Meteoritics & Planetary Science 48, Nr 6, 997–1006 (2013)
doi: 10.1111/maps.12120

Analysis of a prehistoric Egyptian iron bead with implications for the use and perception of meteorite iron in ancient Egypt

Diane JOHNSON[1*], Joyce TYLDESLEY[2,3], Tristan LOWE[4], Philip J. WITHERS[4], and Monica M. GRADY[1,5]

[1]Department of Physical Sciences and Centre for Earth, Planetary, Space and Astronomical Research, The Open University, Walton Hall, Milton Keynes MK7 6AA, UK
[2]Faculty of Life Sciences, The University of Manchester, Stopford Building, Oxford Road, Manchester M13 9PL, UK
[3]The Manchester Museum, University of Manchester, Oxford Road, Manchester M13 9PL, UK
[4]Henry Moseley X-Ray Imaging Facility, School of Materials, University of Manchester, Grosvenor Street, Manchester M13 9PL, UK
[5]The Natural History Museum, Cromwell Road, London SW7 5BD, UK
[*]Corresponding author. E-mail: diane.johnson@open.ac.uk

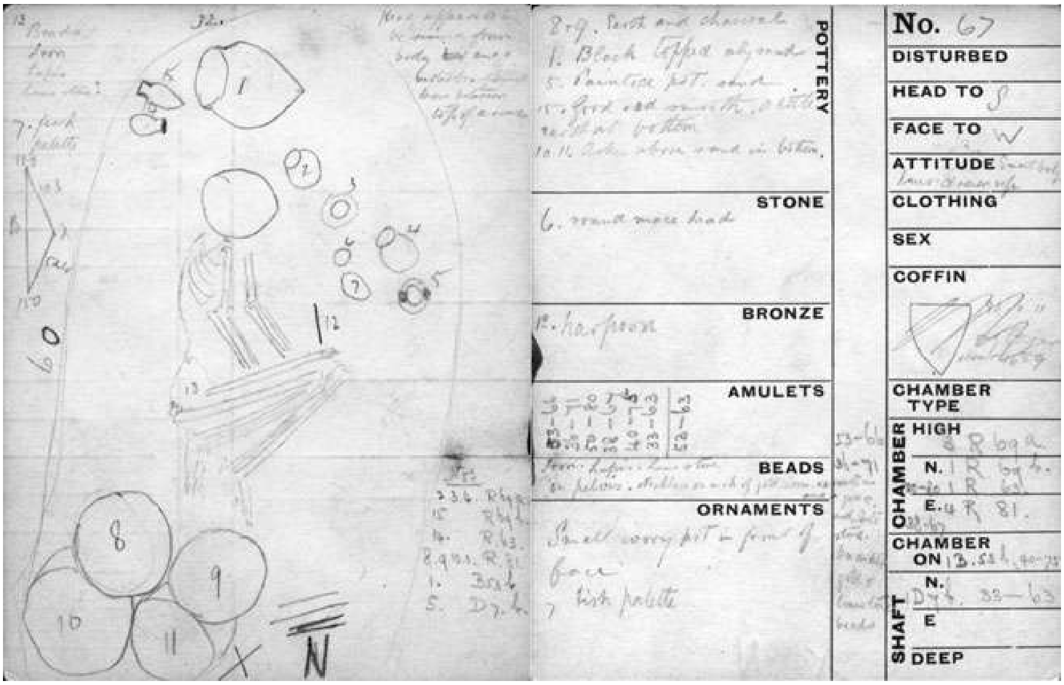
(Received 14 December 2012; revision accepted 29 March 2013)

Abstract–Tube-shaped beads excavated from grave pits at the prehistoric Gerzeh cemetery, approximately 3300 BCE, represent the earliest known use of iron in Egypt. Using a combination of scanning electron microscopy and micro X-ray microcomputer tomography, we show that microstructural and chemical analysis of a Gerzeh iron bead is consistent with a cold-worked iron meteorite. Thin fragments of parallel bands of taenite within a meteoritic Widmanstätten pattern are present, with structural distortion caused by cold-working. The metal fragments retain their original chemistry of approximately 30 wt% nickel. The bulk of the bead is highly oxidized, with only approximately 2.4% of the total bead volume remaining as metal. Our results show that the first known example of the use of iron in Egypt was produced from a meteorite, its celestial origin having implications for both the perception of meteorite iron by ancient Egyptians and the development of metallurgical knowledge in the Nile Valley.

INTRODUCTION

The Gerzeh cemetery is a predynastic site on the west bank of the Nile, approximately 70 km south of Cairo; it dates from approximately 3600 to 3350 BCE (Stevenson 2006). Site excavation revealed 281 grave pits of prehistoric origin, of which two contained tube-shaped metallic (iron) beads: seven in tomb 67 and two smaller ones in tomb 133. The term bead is being used here to refer to a small object featuring a hole through it for the purpose of threading. The tombs also contained other unusual materials exotic to the locality, including obsidian, ivory, and shells from the Red Sea and Mediterranean Sea (Petrie and Wainwright 1912; Wainwright 1912). The celestial or terrestrial origin of ancient Egyptian iron, and when its usage became common are contentious issues, which are subject to debate; evidence is drawn from many areas, including architecture, language, and belief. The earliest potential archeological evidence indicative of iron smelting in Egypt dates in the 6th century BCE largely in the form of iron slag excavated in the delta region at Naukratis and Tell Defena (Petrie 1886). Copper smelting has been known to produce large quantities of iron slag, so this archeological evidence is not definitive proof of iron working and so the date of iron smelting by Egyptians could therefore be much later (Ogden 2009). This situation is complicated further by occasional finds, such as the plate of iron in Khufu's pyramid at Giza (approximately 2560 BCE), which has added to this great uncertainty (Petrie 1883).

