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Iron from the Sky.
The meteoritic origin of Tutankhamun's iron dagger

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Abstract. Since Howard Carter's discovery in 1925[1], the meteoritic origin of the iron dagger blade from the sarcophagus of the ancient Egyptian King Tutankhamun (14th Century BC), part of the King's funerary collection now at the Egyptian Museum of Cairo, has been the subject of debate. In this presentation, we report on the work carried out by the author in collaboration with Comelli et al. (2016). It is shown that the composition of Tutankhamun's iron dagger blade (Fe plus 10.8 wt% Ni and 0.58 wt% Co), accurately determined through portable x-ray fluorescence spectrometry, strongly supports its meteoritic origin. This study confirms that ancient Egyptians attributed great value to precious objects made by meteoritic iron. However, it is as yet unclear if such dagger blade made of meteoritic iron was manufactured in Egypt or imported from Anatolia.

1. Iron in Ancient Egypt: Metal from the Sky?

There is little doubt that ancient Egyptians knew iron in its metallic form at least as far back as five millennia ago. And yet, iron metallurgy, i.e., the technology of separating metals from their ores and preparing them for use by smelting, refining etc., developed in Egypt only around 1000 BC, i.e., at least three centuries after Tutankhamun's death. Did Ancient Egyptian at the time of the Boy-King Tutankhamun (XIV Dynasty, approx 1341 BC) imported iron artifacts from their neighboring countries? After all, the Iron Age in the Ancient Near East is believed to have begun with the discovery of iron smelting and smiting

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[1] Carter and Mace (1923-1927-1933).

techniques in Anatolia or the Caucasus and Balkans just around that right time in the late 2nd millennium BC (c. 1300 BC; Waldbaum 1978).

The earliest-known iron artifacts from Ancient Egypt, shaped by carefully hammering, are nine small beads dating 3200 BC, one of which is shown in Figure 1. These beads were found in burials at Gerzeh, in Lower Egypt about 70 km South of Modern Cairo (Stevenson 2009). Their meteoritic origin was established by Rehren et al. (2013) and by Johnson et al. (2013). Meteoritic iron, a characteristic iron–nickel alloy, was used by various ancient peoples thousands of years before the Iron Age. Such iron, being in its native metallic state, required no smelting of ores. Other example of iron objects belonging to periods prior to Tutankhamun's reign that have been found in Egypt include:
- iron tools from the Great Pyramid at Gizah (IV Dynasty, 2900 BC);
- fragments of iron picks from the Black Pyramid at Abusir (V Dynasty, 2700 BC);
- mass of iron rust from Abydos (VI Dynasty, 2500 BC);
- iron spear head from Nubia (XIII Dynasty, 1750 BC);
- iron sickle from beneath a sphinx of Horemheb near Karnak (XIII Dynasty, 1450 BC).

Fig. 1. Prehistoric iron bead excavated at the Gerzeh cemetery made from meteorite iron, The Manchester Museum.

Nineteen iron objects were discovered in the tomb of Tutankhamun. Among these, a set of blades, which appear very similar to those used in the opening of the mouth ceremony. Other iron objects were wrapped with Tutankhamun's mummy (Figure 2), which confirms that iron was considered as very precious and appropriate for a king at the time of Tutankhamun's death in approx. 1327 BC. Particularly noteworthy among these iron artifacts are a miniature headrest contained inside the golden death mask and an amulet attached to a golden bracelet, both of which manufactured by relatively crude methods (Johnson 2015). But then, of course, is the famous iron dagger blade with gold haft, shown in Figure 3. The iron blade appears magnificent and is clearly expertly produced, although it also appears to have been attached to the golden handle in a rather imperfect way. Could it be that the dagger was imported to Egypt, perhaps as a royal gift from a neighboring territory?

