

The collection of Egyptian artefacts belonging to the broadly defined group of cult objects found its way to Wilanów most probably from the collection owned by Jan Potocki, who acquired them during his expedition to Egypt. Potocki went there in the early nineteenth century, when it was fashionable to create cabinets of antiquities.¹ The bulk of the Egyptian collection comprises metal objects.²

For a long time, the study of Egyptian artefacts focused on their aesthetic qualities and iconography. They were described in typologies; scholars made comparisons, looked for analogies and produced textual analyses to determine the time and place of their creation. This type of research is, of course, extremely important in order to understand the complexity and directions of the form of the artefacts, their scope and local varieties. The material used in their making is one of the aspects that the analyses tend to focus on nowadays. Without going into the issues which were covered in the past, this paper will focus on information that will expand our understanding of the Egyptian metal artefacts belonging to the Wilanów collection. One aspect that is undeniably important in the light of the ongoing studies that may help to clarify previous conclusions concerns determining the composition of the alloys used to make the metal objects; this will also help to expand our knowledge of Egyptian metallurgy.

In ancient Egypt, just like for the majority of civilisations to this day, the most valuable metals were silver and gold. It must be noted, however, that objects made from these metals represent an insignificant part not only of ancient Egyptian artefacts, but also of artefacts coming from the ancient world in general. The vast majority of metal objects that museum specialists deal with today were made of base metal alloys. Utilitarian objects made of metal (e.g. figurines, tools or weapons³), which are well attested in archaeological material in Egypt from the Old Kingdom

COMMUNICATION

ANALYSES OF ALLOYS IN EGYPTIAN ARTEFACTS HELD AT THE MUSEUM OF KING JAN III'S PALACE AT WILANÓW

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1 K. Kludkiewicz, 'Kolekcjonerstwo europejskie na przełomie XIX i XX wieku. Szkic o różnorodności gustów oraz stosunku kolekcjonerów do sztuki współczesnej', *Biuletyn Historii Sztuki*, vol. 76, 2014, no. 2, pp. 241–260; G. Bąbiak, 'Od Puław do Rapperswilu. Polityczne aspekty kolekcjonerstwa polskiego w XIX wieku', in: *Miłośnictwo rzeczy. Studia z historii kolekcjonerstwa na ziemiach polskich w XIX wieku*, eds K. Kludkiewicz, M. Mencfel (Warszawa, 2014), pp. 44–62; M. Mencfel, '„Muzeum” w XVIII wieku. Z dziejów semantyki pojęcia', *Acta Universitatis Nicolai Copernici, Zabytkoznawstwo i Konserwatorstwo*, vol. 52, 2021, pp. 1–15.

2 The entire collection of Egyptian objects, along with the attempts to reconstruct its history, was described by A. Majewska in *The Egyptian Collection at Wilanów* (Warsaw, 2015); some of the objects, such as the *ushabt*, have previously been covered, in a preliminary manner, in I. Pomorska, 'Uszebt w zbiorach polskich Muzeum Narodowego Warszawy', *Rocznik Muzeum Narodowego w Warszawie*, vol. 4, 1959, pp. 93–173.

3 W.M.F. Petrie, *Tools and weapons illustrated by the Egyptian collection in University College, London, and 2,000 outlines from other sources* (London, 1917).

onwards, were mostly made of copper and its alloys with other metals such as tin or lead, resulting in a material commonly referred to as bronze.⁴

Behind the production of these metal objects was not only the craftsman, but also a host of officials who issued to him the specific raw materials needed for the purpose. Metals – and valuable materials in general – were distributed institutionally, by temple treasuries located on temple sites. These treasuries stored, among others, precious items produced in temple workshops, as well as the raw materials distributed to craftsmen who made these objects.⁵ In antiquity, metals and metal products were highly desirable, which made them a target for thieves and thus a subject of subsequent court cases.⁶

In 2020, alloy composition analyses were performed on 24 metal objects (Fig. 1).⁷ They were carried out by Dr Alina Tomaszewska-Szewczyk of Nicolaus Copernicus University in Toruń by means of X-ray spectroscopy conducted with an XRF analyser.

