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Review

Goldwork in Ancient Egypt: workshop practices at Qurneh in the 2nd Intermediate Period

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ABSTRACT

Described by Petrie as '*the largest group of goldwork that had left Egypt*', the jewellery from the intact burial of an adult and child discovered at Qurneh in 1908 is the most important group of gold objects excavated in Egypt dating from the 2nd Intermediate Period (c. 1800–1550 BC). This unique collection has been studied using several non-invasive analytical techniques (μPIXE, PIGE, XRF, and SEM-EDS), while calculation of the effective penetration depth values allowed the degree of surface enrichment to be assessed. The most recent results in respect of gold-working techniques are discussed and related to published work on the techniques used in Egypt in the same era and the subsequent era. The data showed, the coexistence, in a single grave, of jewellery with different levels of wear and colours of gold. The extensive use of hard soldering by the addition of copper to the gold-based alloys was also revealed. All the objects presented PGE inclusions implying the use of alluvial gold and/or recycling of ancient alloys made with this type of gold.

1. Introduction

The most important group of gold jewellery attributed to the 2nd Intermediate Period (c. 1800–1550 BC) forms part of the burial discovered intact by Sir William Flinders Petrie in 1908 at Qurneh,[1] near Thebes (Petrie, 1909). The burial, which is dated to the 16th Century BC on stylistic grounds as well as by radiocarbon dating (Eremin et al., 2000), was centred on a large anthropoid *rishi*-coffin (Miniaci, 2011), painted dark blue and gilded and containing the mummified remains of a young adult female surrounded by a wide range of grave goods, including a large group of gold jewellery items, see Fig. 1 (Petrie, 1909; Eremin et al., 2000; Tate et al., 2009). Above the foot of the woman's coffin was a simple chest-shaped coffin containing the remains of a young child also buried with several jewellery items (Petrie, 1909; Eremin et al., 2000). The richness of the burial was so exceptional that Petrie, when it was brought back to Britain, described it as '*the largest group of goldwork that had left Egypt*' (Petrie, 1932). The burial is today part of the extensive National Museums' Scotland (NMS) Ancient Egyptian collection and several aspects of the mummies and coffins have been investigated in recent years (Eremin et al., 2000; Manley et al., 2002; Tate et al., 2009; Troalen et al., 2009).

The detailed description of the Qurneh jewellery items can be found in Petrie's excavation report (Petrie, 1909) and also in several subsequent publications (Eremin et al., 2000; Roehrig, 2007; Tate et al., 2009; Troalen et al., 2009). The adult individual wore a necklace made of 1699 gold rings[2] (4.5 mm external diameter) strung together to form four decorative strands,[3] two penannular gold earrings or hair-rings, four gold bangles, an electrum girdle consisting of 26 semi-circular so-called 'wallet beads' (10 mm diameter) spaced by two threads of 6 barrel beads (4 mm length)[4] and an electrum button (the latter today missing). The child wore

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[1] Other possible spellings include Qurna, or Gourna.

[2] Petrie measured and weighed the rings of the 4 strands of the necklace and counted a total of 1653 rings (394; 416; 422; 421) (Petrie, 1909). When the necklace was disassembled for conservation at NMS in 2006 the number counted was 1699 (397, 410, 415, 477) (Tate et al., 2009).

[3] The Qurneh necklace has often been described as the earliest example of *shebiu*-type collar, although this is could be an erroneous description. *Shebiu*-type necklaces are made of large, thick lentoid-beads, tied around the neck (Roehrig, 2007 p. 19).

[4] Petrie noted in his description of the girdle that: '*... the spaces between these ('wallet beads') had two threads of six beads each, and in one case a space of seven beads*' (Petrie, 1909). There is a total of 316 barrel beads, of which 5 have fallen inside two 'wallet beads' and are now only visible by X-Radiography (Troalen et al., 2009).

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Fig. 1. The Qurneh adult jewellery set, © National Museums Scotland.

two ivory bangles, several strings of faience beads around the waist and both ankles, a necklace made of 215 small gold rings (<1.5 mm external diameter) strung together, and two asymmetric rings made of three-and-a-half gold rings soldered together, which have been interpreted as earrings from their location in the burial.

From visual examination the workshop practices seem to be the same for all the objects, with the use of sheets or strips of gold which were then hammered, stamped-died or rolled, sometimes chased, with the different parts joined together. However the jewellery items showed variable levels of wear, indicating different amount of usage. The gold items belonging to the young adult female can be separated into three groups according to their level of wear: the necklace and the two penannular earrings are virtually un-used; the four bangles are slightly used; while the girdle shows very intensive wear. The jewellery items belonging to the child also show marks of wear; these are extensive for the necklace beads and less so for the two earrings.

In the jewellery of the adult the wear-marks indicate that the bangles were certainly worn, presumably during the life-time of the woman, in contrast to the girdle, which seems to be a much older piece. Interestingly, on the girdle beads the wear-marks show that the present construction is the original one, as we observed some deformation of the holes in the wallet beads where they sit against the barrel beads (S.I. 1). In the case of the child, the earrings do not show much signs of wear prior to deposit, but these can hardly have belonged to the young child,[5] while the necklace is clearly a re-use of gold beads from different gold items. It is interesting to note that several of the beads exhibit a slight border, suggesting that their form was adjusted slightly to match an adjacent round stone or paste/glass bead, such as a spacer (S.I. 1). Petrie's report only records numerous faience beads around the ankles and waist of the child rather than at the neck (Petrie, 1909), but the adjustments might relate to an earlier use of the beads.

This paper presents a comprehensive study of all the gold jewellery items and the coffin gilding from the Qurneh burial and discusses the diversity in the apparent colours of the gold items, the possible origin of the gold and the joining techniques. The results obtained are discussed in respect of gold-working techniques used in Egypt, and compared to the few published jewellery items that can be attributed to the 2nd Intermediate Period (Miniaci et al., 2013) and the subsequent era (Gale and Stos-Gale, 1981; Schorsch, 2001; Lilyquist, 2003). As part of the study the limitation of the non-invasive analysis of ancient gold is discussed, following calculation of the effective penetration depth values of the different techniques; this confirms the feasibility of comparing the analysis of objects from other collections by using different non-invasive X-ray based techniques.

[5] Closer examination revealed that the child's earrings do not match as a pair. Both earrings were found to fasten together, as would be expected from a clasp for a necklace. It could be that this clasp was recycled as earrings, and deposited next to the ears of the child.