The beads from Gerzeh tomb 67 were first analyzed in 1911 by Gowland, although it is not clear how many or which beads were analyzed. Their composition was reported to be as hydrated ferric oxide, with a note that the beads were completely oxidized, being 78.7% ferric oxide and 21.3% combined water, with traces of CO_2 and "earthly matter" (Wainwright 1912). It was also



No. 67
DISTURBED
HEAD TO S
FACE TO W
ATTITUDE [illegible]
CLOTHING
SEX
COFFIN
CHAMBER TYPE
CHAMBER HIGH 3 R 69a
N. 1 R 69 b.
E. 4 R 81.
CHAMBER ON 13.
SHAFT N. D 7 b. 33–63
E
DEEP

POTTERY
8–9. [illegible]
1. Black topped [illegible]
5. Painted pot [illegible]
15. [illegible]
10. 11. [illegible]

STONE
6. round mace head

BRONZE
12. harpoon

AMULETS

BEADS [illegible]

ORNAMENTS
Small ivory pot in front of face
7 fish palette

Fig. 1. Original tomb card of tomb 67 Gerzeh cemetery showing position and contents of the tomb which included: the human remains, pots, limestone macehead, cosmetic "fish"-style palette, a copper harpoon (labeled by excavator on this diagram with a "12"), ivory pot, and beads. © The Petrie Museum of Egyptian Archaeology, University College London.

suggested that the method of manufacture was through bending of a thin plate of iron into a tube shape. Subsequently, analysis on one of the beads was performed by Desch (1928) on behalf of the British Association for the Advancement of Science and found to be 7.5 wt% nickel, 92.5 wt% iron. Unfortunately, neither study gave analytical details of methods and conditions used, or how data were processed. Buchwald visually examined three of the beads held at the Petrie Museum of Egyptian Archaeology; he noted them to be strongly oxidized and weakly magnetic, also noting that if Desch's analysis was correct, it appeared to be definitive proof of the beads being produced from an iron meteorite (Buchwald 1975).

A more recent study of the beads held at the Petrie Museum of Egyptian Archaeology University College London employed electron microprobe analysis of material scraped from the surface. Most of these surface materials were identified as limonite, with low levels of nickel (up to 0.2 wt%) and traces of copper (up to 0.5 wt%) (El-Gayer 1995). Collectively, these data cast uncertainty upon the meteorite origin previously attributed to the beads. However, this study did not take into account that the beads had been subject to preserving treatment during their museum curation, which had visibly altered the surface, staining the surface oxides black. In addition, this tomb 67 also contained a copper harpoon, which could easily be a source of low level copper contamination, as the beads had been lying close to the harpoon when found (Fig. 1).

The beads from the tombs at Gerzeh are older than any other iron artifact recorded in Egyptian history; they appear to be the most ancient example of worked metallic iron from a region and time with no known worked indigenous source of iron or contemporary record of trade in iron goods. Because previous analyses of the beads had been incomplete and noninvasive analytical methods were now available that would preserve the integrity of the artifacts, we decided to re-examine the Gerzeh beads with modern instrumentation that would yield a 3-D description of the structure and composition of the material. This would help assign a source for the metal from which the beads were manufactured, whether it be terrestrial or meteoritic.

STRUCTURE AND CHEMISTRY OF THE BEAD

Sample

We analyzed a 1.8 cm length iron bead originating in Gerzeh tomb 67 (from the collection of The Manchester Museum, accession number 5303); the bead was examined as an intact specimen—it did not undergo any form of preparation (Fig. 2). Tomb 67 contained a single body, of a "fair sized boy" as described by the excavator. The body was arranged on

Fig. 2. Optical image of the Gerzeh bead analyzed in this study. The bead is held by The Manchester Museum, accession number 5303, scale bar 1 cm.

its side in a contracted position, although the head positioned upright (Fig. 1) and one vertebra was displaced out of position, which led the excavators to believe that this was evidence of mutilation as a grave rite. Beads were present in two places on the body: around the neck and at waist level. By comparison with on-site photography documenting all beads recovered from tomb 67, the bead we analyzed in this study was identified as one that had originally been positioned at the waist level of the body (Fig. 3). Visual examination of the bead shows that areas of its outer surface were significantly altered, having incorporated sand from the tomb (Fig. 2).

METHODS

Scanning Electron Microscopy

Analysis was performed with an FEI Quanta 200 3-D at 20 kV, 0.6 nA beam current, in high vacuum mode. Because the bead is of such archeological significance, it was not possible to coat the sample with a conductive layer prior to analysis; neither was it possible to polish any part of the bead, or take any material for destructive analysis for determination of minor or trace element contents. Oxide compositions were measured across approximate 250 × 200 µm areas. Metal composition was calculated by measuring a series of points as a traverse across metal fragments to ensure identification of data with minimal or no excitation of surrounding oxides, which would otherwise complicate the compositional metal analysis. Data are all quoted as normalized weight percent, to compensate for sample topography, geometry, hydration, and absence of a carbon coating. Composition was determined in situ via energy dispersive X-ray spectroscopy (EDS) with an Oxford Instruments 80 mm X-Max detector using Inca software versus 4.13 in the Department of Physical Sciences at the Open University, UK.

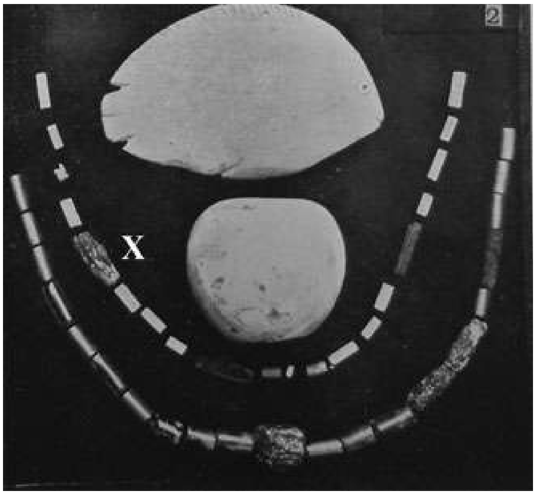


Fig. 3. Photograph of several objects recovered from tomb 67 at Gerzeh cemetery including a fish-shaped palette, a limestone macehead, as well as two strings of beads. The upper ones were found across the waist region of the body, the lower set across the neck. The bead subject to analysis in this study is marked with an X. © The Petrie Museum of Egyptian Archaeology, University College London.