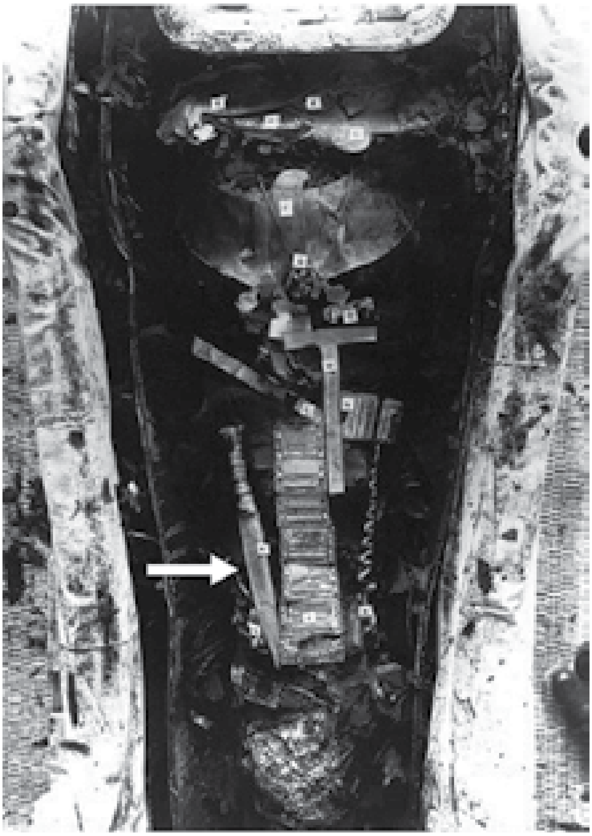

Fig. 2. Black and white picture of Tutankhamun mummy showing the iron dagger (34.2 cm long) placed on the right thigh (arrowed). Copyright: Griffith Institute, University of Oxford.

We now know, with a very high degree of confidence, that Tutankhamun's iron dagger blade was made of meteoritic iron. It appears that ancient Egyptians were well aware of iron falling from the sky. Quoting from George Frederik Zimmer, *The Antiquity of Iron* (1915): "The most ancient name for iron was 'Metal from Heaven'. In the hieroglyphic language, it was pronounced BA-EN-PET, meaning either stone or metal from Heaven. A basic Egyptian idea, expressed in ancient Egyptian texts, was that the firmament of Heaven was made of iron. This belief probably arose from iron's blue color and from the occasional fall of meteoritic iron from the sky". But the importance of iron in ancient Egypt was not only limited to references in religious texts. Referring again to Zimmer (1915), one of the Pharaoh's of the I Dynasty was known by the name MER-BA-PEN, literally, *Lover of this iron.* A Pharaoh would not bear that name if the Egyptians of the I Dynasty had not known iron.

Fig. 3. Tutankhamun's iron dagger blade and sheath. Cairo Egyptian Museum.

This article tells the story of how conclusive evidence was reached on the meteoritic origin of Tutankhamun's dagger blade. It took a multidisciplinary team including physicists, astronomers, Egyptologists and meteorite experts, as well as some degree of good luck, to reach that conclusion. And yet, a question remains open: could the meteorite which made up Tut's dagger blade have fallen and expertly manufactured in Anatolia, before being offered as a royal gift the Boy-King?

We shall begin our story from an antefact: the discovery of Gebel Kamil meteorite crater in Egypt in 2010.