2. Analytical techniques

Several non-invasive techniques were used in order to gain information on the morphology of the objects and their elemental composition with no surface cleaning or polishing. These techniques allowed high spatial resolution with elemental mapping for the study of the areas around the joints, and were undertaken in air allowing the analysis of the larger and more complex-shaped objects. Measurements were also made using portable equipment to analyse the original gilding on the *rishi* coffin.

The objects were examined visually under an Olympus SZX12 stereo-microscope equipped with an Olympus DP70 digital camera and by X-radiography using a 320 kV Pantak system at NMS. Elemental composition of the alloys was determined using: (1) an Oxford Instruments ED 2000 air-path X-ray fluorescence spectrometer (XRF), with Rh target X-ray tube collimated to a point of about 2 × 1.5 mm, coupled to a Si(Li) detector; (2) μPIXE (Particle Induced X-ray Emission) and PIGE (Particle Induced γ-ray Emission) with a proton beam of 3 MeV, with an analytical spot of 50 μm, Si(Li) and Ge(Li) detectors at the AGLAE accelerator of the C2RMF; (3) a Niton XL3t portable XRF system with a 'GOLDD' detector, set to "Precious Metals" mode; (4) CamScan 2500 SEM with a Noran Vantage Energy Dispersive X-ray analysis (EDS) system, at the analytical working distance of 35.0 mm, 300 s measurement at electron beam energies of 20 and 25 kV. A range of Au/Ag/Cu standards were used for calibration in all experiments and the inter-instrument compatibility can be found in a previous publication (Troalen et al., 2009).

2.1. Surface analysis of ancient gold

The main issue with non-invasive surface analysis of ancient gold is the phenomenon of surface enrichment, due to the depletion of copper and silver through either deliberate surface treatment or from corrosion during burial (Scott, 1983; Rapson, 1996). It is accepted however that for a binary gold–silver alloy above 64.6 wt% gold/35.4 wt% silver, corrosion is limited (Scott, 1983). Usually this corrosion layer is in the range of a few μm and some studies have shown that chemical-induced surface depletion is usually less than 10 μm (Grimwade, 1999). Such surface enrichment can particularly affect the composition determined by analytical methods based on X-ray fluorescence spectra, and in some cases the difference between surface and sub-surface composition can reach 8–10 wt% gold by SEM-EDS analysis (Mongiatti et al., 2010).

Depth profiles of gold (Au), silver (Ag) and copper (Cu) depend on the energy and type of the ionising source, the composition of the alloys being analysed, and the spectral lines used for analysis. In order to compare the measurements obtained by PIGE, μPIXE, XRF and EDS analysis, we calculated the density ρ (g cm^{-3}) and mass absorption coefficients μ expressed in cm^2 g^{-1} for four Au/Ag/Cu alloys close in composition to those of the Qurneh items (Table 1). The effective penetration depth values, corresponding to the thickness in μm from which 95% of the detected X-rays are produced, were calculated for Au, Ag and Cu at these experimental conditions (Table 1). The penetration for PIGE depends on the energy of the incident protons (28 μm for 3 MeV), and since the emitted gamma-rays are hardly attenuated by the matrix the

Table 1
Calculated density ρ (g cm^{-3}) and mass absorption coefficient μ expressed in cm^2 g^{-1} for Au/Ag/Cu alloys with different compositions (wt%). Density values were calculated with CASINO 2.42 module and compared to theoretical values (Kraut and Stern, 2000). The given µ values were calculated using the GUCSA module of GUPIX software (Maxwell et al., 1989). The effective penetration depth values represent the thickness in µm from which 95% of the detected X-rays are produced for XRF, µPIXE and SEM-EDS analysis. For PIGE analysis, the proton range in the different type of alloys was calculated in µm. Exciting radiation: XRF – Rh tube, 150 s: 35 kV, 1000 µA, 0.125 mm Rh filter and then 300 s: 50 kV, 1000 µA, 0.5 mm Cu filter; µPIXE and PIGE – 3 MeV protons with 75 µm Cu filter for low energy Si(Li) detector; SEM-EDS - 20 kV accelerating voltage (Trouslard and Tirira on Pyrrole software; Maxwell et al., 1989; Drouin et al., 2007).

					Proton range	Effective penetration depth								
		Mass absorption coefficient µ (cm^2 g^{-1})			PIGE PYRROLE (µm)	µPIXE GUYLS from GUPIX (µm)			XRF GUCSA from GUPIX (µm)			SEM-EDS CASINO 2.42 (µm)		
Au/Ag/Cu (wt%)	Density (g cm^{-3})	Au L_a	Ag K_a	Cu K_a	Au/Ag/Cu	Au L_a	Ag K_a	Cu K_a	Au L_a	Ag K_a	Cu K_a	Au L_a	Ag L_a	Cu K_a
95.8/4/0.2	18.63	127	58	204	28.00	7.40	11.09	5.07	12.68	27.76	7.89	0.50	0.50	0.50
86/12/2	17.17	129	54	202	28.50	7.86	12.11	5.50	13.54	32.36	8.65	0.45	0.45	0.45
68/30/2	15.14	130	46	203	29.10	8.77	13.98	6.15	15.24	43.08	9.76	0.60	0.60	0.50
50/48/2	13.54	130	37	205	29.60	9.64	15.82	6.77	17.04	59.88	10.81	0.60	0.60	0.60

Table 2
Comparing the compositional surface analysis of different types of alloys occurring in the Qurneh burial using XRF, µPIXE, PIGE and SEM-EDS (mean values calculated from 5 to 6 measurements). PIGE were calculated using the γ-ray lines at 279, 309 and 152 keV for the measurement of gold, silver and copper, respectively, with normalisation of the dose to the Standard 6917 from CLAL-France: 75Au-17Ag-8Cu (Guerra and Calligaro, 2004).