- 4 On the raw material acquisition, production technologies, reuse and repairs of metal artefacts, also in a religious context, see G. Verly, J. Auenmüller, L. Delvaux, F. Rademakers, “‘Re-Membering’ Osiris: Late Period Casting Moulds and Osirian Ritual?”, *Le Bulletin de l’Institut Français d’Archéologie Orientale*, vol. 122, 2022, pp. 541–571; J. Auenmüller, G. Verly, F. Rademaker, ‘Bronze casting artefacts from the Qubbet el-Hawa – Moulds, materials and experimental methods’, in: *Studies in Experimental Archaeometallurgy. Methodological Approaches from Non-Ferrous Metallurgies*, eds. G. Verly, F. Rademakers, F. Téreygeol, Monographies Instrumentum, vol. 60, 2019, pp. 141–163; F. Rademakers, T. Rehren, E. Pernicka, ‘Copper for the Pharaoh. Identifying multiple metal sources for Ramesses’ workshops from bronze and crucible remains’, *Journal of Archaeological Science*, vol. 80, 2017, pp. 50–73; J. Auenmüller, ‘Grabungsfunde von der Qubbet el-Hawa im Ägyptischen Museum, Bonn. Die Ergebnisse der bildgebenden Verfahren’, in: *Gegossene Götter. Metallhandwerk und Massenproduktion im Alten Ägypten*, eds M. Fitzenreiter, Ch. E. Loeben, D. Raue, U. Wallenstein (Rahden, 2014), pp. 113–126; S. Heinz, ‘Casting Technologies and Cultural Connections at an Egyptian Harbour Town’, *Anatolica*, vol. 40, 2014, pp. 197–218; D. Schorsch, ‘The Manufacture of Metal Statuary: “Seeing the Workshops of the Temple”’, in: *Gifts for the Gods. Images from Egyptian Temples*, ed. M. Hill (New York, 2007), pp. 189–199; J. Ogden, ‘Metals’, in: *Ancient Egyptian Materials and Technology*, eds P. Nicholson, I. Shaw (Cambridge, 2000), pp. 151–156; H. Gale, Z. Stos-Gale, ‘Ancient Egyptian Silver’, *Journal of Egyptian Archaeology*, vol. 67, 1981, pp. 103–115; A. Wilkinson, *Ancient Egyptian Jewellery* (London, 1971).
- 5 B. Haring, ‘Divine Households. Administrative and Economic Aspects of the New Kingdom Royal Memorial Temples in Western Thebes’, *Egyptologische Uitgaven*, vol. 12, 1997, pp. 127–141; M. Brier, *The Tomb-Builders of the Pharaohs* (Cairo, 1989), pp. 38, 46.
- 6 O. Grieg, *The Language of the Hieratic Ostrakon O. Nash I from the Nineteenth Dynasty. A Grammatical Analysis and Translation*, in *Papers for Discussion Presented by the Department of Egyptology*, eds S. Groll, H. Stein (Jerusalem, 1982), pp. 5–52; J. Černý, ‘Restitution of, and Penalty Attaching to, Stolen Property in Ramesside Times’, *The Journal of Egyptian Archaeology*, vol. 23, 1937, pp. 186–189.
- 7 Artefact inv. no. Wil.5439, which is a nineteenth-century replica of a *zhong* bell, has been excluded from this group; dating and provenance of artefacts after Majewska, *Zbiory egipskie w Wilanowie*, p. 163.