2. The antefact: the discovery of Gebel Kamil meteorite impact crater

Meteors, or, as they are known in every-day language, shooting stars, are caused by debris and small interplanetary rocks from space that cross the Earth atmosphere. According to estimates, between 35 and 80 thousand tons of space debris enter the atmosphere every year. Technically speaking, meteors and meteorites are different things. A *meteor* is the flash of light caused by the debris, not the debris itself. The debris is called a *meteoroid.* Most meteoroids that enter the Earth's atmosphere are so small that they vaporize completely and never reach the planet's surface. If any part of a meteoroid survives the fall through the atmosphere and lands on Earth, then it becomes a *meteorite.* The fact is that very few falling meteoroids ever become meteorites. The dust and rocks from space rarely reach the ground. Earth's atmosphere does a good job of protecting us from this incoming debris. If the size of the meteorite as it approaches the surface of the Earth is sufficiently large (let's say, at least a few meters in diameter), a meteorite impact crater is likely to form. Clearly, through the eons, thousands, if not millions, of impact craters must have formed on planet Earth. Yet, as the Earth is geologically and botanically active, these impact craters tend to become invisible over time. As surprising as it might be, there are only 190 known meteorite craters on Earth to date[2], and only one of them has been found in Egypt: this is the one known as the Gebel Kamil impact crater, discovered in 2010 by an Italian-Egyptian scientific team in the Egyptian desert near the border with Sudan (Folco et al. 2010). The way this discovery was made is a fascinating story to tell.

At the time, I was serving as Scientific Attaché at the Embassy of Italy in Cairo. In early 2009, Mario Di Martino, an Astronomer from the Osservatorio Astronomico di Torino, contacted my office to inform me that a suspicious impact crater was noted by Vincenzo De Michele, former curator of the Civico Museo di Storia Naturale in Milan, by inspection of Google Earth satellite images (Figure 4). An expedition to the suspected crater location was necessary in order to ascertain the crater's meteoritic origin. Since the crater's location was in very deep desert and in a sensitive area from the military point of view, it was immediately clear that such an expedition would be possible only with the full support of the Egyptian authorities and within the framework of a joint Egyptian-Italian scientific project. It was perhaps a piece of luck that 2009 was officially nominated as *The Egyptian-Italian Year of Science* and that therefore scientific and technologically cooperation between the two countries was at its peak. A bilateral Agreement could therefore be negotiated and was signed on 31 July 2009 by Mario Di Martino (on behalf of the National Institute for Astrophysics, INAF) and by Tarek Hussein, at that time President of the Egyptian Academy for Science and Technology (Figure 5).

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[2] Earth Impact Database, http://www.passc.net/EarthImpactDatabase/index.html

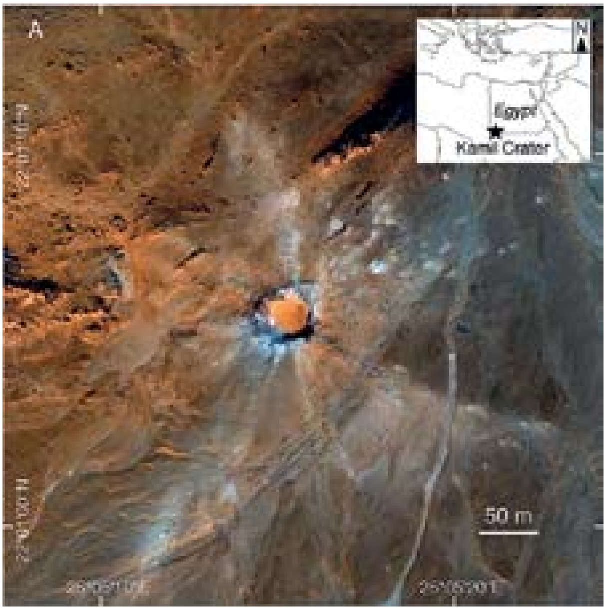

Fig. 4. Gebel Kamil meteorite impact crater as first observed by Vincenzo De Michele on Google Earth.

Egypt - Italy

Egyptian-Italian Collaboration Proposal

A new impact crater in Southwestern Egypt:
an Italian-Egyptian Joint Geophysical Research

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Fig. 6. Images from the Gebel Kamil impact craters, with meteorite fragment resting on Paleolithic paths (bottom left). Photos courtesy of Mario Di Martino.

Fig. 7. Gebel Kamil impact crater visited by the author in 2012.