	Composition in wt%											
	PIGE			XRF			µPIXE			SEM-EDS[a]		
Qurneh *[NMS number]*	Au 279	Ag 309	Cu 152	Au La	Ag Ka	Cu Ka	Au La	Ag Ka	Cu Ka	Au La	Ag La	Cu Ka
Adult's penannular earring *[A.1909.527.18]*	94.0	5.6	0.4	95.4	4.3	0.3	95.6	4.0	0.4	97	3	<0.2
Adult's bangle *[A.1911.527.16]*	88.1	11.6	0.3	88.0	11.9	0.1	88.1	11.6	0.3	Not analysed		
Adult's necklace, Ring 3 *[A.1909.527.19]*	86.1	12.3	1.6	86.3	12.1	1.6	88.0	10.0	2.0	92/86	7/12	1/2
Child's earring *[A.1909.527.4]*	83.5	14.8	1.7	81.1	15.8	3.1	84.6	13.6	2.9	82–89	8–14	3–4
Child's necklace, Ring bead A *[A.1909.527.11]*	69.9	27.8	2.3	71.2	26.4	2.4	71.3	26.8	2.0	75/72	25/26	1/3
Child's necklace, Ring bead B *[A.1909.527.11]*	67.8	29.0	3.2	68.9	29.1	2.0	65.9	32.1	2.0	72/71	27/27	1/2
Adult's girdle, wallet bead 19 *[A.1909.527.17]*	Not analysed			43.9	52.6	3.5	Not analysed			53	44	3

[a] SEM-EDS values correspond to the mean compositions obtained for Surface/Bulk; except for the child's earring, where the EDS values correspond to the range of composition measured and the adult girdle and earrings, where only surface analysis could be undertaken.

quantification of the major elements is less sensitive to the possible heterogeneity of the surface (Guerra and Calligaro, 2004); µPIXE provides a narrower range of depth analysis (10–15 µm for silver), but with comparable depth values for all the elements; in comparison XRF provides variable depths of analysis with the greatest values for the silver K_a lines. Finally, EDS analysis reflects the composition of the first 0.5 µm and is thus very sensitive to the heterogeneity of the surface.

All the Qurneh items were investigated using a combination of these techniques and the polished sections of one of the rings from the adult's necklace and two silver-rich beads from the child's necklace allowed the composition of the surface and the core to be directly compared. As expected, differences were found (Table 2), but the compositions determined from the polished core sections of the metal were equivalent to those obtained by PIGE and XRF analysis. The compositions also agreed well with those obtained by µPIXE (see Table 2). Thus while there may be some surface change from burial or from any deliberate surface treatment, this only affects a very thin layer; and in the absence of any surface preparation this only distorts measurements made using the shallow SEM-EDS analysis.

2.2. The analysis of the gold alloys

2.2.1. Gold alloys from Qurneh

Fig. 2 presents the elemental composition of all the jewellery items from the Qurneh burial. The composition of the rings that constitute the adult's necklace and the tubes of the adult's earrings showed that each group is remarkably uniform. The necklace is made of an alloy containing, on average, 86 wt% Au, 12 wt% Ag and 2 wt% Cu while the earrings are richer in gold with a composition of 95.4 wt% Au, 4.3 wt% Ag and 0.3 wt% Cu. The four bangles are extremely homogeneous and made with an alloy close to the necklace, but with almost no copper (11.6–12.5 wt% Ag and 0.1 wt% Cu). Their great homogeneity in weight was noted by Petrie in his report; with the four bangles and the necklace following the same unit system[6] (Petrie, 1909). Finally, the child's earrings are rather heterogeneous with silver contents varying from 13.5 wt% to 15.3 wt% and copper contents from 1.7 wt% to 3.8 wt%. This variety of the alloys could be explained by the low quality soldering of the rings giving rise to large melted regions, although it must also be noted that visual inspection shows that these pieces have a dirty surface.

The rest of the objects are made of electrum alloys with a silver content higher than 20 wt%. The adult's girdle is made of two types of whitish coloured beads, the wallet beads being made of a single alloy with an average of 52.5 wt% Ag and 3.7 wt% Cu, while the spacer barrel beads are heterogeneous in composition, ranging from 51 to 55 wt% Ag and 2.8–7.4 wt% Cu. The child's necklace is of

[6] Petrie suggested in his report that several of the adult jewellery items were following the 80-grain unit system: each bangle corresponded to 4 of the 80-grain unit; the necklace was 20 of the 80-grain unit while each of the attachment weighted half a unit on each side (Petrie, 1909). The adult earrings weighted 133.8 and 138.8 grains (Petrie, 1909), corresponding together to almost 3 and a half 80-grain unit.

poorer quality than the other pieces and the bead rings were observed to be visually heterogeneous in shape and in colour with silvery, reddish and yellowish alloys. The copper content of these rings varies between 0.6 and 2.6 wt% while their silver content varies between 16.6 wt% and 32.1 wt%. Finally, the analysis of the gold foil on the surface of the coffin showed an average composition of 17 wt% Ag and 1.5 wt% Cu on the ancient parts. This composition with a high level of silver is not unexpected and corresponds to the range of alloys characterised by Hatchfield and Newman in their investigation of gold foils on Egyptian wooden artefacts from the Middle to New Kingdom periods (Hatchfield and Newman, 1991).

2.2.2. Gold polychromy in the 2nd Intermediate Period

The study published by Schorsch on 18th Dynasty artefacts from the time of Tutankhamun identified a range of techniques used to achieve polychromy: the use of different alloys containing variable amounts of silver and copper, and the application of surface treatments to obtain a red-coloured aspect (Schorsch, 2001). The variety of alloys found in the jewellery group from Qurneh, ranging from very pure gold to silver-rich electrum, suggests the use of polychromy in the 2nd Intermediate Period. Figs. 2 and 3 compare the compositions obtained for the Qurneh items with compositions published for four jewellery items from the British Museum attributed to the 2nd Intermediate Period (Miniaci et al., 2013) and the large set of jewellery items from the 18th Dynasty burial of the foreign wives of Tuthmosis III analysed at the Metropolitan Museum (Lilyquist, 2003). In addition to these, the nine 18th Dynasty aurian silver objects from the Ashmolean Museum and one from the 2nd Intermediate Period analysed by Gale and Stos-Gale (1981) are also considered.

The Qurneh items exhibit a range of colour that goes from yellow to whitish and it is notable that, with the exception of the electrum objects, they are richer in gold content than the 18th Dynasty objects investigated at the Metropolitan Museum (Lilyquist, 2003). Nevertheless, similar high gold content (80–89 wt% from XRF analysis) was characterised in the heart-scarab belonging to King Sobekemsaf, the finger ring bearing the prenomen of King Nubkheperre Intef and the two spacer-bars from a bracelet belonging to his wife Queen Sobekemsaf analysed at the British Museum (Miniaci et al., 2013). The Qurneh girdle falls into the region described as whitish, close to the pale greenish-yellow colour of the large group of aurian silver objects characterised by Gale and Stos-Gale (1981). Finally, only the rings from the child's necklace have similar composition to the majority of the objects analysed at the Metropolitan Museum (Lilyquist, 2003).

