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Original article

On the way to the New Kingdom. Analytical study of Queen Ahhotep's gold jewellery (17th Dynasty of Egypt)

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ABSTRACT

The gold jewellery in the collection of the Department of Egyptian Antiquities of the Louvre Museum bearing the names of Queen Ahhotep and King Ahmose I (17th–18th Dynasties, 16th c. B.C.) was analysed using μPIXE, XRF, and SEM-EDS. The items were formed by casting, hammering and rolling, were decorated by chasing, and were mounted using hard-solders obtained by adding copper to the base-alloys. The jewellery bearing the name of Ahhotep is made essentially from cast gold alloys, but the elements of an armband found on the mummy of King Kamose and bearing the name of his brother Ahmose are a skilled goldsmith's work using whitish Ag-rich electrum alloys. The armband and one of Ahhotep's rings with marks of intense wear-use were worn in day-life; the other items could be funerary. The gold employed is alluvial, because the alloys contain PGE inclusions. The composition of the alloys matches the composition of gold grains from the Eastern Desert mines. The analytical data published so far for the scarce Second Intermediate Period jewellery items were compared to the data obtained in this work, showing that the alloys during this period split into two groups: those that are yellowish (containing up to 99 wt% Au) and those that are whitish (containing more than 20 wt% Ag). All the items with marks of intense wear-use except one are contained in the second group. Among them, the armband bearing the name of King Ahmose that is inscribed with the hieroglyphic sign of the moon in its oldest written form. As this change occurred under Ahmose I, it suggests that new and old objects coexisted during that difficult period of struggles in Egypt. Gold jewellery and weapons recovered during the campaigns against the Hycsos, leaded by King Kamose, Queen Ahhotep and King Ahmose, could have also been recycled in Egyptian workshops. This could justify the presence of Os-Ir-Ru-Pt inclusions in the two items with marks of intense wear-use, instead of the Ru-Os-Ir inclusions usually found in Egyptian productions.

1. Introduction

Among the most outstanding examples of the art of the Egyptian goldsmith are the jewellery groups found in female burials associated to royal tombs excavated at Dahshur [1], at Lahun [2], at Lisht [3], and at Hawara [4]. Like the remarkable treasure of Tôd [5], found in a temple dedicated to god Montu nearby Luxor, those abundant groups of jewellery are dated to the Middle Kingdom (*c.* 2040–1780 B.C.). If in this period the art of the goldsmith attained such a superb skill and taste that have never been surpassed [6], jewellery from the Second Intermediate Period (2nd IP, c. 1800–1550 B.C.) is very scarce and of very variable quality.

Only one impressive group of jewellery is dated to the 2nd IP. Today in the collection of the Egyptian Museum in Cairo, it was found in 1859 by A. Mariette at Dra 'Abu el-Naga', in the burial of Queen Ahhotep [7], the mother of Ahmose I (1550–1069 B.C.), the first king of the 18th Dynasty. She served as regent after de death of her elder son, Ahmose's elder brother Kamose (c. 1555–1550 B.C.), the last king of the 2nd IP. This impressive group of jewellery and weapons dates from the end of the 2nd IP – beginning of the 18th Dynasty. This could be explained by the fact that the 2nd IP is an obscure era, when the Hycsos invaded Egypt and ruled from the eastern Delta over the northern territories [8]. After a long period of struggles, it was the founder of the New Kingdom, King Ahmose I, from the line of Egyptian Kings that reigned over Thebes, who defeated the Hycsos and started the reunification of Egypt.

The jewellery from Queen Ahhotep's burial has never been submitted to analytical study, but another important group of jewellery dated to the 2nd IP, today in the collection of the National Museums Scotland, found by Flinders Petrie at Qurneh in the intact burial of an adult and child [9], was recently studied [10]. The analytical data revealed the presence in the burial of new and very wear-used

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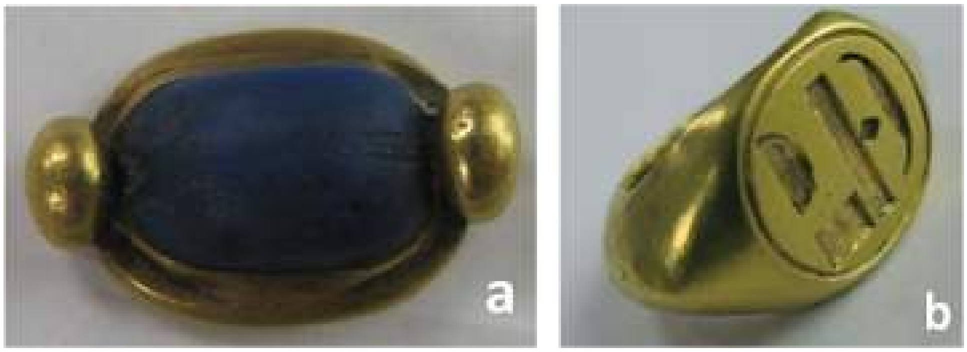

Fig. 1. Queen Ahhotep's blue lapis lazuli scarab in a gold tray E3297, which is the bezel of a swivel ring, and gold signet ring E7725.

items, suggesting the continual use, during a large period, of some jewellery items as well as the recycling without melting of the most common gold beads. The objects were made using a large variety of coloured alluvial gold alloys containing platinum group elements (PGE) inclusions and were mounted using the hard-soldering process, with joints going from almost invisible to an excess of solder. The very variable quality and wear-use observed for these items led to the study of the small number of 2nd IP objects in the collection of the British Museum belonging to a King Sobekemsaf, and to King Nubkheperre Intef and his wife Queen Sobekemsaf [11]. Although showing the use of the same workshop practices and of gold containing PGE inclusions, the objects in the British Museum collection had no marks of intense were-use and were made from quite similar gold alloys.