Fig. 1. Egyptian artefacts analysed with XRF

No.	Inventory number	Artefact	Dating	Provenance	Cast type
1	Wil.5432	Bastet	Late / Ptolemaic Period	?	Hollow cast
2	Wil.5433	Necho II	Late Period (Twenty-Sixth Dynasty)	?	Solid cast
3	Wil.5434	Kneeling pharaoh	Third Intermediate Period (Twenty-First – Twenty-Second Dynasty?)	?	Solid cast
4	Wil.5435	God in an Atef crown	Late Twenty-Fifth – early Twenty-Sixth Dynasty	?	Solid cast
5	Wil.5436	Osiris	Late Period (Twenty-Sixth Dynasty)	Lower Egypt	Solid cast
6	Wil.5437	Osiris	Late Period (Twenty-Sixth – Twenty-Seventh Dynasty)	Lower Egypt	Solid cast
7	Wil.5438	Osiris	Late Period (Twenty-Sixth Dynasty)	Lower Egypt	Hollow cast (base); solid cast (figure)
8	Wil.5440	Harpocrates	Late Period (mid- Twenty-Sixth – Thirtieth Dynasty)	?	Solid cast
9	Wil.5441	Ushabti	Third Intermediate Period (Twenty-First – Twenty-Third Dynasty)	?	Solid cast
10	Wil.5442	Osiris	Late Period (Twenty-Sixth Dynasty)	Lower Egypt	Solid cast
11	Wil.5443	Harpocrates	End of the Ptolemaic Period – Roman Period	?	Solid cast
12	Wil.5444	Osiris	Late / Ptolemaic period (second half of the seventh century – second half of the fourth century BC)	Central Egypt	Solid cast
13	Wil.5445	Osiris	Third Intermediate Period (Twenty-Fifth Dynasty)	Lower Egypt	Solid cast
14	Wil.5446	Osiris	Third Intermediate Period (Twenty-Fifth Dynasty)	Central Egypt	Solid cast
15	Wil.5447	Osiris	Third Intermediate Period (Twenty-Fifth Dynasty?)	Central Egypt (?)	Solid cast
16	Wil.5449	Cat on a capital	Late / Ptolemaic period	?	Hollow cast (capital); solid cast (figure)

No.	Inventory number	Artefact	Dating	Provenance	Cast type
17	Wil.5450	Thoth	Roman period (first – fourth century AD)	?	Solid cast
18	Wil.5451	Ptah	Third Intermediate Period (Twenty-Fifth Dynasty)	?	Solid cast
19	Wil.5452	Neith	Late Period (Twenty-Sixth Dynasty)	Lower Egypt (Sais?)	Solid cast
20	Wil.5453	Egida	Third Intermediate Period	?	Solid cast
21	Wil.5454	Griffin	Ptolemaic Period (second half of the fourth century – third quarter of the first century BC)	?	Solid cast
22	Wil.5455	Baboon	Roman Period (second half of the first century – second century AD)	?	Solid cast
23	Wil.6160	Sakhmet	Third Intermediate Period (Twenty-First – Twenty-Second Dynasty)	?	Solid cast

Even though metal alloys used to make historic objects are studied, they are not a frequent or a main topic covered in scholarly papers, especially in the Egyptological literature. This is a shame, because the results of these studies lead to some very interesting conclusions. Although the number of artefacts of its kind in Wilanów is not sizeable, it can already at the outset be said that metal alloys used for casting them (Fig. 2) are similar in composition to metal objects dating from the same periods held by other museums, including the British Museum and the Cairo Museum. It should be noted, however, that for some objects in the Wilanów collection, the study was carried out several times and the results show that the distribution of metals in the alloy is not uniform;⁸ it can, in fact, vary considerably, depending on the exact area that underwent the analysis. This means that there may appear a rather significant variance in the composition of one and the same object; this too is important when trying to draw comparisons with objects from other collections. For this reason, such samples cannot be clearly compared on the basis of a single test; a case in point are artefacts Wil.5432 and Wil.5437, where the difference between individual measurements is significant. Relying on singular measurements may thus lead to wrong conclusions.