It seems that at the end of the 2nd Intermediate Period a range of coloured gold alloys close to the polychromy expected in the 18th Dynasty was already being used (Schorsch, 2001), although for the Qurneh burial, each object exhibits a single colour without the use of surface treatment. It is reasonable to deduce from Fig. 2 that different gold deposits with different Ag/Au ratios were exploited and that addition of different quantities of copper to the gold alloys was current practice. The copper content is consistent with what would be expected for alluvial gold, below 2 wt% (Ogden, 2000; Klemm and Klemm, 2013), with the exception of the girdle, where the wallet beads contain up to 3.7 wt% copper, and the barrel beads have a copper-content ranging from 2.8 to 7.4 wt%. Similarly high amounts of copper were found in aurian silver objects from the Ashmolean Museum, ranging from 0.2 to 26 wt% (Gale and Stos-Gale, 1981). The addition of copper to debase gold is known to be common practice from the 18th Dynasty onwards (Lucas and Harris, 1962), but the amount of copper in the girdle indicates that this practice was also in use in the 2nd Intermediate Period, and according to the results published by Gale and Stos-Gale for aurian silver even in the Old and Middle Kingdom periods (Gale and Stos-Gale, 1981). Finally, the high gold content of several items from the Qurneh burial demonstrates that the quality of gold alloys alone cannot be used as a criterion of authenticity.

2.2.3. PGE inclusions and alluvial gold

Platinum Group Element (PGE) inclusions were observed in all the jewellery from Qurneh, including the adult earrings made of high purity gold. The presence of these inclusions in Egyptian gold

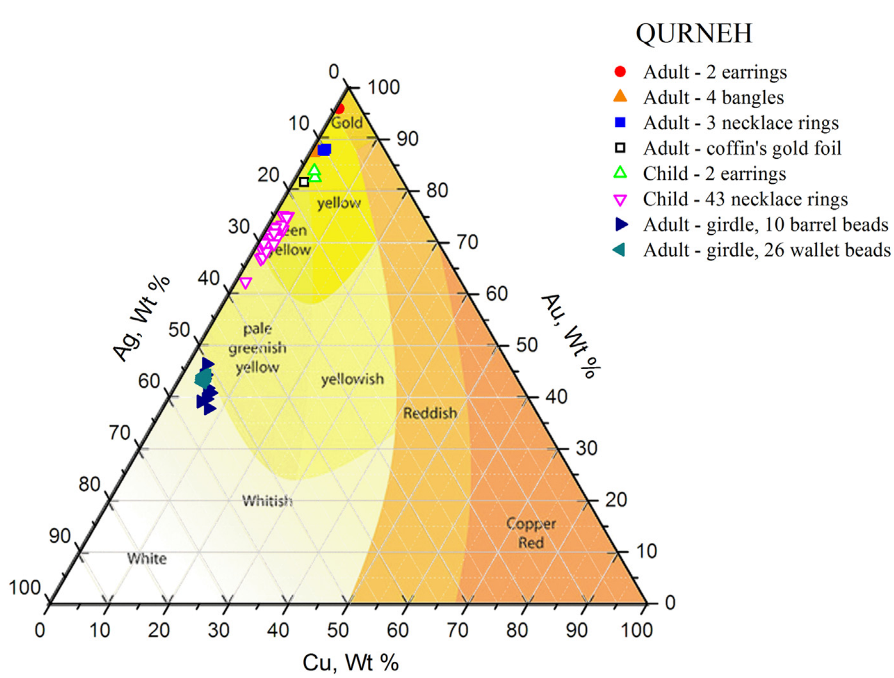

Fig. 2. Ternary copper, gold, silver diagram in wt% of the Qurneh jewellery, with the colour of gold alloy adapted from McDonald and Sistare, 1978 (McDonald and Sistare, 1978).

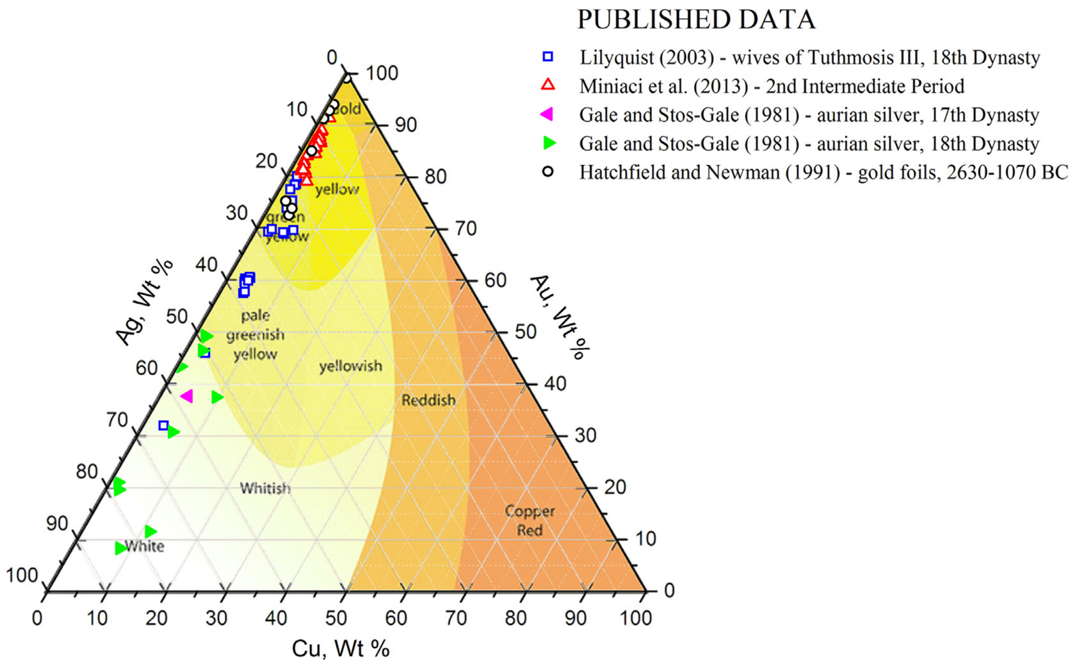

Fig. 3. Ternary copper, gold, silver diagram in wt% of published Egyptian gold and electrum jewelleries dated from the 2nd Intermediate Period, 17th and 18th Dynasties (Gale and Stos-Gale, 1981; Hatchfield and Newman, 1991; Lilyquist, 2003; Miniaci et al. 2013) with the colour of gold alloy adapted from McDonald and Sistare, 1978 (McDonald and Sistare, 1978).