Objects dated to the 2nd IP are indeed very scarce, but to shed more light on the work of gold during this period, are analysed in this work a group of objects in the collection of the Department of Egyptian Antiquities of the Louvre Museum. These objects, one gold signet ring, one blue scarab set in a gold tray, two cast gold amulets, and three gold elements of an armband are dated to the end of the 17th Dynasty – beginning of the 18th Dynasty, because bearing the names of Queen Ahhotep and of King Ahmose I.

To describe their construction, determine the composition of their alloys, and identify the type of gold employed in their fabrication, the objects in the collection of the Louvre Museum were analysed when the exhibition room was shortly closed using 3 MeV proton particle induced X-ray emission (μPIXE), handheld X-ray fluorescence spectrometry (XRF) and energy dispersive X-ray spectroscopy (SEM-EDS). An overview of the art of the 2nd IP goldsmith was searched by comparing the data obtained in this work with data published for the other 2nd IP jewellery above-mentioned. To search for the origin of the gold, data obtained for the alloys used in the production of 2nd IP jewellery was compared with the composition published for gold grains collected in mines situated in the Eastern Desert.

2. Materials and methods

2.1. Objects analysed

Are in the collection of the Department of Egyptian Antiquities of the Louvre Museum inscribed with the name of Ahhotep (Fig. 1) one gold signet ring (E7725), one blue scarab set in a gold tray (E3297), and two cast gold amulets (E7715 and E7669) representing the standing figure of god Seth [12]. The amulets have the same dimensions and postures, but their decorative details, like the loincloths they wear, are different. They were purchased from different art collectors, E7659 from E. Allemant and E7715 from H. Pennelli [13]. Amulet E7715 has casting defects on the legs, an unreadable inscription on the plinth, and the suspension ring restored by soldering.

Bearing the name of Ahmose I, are in the collection of the Louvre Museum the three gold elements of an armband (E7168), two lying lions (Fig. 2) and one cartouche (Fig. 3) with gold rings that should originally attach them to a (today missing) support. A. Mariette found these elements at Dra 'Abu el-Naga', in the *rishi* coffin of Ahmose's elder brother, King Kamose, on the breast of the King [14]. They are typologically very similar to the richly decorated elements of the armband found in Ahhotep's burial, today in the collection of the Egyptian Museum in Cairo [15].

The blue scarab set in a gold tray (E3297) and the three gold elements of an armband (E7168) were certainly daily life objects as they have marks of intense use-wear. The hieroglyphic sign of the moon (hieroglyph "iah") is represented in the inscriptions of both of them in a different direction compared to the other studied objects. The moon sign written form appears to have changed during the reign of Ahmose I [16], which fits with Ahhotep's lifetime and in the case of the armband with the fact that the object was found inside the burial of Ahmose's elder brother.

2.2. Analytical methods

The objects were examined under a SMZ1000 Nikon stereomicroscope equipped with a digital camera. The elemental composition of the alloys was determined at the extracted beam line of the AGLAE accelerator facility from the Centre de recherche et de restauration des musées de France (C2RMF, in Paris), using μPIXE (Fig. 2). Measurements were carried out with a 3 MeV proton beam and the recently implemented detection system consisting of several SDD detectors with high active surfaces, increasing the total solid angle of detection of the emitted X-rays [17]. To search for minor and trace elements at the conditions defined for the analysis of gold alloys [18], one of the detectors was covered with a selective filter consisting of 75 μm of Cu. In some cases, small details like PGE inclusions and joints were analysed with the scanning system for fast elemental mapping with high spatial resolution that goes down to $10 \times 10\ \mu m^2$ [19]. Quantitative processing of the spectra was carried out in all cases with GUPIXWIN software [20], which was coupled to the in-house TRAUPIXE software developed at the AGLAE facility [21].

The objects were further analysed by handheld XRF using a Thermo Scientific Niton XL3t analyser with a 'GOLDD' detector, and a 50 kV, 200 μA X-ray tube with an Ag anode. The analysis was carried out with the 3 mm spot collimator, in "precious metals" alloy mode, and the regions of analysis were located with the CCD camera. The analytical results obtained by XRF and μPIXE could be related by analysis of two certified gold alloys as shown in Table 1.

SEM was used to observe construction details and traces of wear-use, and data obtained using EDS complemented the analysis of small details such as joints, wires and PGE inclusions. SEM-EDS was undertaken using a FEI Philips XL 30 CP with controlled pressure, equipped with an integrated Link Isis 300 EDX system for

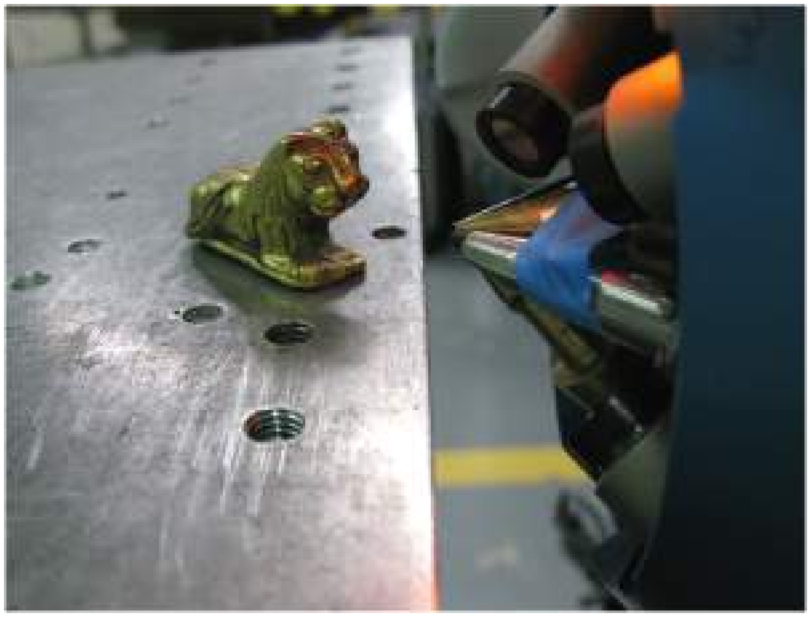

Fig. 2. One of the gold lions from King Ahmose's armband E7168 during μPIXE analysis at the extracted beam line of the AGLAE accelerator facility (C2RMF).