X-Ray Microcomputer Tomography

To examine the internal structure of the bead, we performed X-ray microcomputer tomography (X-ray CT) with a Nikon 320 kV custom bay, 2501 projections were recorded at an X-ray voltage of 95 kV, spot size of 3 µm, producing a voxel size of 10 μm^3. The resulting image data set was used to build a model using Avizo®Fire software at the Henry Moseley X-ray Imaging Facility, University of Manchester, UK.

RESULTS

Scanning Electron Microscopy

Energy dispersive X-ray spectroscopy of the surface identified it to be composed of hydrated iron oxides with 0.86 wt% average nickel content. On parts of the bead, this outer layer was missing, allowing direct analysis of the interior oxides and remaining metal. Here, the oxidized areas have average compositions of 47.5 wt% iron, 42.9 wt% oxygen, 4.8 wt% nickel, 0.6 wt% cobalt (see Table 1 for full results). The elements present at levels less than 1 wt%, such as sodium, magnesium, silicon, sulfur, and calcium are likely to be contamination from the sand that filled the tomb, in addition to the other grave goods (Figs. 1 and 3). An absence of arsenic was noted from data recorded in all areas. Fragmented bands of metal were found; a series of point spectra were recorded at 20 µm intervals

Table 1. Energy dispersive X-ray spectroscopy from 250 × 200 μm areas recorded on three areas of the beads surface and three areas of interior oxides, all reported as normalized data.

Elements	Surface oxides spectrum 1	Surface oxides spectrum 2	Surface oxides spectrum 3	Interior oxides spectrum 1	Interior oxides spectrum 2	Interior oxides spectrum 3
C	18.1	28.4	20	—	—	—
O	36.4	36.8	34.6	44.7	40.6	43.3
Na	0.1	0.7	0.4	0.6	0.4	0.5
Mg	0.3	0.4	0.5	0.5	0.5	0.6
Al	—	0.3	0.4	0.1	—	0.1
Si	0.7	0.9	1.2	0.9	0.7	0.8
P		0.1	0.1	0.5	0.5	0.5
S	0.1	0.2	0.1	0.2	0.2	0.2
Cl	0.2	0.7	0.5	1.1	1	1
K	—	0.2	0.1	—	—	—
Ca	4.1	1.7	4.8	0.6	0.6	0.6
Fe	38.4	28.5	36.3	45.4	50.1	47
Co	0.4	0.2	0.2	0.6	0.6	0.6
Ni	0.9	0.9	0.8	4.8	4.7	4.8
Br	0.3	—	—	—	0.1	—
Totals	100	100	100	100	100	100

across a linear traverse 800 μm length, crossing four metal bands (Fig. 4). The bands have a peak nickel content at approximately 30 wt%, coincident with the presence of metallic iron, as defined by an increase in iron content matching a decrease in oxygen content. The distribution of fragmented metal bands and oxides, plus the chemistry of the metal, are consistent with the distorted Widmanstätten pattern of a weathered iron meteorite, in which lineations of flattened nickel-rich taenite define the edges of broader kamacite bands, which subsequently oxidized.

The presence of Widmanstätten pattern within iron-nickel alloys of this composition is accepted as definitive proof of meteoritic origin. Then based upon the assumption of nickel-rich metal bands marking kamacite band edges, we estimate this meteorite band width to be less than 0.2 mm; therefore, the Gerzeh meteorite is a finest octahedrite. Distorted Widmanstätten patterns have been documented in other ancient meteorite iron artifacts. The prehistoric American Indian iron beads found in the Hopewell burial mounds, Illinois, approximately 400 BCE (Arnold and Libby 1951) were proved of meteoritic origin via structure and chemistry (Grogan 1948; Wasson and Sedwick 1969; McCoy et al. 2008). Of almost identical appearance to the Gerzeh beads, kamacite was found to be preferentially weathered, with readily recognizable, but distorted taenite bands.

Example artifacts with a similar weathering state to the Gerzeh beads are found in two Chinese bronze weapons with meteoritic iron blades of the early Chon dynasty approximately 1000 BCE (Gettens et al. 1971). They comprise of broad and dagger axe blades with iron meteorite chemistry and distorted weathered Widmanstätten, with metal chemistry in agreement with that recorded in points across metal bands in Gerzeh. The least weathered of all examples of this type of microscopic structure and chemistry were observed within pieces of the Cape York meteorite after being worked into tools by prehistoric Inuit of Greenland (Buchwald 1992).

Computer Tomography Results

The extent of metal preservation was assessed by X-ray CT (Figs. 5 and 6). Different phase densities in the CT scan correspond to the differing X-ray attenuations of individual components. Combining the images from the CT scan with the EDS results, and using 3-D modeling software (Yoshikawa et al. 2008), we were able to produce a semiquantitative characterization of the components present in the bead. Based on the CT model, we calculate the relative amounts of metal, nickel-rich oxides, and nickel-poor oxides at 2.4 vol%, 68.6 vol%, and 29.0 vol%, respectively.