⁸ No. 1–10, 16–23.

Fig. 2. Table of results for alloy composition in Egyptian artefacts based on XRF analysis

	Inventory Number	Object	Ag	As	Al	Bi	Cd	Co	Cr	Cu	Fe	Ir	Mn	P	Pb	S	Sb	Si	Sn	Ti	V	Zn	Zr
1	Wil.5432	Bastet	-	-	4.99	-	-	-	-	37.96	2.97	-	0.06	-	11.47	-	0.94	8.86	9.44	1.28	0.69	21.28	0.057
			-	-	-	-	-	-	-	66.43	0.84	1.99	-	0.45	21.40	-	-	8.11	0.65	-	-	-	-
2	Wil.5433	Necho II	-	-	-	-	-	-	-	68.04	0.48	1.83	-	-	21.10	-	0.28	3.56	4.71	-	-	-	-
			-	-	4.65	-	-	-	-	61.22	1.39	-	-	0.51	11.07	-	-	20.12	1.05	-	-	-	-
3	Wil.5434	Kneeling pharaoh	-	-	-	-	-	-	-	83.86	-	-	-	-	4.13	-	-	0.24	11.62	-	-	-	-
			-	-	-	-	-	-	-	72.70	0.32	1.30	-	-	10.42	-	-	0.71	14.55	-	-	-	-
4	Wil.5435	God in an Atef crown	-	-	-	-	-	0.125	-	83.14	0.15	-	-	-	0.83	0.333	-	0.27	15.14	-	-	-	-
			-	-	-	-	-	0.050	-	90.84	0.06	-	-	-	0.56	0.309	-	-	8.18	-	-	-	-
5	Wil.5436	Ostris	1.63	-	-	-	-	-	-	79.09	0.24	0.54	-	0.65	0.98	-	-	0.91	15.97	-	-	-	-
			0.86	-	-	-	-	-	-	79.82	0.22	0.53	-	0.40	0.86	-	-	0.67	16.54	-	-	-	-
			2.07	-	-	-	-	-	-	77.69	0.24	0.52	-	0.69	0.97	-	-	1.01	16.81	-	-	-	-
			1.96	-	-	-	-	-	-	78.71	0.21	0.53	-	0.49	1.07	-	-	0.82	16.21	-	-	-	-
6	Wil.5437	Ostris	-	0.23	-	-	-	-	-	90.80	0.06	-	-	-	0.47	0.406	0.42	-	7.61	-	-	-	-
			-	-	-	-	-	-	-	48.99	1.24	2.22	-	0.12	16.51	-	0.55	2.40	27.96	-	-	-	-
7	Wil.5438	Ostris	-	-	-	0.27	-	-	-	50.11	1.30	-	-	0.09	16.27	-	0.70	2.59	28.67	-	-	-	-
			-	-	-	-	-	-	-	69.51	0.72	1.51	-	0.046	10.09	-	-	0.50	16.92	-	0.71	-	-
8	Wil.5440	Harpocrates	-	-	-	0.48	-	-	-	50.10	0.79	3.83	-	0.45	29.27	-	-	7.69	3.02	1.25	3.06	-	0.063
			-	-	-	-	-	-	-	51.66	0.45	2.84	-	0.97	28.52	-	-	7.09	4.62	-	3.79	-	0.062
9	Wil.5441	Ushabti	-	-	4.20	-	-	-	-	72.61	3.89	0.88	0.031	0.13	2.33	-	0.17	8.17	1.53	-	-	6.05	-
			-	1.98	-	-	-	-	-	63.10	2.31	5.87	-	-	15.73	-	0.42	3.50	3.17	-	-	3.92	-
10	Wil.5442	Ostris	-	-	-	0.41	-	-	-	55.06	1.47	3.83	-	1.19	22.50	-	-	7.00	5.97	-	2.48	-	0.1.1
			-	-	3.13	0.50	-	-	-	43.41	1.81	4.84	-	0.63	30.53	-	-	9.52	2.58	-	2.96	-	0.082
11	Wil.5443	Harpocrates	-	-	-	-	-	-	-	67.29	0.51	-	-	-	21.12	-	-	3.46	7.59	-	-	-	0.039