Fig. 3. The cartouche from King Ahmose's armband E7168 is a box shown (a) closed and (b) opened. The closing system consists of two pairs of gold tubes made from rolled gold sheets, with compatible sections to fit together and close the box.

Table 1
Certified gold standards Comptoir Lyon-Alemand (CLAL) analysed to relate XRF and PIXE quantitative data and check precision and accuracy of the methods.

Standard	Technique	Ag wt%	Au wt%	Cu wt%
CLAL6906	Certified	12.5	75	12.5
	XRF	12.5	74.6	12.9
	PIXE	12.5	74.9	12.6
CLAL6917	Certified	17.5	75	7.5
	XRF average 3 analyses	17.1	75.4	7.5
	Standard deviation	0.1	0.01	0.1
	PIXE average 8 analyses	17.7	74.8	7.5
	Standard deviation	0.2	0.2	0.1

microanalysis consisting of an Oxford Instrument Si(Li) detector and an ultrathin window. All image capture and analysis (collected in spot mode analysis for a 300 s acquisition time) was carried out with an acceleration voltage of 20 kV, and using the ZAF matrix correction model.

3. Results and discussion

3.1. The objects construction

The oval shaped signet ring E7725 and the amulets E7715 and E7769 were cast in one piece. The deeply incised hieroglyphs in the ring bezel and the details of the amulets were cut in the wax mould. After casting, some details were enhanced by chasing and the surface finished by polishing, except the inner side of the signet ring.

The blue lapis lazuli scarab E3297 is encircled, using an unidentified blackish organic material, by a gold band that forms an oval shaped tray, to which are soldered two undecorated gold collars. The deformation of the collar holes shows that this item is the bezel of a swivel ring, a type particularly common in Egypt [22]. It shows marks of intense use-wear that almost wiped out the inscription "Royal wife and mother Ahhotep" [23] and faded

Table 2
Data obtained by μPIXE and handheld XRF for the jewellery bearing the names of Queen Ahhotep and King Ahmose I, in the collection of the Louvre Museum.

Reference	region of analysis	Ag wt%	Au wt%	Cu wt%	Technique
Ring E7725		10.0	86.1	3.8	XRF
		9.9	86.3	3.8	XRF
		9.9	86.3	3.8	PIXE
Bezel E3297	Collar 1	6.8	92.5	0.7	XRF
		6.9	92.4	0.7	PIXE
	Collar 2	6.7	92.8	0.6	XRF
		6.5	92.9	0.6	PIXE
	Tray	5.9	93.8	0.3	PIXE
		5.9	93.9	0.2	PIXE
Amulet E7659	Body	1.1	97.2	1.7	XRF
		1.1	97.3	1.6	XRF
		0.8	97.5	1.7	PIXE
Amulet E7715	Body	0.5	99.2	0.4	XRF
		0.4	99.2	0.4	PIXE
		0.4	99.2	0.4	PIXE
Cartouche E7168	Bottom sheet	31.0	65.8	3.2	XRF
		30.6	66.2	3.2	PIXE
	Wall sheet	29.2	68.2	2.5	XRF
		30.2	67.7	2.1	PIXE
	Loop	29.2	68.2	2.5	XRF
		29.3	68.1	2.7	PIXE
	Duck body	31.5	65.5	3.1	PIXE
	Duck eye	30.4	66.5	3.1	PIXE
	Sun	24.6	74.0	1.4	PIXE
	Wire braid	30.9	65.9	3.2	PIXE
	Ring	28.8	69.9	1.2	PIXE
Lion E7168	Body right	25.8	72.7	1.5	XRF
		25.2	73.4	1.4	XRF
		25.6	73.2	1.2	PIXE
	Body left	25.7	72.9	1.4	XRF
		25.4	73.2	1.4	XRF
		26.4	72.2	1.4	PIXE
	Wire	26.0	72.4	1.5	PIXE
	Ring	27.7	71.0	1.3	PIXE

the gold joints. On the contrary, the signet ring and the amulets show scratch patterns more likely caused by the use of an abrasive cleaner. Black and brown substances are still visible in almost all the cavities. The brown one, that is also visible on the elements of armband E7168, is fluorescent under UV illumination, certainly an organic resin considering the morphology observed under the stereomicroscope.

The three gold elements of an armband, with marks of intense wear-use, were made by joining gold elements made by hammering and rolling. The hollow lions (Fig. 2) decorated by chasing, consist of two halves soldered together. The tail is a strip-drawn wire coiled around a rod soldered to the body. The cartouche with a closing system and an oval loop is made from gold sheets (Fig. 3). The decoration is a delicate mounting of gold sheets and strip-twisted and strip-drawn wires, as shown in Fig. 4. Contrary to the 2nd IP gold heart-scarab of a King Sobekemsaf in the collection of the British Museum [11], no signs of a filler could be found.

3.2. *The gold alloys*

Table 2 summarises the results obtained by μPIXE and XRF for the different parts that make up the objects. At our experimental conditions, the effective penetration depths of the techniques employed depend on the composition of the alloys [26]. For our alloys, μPIXE, with lower penetration than XRF, analyses the first 5–14 μm [10], but data obtained by both methods match together.