Structurally, the bead shape was shown to be a hollow tube; successive virtual CT slices revealed bending points and a joining edge, suggesting production by beating flat a fragment of iron, followed by bending to produce the tube (Fig. 6). The model reconstruction from CT data clearly shows patches of nickel-rich oxides where the nickel-poor layer is missing (Fig. 5a), as well as the 3-D distribution of the remaining metal (Fig. 5c). As might be expected, upon oxidation, the tube structure has expanded

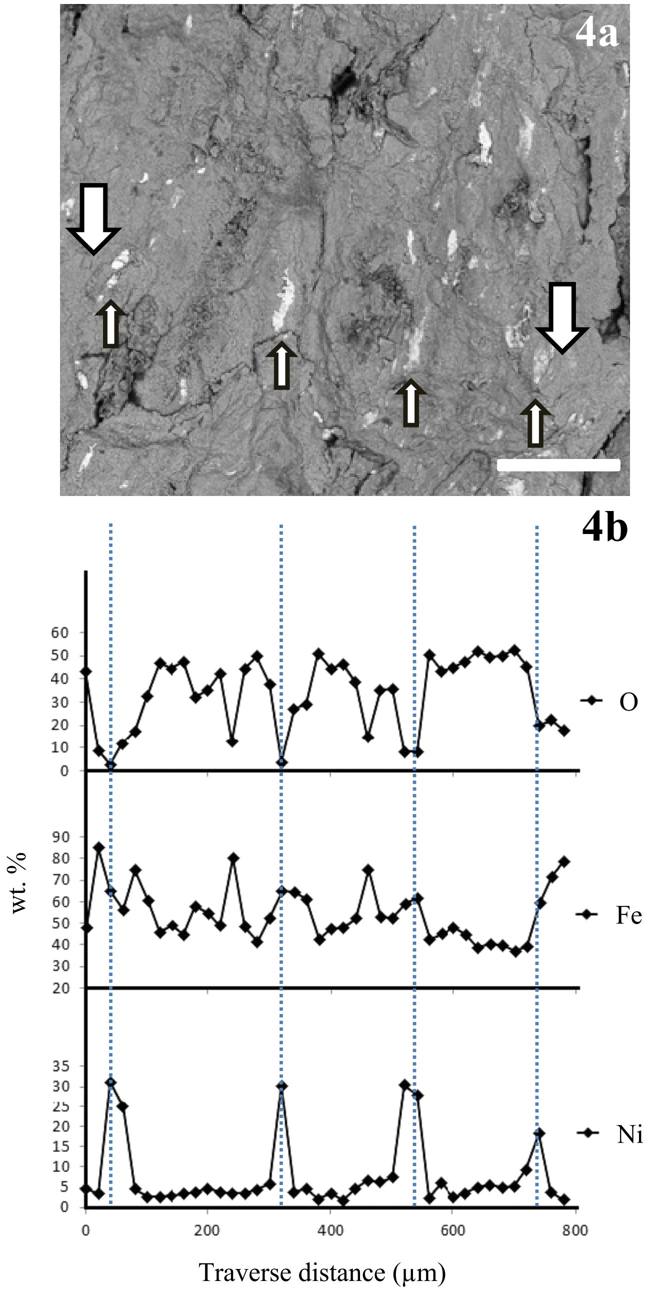


Fig. 4. Backscattered electron image and EDS data showing an array of taenite fragments (as indicated by small arrows). a) Backscattered electron image of bead surface with the surface oxide layer missing. Thin bands of nickel-rich metal form arrays across the area, some distortion is present because of cold working of this material. Large arrows note the start and end points of the linear traverse of data displayed in (b), small arrows mark the features coincident with features on (b). Scale bar is 200 μm. b) EDS point analysis results for Ni, Fe, O, recorded as a linear traverse across four metal bands, the start and end positions indicated in (a), the dashed vertical lines mark positions of the metal features.

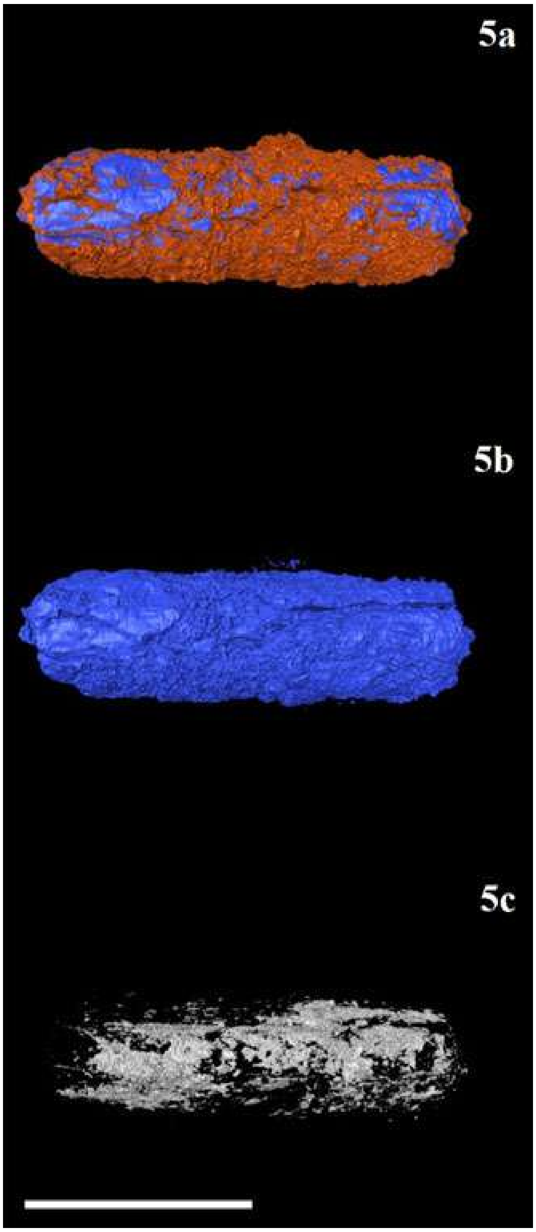


Fig. 5. Images of Gerzeh bead CT model showing oxide and metal components. With orange representing hydrated nickel-poor oxide, blue representing nickel-rich oxide, and white representing metal. a) The nickel-rich oxide patches visible where patches of the hydrated oxides are missing; b) the nickel-rich oxide structure only, deep fractures run throughout this oxide; c) the preserved metal fragments in the interior of the bead, scale bar 1 cm.

macroscopically, leaving misaligned metal fragments within the bulk oxide. A fragment of the woven thread originally used to string the beads is also visible on virtual CT slices running through the center of the bead. One exposed end of this thread displays structures