	Inventory Number	Object	Ag	As	Al	Bi	Cd	Co	Cr	Cu	Fe	Ir	Mn	P	Pb	S	Sb	Si	Sn	Ti	V	Zn	Zr
12	Wil.5444	Osiris	-	-	1.69	0.63	-	0.08	-	30.08	1.19	6.02	-	0.58	44.76	-	-	5.79	3.94	-	4.88	-	0.072
13	Wil.5445	Osiris	-	-	2.07	0.53	-	-	-	45.94	1.03	4.24	-	0.71	27.74	-	0.28	7.34	6.07	-	3.97	-	0.066
14	Wil.5446	Osiris	-	-	3.51	0.38	-	-	-	62.28	0.86	1.40	0.04	0.11	17.85	-	-	7.05	6.29	-	0.17	-	0.045
15	Wil.5447	Osiris	-	-	6.24	0.42	-	-	-	42.04	2.20	4.06	-	0.81	25.46	-	-	14.57	1.09	0.21	2.80	-	0.097
16	Wil.5449	Cat on a capital	-	-	-	1.82	-	-	-	72.01	0.25	1.67	-	-	13.90	-	-	1.40	8.94	-	-	-	-
17	Wil.5450	Thoth	-	-	-	-	-	-	-	75.16	0.16	1.44	-	0.22	15.84	-	-	3.21	3.98	-	-	-	-
18	Wil.5451	Ptah	-	-	-	0.57	-	-	-	45.02	1.30	6.18	-	0.83	30.30	-	0.47	7.07	4.14	-	4.02	-	0.096
19	Wil.5452	Neith	-	-	-	0.40	50.48	-	-	50.48	0.68	4.82	-	0.60	27.85	-	0.53	7.29	4.24	-	3.04	-	0.062
20	Wil.5453	Egida	-	-	-	-	-	-	0.09	43.75	1.09	-	-	0.69	31.66	-	-	7.14	10.33	-	-	-	0.041
21	Wil.5454	Griffin	-	-	-	-	-	-	-	95.70	0.031	-	-	-	0.50	0.253	-	0.13	3.38	-	-	-	-
22	Wil.5455	Baboon	-	-	-	-	0.50	0.19	-	89.61	0.12	-	-	-	3.48	-	-	2.82	3.98	-	-	-	-
23	Wil.6160	Sakhmet	-	-	-	0.37	-	-	-	93.24	0.13	-	-	-	1.52	-	-	1.28	3.83	-	-	-	-
			-	-	-	-	-	-	-	74.911	0.36	-	-	0.23	8.82	-	-	8.95	6.63	-	0.09	-	-
			-	-	-	-	-	-	-	-	-	5.33	-	-	91.62	-	-	1.01	1.34	-	-	-	-
			-	-	-	-	-	-	-	51.18	0.93	4.51	-	0.13	22.51	-	-	1.04	18.82	-	0.51	-	-
			-	-	-	0.49	-	-	-	50.87	1.00	3.20	-	0.08	19.73	-	-	3.08	20.92	-	0.58	-	0.034

