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Inhalt

Investigation of Ancient Egyptian Metallic Artefacts by Means of Micro-Computed Tomography

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Abstract

In this paper we present the results of imaging studies of ancient Egyptian metallic artifacts using micro-Computed Tomography (micro-CT). Micro-CT is a non-destructive imaging method with high spatial resolution, which enables the examination of the internal structure of objects. It is thus especially suitable for the investigation of cultural heritage and archaeological findings, when it is not possible to sample or difficult to manipulate the object. Using specialized software for 3D visualization and segmentation, data sets of two objects were analyzed. We gained a clear view of the inner structure of a metallic archaeological artifact from the necropolis of Abusir el-Meleq, which is believed to be very ancient in the Egyptian archaeological context (from the Predynastic Era), and were able to distinguish its different components under the thick layers of external concretions. These components give hints about the production technology of the object. We also investigated the contents of a closed metal box found near Abusir dated to the Late/Greco-Roman Period. The identified content corresponds either to sediments or to mineral remains of the original content of the box. Both artifacts are from excavations conducted in Egypt and are part of the archeological collection of the Ägyptisches Museum und Papyrussammlung in Berlin.

1 Introduction

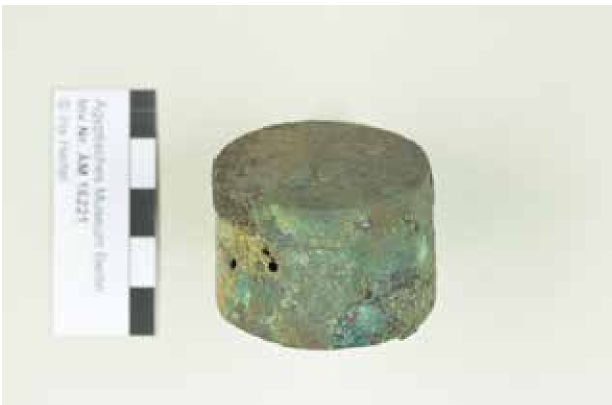
X-ray Computed Tomography (CT) (Goebbels 2013) has found many applications for the investigation of Cultural Heritage and archaeological findings since it is a non-destructive analysis method which permits a close examination of the object without damaging it in any manner. It is particularly useful in those cases when it is not possible to sample, especially when the aim of the investigation is to get information of the internal structure of the object. Three-dimensional imaging provides a clear view of the interior of the objects and is ideal for examining its contents (Scott et al. 1991).

In this paper we report on X-ray CT imaging of two ancient Egyptian objects. Two different investigations took place: a metal bar has been measured in order to clarify its production technology and a metal box to verify its contents (Tab. 1).

1.1 Metal Bar ÄM 19046

The archaeological artifact, catalogued as ÄM 19046 (and ÄM 26307) at the Ägyptisches Museum und Papyrussammlung, is a metallic, heavily corroded object, composed of five different fragments.

Tab. 1: Object descriptions

ÄM 19046	ÄM 16221
	
Width: 2.6 cm Height: 24.8 cm Depth: 2.6 cm Weight: 166.6 g	Diameter: 4.1 cm Height: 3.0 cm Weight: 25.8 g

It was found in a tomb of the pre- and early-dynastic necropolis of Abusir el-Meleq, in a fragile state of conservation, during a scientific excavation under the direction of the German Egyptologist G. Möller during his second season in 1906.

So far it is believed that the object belongs to the original inventory of a Naqada III tomb (ca. 3300–3100 BC). As it is suggested by the remainders, the metallic object was composed by one U-shaped rod, which ended on one side with a tripodal structure. At present it is not clear what was the original structure and use of the metal artefact.

Thanks to previous analysis, carried out by the Rathgen-Forschungslabor with the X-Ray Fluorescence method, the surface composition was verified to be of copper (95%) with traces of other elements as zinc (5%), lead, iron, arsenic and selenium (<1%) (internal report RF 72_072315). In fact, ancient copper artefacts are never made by just pure copper. They always contain a large variety of impurities, which can provide many information, including evidence of authenticity (Ogden 2000).

The biggest of the fragments, which is approximately 20 cm in length, has been measured by means of micro-CT in order to better examine the characteristics of the artifact and to acquire precise information about the technology used for its production. The non-destructive investigation has been focused on the region where the principal rod splits into three prongs and becomes similar to a trident. Because of the thick layer of corrosion products it is impossible to see the original surface and to judge how the three parts were kept together, if there was a soldering joint or something to tie tightly the pieces.