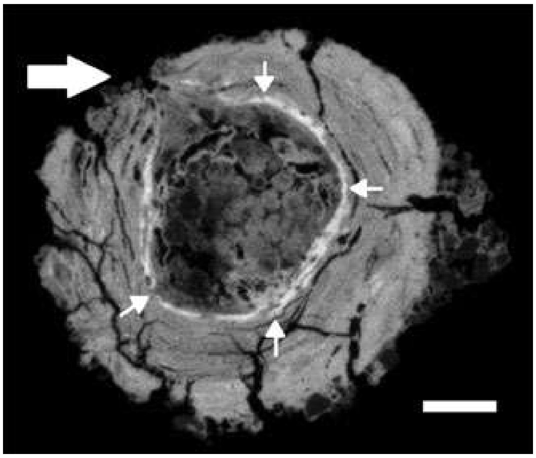


Fig. 6. Virtual CT slice through width of the bead. The angular points in the highly attenuating bright band toward the center are noted by small arrows and represent points where the bead was bent into shape during manufacture, the large arrow marks the feature corresponding to the joining of the two ends of the flattened iron sheet mechanically merged; also present are significant fractures throughout the bead as the dark irregular bands, scale bar 1 mm.

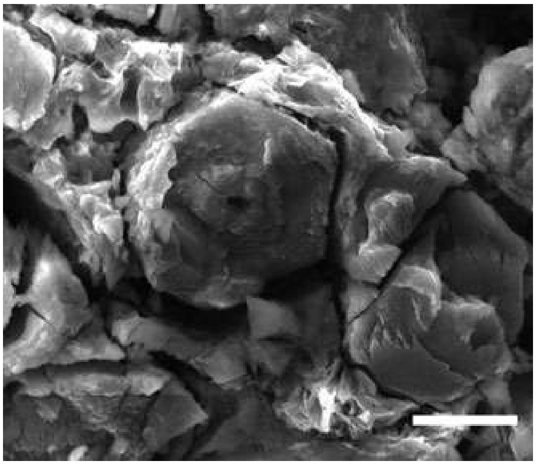


Fig. 7. Scanning electron microscopy secondary electron image of an exposed area of one fiber which exists through the center of the bead, the hexagonal shape is the remains of a cellular structure of the flax plant, scale bar 10 μm.

with the morphology of flax fiber cells as identified by scanning electron microscopy (Fig. 7).

Meteorite Weathering Processes

The weathering effects on meteorites appear to be influenced by their environment and terrestrial age, in addition to individual meteorite chemistry and structure. Numerous studies have enhanced our knowledge of the alteration processes that take place within iron meteorites (Buchwald 1979; Bender and Buchwald 1994; Buchwald and Koch 1995). Most weathered meteorite materials are composed of nickeliferous iron oxides and oxyhydroxides γ-$(Fe,Ni)_2O_3$ (Tilley and Bevan 1998) and form via nickel substitution for iron, where little loss of nickel occurs during maghemite formation. Metals in iron meteorites undergo a chlorine precipitation process forming the mineral akaganéite, (β-FeO(OH,Cl)), which tends to accelerate the corrosion process (Buchwald and Clarke 1989; Tilley and Bevan 1998). But as akaganéite ages, it evolves into two major components, goethite (α-FeO(OH)) and maghemite (γ-Fe_2O_3) (Buchwald and Clarke 1989).

The Microstructure and Chemistry of Early Iron Smelting and Iron Meteorite Artifacts

Microstructural layering is sometimes observed within forged metal, such as Damascus steel, classically known for its use in Middle Eastern sword production, making use of wootz steel originating in India and Sri Lanka (Juleff 1996) from where it was exported to the Middle East from as early as the 3rd century ACE (Sinopoli 2003), where layers of metal were stacked, heated, and in some cases folded, producing microstructural phases of distinct composition (Sherby and Wadsworth 1985; Reibold et al. 2006). The nickel concentration in these Middle Eastern manufactured steels is significantly less than that of meteorite iron. A small number of manufactured nickel-enriched laminated iron artifacts of greater antiquity are also known of in well defined collections worldwide (Photos 1989). But complications exist in determining their exact methods of manufacture, many being analyzed at different times by different methods; studies detailing their microstructure and chemistry were generally found to be the most revealing. From these results, theories have been proposed to explain their nickel enrichment, some of which are too low in nickel to be interpreted simply as a worked iron meteorite. Others have high localized nickel content in the concentrations expected for meteorites, but this exists as layers frequently containing elevated levels of arsenic and cobalt between what are obviously manufactured bands of iron containing little or no nickel. These bands also bear evidence of industrial processing, such as slag inclusions, ferrite, and pearlite structures. The earliest example of this type being the Etruscan spearhead of 3rd to 4th century BCE Italy, which was extensively studied (Panseri and Leoni 1967) and concluded by the study authors to be components of a worked iron meteorite welded to form a very early version of laminated steel.

However, others have proposed alternative explanations for these types of materials, such as the use of rare minerals such as chloanite $(FeNiCoAs)S_2$ to produce a high nickel content smelted iron layer (Piaskowski 1982). The exact method of manufacture for these types of artifacts, which are obviously at least partially manufactured examples of iron, is still subject to debate among archeometallurgists today.

Experimental archeology has failed to produce forged steel objects with layers of high nickel composition: whenever the nickel content exceeds approximately 3 wt%, the increased brittleness of the metal causes the nickel-rich fractions to fail and shatter (Photos 1989). This explains why almost all nickel-rich iron recorded within steel artifacts is within the range of 3–5 wt% nickel (Photos 1989), examples with higher nickel content are frequently those which required less working, such as bars of iron, although occasional examples are discovered that have been worked more heavily presumably by an expert ancient metalworker. Mycenaean iron artifacts have also occasionally been found with a slightly higher nickel content, up to approximately 10.7 wt% (Varoufakis 1982), but these examples never have Widmanstätten microstructure. Hence, the presence of the metallic taenite bands of the Widmanstätten structure within an artifact of an oxidized iron-nickel alloy is definitive recognition that the material has an extraterrestrial origin, and is not manufactured steel.