The ternary diagram of Fig. 5 shows that the alloys are of variable quality. The amulets contain 97–99 wt% Au, the signet ring contains about 86 wt% Au, and the parts in gold of the blue scarab bezel contain 92–94 wt% Au. The whitish alloys used to produce the armband elements are on the contrary Ag-rich electrum alloys. In

Table 3
Data obtained by μPIXE and EDS mapping of the joints and base-alloys of Ahmose's armband and Ahhotep's blue scarab bezel.

Reference	Region of analysis	Au wt%	Ag wt%	Cu wt%
Lion E7168	Body	*72.7*	*25.8*	*1.5*
	Solder	66.7	26.2	7.1
	Wire	*72.4*	*26.1*	*1.5*
	Solder	63.4	25.4	11.2
Cartouche E7168	Wall sheet	*68.2*	*29.2*	*2.5*
	Solder	65.2	27.4	7.4
	Duck body	*65.5*	*31.5*	*3.1*
	Solder	60.4	31.0	8.6
	Duck eye	*66.5*	*30.4*	*3.1*
	Solder	53.9	33.7	12.4
	Sun	*74*	*24.6*	*1.4*
	Solder	61.1	29.4	9.5
Bezel E3297	Collar	*92.5*	*6.8*	*0.7*
	Solder	88.3	6.6	5.1
	Tray	*93.8*	*5.9*	*0.3*
	Solder	86.9	7.0	6.1

average, the lions contain 25 wt% Ag and the cartouche 30 wt% Ag, showing that they come from different batches. The difficult soldering process of the many cartouche elements may justify the differences observed.

The presence of Cu in the electrum alloys is expected. The intentional addition of this element to gold alloys was revealed for other Egyptian productions [10,19,26,27]. In general, copper enhances the colour and changes the properties of gold alloys. In Egyptian jewellery, the role of this element is very significant when the objects are mounted by soldering different parts, as shown in Table 3 that summarises the data obtained by μPIXE and EDS for the base-alloys and by mapping the joints [19] of the blue scarab bezel E7725 and of the lions and cartouche of armband E7168. In fact, the solder alloys were always obtained by addition of Cu to the base-alloys. This metallurgical practice has been noticed as regularly employed in Ancient Egypt for hard-soldering [10,26].

Were added to the ternary diagram of Fig. 5 the 2nd IP jewellery items so far analysed: the contextualised group found in Qurneh in the collection of the National Museums Scotland [10], and a few items in the collections of both the British Museum [11] and the Ashmolean Museum [27,28]. The jewellery items from Qurneh and those studied in this work follow the same "chemical pattern". The alloys roughly split into two groups: one containing the objects made from gold alloys and another containing those made from electrum alloys. The first group contains the jewellery bearing the name of Ahhotep, the jewellery in the British Museum, and the majority of the jewellery from the Qurneh burial. The second group contains Ahmose's armband and part of the Qurneh jewellery, including the wear-used adult's girdle that contains the highest Ag contents observed (42–44 wt%). All the objects that show marks of intense wear-use except blue scarab bezel E7725 are contained in the second group, suggesting a chronological difference between these two groups.

3.3. *Gold in Egypt*

If copper can be easily removed from natural gold by cupellation, and be added to the natural alloys to change their properties, silver can only be removed by parting, but this process is not expected to be fully practised as early as the 2nd IP. The variety of the silver amounts contained in the Egyptian jewellery from this period should consequently be the result of an access to several gold sources.

Gold is very much present in Egypt, in different lithologies, occurring mainly in the Eastern Desert in quartz veins accompanied by abundant pyrite and arsenopyrite [29–31]. The concentration of

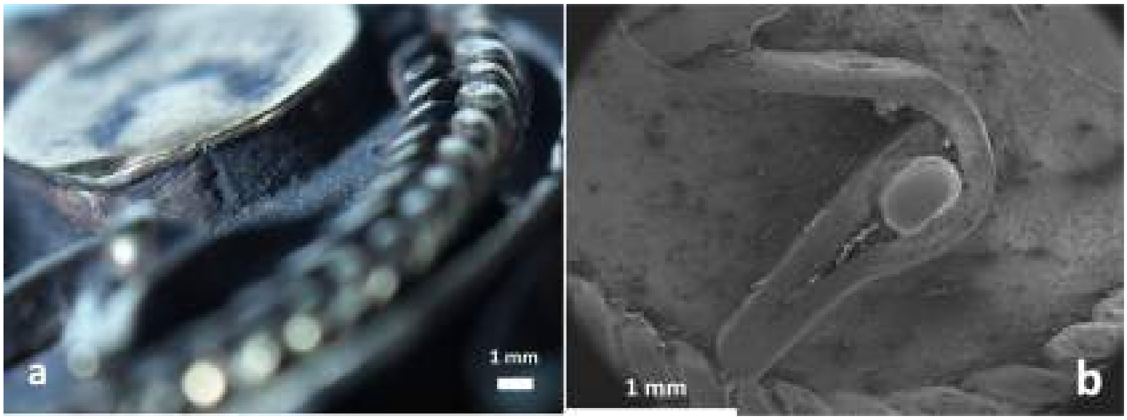

Fig. 4. Details of King Ahmose's name in cartouche E7168. The hieroglyphs "the sun of Re" represented by one sun disk and one duck are a mounting of gold sheets and strip-drawn wires (a technique used in Egypt [24,25]). (a) Under the stereomicroscope, it can be seen that the sun disk is made by joining one gold sheet to one gold strip; and (b) under the SEM, it can be seen that the duck is made by joining wires to one gold sheet and one granule.

