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Gold, Elekron, und Silber
L'or, l'électrum, et l'argent

For millennia, gold, electrum, and silver were the most admired and coveted metals in ancient Egypt, prized for their magnificent appearance and physical properties such as malleability and ductility. Initially, they were available as native metals, requiring no advanced smelting procedures for use and manipulation. As time progressed, sophisticated techniques were developed for mining and processing, particularly for creating specific alloys. Today, advanced scientific methods aid in our understanding of the diverse techniques anciently employed in working with gold and silver, illuminating their origins, exchange, and trade, as well as locations of production. These, in turn, give us insight into the genesis of technical innovations, the various chaînes opératoires *and local workshop organizations, and the ways in which expertise and technology were transferred or passed down through generations and/or exchanged geographically between Egypt and its neighbors. Additionally, they can help us understand how foreign styles and techniques diffused into the Egyptian repertoire, were further developed, and were adapted to local needs and tastes, or vice versa. Scenes from Theban tombs and other sources provide particularly useful information about the mining and processing of these metals, as well as their exchange and trade, craftsmanship, usage, theft, and the high esteem in which they were held.*

لعدة آلاف من السنين، كان الذهب والإلكتروم والفضة من أكثر المعادن المرغوبة في مصر القديمة بسبب مظهرها الرائع وخصائصها الفيزيائية مثل القابلية للطرق والتمدد. كانت هذه المعادن متوفرة في البداية كمعادن طبيعية، لا تتطلب تقنيات متقدمة لاستخدامها ومعالجتها. ومع مرور الوقت، تم تطوير تقنيات متقدمة للتعدين والمعالجة، خاصة في صناعة سبائك محددة. واليوم، تساعدنا الأساليب العلمية الحديثة في فهم التقنيات المتنوعة التي تم استخدامها في العصور القديمة في صناعة الذهب والفضة، مما يوضح لنا أصولها وتبادلها وتجارتها، وكذلك مواقع إنتاجها. كل ذلك يوفر لنا رؤى حول نشأة الابتكارات التقنية؛ "سلاسل العمليات" المختلفة وتنظيم الورش المحلية؛ الطرق التي تم بها نقل المعرفة والتكنولوجيا عبر الأجيال أو تبادلها بين مصر وجيرانها. بالإضافة إلى ذلك، يمكنها أن تساعدنا في فهم كيف أثرت الأساليب والتقنيات الأجنبية على مصر، حيث تم تطويرها وتكييفها لتلبية الاحتياجات والأذواق المحلية. توفر مشاهد من مقابر طيبة معلومات مفيدة حول تعدين هذه المعادن ومعالجتها، وكذلك حول تبادلها وتجارها وحرفيتها واستخدامها وسرقتها، والتقدير الكبير الذي كانت تحظى به.

In Egypt, "gold was as abundant as dirt"—an exaggerated claim made by two petitioners, the Assyrian King Aššur-uballit I and the Mitannian King Tušratta, who were contemporaries of Amenhotep III (1389 – 1349 BCE) and IV (1349 – 1332 BCE) (Moran 1992: 39 [EA 16, 13-18], 44 [EA 19, 59-70], 85 [EA 26, 30-48]).

Their claim, however, should not come as a surprise, given that the territories controlled by the rulers of the 18th Dynasty (1548 – 1302 BCE) were rich in deposits of gold. Almost every conceivable object of prestige had gold in it or on it; gold was even incorporated into architectural design.

Gold has always been a highly desirable metal due to its radiant, sun-like luster and special properties. It is not very susceptible to tarnishing and corrosion, is easy to recycle, and relatively easy to work, making it a highly desirable material along with electrum and silver (Guerra 2023a: 3-4).

As a result, precious metals became the primary target of tomb robbers, often being melted down and reused early on. Given this, it is quite remarkable that a considerable number of objects from various periods have managed to survive. Apart from architectural elements, which have mostly been lost, these objects offer a sufficient representation of the wide range of items crafted using precious metals.