jewellery was first reported by Petrie in 1895 in his report on Naqada and Ballas (Petrie and Quibell, 1895). Their presence is characteristic of the use of alluvial gold deposits, and the classification of PGE elements depends on their composition as defined by Harris and Cabri (Ogden, 1976; Harris and Cabri, 1991). Meeks and Tite published the composition of forty-nine inclusions in twelve Egyptian jewellery items dating from 3000 BC to 300 AD (Meeks and Tite, 1980), and furthermore two inclusions were analysed by Miniaci et al. in King Nubkheperre's finger ring and King Sobekemsaf's heart scarab (Miniaci et al., 2013). In their study, Meeks and Tite stressed the heterogeneity of these inclusions, sometimes within the same object, but suggested the use of ruthenium concentration to separate the gold sources in Egypt before and after the 12th Dynasty (25–40 wt% to less than 25 wt%), reflecting the

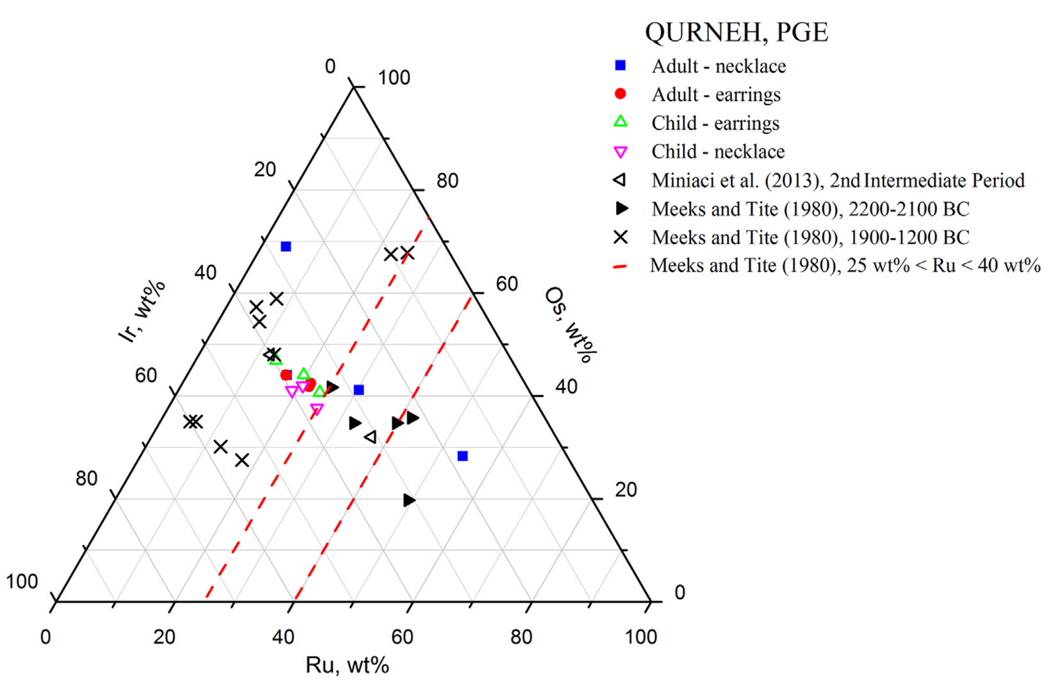

Fig. 4. Ternary ruthenium, osmium, iridium diagram showing the average composition of the PGE inclusions characterised by SEM-EDS analysis in the Qurneh jewellery items, expressed in wt% [Osmiridium: Os < 38%, Ru < 5%; Iridosmine: Os > 55%, Ru < 5%; Rutheniridosmine: Ru > 5%, Ru + Os > 50%].(Ogden, 1976) These results should be regarded as semi-quantitative due to the geometry of the inclusions and the lack of comparative analytical standards. The red lines indicate the ruthenium concentration defined by Meeks and Tite (Meeks and Tite, 1980): 25–40 wt%.

change from the exploitation of gold sources in the Eastern Desert to those in the Nile Region north of the eighteenth parallel (Ogden, 1976; Meeks and Tite, 1980).

Thirteen PGE inclusions were analysed in the adult's and child's earrings and necklaces by EDS analysis. From these results, all the inclusions were found to be Rutheniridosmine with an average composition of 22 wt% ruthenium, 35 wt% iridium and 43 wt% osmium (Fig. 4). Most of the inclusions contain less than 25 wt% ruthenium, although several inclusions from the adult's necklace exhibit up to 55 wt% ruthenium and in another case 69 wt% osmium. Even accepting that these compositions are quite variable, we note that the level of ruthenium in most of the PGE inclusions is higher than that found in the objects attributed to the 12th Dynasty onwards investigated by Meeks and Tite. These results highlight the need for analysis of a larger number of PGE inclusions in Ancient Egyptian artefacts, but would suggest the use of alluvial gold deposits close to the Eastern Desert or Nubia. Furthermore the Qurneh burial shows some links with Nubia (Eremin et al., 2000; Manley et al., 2002) and gold mines from Nubia exhibit a lower level of silver than the mines from the Eastern Desert (Klemm and Klemm, 2013). Nevertheless, the presence of these inclusions in all objects from the 2nd Intermediate Period analysed in this study and by Miniaci et al. proves that either alluvial gold deposits were exploited during this period or that re-melting of previously used alluvial gold was a current practice. Finally, the PGE inclusions analysed in the adult's earrings confirm the exploitation of gold-rich alluvial deposits. In principle a similarly high purity gold alloy could have been obtained using a cupellation refining process, but there is no recorded evidence of parting (Ramage and Craddock, 2000) at that time in Egypt.