Ancient Text References to Iron and Meteorites

Within the near east, we find text references to iron and meteorites, but the exact origins of the words used for iron within the region are complex and despite many previous studies remain largely unproven. In the third millennium BCE, Mesopotamian references to *KU.AN* exist, which may be interpreted as iron, but tin is also possible (Maxwell-Hyslop 1972; Bjorkman 1973). The term *AN.BAR* (Maxwell-Hyslop 1972; Bjorkman 1973) is found approximately 2000–1500 BCE, some slightly earlier use *AN* sign to mean iron (Bjorkman 1973). The Hittites also appeared to differentiate the quality or type of iron, for example the use of *AN.BAR SIG* meaning good iron (Siegelova 1984), but there is also evidence that the Hittites described the sky itself as iron (Reiter 1997). Thus, not all ancient references to iron and sky necessarily equate to meteorites—they sometimes may simply be descriptions of light, and a comparison of the color of the sky with the sheen and color of metallic iron.

Complex linguistic issues regarding difference in the reading of ancient Egyptian terms for copper and iron caused massive confusion in early translations. Some linguists made no acknowledgment of the difference; early distinctions defined one as copper, the other as "hard mineral" and numerous linguists considered the ideogram of the copper term to be a crucible (Harris 1961). The term *biA* eventually translated to mean iron; these early references to iron typically describe objects or aspects of the sky and so have a relatively broad meaning. As Egyptians at this time would not have understood the intricacy of iron metal chemistry, such early terms possibly reflected other iron-related materials, such as haematite or any material that had a visual resemblance to fresh or weathered iron.

However from the late 18th Dynasty, approximately 1300 BCE, the term *biA-n-pt* starts to be used, which literally reads *iron from the sky* and from this point onwards, it is applied to describe all types of iron (Bjorkman 1973), the term becoming synonymous with metallic iron in general. Reasons for the creation of this new word at this particular point in time are unknown, but it is possibly a literal description resulting from the observance of a major event by the Egyptian population; this would both create the specific need for a new term and for it to be used for all forms of metallic iron. The witnessing of a localized event would probably not be sufficient to influence the Egyptian literate minority (scribes) to make and use a new word so dominantly, whereas a larger event, such as a shower of meteorites or large impact event would leave little doubt to where the iron had originated and would be witnessed by many. One possibility, for example, might be formation of the 45 m diameter Gebel Kamil crater in southern Egypt, which was produced by the impact of an Ataxite iron meteorite within the last 5000 yr (Folco et al. 2010). The unpredictable nature of such an event may have been sufficient to require a new descriptor, and sufficiently significant for the term "iron from the sky" subsequently to be used indiscriminately for all metallic iron.

Other Examples of Ancient Egyptian Nickel-Rich Iron

Early examples of Egyptian iron exclusively take the form of high quality tomb goods, the nickel-rich objects having provenance based upon excavation from three locations: the Gerzeh cemetery, Deir el-Bahari, and the Valley of the Kings, the second two sites being on the west bank of ancient Thebes (modern Luxor). Nickel-rich iron makes up the blade of the *pesesh-kef* amulet recovered at Deir el-Bahari from the tomb of Ashait, a secondary wife of King Mentuhotep II, approximately 2055–2004 BCE (Winlock 1921; Brunton 1935). Pesesh-kef amulets have connections with the magic rituals involved in ancient Egyptian funerary customs, such as the opening of the mouth ceremony, which allows the mummy to receive food offerings. The blades may also represent those used to cut the umbilical cord (Roth 1992), perhaps symbolically functioning in the tomb as a tool for rebirth.

The presence of iron in the tomb of King Tutankhamen, approximately 1327 BCE, reflects the fact that many rare and precious materials were employed in the manufacture of tomb goods, and iron was occasionally referenced in communications between royalty throughout the near east region at this time. A dagger blade, sixteen miniature blades, a miniature head rest, and an amulet all made of iron were discovered in Tutankhamen's tomb (Carter 1927, 1933); with the exception of the amulet, all were analyzed, and all were originally noted to be sufficiently rich in nickel to be attributed to a meteorite origin (Bjorkman 1973). All except the dagger are consistent with cold iron working by Egyptians unaccustomed to manufacturing hard, high temperature metals, such as nickel-rich iron. However, in the light of more recent studies of iron production in the near east at this time, we cannot assume that the Tutankhamen grave goods are meteorites without further microstructural analysis (Piaskowski 1982; Varoufakis 1982; Photos 1989). Interestingly, the most recent analysis of the dagger blade by XRF recorded a nickel content of 2.8 wt%, which is inconsistent with meteorite iron, although this study did not attempt to identify any possible microstructures (Helmi and Barakat 1995). Dagger blades made from iron appear to be a specialist product; within the near east, evidence suggests Mitanni or Kizzuwadna as places producing such items (Forbes 1950). Further studies are needed to understand iron production and methods of iron working in the region at this time. Within one of the Amarna letters (clay tablets found at the Amarna site documenting Egyptian diplomatic correspondence dating over an approximate 30 yr period until this capital city was abandoned at the start of Tutankhamen's reign) is a reference that Tushratta, King of Mitanni, sent as part of a dowry, to King Amenhotep III of Egypt a dagger blade of *khabalkinu*, which has been interpreted by some to mean steel (Mercer 1939) (the exact origin of this word is unknown, but based within ancient Hittite and not linked to the kaaba stone, where the name kaaba is from modern Arabic meaning cube and is not composed of iron). Given the rarity of such a material at this time, it is possible that this dagger was inherited by Tutankhamen either in life as a family heirloom (Amenhotep III is generally accepted to be a close relative of Tutankhamen, probably his grandfather) or on his unexpected death when suitable tomb goods were acquired. All other iron objects recovered from Tutankhamen's tomb are of symbolic form, such as the 16 miniature blades, again suggesting links to the opening of the mouth ceremony. It was speculated that iron was considered especially powerful in the context of gifts for the afterlife because of its relationship with meteorites and thunderbolts (Petrie and Wainwright 1912), but this hypothesis cannot be fully verified, as there is no indication of the contemporary state of Egyptian knowledge of meteorites at the time.