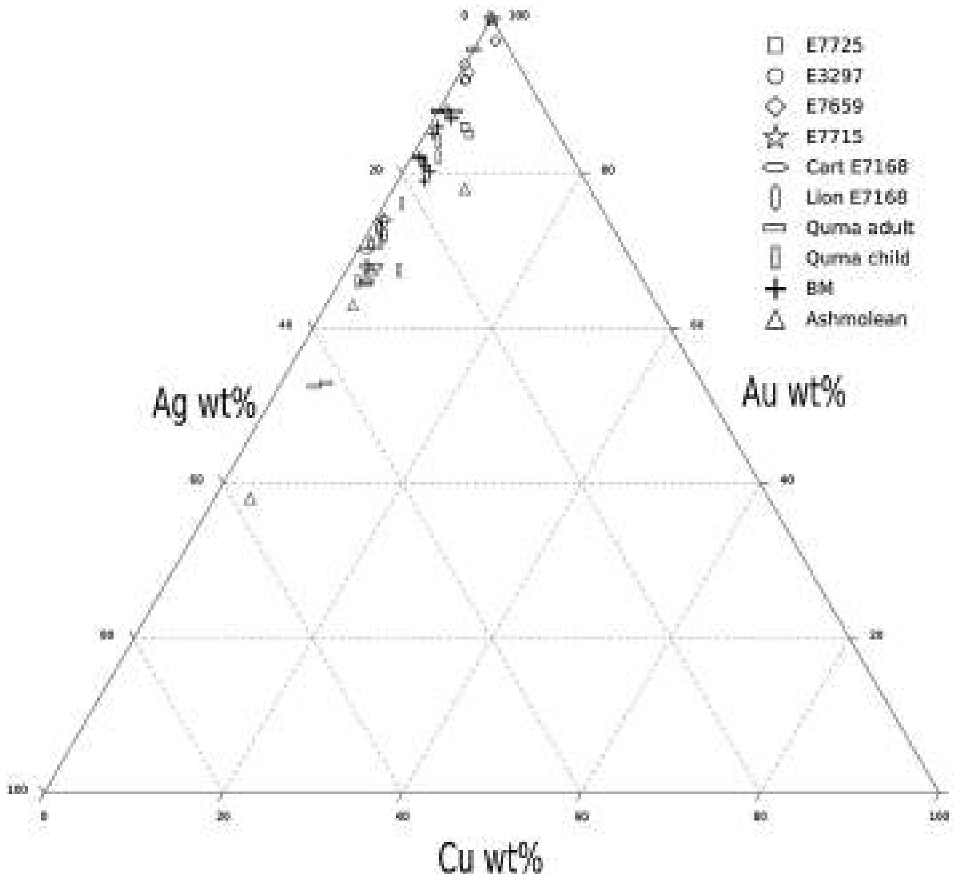

Fig. 5. Ternary diagram representing the distribution of the 2nd IP gold alloys. Those determined in this work are plotted with those published for the jewellery from the Qurneh burial [10], the British Museum [11], and the Ashmolean Museum [28].

Cu in native gold is hardly ever provided in publications, but gold grains in minerals from Wadi Hammad (Eastern Desert) contain amounts of Cu lower than 0.01 wt% [32]. A study of the gold mines in Egypt and Nubia by R. Klemm and D. Klemm has shown that primary gold contains silver ranging from c. 7 wt% to c. 30 wt% [30]. However, high purity alloys, such as those used to produce amulets E7715 and E7669, were employed in Egypt in the production of gold leaves. Examples are the gilded King Tutankhamun's mask and throne [33], the gold foils from different supports found in the Middle Kingdom tombs 381 and 533 at Abydos [34] and one 2nd IP leave in the collection of the Ashmolean Museum [27].

We plotted in Fig. 6 in addition to data considered in [30], analytical data published for gold grains in minerals collected in Eastern Desert mines. It can be seen that, as suggested [30], Egyptian gold contains in general quite high Ag contents. This is well represented by data from Um El Tuyor mine [35] where Ag varies from 5 wt% to 20 wt%. However, rich-Ag electrum and high purity gold grains, like those from Wadi Hammad [32], are also contained in the drawn chemical pattern, which expands the possible range of silver contents in Egyptian gold. When the jewellery analysed in this work is plotted in Fig. 6a, together with the other 2nd IP jewellery, the same chemical pattern is obtained. The objects in the collection