3. Joining technique

Several techniques can be used to join metal alloys: welding, soft-soldering, hard-soldering or brazing. Maryon defines the soldering process as the use of '*any metal or alloy whose melting point is lower than that of the metal or alloy to be soldered, which may be run between the parts to be joined to fasten them together*' (Maryon, 1949). The predominant use of soldering technique instead of mechanical joints in gold jewellery was reported by Ogden in his

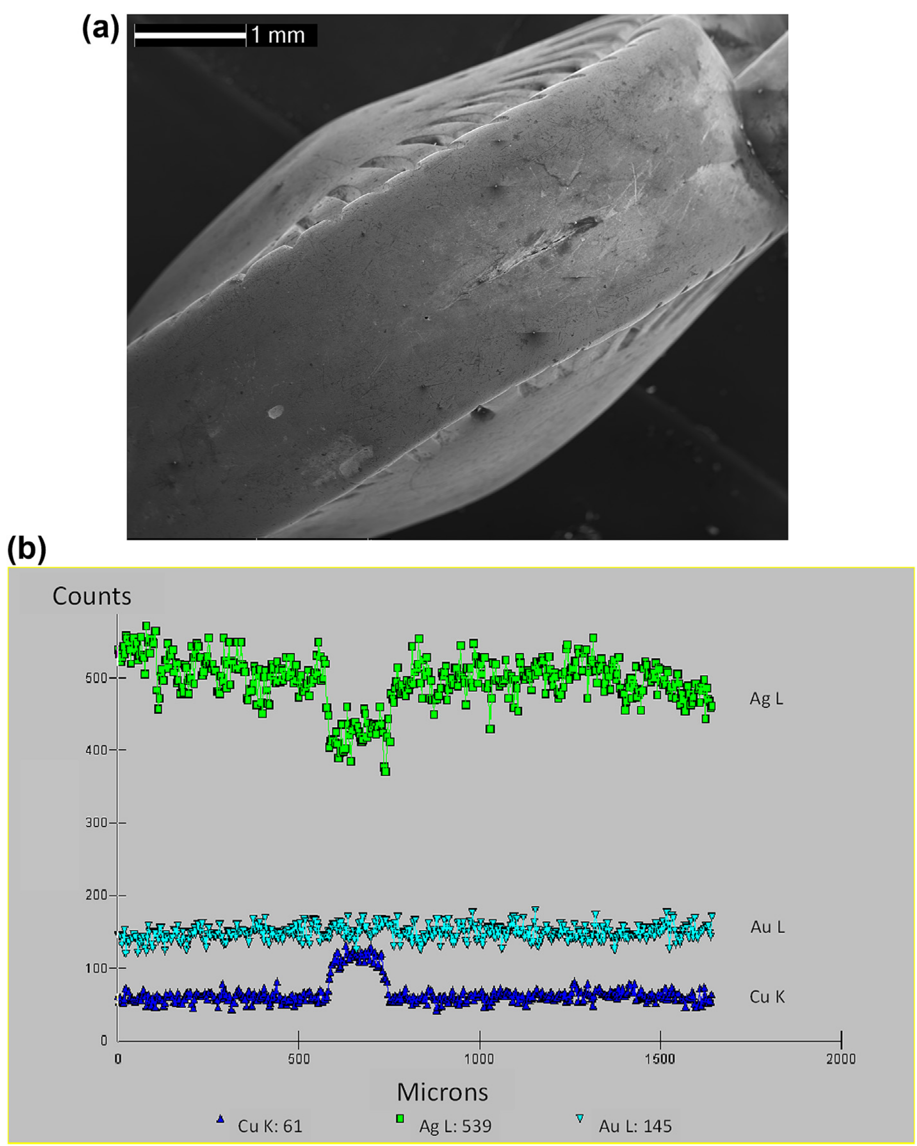

Fig. 5. (a) SEM-BSC micrograph of a single ring from a wallet bead from the Qurneh adult girdle, scale bar is 1 mm, (b) EDS line-scan illustrating the slight change in composition at the hard-soldered joint.

review of Ancient Egyptian metalworking techniques, although it was also suggested that colloidal hard-soldering or diffusion bonding might have been used for more delicate soldering work, but without specifying as from which period onwards (Ogden, 2000). The use of gold-based brazing alloys in Ancient Egypt is also supported through archaeological evidence and it is reported that some form of bellows were used in Egypt by about 2500 BC (Wolters, 1975). However, little scientific analysis is available for Ancient Egyptian gold jewellery and the use of hard-solder made by the addition of copper and/or silver to a base gold alloy was so far only considered in a few artefacts, including a granulated gold cylinder-pendant from el-Harāgeh (Ogden, 1992) and demonstrated for some Middle Kingdom gold beads from the burial of Wah (Schorsch, 1995). However, when considering the analysis published on the jewellery items from the 18th Dynasty burial of the foreign wives of Tuthmosis III, it is observed that an increase of copper was also found in several of the items in the regions where soldering was expected (Lilyquist, 2003 – Appendix 2).

With the exception of the child's necklace and the barrel beads from the adult's girdle, all the pieces from the Qurneh jewellery set were hard-soldered. The soldering seams are more or less visible in each element either because of its level of wear, or because of the craft worker's skill (or both), the latter being of such variability that it suggests production by different goldsmiths. The most visible joints were found in the earrings from both bodies. In the adult's earrings, the joints are thick but perfectly crafted (S.I. 2), while for the child's earrings the joints indicate a lack of temperature control as the parts that were joined show signs of melting (S.I. 3). Petrie noted in his report that the child's earrings '*had been over-heated while on a mandril in the furnace for soldering; the solder had stuck them together, and they parted and began to drop away, being half melted*' (Petrie, 1909). The joints in the bangles are very thin and [near] invisible to the naked eye, but could be found by X-radiography with a 400 kV tube, showing that they had been formed from a solid tube, the joints cut at an angle and soldered (S.I. 4).

The least visible joints occur in the adult's necklace and girdle but for different reasons. The very high level of abrasion of the girdle due to its use has removed almost all of the joint seams so that hard-soldering could only be detected by mapping Cu(K_a), Ag(L_a) and Au(L_a) with SEM-EDS in the assumed joint region of one of the wallet beads (Fig. 5a, b). For the adult's necklace, which showed no particular signs of wear, only the clasp clearly shows signs of hard-soldering. However, a clear joint made with an alloy of higher copper content could be seen when one of the small rings, removed during conservation treatment, was polished and etched with an *aqua regia* mixture (Fig. 6, Tate et al., 2009). The composition of the different solders was estimated by analysing the cross-section with SEM-EDS or in other pieces by mapping the region around the joints using μPIXE or XRF systems. The solders stand out due to their copper contents, which corresponds to an addition of copper in order to lower the melting point and allow the parts to be joined (Maryon, 1949). For all the Qurneh objects, the solders and the parts to be soldered contain very similar Ag/Au ratios, which suggests that a similar soldering technique was used for all the objects, with the use of the basic gold/electrum alloys mixed with additional copper (Fig. 7).

