heat on the metal it contained. With a lid on it, the crucible became a furnace retaining much of the heat generated.

The refractory fabric of the crucibles prevented the exterior surface heating excessively so that the Mereruka relief image of the crucible being carried is quite plausible. Rehren's previously referred to comment about this aspect of the crucible scenes depicted in the Tomb of Rekh-mi-re applies equally to those of the Tomb of Mereruka (Rehren 1995: 103).

The stress cracks in the Tell edh-Dhiba'i shows them to have a limited life and explains how they could break if used for one casting too many. The thermal stresses associated with differential heating, the physical stresses of being carried fully charged and the shock generated by the dislodging of the gate at the time of casting may all have led to the breakages.

The volume of metal that can be melted in the crucible is limited to about 50ml. The size of objects that could be cast is therefore not large, although it is possible that metal from more than one crucible could be poured into the same mould one immediately following the other. The fact that two crucibles are used simultaneously in the Tomb of Mereruka scene makes this possibility likely. It also means that the crucible is more appropriate for the use of village metal-smiths than for large state sponsored enterprises such as those depicted in the New Kingdom Tomb of Rekh-mi-re.

CONCLUSIONS

The experiments have demonstrated the practicalities of using the Tell edh-Dhiba'i -Mereruka-style crucibles to melt copper alloy and they have shown that there is no reason why the scenes depicted in the Tomb of Mereruka are not plausible. The height of the pour depicted in the tomb reliefs may have been increased to emphasise the nature and success of the operation, but that aside, the representations are accurate.

The experiments also revealed the failure pattern of the Tell edh-Dhiba'i -Mereruka-style crucible pro-

ducing fragments of a shape consistent with broken crucibles from sites elsewhere in the arid regions of western Asia. This leads to the belief that they were the normal means of melting metal in that area for at least part of the Bronze Age. This has not previously been recognised.

The fuel efficiency of the crucibles was not reliably quantifiable from the experiments, however it may be dependably inferred from the nature of the operation. Heat was applied directly to the metal being melted and much of this heat was retained in the immediate vicinity of the molten metal because of the crucible's insulating fabric and the lid placed on it.

Contemporary practice in Lebanon, Anatolia and Europe saw the use of bowl type crucibles that were sometimes placed on top of a heat source. The operation of such crucibles was straight forward, but the heat losses were many. The skill of the metal-smiths in these areas was to be seen more in their moulding technology than their crucible operations.

The operation of the Tell edh-Dhiba'i -Mereruka-style crucibles was not straight forward and the metal-smiths using it had to be skilled in their use. The reason why such complex crucibles were used for what was otherwise a simple operation needs explanation, especially as it appears that these crucibles were ubiquitous in some regions.

The original conclusion that the Tell edh-Dhiba'i -Mereruka-style crucible was used where fuel sources were limited seems to be strengthened. The plausibility of the crucible operation in a fuel efficient manner has been demonstrated by experiment. The occurrence of fragmentary Tell edh-Dhiba'i -Mereruka-style crucibles in the drier regions of the Levant adds support to the conclusion.

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