The Significance of Unusual Materials and Objects in Ancient Egypt

Unusual materials appear to have held a particular fascination for prehistoric Egyptians (Stevenson 2009) as can be seen in the Gerzeh tomb contents, which include shiny stones as well as rare materials from distant lands. Each item appears to carry its own special function or significance. The exact meaning and importance of the grave goods is difficult to define, but they may have been thought to possess beneficial protective properties or may have been indicators of social status. No clear evidence exists of iron being used functionally, such as tools or weapons until much later in Egyptian history, predominantly during the Egyptian iron-age from approximately the 6th century BCE.

In later times, certain materials were linked to the gods, such as gold representing the flesh of the gods and the "iron bones of Seth" as documented by the ancient historians Plutarch and Diodorus (Forbes 1950). Cult worship of stones, including potential meteorites, appeared to have occurred in ancient Egypt (Kemp 1991), as with other parts of the ancient and sometimes modern world. A prime example of this is the (now vanished) Benben stone of Heliopolis (now a suburb of Cairo). It was a cult site of solar worship and the Benben stone, thought to have had the shape of a mound or pyramid, was located in the solar temple, where it was displayed on the top of a tall pillar, providing a significant focus of worship (Remler 2010), this stone was named after the sacred mound of creation, which, according to ancient Egyptian cosmological theories dating back to the Old Kingdom (approximately 2686–2125 BCE), arose from the waters of Chaos where the creator god Atum (Lord of Heliopolis) appeared bringing light to the world (Tyldesley 2010). Explanations for why the Benben stone was considered so important include a meteorite origin (Budge 1926). Unfortunately, the original Benben stone was lost in antiquity, its origin is still a subject of debate.

CONCLUSIONS

The analysis described here of the bead from tomb 67 at Gerzeh shows that the earliest example of exploitation of iron in Egypt used meteoritic iron as the metal source. As such, this study is the first detailed scientific report of meteorite iron within Egyptian culture; it is also the first identification of preserved prehistoric metallic iron fragments by 3-D microstructural and chemical definition.

The remnant fragments of unaltered taenite grains form periodic bands that are traces of a Widmanstätten structure, the distance between the relic lamellae in the Gerzeh meteorite imply a classification of finest octahedrite. The chemical group of the meteorite is unknown, as nickel content cannot by itself be used to classify a sample.

Implications of this study extend beyond this specific prehistoric Egyptian use of iron; 28 nickel-rich iron objects of Egyptian antiquity are known, collected from four tombs spanning some 2000 yr. Within this time period, iron seems to be used exclusively for high status funerary goods, implying that a particular importance was placed upon it, although alternative supporting evidence for the recognition of ancient Egyptian meteorites is lacking. The Gerzeh beads provide no evidence to support iron smelting either locally or imported to prehistoric Egypt.

Acknowledgments—We thank K. Exell (formerly of The Manchester Museum, now at UCL Qatar), B. Sitch (The Manchester Museum), and C. Price (The Manchester Museum) who made this study possible by loan of a Gerzeh iron bead; S. Quirke (Petrie Museum) who awarded access for visual examination of three Gerzeh iron beads; A. Stevenson (Pitt Rivers Museum) for advice on the Gerzeh site; G. Godenho (University of Liverpool and University of Manchester) for discussions of ancient linguistics; A. Tindle (Open University) for expertise in optical photographic imaging methods, including provision of the image used in Fig. 2. This work was supported by STFC (grant ST/I001964/1) and EPSRC (grants EP/F007906/1 and EP/F028431).

Editorial Handling—Dr. A. J. Timothy Jull

REFERENCES

Arnold J. R. and Libby W. F. 1951. Radiocarbon dates. *Science* 113:111–120.

Bender K. C. and Buchwald V. F. 1994. Weathering of iron meteorites from Monturaqui, Chile. *Meteoritics & Planetary Science* 29:443.

Bjorkman J. K. 1973. Meteors and meteorites in the ancient near east. *Meteoritics & Planetary Science* 8:91–132.

Brunton G. 1935. Pesesh kef amulets. *Annales du Service des Antiquités de L'Egypt* 35:213–217.

Buchwald V. F. 1975. *Handbook of iron meteorites*. Berkeley: University of California Press. pp. 583–584

Buchwald V. F. 1979. Seven severely altered hexahedrites, sensitive to grain boundary corrosion. *Meteoritics & Planetary Science* 14:359–361.

Buchwald V. F. 1992. On the use of iron by Eskimos in Greenland. *Materials Characterisation* 29:139–176.

Buchwald V. F. and Clarke R. S. 1989. Corrosion of Fe-Ni alloys by Cl- containing akaganéite (β-FeOOH): The Antarctic meteorite case. *American Mineralogist* 74:656–667.

Buchwald V. F. and Koch C. B. 1995. Hibbingite (β-$Fe_2(OH)_3Cl$) a chlorine-rich corrosion product in meteorites and ancient iron objects. *Meteoritics & Planetary Science* 30:493.

Budge E. A. W. 1926. *Cleopatra's needles and other Egyptian obelisks*. London: The Religious Tract Society.

Carter H. 1927. *The tomb of Tutankhamen: The burial chamber*. London: Cassel and Company. Reprinted by Duckworth and Co., 2001.

Carter H. 1933. *The tomb of Tutankhamen: The annex and treasury*. London: Cassel and Company. Reprinted by Duckworth and Co., 2000.

Desch C. H. 1928. *Reports on the metallurgical examination of specimens for the Sumerian Committee of the British Association*. London: Reports of the British Association for the Advancement of Science. 437 p.

El-Gayer E. S. 1995. Predynastic iron beads from Gerzeh. *Institute for Archaeo-metallurgical Studies* 19:11–12.