Regardless of the time when these objects were created, the composition of the alloys is characterised by significant diversity in terms of raw materials used in their making. This means that the use of specific proportions of metals in alloys cannot be linked to a specific historical period. The main component of the alloys is copper, and the amount used varies quite considerably from object to object. Lead is the second most abundant material. Taking into account the results of other studies, it can be assumed that the maximum amount of lead present in the alloy without human intervention is 2% (although it is never certain whether it has not been added intentionally).⁹ Only objects Wil.5435, Wil.5436, Wil.5437, Wil.5453 and Wil.5454 are characterised by a low proportion of lead, amounting to less than 2%.¹⁰ Above this value, the addition of lead can be considered deliberate. The presence of other elements, such as aluminium, at such a low proportion in the alloy can be considered incidental.¹¹ The presence of silicon in the tested samples affected the strength of the object and its resistance to mechanical damage and corrosion. Iron, except in one case (Wil.5441), was found in trace amounts; its presence in the alloys can thus be considered not to have arisen through a human factor. An interesting element is arsenic, which rarely appears in post-New State objects.¹² The presence of zinc, on the other hand, is generally very rare in pieces dating from the pharaonic era, and its occurrence at a level of 2–3% in the alloy is usually attributed to accidental addition. Its greater concentration in metal products does not occur until the Roman Period.¹³

The exact place of origin of the Egyptian artefacts in the Wilanów collection is unknown. These days, it can only be guessed – on the basis

9 Ogden, 'Metals', pp. 154–155.

10 Following a repeated analysis, Wil.5437 and Wil.5454 show a significantly higher proportion of lead in the alloy, which is linked to uneven mixing of the liquid alloy before casting.

11 Wil.5432, Wil.5433, Wil.5441, Wil.5442, Wil.5444, Wil.5445, Wil.5446, Wil.5447, Wil.5452. It is worth noting that the amount of aluminium admixture in these objects is mostly approximated. Aluminium has only been in wide use since the mid-nineteenth century.

12 J. Kmošek et al., 'Archaeometallurgical study of copper alloy tools and model tools from the Old Kingdom necropolis at Giza', in: *Old Kingdom Copper Tools and Model Tools*, ed. M. Odler, Archaeopress Egyptology, vol. 14, 2016, p. 238. Adding arsenic to copper lightens its hue. Arsenic in alloys was most common during the Old and the Middle Kingdom. In the period of the New Kingdom, its presence above 2% may suggest a deliberate admixture, as in the case of antimony, see Ogden, 'Metals', pp. 152–153. Ushabt figurine no. Wil.5441 contains 1.8% arsenic; the proportion of iron (2–3%) suggests that the figurine may have been cast using other objects that were melted down. The presence of arsenic at this level may suggest the secondary use of the raw material during casting – Wil.5437 and Wil.5441, see Schorsch, 'The Manufacture of Metal Statuary', p. 191.

13 Ogden, 'Metals', p. 155; artefacts Wil.5432 and Wil.5441 display a large concentration of zinc, which most probably suggests contamination.

of analogies and typologies relating to these objects – where they may have originated, without narrowing the area down to a specific centre of worship; however, alloy composition studies offer opportunities to determine the location of the ore from which these objects were made. These can be determined by analysing the isotopes of copper and lead present in the analysed alloy.¹⁴

Given the above test results, it is apparent that, when manufacturing the objects in question, the metallurgist had complete freedom in terms of the selection of metals. Several factors may have influenced his choice. Recycling of already existing objects, namely melting them down and reusing the metal at a later date, was a common practice.¹⁵ This conclusion can be drawn from the analysis of artefact Wil.5436, where the silver admixture may have originated from a previously melted object.¹⁶ Notable about the objects analysed is the presence of a large amount of lead in the alloys from which they were cast. Castings produced in the Late Period are characterised by a high content of lead and tin, with lead being the dominant component.¹⁷ This phenomenon is characteristic of this time, particularly in the case of cult objects or votive objects, especially representations of Osiris.¹⁸

14 Rademakers, 'Copper for the Pharaoh', pp. 50–73; lead was mostly imported to Egypt. The tests conducted so far on metal alloys from Egyptian objects held in Wilanów have not determined the amount of lead and copper isotopes, which currently makes it impossible to identify the region of their origin, see A. Masson-Berghoff, '(Re)sources: Origins of metals in Late Period Egypt', *Journal of Archaeological Science. Reports*, vol. 21, 2018, pp. 326–328; Ogden, 'Metals', p. 168. Additionally, when dealing with repeatedly mixed raw materials, trying to determine the origin of the metal becomes more difficult, especially as they were imported from outside Egypt, including from Anatolia and Cyprus, see Rademakers, 'Copper for the Pharaoh', p. 69.