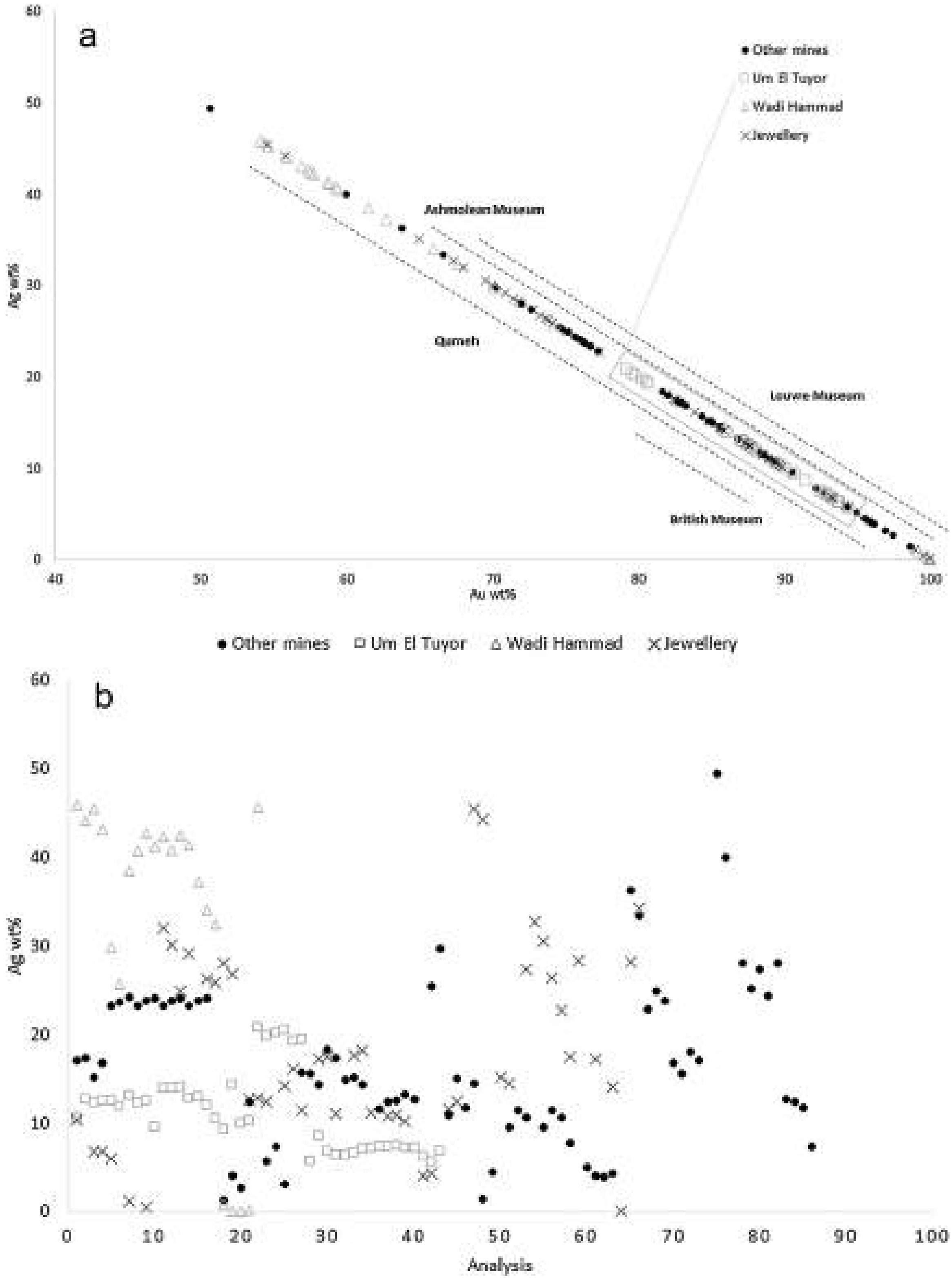

Fig. 6. (a) Diagram representing the Ag and Au contents of the 2nd IP jewellery so far published [10,11,28] and of the jewellery studied in this work, plotted together with data published for gold grains from several mines situated in the Egyptian Eastern Desert [32,35–47]; (b) Diagram representing the Ag amounts.

of the British Museum are concentrated is a small area and match well the most common compositions of Eastern Desert gold grains, contrary to those in the collection of the Louvre Museum and those from Qurneh that are quite dispersed in the diagram. The silver amounts plotted in Fig. 6b show that all items are contained in the range defined by the published gold grains.

3.4. PGE inclusions

The use of alluvial gold in the manufacture of the jewellery bearing the name of Ahhotep and Ahmose I was confirmed by the presence of visible PGE inclusions at the surface of the objects with the exception of the amulets. The signet ring contains a few inclu-

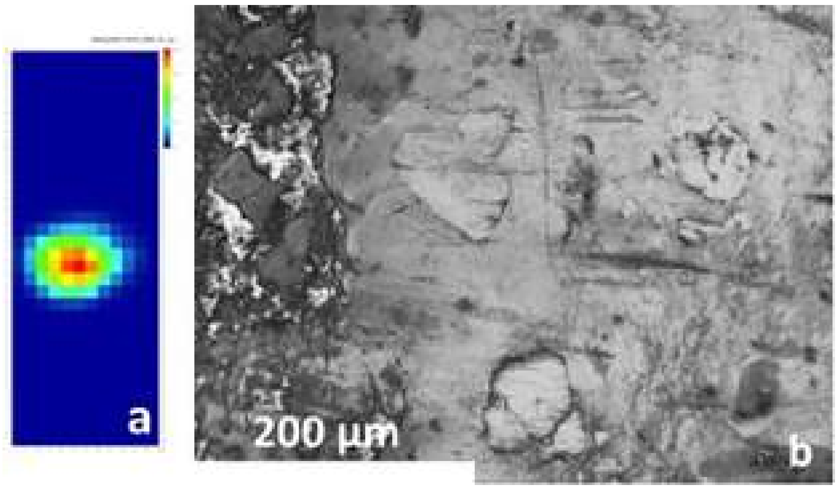

Fig. 7. (a) Elemental distribution by µPIXE in colour scale of the Ir (Lα-line) in an area shown under the SEM (b) of the cartouche E7168 cover sheet containing PGE inclusions.

Table 4
Data obtained by µPIXE and EDS mapping of the PGE inclusions identified on Ahmose's armband and Ahhotep's blue scarab bezel and signet ring.