1.2 Metal Box ÄM 16221

The small metal box, catalogued as ÄM 16221, is an archeological finding coming from the archeological excavation near Abusir, near a buried body, and it is dated to the Late/Greco-Roman Period. The artifact is almost intact, with the exception of few small holes on the bottom side of the box. However, the dimension of the holes does not permit examination of the contents.

2 Methods

The measurements have been performed by means of a micro-CT device situated in the Bundesanstalt für Materialforschung und -prüfung, which provides very high resolution for investigation of small objects.

The micro-CT system (Fig. 1) is composed of X-ray tube (X-RAY WorkX Modell XWT 225-SE), specimen stage, detector (Scintillator, 2048×2048 detector-elements of 0.2 mm pitch) and the operator station with dedicated software.

Fig. 1: Picture of the Set-up with the packaged sample (ÄM 19046) before starting the analyses.

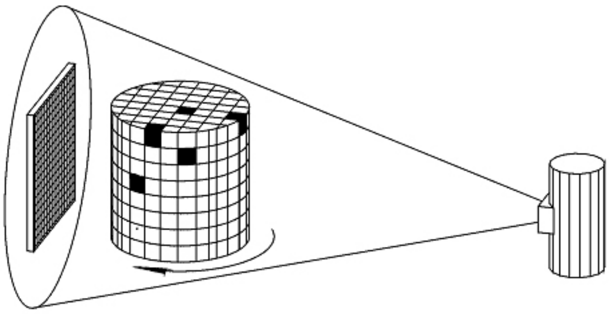


Fig. 2: Schematical view of the cone-beam geometry used for obtaining the projections.

The measurement parameters used for the bronze bar ÄM 19046 and for the metal box ÄM 16221 are listed below:

Pre-filters of Cu (0.5 mm) and of Ag (0.25 mm) were used to reduce the low-energy contribution to the X-ray spectrum for reducing the beam-hardening effect.

The general principle of tomography is to obtain the reconstruction of a structure by means of series of bidimensional projections. In order to get bidimensional projections of a sample, we register the flux of X-rays coming to the detector after it has been attenuated by the sample. The radiation detected for monochromatic X-ray radiation and a sample of homogeneous material, which is the most simple condition obtainable, is correlated to the incident radiation I_0 by the Lambert-Beer equation: $I = I_0 e^{-\mu \Delta x}$, where Δx is the geometrical length of the sample along the propagation direction of the radiation beam and μ is the attenuation coefficient, which depends on the material and on the wavelength λ of the radiation. When the analyzed material is not homogeneous, the attenuation coefficient μ is not constant for the entire object. It instead becomes the integral of μ_n (spe-

Tab. 2: Experimental conditions of the micro-CT experiments

	Dimension of the scanned area (pixel)	*Electric potential energy (Volt)*	*Electric current (Ampere)*	*Number of angular acquisitions*	*Voxel dimension*
ÄM 19046 (file 5872a)	1097×2009 px	210 kV	100 µA	800	0.050 mm
ÄM 16221 (file 5873a)	1001× 656 px	210 kV	100 µA	1000	0.059 mm

cific for every n-th kind of material) over the respective path length.

The process includes sequential acquisitions from several directions over 360°, which produces a large number of radiographic projections. Those projections, digital images in different grey levels which are proportional to the radiation that reach the detector, are then processed by software. First, the influence of the system is removed by means of the dark-frame subtraction and, in order to account for the different sensitivity of the single detector-pixels and the illumination characteristics of the X-ray tube, the projections are divided by the free beam. Afterwards the images are normalised (i.e. the brightness of the free beam is adjusted), inverted, and logarithmised. The reconstruction with a specific algorithm depends on the acquisition geometry (Fig. 2) used for the measurements. In our case it was cone-beam geometry and the reconstruction was done with a standard Feldkamp filtered-backprojection algorithm. We obtain therefore a 3D image matrix, in which each point represents a single volume element in the sample, a voxel. The Software used for segmentation, visualization and measurement of the 3D model was VGStudio MAX 2.2.

3 Results and Discussion

The measurements allowed the realization of an extremely accurate 3D model of both the archaeological artifacts of the Egyptian Collection. Thanks to the software VGStudio MAX2.2 it is possible to manipulate the model in order to acquire the data needed for the investigation of the objects. Three-dimensional imaging provides a clear view of the internal structure of the objects and allows examining the contents without damaging the fragile archeological artifacts.