The expedition members, the *Kamillers*, actually reached the site in Spring 2010. The results of this expedition were published in Science on 22 July 2010 (Folco et al. 2010). Figures 6 and 7 show images from the first expedition and from a later visit to the impact crater in 2012. What is especially interesting about Gebel Kamil impact crater is that it is very young on geological times. It has been estimated to have been formed between 1600 and 400 BC. The event occurred a few hundred kilometers from the Nile Valley, but most likely it was such a dramatic event to be quite visible by the Ancient Egyptians from places like Aswan. On the other hand, the ancient Egyptians do not seem to have ever reached the impact site. Indeed, the scene that was presented to the Kamillers is that of a place never visited by human beings since the crater formation. Meteorite fragments, estimated at around 2000 kg (nearly half of which collected by the Kamillers and brought to the Geological Museum in Cairo) were everywhere to be seen. Many of these fragments rested on Paleolithic paths (bottom left in Figure 6), which suggested at once the relatively young age of the crater (the actual dating was made after a careful study of the meteorite ejecta and other technical considerations beyond the scope of the present article).

As I already pointed out, Gebel Kamil impact crater is the only known impact crater in Egypt to date and the evidence is that the ancient Egyptians did not visit it. Therefore, I am tempted to conclude that, in all likelihood, the ancient Egyptians never found a site rich of meteoritic iron fragments such as the one discovered in 2010. Thus, finding meteoritic iron must have been a very rare, occasional and sporadic event – very small meteorites that do not form impact crater can occasionally be found, but this event is indeed very rare and the amount of recovered meteoritic material is then very limited.

3. The debate around the origin of Tut's iron dagger blade

It was at the time of the Kamillers' expedition that I learnt about the heated debate surrounding the origin of Tut's iron dagger blade. Egyptologists were more or less equally divided in two camps. One camp supported the idea that Tut's iron dagger blade was likely made of meteoritic iron. Their argument was based on the fact that iron artifacts were indeed very rare in Ancient Egypt at the time of the XIV Dynasty, and the ones that had been found were most likely of meteoritic iron, such as the beads found at Gerzeh as mentioned before. Furthermore, iron metallurgy in Egypt developed at least three centuries after Tuankhamun's reign.

People in the other camp, however, were convinced that Tutankhmun's iron dagger blade (if not the complete dagger, handle and knob included) could have been imported from Anatolia. Indeed, diplomatic documents from the Egyptian royal archives from the 14th C. B.C. - the Amarna letters - mention royal gifts made of iron in the period immediately before Tutankhamun's reign. In particular, it is reported that Tushratta, King of the Mitanni nation, sent precious iron objects to Amenhotep III, who may have been the grandfather of Tutankhamun. Daggers with iron blades and a gilded iron hand bracelet are mentioned in the gift list (Rainey 2014). In the 14^{th} century BC, the Mitanni occupied an area in Eastern Anatolia between Assyria and the Hittite Empire.

Mario Di Martino and two other Kamillers, Luigi Folco and Massimo D'Orazio, now both at the University of Pisa, suggested to me in 2010 that the best way to settle the dispute was to perform X-Ray Fluorescence (XRF) spectrometry on the iron dagger blade. A proposal was put forward to the Egyptian authorities – the Ministry of Antiquities and the Direction of the Egyptian Museum in Cairo. This proposal, however, was initially refused, in spite of gentle insistence and several attempts on my part. Indeed, between 2010 and 2014, several Italian researchers approached the Scientific Office at the Italian Embassy of Italy in Egypt, expressing an interest in carrying out this type of XRF analysis on Tut's dagger. And every time this happened, I raised the issue once again with the Egyptian authorities, but to no avail. Until circumstances changed in 2014: a new Museum Director was nominated in 2014 - Dr. Mahmoud El-Halwagy – and, equally important, a team of physicists led by Prof. Daniela Comelli of the Polytechnic University of Milan came to the Cairo Egyptian Museum with just the right instrument: a last-generation tripod-supported XRF spectrometer developed by XGLab s.r.l., a Milan-based spin-off company set up by former students of the polytechnic university. They actually came to the Cairo Museum to analyze other objects not connected with Tutankhamun's funerary treasure, within the framework of a joint Egyptian-Italian cooperation project partially financed by the Italian Ministry of Foreign Affairs. The Embassy Scientific Office, therefore, was supposed to monitor the project. When they called me to let me know that they had arrived in Cairo with the XRF spectrometer and that they were about to start their work at the Egyptian Museum, I almost fell off my chair. I immediately went to the Museum, met with them and asked whether they would be interested in performing the analysis of Tut's dagger blade's elemental concentration using their XRF spectrometer. They were not aware of the debate surrounding the origin of the dagger iron blade. Nevertheless, they enthusiastically agreed. The next move was to convince the new Museum Director, who, however, was much more motivated by scientific research then his predecessors. The special XRF survey on Tut's was granted! Instrumental to this decision was also Prof. Abdelrazek Elnaggar from El-Fayoum University, partner to the joint Egyptian-Italian cooperation project together with Daniela Comelli and co-workers.