1. Major Finds

1.1. Gold

Today, gold-silver-copper alloys containing at least 75% gold are classified as gold. With its enduring luster, gold possesses a timeless and universal beauty, requiring no explanation for its allure. It is therefore unsurprising that gold, like so many other precious materials, was initially available primarily to the pharaohs and the country's elite. However, gold objects have also been discovered in less elaborate, and presumably less prestigious, burials (Grajetzki 2023: 75-86).

In its early stages, during the Predynastic Period (4500 – 2950 BCE), like all metals, gold was predominantly fashioned into modest items for personal adornment, mainly in the form of beads used as pendants or for necklaces, bracelets, and anklets, or as thin foils for decoration (Baumgartel 1960: 3-6, pl. II, 6-8).

Rare finds of small finger-rings from the Early Dynastic Period (2950 – 2670 BCE) were recovered alongside an undecorated gold sheet diadem, gold beads, and amulets at Naga el-Deir (e.g., Reisner 1908: 29-31, fig. 54, pls. 5-7, 9; or Andrews 1990: fig. 11), and a more elaborate gold spoon (fig. 1) from a child's tomb at Hierakonpolis (Quibell and Green 1902: II, 50). At Memphis, the pillars of a burial chamber were discovered decorated with narrow strips of gold foil (Emery 1954: 9-12).

Figure 1. Gold spoon from a child's tomb at Hierakonpolis, 8.5 cm long.

Figure 2.

The gold-headed falcon standard of Pepi I.

Few gold items are known to exist from the Old Kingdom (2670 – 2168 BCE). Notable among these are the preserved stone ointment containers from the tomb of Khasekhemwy at Umm el-Qaab, Abydos. These containers boast circular golden lids laced with filigree wire, representing the first known use of gold to decorate funerary objects (e.g., A. J. Spencer 1980: 235; Ogden 2023: 92-93, figs. 4.9-4.12). Additionally, a cache of jewelry found in the pyramid of the 3rd Dynasty king Horus Sekhemkhet (c. 2670 – 2600 BCE) at Saqqara includes 21 gold hoop bracelets and over 380 hollow gold spheres serving as beads (Goneim 1956: 40).

The tomb of Queen Hetepheres I of the 4th Dynasty (2600 – 2480 BCE) at Giza revealed elegantly designed gilded furniture and gold tableware (Reisner 1927: 25-26; 1929; Manuelian 2017). Similarly, within the mastaba complex of Ptahshepses at Saqqara, a gold girdle with exquisite beadwork was found in his sarcophagus (Brunton 1947: 125-128, 132; Moustafa 1957), and a diadem and a precious necklace made of 50 gold click-beetle beads were discovered in the tomb of an anonymous woman in Giza (Hassan 1936: 159, pls. 50 and 52).

The falcon standard of Pepi I (6th Dynasty, 2350 – 2200 BCE) from Hierakonpolis (Eckmann and Shafik 2005: 51-69, figs. 32-45, 44-48 and color figs. 32-45) is adorned with a head and crown made of gold (fig. 2). This depiction holds significant historical impor-

Figure 3. Leopard-head girdle of Sithathoryunet, with a circumference of 81 cm.

tance, as it can be interpreted as the first surviving physical representation of the pharaonic title "Golden Horus" (Spalinger 2015).

At Lahun, Dahshur, and Hawara, significant discoveries were made regarding jewelry belonging to the elite women of the Middle Kingdom royal families of Amenemhat II (1928 – 1893 BCE) and Senusret II (1896 – 1887 BCE). Notably, Princess Sithathoryunet's jewelry was found hidden in a cache located in the antechamber of a robbed tomb within the pyramid of Senusret II at Lahun. The cache included a precious diadem (Brunton 1920: 24, 26-27, pl. V) and two girdles made, respectively, of either large, hollow gold cowrie shells or gold feline-head beads (fig. 3) encasing small metal pellets, spheres, or stone pebbles that rattle and jingle when worn (Andrews 1994: 42, fig. 69a; Patch 2015: 117-118, no. 56, and 118-119, no. 57C). An X-ray imaging study conducted on the mummy of Merit, wife of the architect Kha, also revealed a similar girdle dating several hundred years later (Curto and Mancini 1968; Bianucci et al. 2015: 15, figs. 8-9). Merit and Kha were buried near Deir el-Medina, Thebes, during the reign of Amenhotep III (1389 – 1349 BCE).