3.1 Metal Bar ÄM 19046

As mentioned previously, the investigation in case of the artifact ÄM 19046 was focused on the region where the main rod becomes similar to a trident. The analyzed artifact is covered with a thick layer of concretions with different morphology. Furthermore, the analysis has revealed that under the layer of corrosion products the object contains parts that are radiographically denser (Fig. 3). Two well-defined and quite flat parts can be distinguished, probably soldering joints, which are more radiopaque than the surrounding material. Those small parts are likely made of different metallic alloys and furthermore it can be easily noticed that the constituent material of those parts are characterized by high-level porosity. There is also a third part that seems to be made by a "heavier" metal, which is closer to the external surface of the object. Furthermore, there are two other metal parts observable manipulating the 3D model, one of whom is more damaged than the other. It is not clear if all these different parts are fragments of a single solder joint around the central rod to connect the other two rods, or if the original mechanism was composed of different elements. After the CT scans it could also be possible that the original constitution of the metal bar was a four-arm structure. This has to be clarified in further research activities.

In the mid-sagittal view of the central rod shown in Fig. 4, we can see in light grey the not-corroded part of the copper and the two layers of corrosion with darker

Fig. 3: Visualization of the artifact ÄM 26307 realized with the software VGStudio MAX 2.2.

Fig. 4: Mid-sagittal view of the central rod.

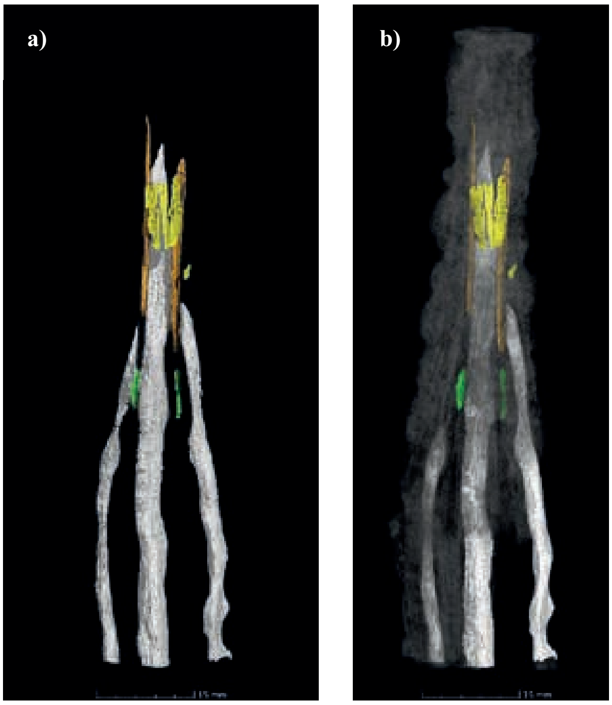


Fig. 5: a) Elaboration of the artifact without the layer of corrosion products, which permit to better locate the soldering elements;
b) Metal bar with the corrosion layer not fully transparent to show the locations of the soldering elements in the object.

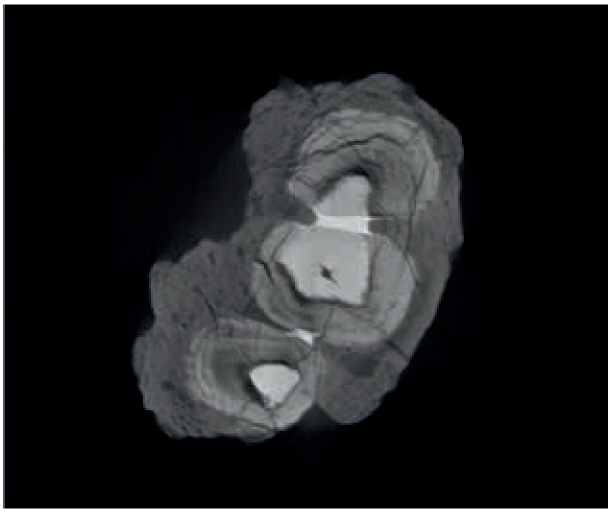


Fig. 6: The horizontal cross-section shows the soldering joint connecting the not-corroded material.

grey values indicating lower X-ray attenuation. The more external layer seems to have also a high level porosity. Furthermore, the inner part presents fracture-shaped empty space that could suggest that the technology of production was more likely mechanical machining instead of metal casting (Fig. 4). Varying transparency and brightness in the 3D model, it is possible to visualize parts which could be soldering joints (Fig. 5), stressed in