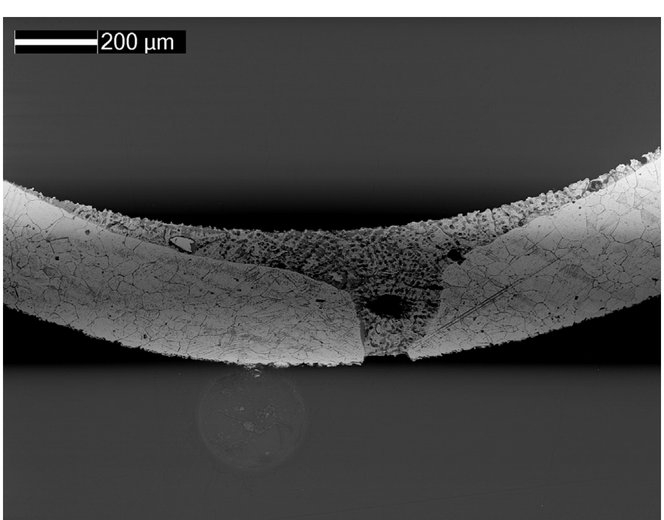

Fig. 6. SEM-BSC micrograph of a single ring from the Qurneh adult necklace, polished and etched with *aqua regia* (nitric acid and hydrochloric acid, 1:3 v/v), exhibiting the presence of a hard-solder, scale bar is 200 μm (from Tate et al., 2009).

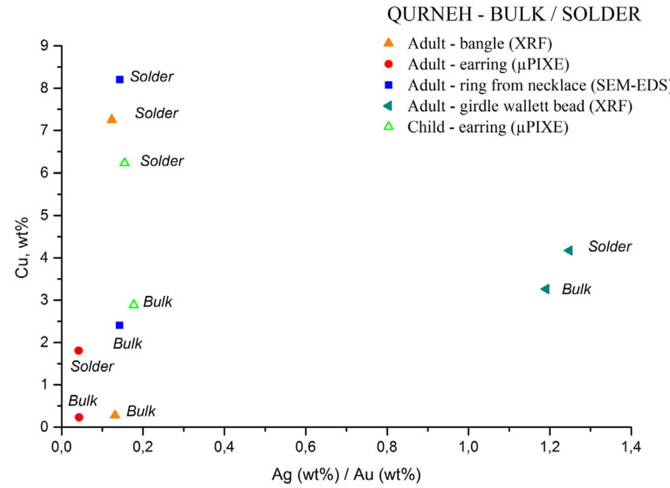

Fig. 7. Comparison of the average composition of the Qurneh jewellery items with their solder composition (values exhibiting the highest level of copper), by expressing the content of copper in wt% as a function of the ratios of silver/gold both in wt%.

4. Conclusions

The study of the gold jewellery from Qurneh has provided an initial overview of the workshop practices at the end of the 2nd Intermediate Period in Egypt, revealing technologically high goldsmithing skills across a large variety of gold items for two mummified individuals.

New and old items were deposited together in the burial of the young woman, while for the child, only objects made by recycling without melting were used. The burial practices seem different for both individuals, who were certainly of high-ranking, but for both the presence of gold objects seems to be of fundamental importance. These observations support the hypothesis that some jewellery items correspond to a re-use, in particular the adult's electrum girdle and the child's necklace, neither of which follow the unit system observed in the other adult jewellery items. This suggests the continual use of 'family' jewellery such as the girdle, handed down perhaps as heirlooms. It could be that such practices resulted, at least in some regions, from the absence of the practice of goldsmithing or else from a lack of raw materials leading to recycling of older pieces; alternatively (or additionally), the older objects may well have been treasured as manifestations of material links with the ancestors.

The composition of the alloys corresponds to what is expected for secondary gold coming from different deposits and containing naturally different silver contents: the goldsmiths combined a large variety of polychrome gold alloys, ranging from high-carat gold to silver-rich electrum with the addition of different quantities of copper. However, the composition of the adult's earrings (items which show very little evidence of wear) is particularly notable, and could correspond to a particular deposit, bearing in mind that the burial shows definite links with Nubia. All the jewellery items were found to contain several PGE inclusions, indicating the systematic use of alluvial gold instead of a more intensive use of primary gold. This suggests that alluvial deposits were exploited during the 2nd Intermediate Period or else that re-melting and re-use of earlier alluvial gold was a current practice.

The study of the joints revealed the systematic use of hard-soldering techniques with the use of basic gold/electrum alloys mixed with additional copper to lower the melting point. This confirms a certain unity for the workshop practices in Egypt. All the items are soldered except the female's girdle spacers and the beads that constitute the child's necklace, which by their form could at least partially be considered as spacers deriving from other items. This joining technique was nevertheless practiced at very different skill levels, from invisible small joints for each ring in the adult's necklace, to an excess of solder with large melted areas in the fastening of the adult's necklace and the child's earrings, suggesting the work of a less-skilled craftsman but not a divide between the two burials. Furthermore, the work of different goldsmiths is indicated in the same item, specifically where two types of chisels and characteristic differences in craftsmanship were visible in the wallet beads of the girdle (S.I. 5).

Finally, with regard to the composition of the alloys, it was found that while there may be some surface changes, these are only a very thin layer and hence are observed only by the shallow SEM-EDS analysis without surface preparation. The compositions determined from the polished core sections of the metal were equivalent to those obtained by both μPIXE/PIGE and XRF analysis.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2014.07.010.

References

Drouin, D., Real Couture, A., Joly, D., Tastet, X., Aimez, V., Gauvin, R., 2007. CASINO V2.42-A fast and easy-to-use modelling tool for scanning electron microscopy and microanalysis users. Scanning 29, 92–101.

Eremin, K., Goring, E., Manley, W.P., Cartwright, C., 2000. A 17th dynasty Egyptian queen in Edinburgh? KMT 11, 32–40.