	Ru wt%	Rh wt%	Os wt%	Ir wt%	Pt wt%	Pd wt%	Fe wt%	Ni wt%
EDS								
Bezel E3297	18		40	43				
	13			79	8			
	25		35	40				
Ring E7725	29	2	36	34				
	29	2	35	35				
	29	2	35	33				
µPIXE Cartouche E7168	5.2	0.3	51.7	39.6	1.4	0.3	1.4	0.2
	20.4	0.9	38.2	36.0	3.8		0.4	0.2
	21.9	1.2	37.4	34.8	3.5		1.0	0.2
	9.6	0.5	45.0	42.1	2.0		0.6	0.2
	16.2	1.5	41.6	38.5		0.7	1.2	0.4
	10.5	1.9	49.3	32.0	5.0		1.1	0.3
	19.8	1.2	40.5	34.8	2.7		0.9	0.2
	20.4	0.8	38.2	36.7	3.4		0.4	0.1
	1.1	0.4	17.1	66.9	9.4	0.1	4.6	0.2
	7.5	0.4	50.0	39.8	1.9		0.4	0.1
	8.3		50.3	41.4				
Lion E7168	15.6	0.7	41.0	39.2	3.0		0.4	0.1
	0.9	0.5	33.7	58.1	6.2	0.2	0.2	0.1
	29.8		36.6	28.3	5.3			
Ring E3297	32.7	0.4	33.8	30.9	1.1		0.9	0.3
	23.4	1.0	33.4	38.3	2.8		0.8	0.3
	1.8		82.6	9.2	4.6		1.5	0.3
	93.8			6.2				
	15.0	0.4	42.3	38.7	3.3		0.3	0.1

sions, the blue scarab bezel tray and collars contain some, but the armband contains numerous inclusions. Several of them were mapped using µPIXE and EDS (Fig. 7). Their composition, summarised in Table 4, was calculated as described by Lemasson and collaborators [19].

The inclusions in signet ring E7725 are Os-Ir-Ru alloys, as expected for Egyptian productions [10,26,48]. In spite of the very low Pt contents in the gold foils from tombs 381 and 533 at Abydos [34] analysed using synchrotron radiation [49], to our knowledge the Egyptian gold objects so far analysed regularly contain PGE inclusions belonging to that system. The inclusions in the gold parts of blue scarab bezel E3297 and in the elements of armband E7168, which are possibly the oldest objects in the group, are however, Os-Ir-Ru-Pt alloys. To our knowledge, the only objects containing visible PGE inclusions from this system, one of them containing very numerous inclusions, are three gold penannular earrings in the collection of the Louvre Museum, made from alloys containing in average 20 wt% Ag and 1–5 wt% Cu [26]. B. Bruyère found these earrings dated to the 18th Dynasty in female burials at the Deir el-Medina East Cemetery [50,51], a village situated on the other side of the Nile River that housed the builders of the royal Theban tombs.

3.5. Query on gold supplies

Gold jewellery production is associated to societal situations and to workshop practises. It is therefore necessary to point out that Ahhotep's blue scarab bezel E3297 and Ahmose's armband E7168 contain Os-Ir-Ru-Pt inclusions, have marks of intense wear-use, and the hieroglyphic sign of the moon is in its oldest writing form.

When the political situation of Egypt in the 2nd IP is considered, we can suggest that those objects could have been produced in the Theban workshops, hypothesis reinforced by the presence of the same type of inclusions in three earrings found at the Deir el-Medina East Cemetery, in the Theban area [26]. In fact, after invading Egypt, the Hycsos ruled over the northern territories from the eastern Delta until their defeat by Ahmose I, who belonged to the