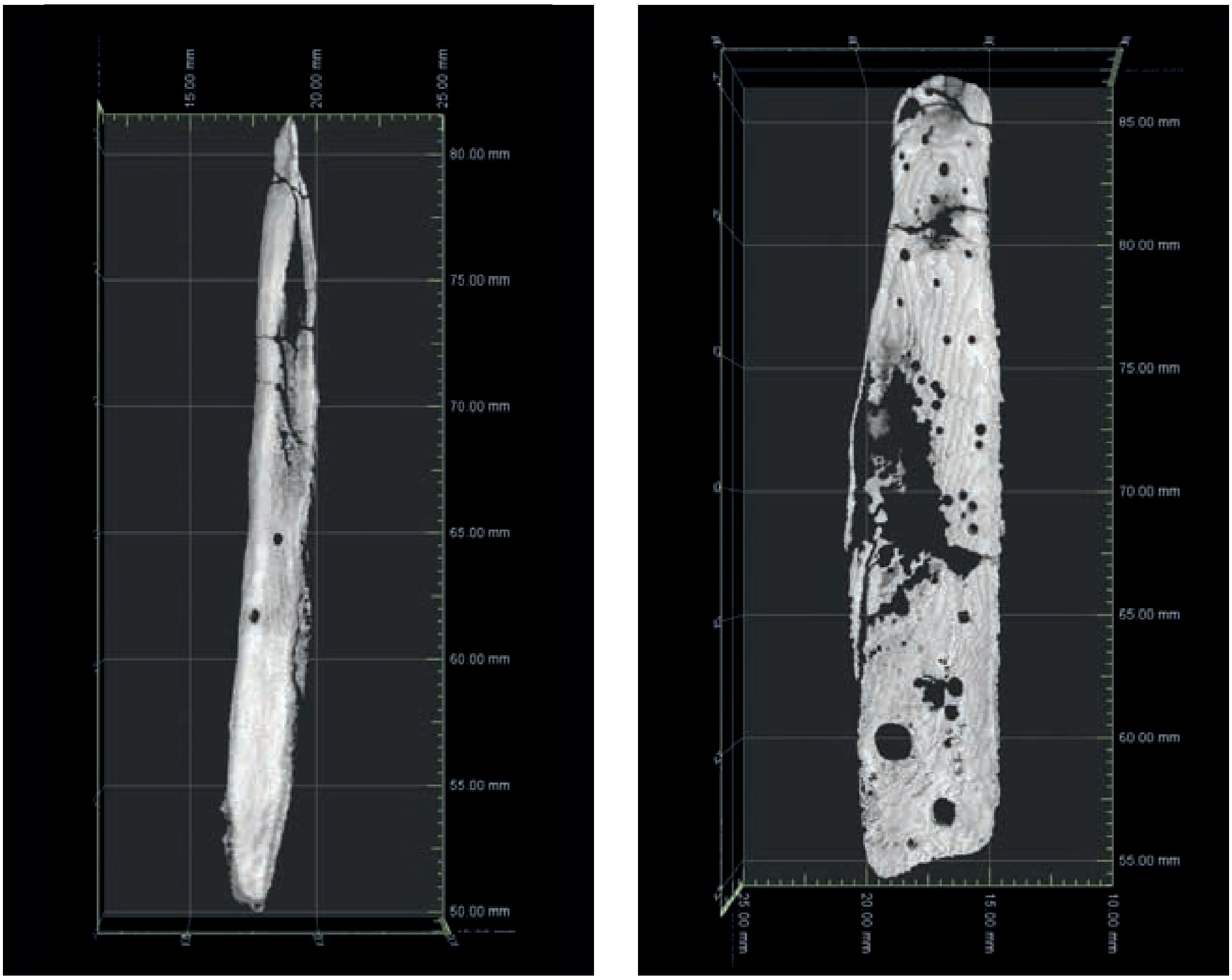


Fig. 7: The two flat elements isolated from the other parts of the artifact and shown with length scales.