Folco L., Di Martino M., El Barkooky A., D'Oranzio M., Lethy A., Urbini S., Nicolosi L., Hafez M., Cordier C., van Ginneken M., Zeoli A., Radwan A. M., El Khrepy S., El Gabry M., Gomaa M., Barakat A. A., Serra R., and El Sharkawi M. 2010. The Kamil crater in Egypt. *Science* 329:804.

Forbes R. J. 1950. *Metallurgy in antiquity: A notebook for archaeologists and technologists*. Leiden: E.J. Brill.

Gettens J. R., Clarke R. S., and Chase W. T. 1971. *Occasional papers,* vol. 4. Washington, D.C.: Smithsonian Institution Press. 1 p.

Grogan R. M. 1948. Beads of metal iron from an Indian mound near Havana, Illinois. *American Antiquity* 13:302–305.

Harris J. R. 1961. *Lexicographical studies in ancient Egyptian minerals*. Berlin: Verlag.

Helmi F. and Barakat K. 1995. Micro analysis of Tutankhamun's Dagger. Proceedings of the First International Conference on Ancient Egyptian Mining & Metallurgy and Conservation of Metallic Artifacts. Cairo: Egyptian Antiquities Organizational Press.

Juleff G. 1996. An ancient wind powered iron smelting technology in Sri Lanka. *Nature* 379:60–63.

Kemp B. J. 1991. *Ancient Egypt: Anatomy of a civilization*. New York: Routledge. 85 p.

Maxwell-Hyslop R. 1972. The metals Amutu and Asiu in the Kultepe Texts may also mean iron. *Anatolian Studies* 22:159–162.

McCoy T. J., Marquardt A. E., Vicenzi E. P., Ash R. D., and Wasson J. T. 2008. Meteoritic metal from the Havana, Illinois Hopewell mounds (abstract #1984). 39th Lunar and Planetary Science Conference. CD-ROM.

Mercer S. A. B. 1939. *The Tell el Amarna Tablets*, vol. 1. Toronto: Macmillan.

Ogden J. 2009. Metals. In *Ancient Egyptian materials and technologies*, edited by Nicholson P. T. and Shaw I. Cambridge: Cambridge University Press. pp. 148–176.

Panseri C. and Leoni F. 1967. Research on an iron spearhead from the Etruscan Sanctuary of Fanum Voltumnae, fourth to third century B.C. In *Archaeological chemistry. A symposium*, edited by Levy M. Philadelphia: University of Pennsylvania Press. pp. 205–229.

Petrie W. M. F. 1883. *The Pyramids and temples of Gizeh*. London: Field & Tuer. pp. 212–213.

Petrie W. M. F. 1886. *Naukratis*, vol. I. London: The Egypt Exploration Fund. 39 p.

Petrie W. M. F. and Wainwright G. A. 1912. *The labyrinth Gerzeh and Mazghuneh*. London: British School of Archaeology in Egypt, University College.

Photos E. 1989. The question of meteoritic versus smelted nickel-rich iron: Archaeological evidence and experimental results. *World Archaeology* 20:403–421.

Piaskowski J. 1982. A study of the origin of the ancient high nickel iron generally regarded as meteoritic. In *Early technology*, edited by Wertime T. A. and Wertime S. F. Washington, D.C.: Smithsonian Institution. pp. 237–423.

Reibold M., Paufler P., Levin A. A., Kochmann W., Patzke N., and Meyer D. C. 2006. Materials: Carbon nanotubes in an ancient Damascus sabre. *Nature* 444:286.

Reiter K. 1997. *Die Metalle im Alten Orient unter besonderer Berucksichtigung altbabylonischer Quellen*. Munster: Ugarit-Verlag.

Remler P. 2010. *Egyptian mythology A to Z*, 3rd ed. New York: Chelsea House. 24 p.

Roth A. M. 1992. "The *psš-kf*" and the "opening of the mouth" ceremony: A ritual of birth and rebirth. *Journal of Egyptian Archaeology* 78:113–147.

Sherby O. D. and Wadsworth J. 1985. Damascus steels. *Scientific American* 252:112–120.

Siegelova J. 1984. Gewinnung and Verarbeitung von Eisen im Hethitischen Reich im 2 Jahrtausends V.U.Z. *Annals of the Naprstek Museum* 12:71–168.(Prague).

Sinopoli C. M. 2003. *The political economy of craft production: Crafting empire in South India, c. 1350–1650*. Cambridge: Cambridge University Press.

Stevenson A. 2006. *Gerzeh, a cemetery shortly before history*. London: Golden House Publications. 67 p.

Stevenson A. 2009. Social relationships in Predynastic burials. *Journal of Egyptian Archaeology* 95:175–192.

Tilley D. and Bevan A. 1998. The prolonged weathering of iron and stony-iron meteorite and their anomalous contribution to the Australian regolith. In *New approaches to an old continent, Proceedings of the 3rd Australian Regolith Conference, Kalgoorlie, Canberra*, edited by Taylor G. and Pain C. F. Perth: Cooperative Research Centre for Landscape Evolution & Mineral Exploration (CRC LEME). pp. 77–88.

Tyldesley J. 2010. *Myths and legends of ancient Egypt*. London: Penguin Books Ltd.

Varoufakis G. 1982. The origin of Mycenaean and Geometric iron on the Greek mainland and in the Aegean islands. In *Early metallurgy in Cyprus*, edited by Muhly J. D., Maddin R., and Karageorghis V. Nicosia: Pierides Foundation. pp. 315–322.

Wainwright G. A. 1912. Pre-dynastic iron beads in Egypt. *Revue Archéologique* 19:255–259.

Wasson J. T. and Sedwick S. P. 1969. Possible source of meteoritic materials from Hopewell Indian burial mounds. *Nature* 222:22–24.

Winlock H. E. 1921. Excavations at Thebes. *Bulletin of the Metropolitan Museum of Art, part II* 50:29–53.

Yoshikawa H., Gunji E., and Tokuda M. 2008. Long term stability of iron for more than 1500 years indicated by archaeological samples from the Yamato 6th tumulus. *Journal of Nuclear Materials* 379:112–117.