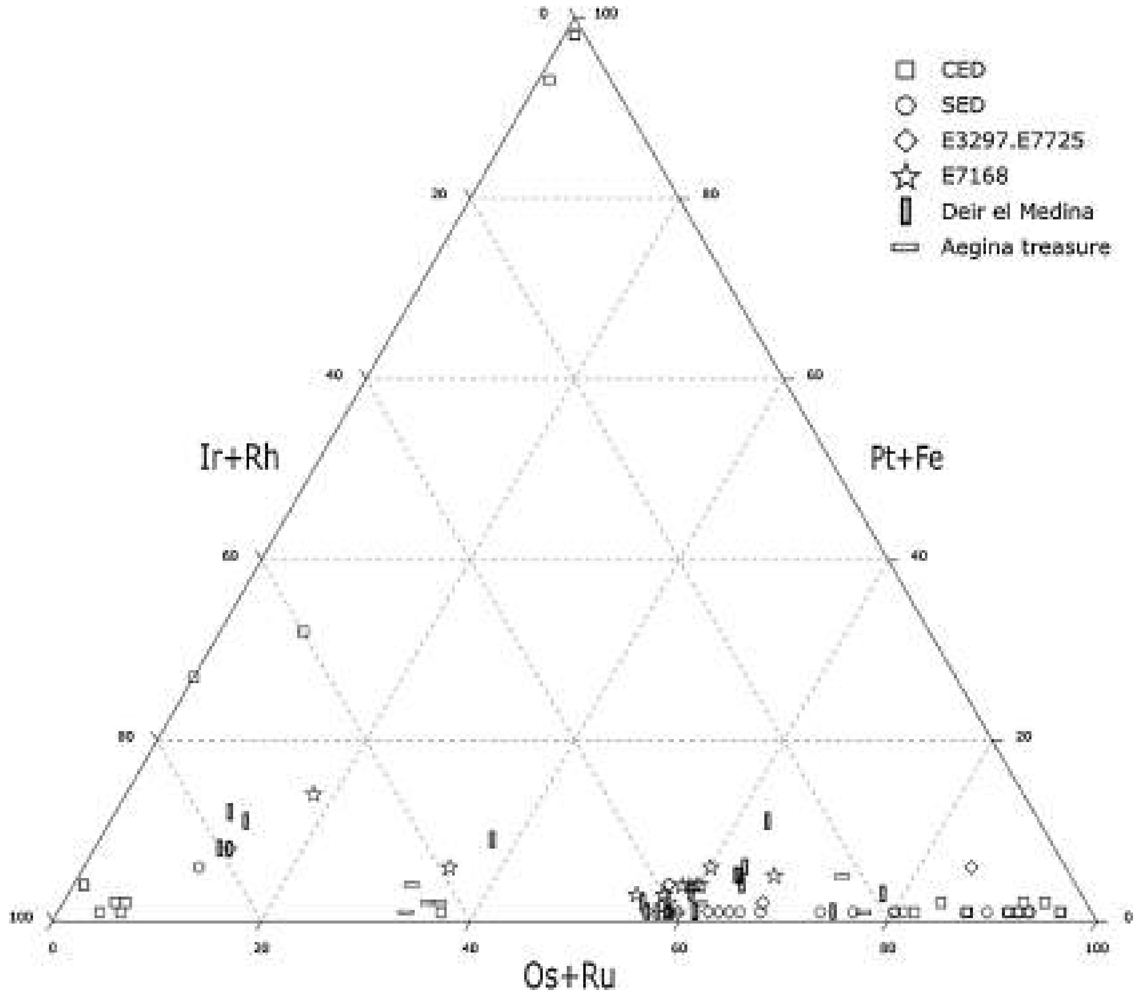

Fig. 8. Ternary diagram representing the Slansky's system Pt+(Fe), Os+(Ru), Ir+(Rh) [60] for the PGE inclusions analysed in this work, those published for jewellery from Deir El-Medina [26], and those published for PGM grains from deposits situated in central (CED) and south (SED) Egyptian Eastern Desert [56,59].

line of the Egyptian Kings that reigned over Thebes. Gold supplying the Theban workshops could have been of different sorts: 'fresh' metal and 'reused' metal obtained by melting gold objects. Reuse (either with or without melting) could had included broken and old-fashioned Egyptian objects, but also objects recovered during the battles against the Hyksos. From the numerous military actions against the Hyksos, the Theban kings brought "gold, lapis lazuli, silver, turquoise" [52]. In addition, lying lions are represented in Hyksos' jewellery [53] and two gold objects from the Aigina treasure, that contains items made in the Hyksos tradition [54], have PGE inclusions that are Os-Ir-Ru-Pt alloys [55].

It is however difficult to suggest sources of 'fresh' metal for this period. There are rather scarce platinum group minerals (PGM) in Egypt, which could reinforce the hypothesis of a reuse of gold objects from different origins. PGM occur in the Eastern Desert, nearby the Theban workshops, either hosted in chromite-rich rocks or associated with sulfides [56]; the sulfides are commonly palladium bismuthotellurides. They occur with a few Ru-Os-Ir alloys and electrum in some deposits [57], and with electrum and Au tellurides in other deposits [58]. The main chromite PGM deposits are concentrated in the central and southern parts of the Eastern Desert and northeast Sudan, and they contain PGM alloys richer in Os and Ir than in Ru: mainly Os-Ir alloys, some Os-rich laurite, and a few Ru-Os-Ir alloys [59].

The diagram in Fig. 8 contains data published for grains from several Eastern Desert deposits [56,59] using the Slansky's ternary diagram [60] that represents the Pt+(Fe), Os+(Ru), Ir+(Rh) system. The fact that Pd is nearly absent from the composition of the PGE inclusions analysed in blue scarab bezel E3297, signet ring E7725, and armband E7168 justifies this choice. The PGE inclusions analysed in this work and those published for the gold penannular earrings from Deir el-Medina [26] were added to the diagram. The earrings and the objects analysed in this work match together and seem chemically close to the PGM from the south Eastern Desert deposits, nearby Aswan. Although these deposits are situated close to Thebes, and thus one might be tempted to suggest the use of the PGE composition as an indicator of provenance or chronology – this was done for the goldwork from the Filippovka burial in the Southern Urals [61,62] – it has been suggested that PGE inclusions should not be used for Egyptian gold provenancing [48]. The few data published on the composition of PGE inclusions in Egyptian gold objects does not allow further discussion.

4. Conclusions

The analysis of the jewellery inscribed with the names of Queen Ahhotep and King Ahmose I confirmed the use of regular workshop practices in Egypt during the 2nd IP, such as the use of a large variety of gold colours, the forming by casting, hammering and rolling, and the mounting using hard-soldering processes. Hard-solder alloys were obtained by adding copper to the base-alloys. The alloys were made using alluvial gold and contain low amounts of copper and quite variable amounts of silver. The finished objects contain in general visible PGE inclusions that differ in number, except Ahhotep's amulets that are made from very high quality alloys.

The blue scarab set in a gold tray is the bezel of a swivel ring and, like armband E7168, has in addition to marks of intense use-wear, the crescents in the hieroglyphic sign of the moon in a writing in use before the modification observed under Ahmose I. This suggests that both objects were worn in day-life and that they are older than the signet ring and the amulets bearing the name of Ahhotep.

The alloys employed in the production of the jewellery in the Louvre Museum match the composition of the jewellery from Qurneh and of gold grains from the Eastern Desert mines. When all the 2nd IP items analysed so far are considered, their alloys roughly split into two groups: one containing the yellowish objects made from gold alloys and another containing the whitish ones made from Ag-rich electrum alloys. All the objects showing marks of intense wear-use except the blue scarab bezel are in the second group, suggesting a chronological separation. It is possible to suggest that in the 2nd IP co-occur freshly made items with day-life objects, and new productions made by reuse with or without melting of ancient parts.

Swivel ring bezel bearing the name of Ahhotep and the elements of the armband bearing the name of Ahmose contain PGE inclusions that are Os-Ir-Ru-Pt alloys. No other Egyptian object so far analysed showed inclusions of this type, except three 18th Dynasty penannular earrings from the excavation of the East Cemetery at Deir el-Medina, a village facing Thebes [26]. As the few PGE inclusions published for the Aigina treasure, which contains objects in the Hyksos tradition, are Os-Ir-Ru-Pt alloys [55], this could denote reuse practices in the Theban workshops by (also) recycling objects recovered during the struggles against the Hycsos.

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