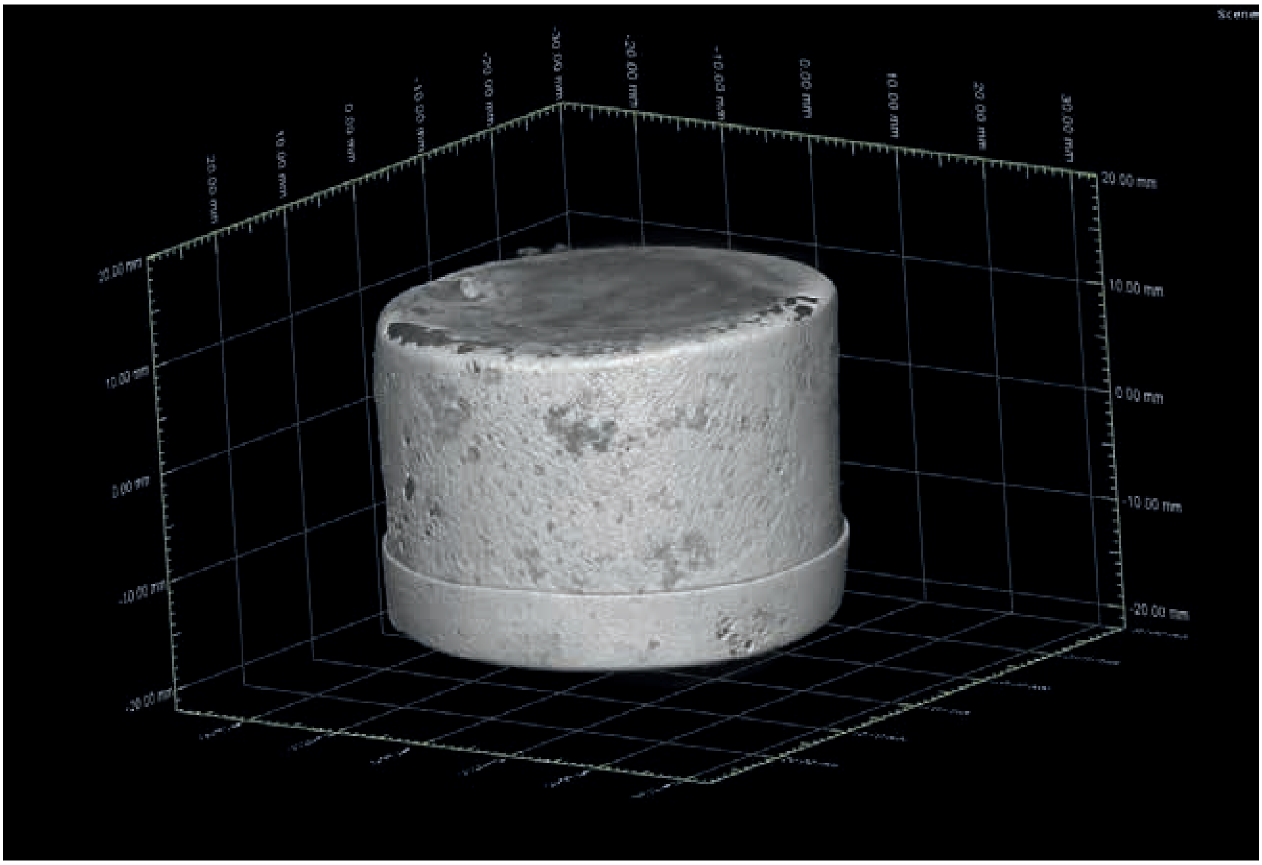


Fig. 8: The 3D model of the object. The bottom (on top) is affected by cone-beam artifacts, visible as the cloudy-dark grey signal.

orange and green, and in yellow the third one which seem to be slightly curved and broken in various fragments. A horizontal slice through the data set shows the assumed soldering joint connecting directly to the not-corroded material (Fig. 6).

Two of those parts, flat elements with a length of less than 3.5 cm (in orange in Fig. 5), show gas pores, as it can be seen in Fig. 7. The original use had probably been to keep the two rods tightly fastened to the main one.

Fig. 9: Rendering of the box after stressing the low signal in the histogram. Ring artifacts are visible in the CT image due to the low signal-to-noise ratio.

3.2 Metal Box ÄM 16221

The measurements showed that the small box (Fig. 8) contains material resembling soil agglomeration. It was possible to virtually remove some of the denser material in order to see the morphology of the content.