Gale, N.H., Stos-Gale, Z.A., 1981. Ancient Egyptian silver. J. Egypt. Archaeol. 67, 103–115. http://dx.doi.org/10.2307/3856605.

Guerra, M.F., Calligaro, T., 2004. Gold traces to trace gold. J. Archaeol. Sci. 31, 1199–1208.

Grimwade, M., 1999. The surface enrichment of carat gold alloys – depletion gilding. Gold Technol. 26, 16–23.

Harris, D.C., Cabri, L.J., 1991. Nomenclature of platinum group element alloys: review and revision. Can. Mineral. 29, 231–237.

Hatchfield, P., Newman, R., 1991. Ancient Egyptian gilding methods. In: Bigelow, D., Cornu, E., Landrey, G., van Home, C. (Eds.), Gilded Wood Conservation and History. Sound View Press, Madison CT, pp. 291–299.

Klemm, R., Klemm, D., 2013. Gold and gold mining in Ancient Egypt and Nubia. In: Herrmann, B., Wagner, G.A. (Eds.), Geoarchaeology of the Ancient Gold Mining Sites in the Egyptian and Sudanese Eastern Deserts, Series in Natural Science in Archaeology. Springer-Verlag, Berlin-Heidelberg.

Kraut, J.C., Stern, W.B., 2000. The density of gold-silver-copper alloys and its calculation from the chemical composition. Gold Bull. 33, 52–55.

Lilyquist, C., 2003. The Tomb of the Three Foreign Wives of Tuthmosis III. The Metropolitan Museum of Art, New York.

Lucas, A., Harris, J.R., 1962. Ancient Egyptian Materials and Industries. Edward Arnold Publishers Ltd.

Manley, W.P., Eremin, K., Shortland, A., Wilkinson, C., 2002. The facial reconstruction of an Ancient Egyptian Queen. J. Audiov. Media Med. 25, 155–159. http://dx.doi.org/10.1080/0140511021000051144.

Maryon, H., 1949. Metal working in the Ancient World. Am. J. Archaeol. 53, 93–125.

Maxwell, J.A., Campbell, J.L., Teesdale, W.J., 1989. The Guelph PIXE software. Nucl. Instrum. Methods.Phys. Res. B 43, 218–230.

McDonald, A.S., Sistare, G.H., 1978. Part I - coloured gold alloys. Gold Bull. 11, 128–131.

Meeks, N.D., Tite, M.S., 1980. The analysis of platinum-group element inclusions in gold antiquities. J. Archaeol. Sci. 7, 267–275.

Miniaci, G., 2011. Rishi Coffins and the Funerary Culture of Second Intermediate Period Egypt. In: Egyptology, vol. 17. Golden House Publications, London.

Miniaci, G., La Niece, S., Guerra, M.F., Hacke, M., 2013. Analytical Study of the First Royal Egyptian Heart-scarab, Attributed to a Seventeenth Dynasty King, Sobekemsaf. In: British Museum Technical Research Bulletin 7. Archetype, London, ISBN 9781909492073, pp. 53–60.

Mongiatti, A., Meeks, N., Simpson, St J., 2010. A Gold Four-horse Model Chariot from the Oxus Treasure: a Fine Illustration of Achaemenid Goldwork. In: British Museum Technical Research Bulletin 4. Archetype, London, ISBN 9781904982555, pp. 27–38.

Ogden, J., 1976. The so-called “platinum” inclusions in Egyptian goldwork. J. Egypt. Archaeol. 62, 138–144. http://dx.doi.org/10.2307/3856354.

Ogden, J., 1992. Interpreting the Past: Ancient Jewellery. University of California Press/British Museum, Berkeley and Los Angeles, pp. 51–52.

Ogden, J., 2000. Metals. In: Nicholson, P., Shaw, I. (Eds.), Ancient Egyptian Materials and Technology. Cambridge University Press, Cambridge, pp. 148–175.

Petrie, W.M.F., Quibell, J.E., 1895. Naqada and Ballas. B. Quaritch, London.

Petrie, W.M.F., 1909. Qurneh. British School of Archaeology in Egypt and EgyptIan Research Account. Fifteenth Year. B. Quaritch, London.

Petrie, W.M.F., 1932. Seventy Years in Archaeology. H. Holt & Co., London.

Ramage, A., Craddock, P., 2000. King Croesus's Gold. Excavations at Sardis and the History of Gold Refining. In: Archaeological Exploration of Sardis, Monograph 11. British Museum Press with Harvard University Press, London, Cambridge MA.

Rapson, W.S., 1996. Tarnish resistance, corrosion and stress: corrosion cracking of gold alloys. Gold Bull. 29, 61–69.

Roehrig, C.H. (Ed.), 2007. Hatshepsut: from Queen to Pharaoh. The Metropolitan Museum of Art - Yale University Press, New Haven and London. http://www.metmuseum.org/research/metpublications/Hatshepsut_From_Queen_to_Pharaoh.

Schorsch, D., 1995. The gold and silver necklaces of Wah: a technical study of an unusual metallurgical joining method. In: Brown, C., Macalister, F., Wright, M. (Eds.), Conservation in Ancient Egyptian Collections. Archetype Publications, London, pp. 127–135.

Schorsch, D., 2001. Precious-metal polychromy in Egypt in the time of Tutankhamun. J. Egypt. Archaeol. 87, 55–71. http://dx.doi.org/10.2307/3822371.

Scott, D.A., 1983. The deterioration of gold alloys and some aspects of their conservation. Stud. Conserv. 28, 194–203.

Tate, J., Eremin, K., Troalen, L.G., Guerra, M.F., Goring, E., Manley, W.P., 2009. The 17th dynasty gold necklace from Qurneh, Egypt. ArchéoSciences 33, 121–128. ISSN 9782753511811.

Troalen, L.G., Guerra, M.F., Tate, J., Manley, W.P., 2009. Technological study of gold jewellery pieces dating from the Middle Kingdom to the New Kingdom in Egypt. ArchéoSciences 33, 111–119. ISSN 9782753511811.

Trouslard, P., Tirira, J.: Pyrrole Software V 3.93, CEA (INSTN).

Wolters, J., 1975. Zur Geschichte der Löttechnik (The origin of gold brazing). In: Degussa Geschäftsbereich Verbindungstechnik Metall (Germany).