15 D. Schorsch, 'Ritual Metal Statuary in Ancient Egypt: "A Long Life and a Great and Good Old Age"', in: *Statues in Context. Production, meaning and (re)uses*, ed. A. Masson-Berghoff (Leuven–Paris–Bristol, 2019), p. 249.

16 It cannot be ruled out that the silver is a residue from the smelting of lead or copper.

17 In the case of the Late Period, the lead content may have been 20% or more. The tin content was generally around 10% in the casting process, but its proportion increased in the Late Period (Ogden, 'Metals', pp. 154–155). Studies have shown that the use of a small amount of tin (about 2.5%) combined with a large admixture of lead (about 15%) is typical for votive objects; however, the average tin content in Late Period alloys is less than 5%. The high tin content may suggest that the object may have been made by melting down other objects. The high amount of lead causes problems during analyses. Tin and lead corrode and form insoluble compounds on the object's surface that can interfere with readings, see Masson-Berghoff, '(Re)sources: Origins of metals', pp. 327–328.

18 Similarly to the Wilanów collection, other collections also feature predominantly images of Osiris, due to the worship of this god being intense during the first millennium BC; see *Gifts for the Gods*, p. 191; C. Jurman, 'The Osiris Chapels of the Third Intermediate Period and the Late Period at Karnak. Some Aspects of Their Religious and Historical Significance', in: *Acta Symposii anno 2004, Aegyptus et Pannonia III 2006*, ed. H. Gyory (Budapest, 2008), p. 118; C. Zivie-Coche, 'Late Period Temples', in: *UCLA Encyclopedia of Egyptology*, ed. W. Wendrich et al. (Los Angeles, 2008), p. 6.

The increased use of lead was dictated by economic factors and the mass production of votive objects.¹⁹ Lead was a by-product from the extraction of silver and, until the Roman Period, it was not widely used as raw material relevant to industry. Its low price, compared to copper and other metals, was key to meeting the needs of the market at the time. Lead as the main raw material for casting did not appear on a large scale until the Ptolemaic Period, but the Roman Period is the source of the majority of objects made of this metal.²⁰ During the period in question – starting in the Third Intermediate Period – the demand for votive objects made for sale to pilgrims increased, which meant that copper had to be used sparingly.²¹

It is significant that specific groups of Late Period artefacts still cannot be conclusively linked to specific alloys; however, it is worth noting that a comparison of results of analyses of objects dating from the Late Period, such as those from the Cairo Museum,²² reveals that their copper content is significantly higher than in the objects from Wilanów. In this case, however, the difference in alloy composition may depend on the class of the object or, more likely, on the availability of raw materials. In both cases we are dealing with depictions of deities, but in the case of Wilanów artefacts, we noted a lower copper content, which is compensated by a higher content of lead (nos 10, 12, 13, 14, 15, 23) or, in some cases (nos 3–7), tin. However, copper remains the dominant alloy component. The results show that the level of workmanship and the nature of the product played a crucial role in the selection of raw materials. The objects that show the highest proportion of lead were mass-produced, as was the case with the Osiris figurines (for instance, artefacts no. 10 and 12 were amulets that were worn around the neck).²³ The other depictions of Osiris (nos 5, 6, 7) are characterised by better craftsmanship, which may support the idea that they were made for wealthier individuals who

19 V.K. Gouda, G.I. Youssef, N.A. Abdel Ghany, 'Characterization of Egyptian bronze archaeological artifacts', *Surface Interface Analysis*, vol. 44, 2012, no. 10, p. 1341.