It was immediately clear to all that, in order to be able to carry out first-class scientific work, it was necessary to involve in the analysis of XRF data also meteorite experts, as they would help with the search of the specific elements of which meteorites are made of and would be able to help reach a conclusion on whether Tut's iron dagger blade was indeed of meteoritic origin once its elemental concentration had been determined. I decided to involve the two Kamillers Folco and D'Orazio, mentioned above. I also suggested to invite to our collaboration an Italian Egyptologist, Dr. Giuseppina Capriotti, who, together with the Director of the Cairo Egyptian Museum and his curators, could advise us on the Egyptological impact of our work.

4. XRF spectrometry of king Tut's iron blade

The results of the XRF spectrometric analysis of King Tut's iron dagger blade are reported in Comelli et al. (2016) and so I refer the interested reader to that article for details. Here, I limit myself to a summary of the main results.

Iron meteorites are mostly made of Fe and Ni, with minor quantities of Co, P, S and C, and trace amounts of other siderophile and chalcophile elements. The chemical composition of iron meteorites is typically determined by means of sensitive, yet destructive, analytical methods – e.g., neutron activation analysis and inductively coupled mass spectrometry. Conversely, X-ray fluorescence spectrometry offers a rapid, low cost and non-destructive method for the analysis of bulk iron meteorites and the quick identification of the extraterrestrial origin of archaeological metallic artifacts.

Bjorkman (1973) referred to a meteoritic origin of the iron dagger on the basis of its high nickel content; however, to the best of our knowledge, this study had not been published and the analytic technique was not specified. A few years later, in 1994, Helmi and Barakat reported that, on the basis of XFR fluorescence analysis, the dagger blade had a Ni content of 2.8 wt%, too low to be consistent with a meteoritic origin (Helmi and Barakat 1995). For some time, this result appeared to lend support to those who believed that Tut's iron dagger was imported from Anatolia, were iron metallurgy was being developed at that time. However, the analysis carried out in 1994 was performed on the basis of a primitive hand-held XRF spectrometer, which was not as accurate as today's devices. Indeed, in the last twenty years, a dramatic improvement in solid-state detectors technology has allowed new, more accurate analytic applications. Modern energy-dispersive XRF spectrometers exhibit typical energy resolutions below 135 eV for the Mn-K line, allowing the deconvolution of close peaks in the diffused energy spectrum, as required for correctly estimating minor amounts of cobalt in meteoritic iron. The XRF spectrometer ELIO, developed by XGLab, is based on a 25 mm^2 active area drift detector and on a 50 kV-4W X-ray tube generator, which employs a Rh anode. The excitation X-ray beam is collimated to a 1.2 mm spot diameter on the sample surface. The typical energy resolution of the spectrometer is good enough to detect the asymmetry of the Fe K-beta peak due to the presence of the underlying low-intensity Co K-alfa peak, as is often the case in iron meteoritic samples.