However, the signal related to the contents is very weak in comparison with the signal of the thin metal layer of the box, for this reason we can immediately exclude that the box contains little metal artifacts but nonetheless the possibility cannot be ruled out that it had contained different kind of material, which are now completely deteriorated, perhaps organic materials. It is also possible,

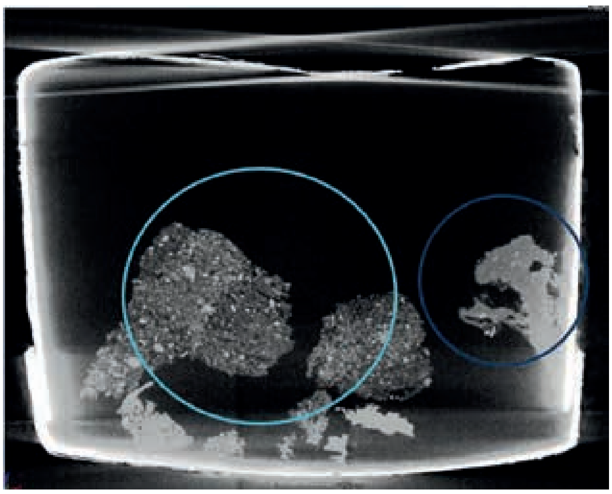


Fig. 10: Cross section of the bronze box.

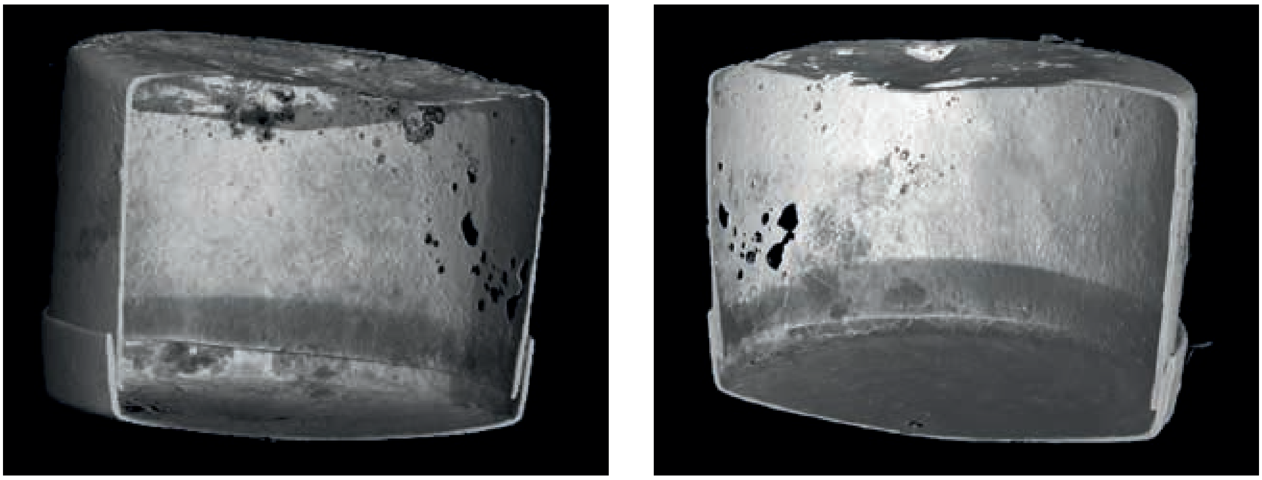


Fig. 11: Visualisation of the inner surface of the box, obtained removing the signal connected to the content.

with dedicated software tools for processing data, to see the morphology of the material inside the box (Fig. 9), which is clearly heterogeneous and deteriorated, perhaps loose material.

The section through the box in figure Fig. 10 shows that the content is composed of two different materials, the first (dark-blue circle) is more homogenous than the second one (light-blue circle), and also with stronger attenuation. Fig. 11 shows the inner surface of the box, with the content virtually removed. Unfortunately, the cone-beam artifacts strongly influence the measurement of the top and the bottom of the box, which makes the visualization in those parts unreliable.

4 Observations and Conclusions

In conclusion, thanks to micro-CT, which is a completely non-destructive imaging method with high resolution, we have obtained detailed and important information on the inner structure of the two analyzed Egyptian metal objects. We have taken an essential step towards the comprehension of these two ancient artifacts, their function and original use in ancient Egypt.

Further analyses should be performed in order to identify the constituent metals forming the soldering parts in the copper artifact ÄM 19046 and to clarify if the content of the bronze box ÄM 16221 is composed by mineralized remains of organic material as hypothesized.

The non-destructive imaging method that could be a great help to achieve this aim is the Neutron tomography, since it is widely considered complementary to X-ray imaging: although neutron imaging cannot compete with X-ray imaging in terms of resolution, neutrons are more sensitive than X-rays to light elements such as hydrogen, lithium, boron, carbon, and nitrogen and have a higher penetration depth than X-rays (Strobl et al. 2009).

5 Acknowledgements

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