20 Heinz, 'Casting Technologies', p. 207. Among the analysed artefacts, only figurine Wil.5455 made of lead (91.62%) is dated to the Roman Period. It shows strong parallels with those found at Thonis-Heracleion, which may suggest its origin; see Majewska, *Zbiory egipskie w Wilanowie*, p. 123.

21 This, however, affects the appearance of the final product, as the surface of an object with a high admixture of lead is dull, grey and prone to corrosion, see Masson-Berghoff, '(Re)sources: Origins of metals', p. 326; on the other hand, a large admixture of lead has a positive impact on the manufacturing process and nonetheless increases resistance to surface corrosion, see V.K. Gouda, G.I. Youssef, N.A. Abdel Ghany, 'Characterization', p. 1344. Lead added in large amounts also makes the viscosity of the alloy lower, and the consistency is more liquid. Additionally, it makes it less prone to melting down and reduces the solidification time of the cast, see Ogden, 'Metals', p. 154.

22 V.K. Gouda, G.I. Youssef, N.A. Abdel Ghany, 'Characterization', p. 1341.

23 Similar proportions can be found in Wil.5443 (no. 11), which was also used as a pendant.

could afford objects of higher quality. In these artefacts, lead content is lower in favour of tin.²⁴

The question remains whether the material used by the metalworkers to make objects for personal use came from temple treasuries or was obtained by other means. This question is difficult to answer unequivocally. The sourcing of raw materials was an expensive undertaking and involved a large group of people. The mere transport of ore over the distance of even fifty kilometres from the excavation to the nearest body of water, which was the Nile, increased the cost of the metal, not to mention the raw materials imported into Egypt from other areas of the Mediterranean. Metal is known to have been used as means of payment as far back as the New Kingdom, and was subsequently traded in the 'private' sector.²⁵ Only from the Third Intermediate Period onwards do we see a greater number of, for instance, votive metal objects, which means that there had been a change in the circulation of metals after the New Kingdom. A further increase in the production of metal objects is observed in the Late Period and the Ptolemaic Period. At that time, there were significant changes in the organisation of temple operations, with priestly institutions combining many functions, including administrative ones, which provided even more opportunities. Most votive and cult objects made of metal date from this period. This coincides with increased trade through centres such as Naucratis, founded in the seventh century BC by Greek settlers, which had a significant impact on the economy of the time. It remains an open question to what extent metal objects constituted a luxury commodity, and what their value was when they were sold, during the Late Period and the Ptolemaic Period. Both metals and finished products with no further use, as well as production waste, were sourced for metallurgy workshops, while mass production could contribute to low prices for such products.²⁶ Based on the number

24 It is important to remember, however, that the final product does not always have to be made of a higher-quality alloy. In the case of Wil.5438 (no. 7), Wil.5451 (no. 18) and Wil.6160 (no. 23), in spite of the object's better quality, the alloy used to cast it is similar to that used for mass-produced objects and shows a higher proportion of lead and tin. In the case of artefacts no. 1–4, we instead observe a higher copper content, but it is not as high as would be expected from objects which were not mass produced. Among the objects that have been analysed, the highest copper content in the alloy was seen in the case of Wil.5453 (no. 20), which is a model example of craftsmanship for objects of its class.

25 Haring, 'Divine Households', pp. 262–264.

26 Rademakers et al., 'Copper for the Pharaoh', p. 69; The situation regarding the acquisition of metal for temple purposes can be observed, for example, in the case of the temple of Seti I in Abydos or the temple in Memphis, where designated people obtained gold and silver in exchange for temple surpluses. The bullion was then stored in the temple treasury for later use in workshops. A similar mechanism may also have been in place in the Late Period for the acquisition of other metals, see Haring, 'Divine Households', pp. 181, 203.

of these objects in museum collections, it can be assumed that figurines (especially those with a higher lead content) were available not only to the upper class, but also to members of the lower strata, who made up the vast majority of Egyptian society.

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