Quantitative determination of the Ni and Co contents in Tut's dagger blade was carried out by external calibration methods using XRF data from 11 steel metal standards and 11 iron meteorites of well-known composition. After careful calibration and statistical data analysis (see Comelli et al. 2016, for details), we were able to conclude that Tut's iron dagger blade includes Nickel with a concentration of 10.8 +/- 0.3 wt% and Cobalt with a concentration of 0.58 +/- 0.04 wt% Co, within a 95% fitting confidence interval. The blade's high Ni content, along with the minor amount of Co and a Ni/Co ratio of about 20, strongly suggests an extraterrestrial origin. The conclusion is based on the following considerations:

1. The Ni content in the bulk metal of most iron meteorites ranges from 5 wt% to 35 wt%, whereas it never exceeds 4 wt% in historical iron artifacts from terrestrial ores produced before the 19th C.
2. The Ni/Co ratio in the Tut's dagger blade is consistent with that of iron meteorites, average Ni/Co = 18 +/- 2, which have preserved the primitive chondritic ratio during planetary differentiation in the early solar system.

Remarkably, a representative set of 76 iron meteorites with a moderately high Ni content (10–12 wt%), i.e., with composition similar to Tutankhamun's blade, have average Co content of 0.57 +/- 0.08 wt%. Meteorites in this group have fine (mm scale) or very fine (micron scale) homogeneous structures. Smiting is expected to produce a homogeneous, structure-less iron artifact like Tut's iron dagger blade.

We sorted all the known iron meteorites found in the region from the MetBase[3], within an area 2000 km in radius arbitrarily centered in the Red Sea off the coasts of Egypt. Twenty iron meteorite finds are present in the database. Only one known meteorite, named *Kharga* (Egypt, 31^{0}07'57''N, 25^{0}02'50''E) (Grossman and Zipfel 2001), found on 8 May 2000, has Ni and Co contents within 10% of the Tut dagger blade's composition. By contrast, Gebel Kamil meteorite has a Ni concentration that is about twice that of Tut's iron dagger blade.

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[3] http://www.metbase.org

5. Conclusions

We have documented the meteoritic origin of the iron of the dagger blade belonging to the ancient Egyptian King Tutankhamun (14th C B.C.). This solves a longstanding heated debate among scholars since the discovery of the dagger in the wrapping of the king's mummy in 1925, by archaeologist Howard Carter. By employing non-invasive X-ray fluorescence spectrometry, we have revealed that the iron dagger blade, today on display at the Egyptian Museum in Cairo, contains nickel (11 wt%) and cobalt (0.6 wt%) in concentrations characteristically observed in iron meteorites (Comelli et al. 2016).

The study confirms that ancient Egyptians attributed great value to meteoritic iron for the production of precious objects, and the high manufacturing quality of Tutankhamun's dagger blade is evidence of significant mastery of ironworking already in Tutankhamun's time.

Among all the known meteorites within a within an area 2000 km in radius arbitrarily centered in the Red Sea, that are part of the MetBase data base, the Kharga meteorite, discovered in Egypt in 2000, has the elemental concentration that comes closest to that in Tut's iron dagger blade. However, not sufficiently close to allow for a positive identification of Tut's iron with that meteorite.

Even though the meteoritic origin of Tutankhamun's iron dagger has been established with a very high degree of confidence, we still cannot exclude that the dagger was imported as a gift manufactured in Anatolia. Even though iron metallurgy was being developed in Anatolia at the time of the Egyptian XIV Dynasty, it is nevertheless possible that nations like the Mitanni were capable of working with meteoritic iron. Could one of the daggers with iron blades mentioned in the Amarna letters as part of the royal gift by the Mitanni to Amenhotep III be the one found wrapped with Tutankhamun's mummy? More work is needed to answer this question. It would be important, in this respect, to find any evidence showing that the Mitanni or other nations in Anatolia were manufacturing objects out of meteoritic iron in the second half of the second millennium BC.

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