A particularly spectacular find is the burial of Princess Khnumit at Dahshur, which includes two diadems, necklaces, bracelets, and anklets, as well as a beaded apron and pendants with open-work gold granulation and filigree (see figs. 22c and 24c; de Morgan 1903: 40-44, 55-68, pls. V-XII). The dating and origin of these artifacts are subjects of considerable debate (Lilyquist 1993: 36-37).

In the mid-nineteenth century, Auguste Mariette discovered the tomb of Queen Ahhotep (late 17th/early 18th Dynasty) at Dra Abu el-Naga, near Thebes (Miniaci 2022). Among the treasures found were an array of jewelry, weapons, and a model boat made of gold and silver. Three "golden flies" (or "flies of honor") were also found (fig. 4), believed to have been bestowed upon the queen as recognition for thwarting a Hyksos attempt to seize the throne of Ahmose (Gestoso Singer 2009; Lacovara 2022). It is worth noting that such military honors in a female tomb are unique.

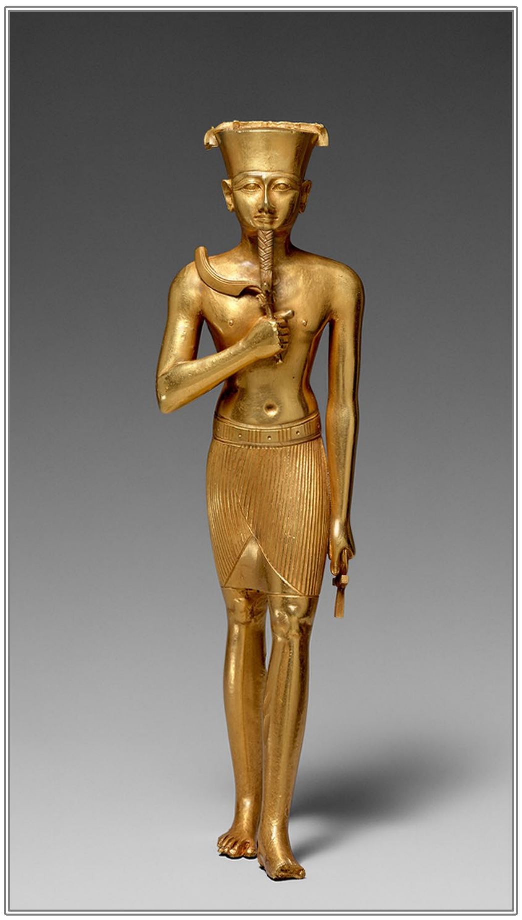
During the New Kingdom (1548 – 1302 BCE), gold was worked into all kinds of elaborate jewelry, amulets, and *objets de vertu*, ranging from vessels to decorative weapons, small boxes, and even royal coffins. Even less prominent members of royal families were buried with lavish gold treasures. For instance, the so-called "three foreign wives" of Thutmose III (1479 – 1425 BCE) were buried with similar assemblages of gold jewelry and

Figure 4. Necklace with three large golden flies from the tomb of Ahhotep at Dra Abu el-Naga.

various funerary objects (Lilyquist 2003; H.-W. Müller and Thiem 1999: 158-166). The abundance of gold and gilded objects discovered in the tomb of Tutankhamun (1328 – 1319 BCE), where the glint of gold was omnipresent, is perhaps unparalleled. In addition to pure goldsmith's works like the mummy mask (Broschat and Eckmann 2022; Reeves 2022: 222-226; Eckmann, Broschat, and Hardwick 2023), the innermost coffin (Rehren et al. 2022b), a dagger (Broschat et al. 2022: 34-48, figs. 27-46; Reeves 2022: 347-349), a diadem (fig. 5) (Broschat and Mertah fc.), and the hundreds of amulets and pieces of jewelry, gold was used in large quantities in the form of sheets and foils for decorating objects made of wood and ivory, leather, textiles, faience, glass, calcite alabaster, and other precious stones. Jewelry from a non-elite tomb was brought to light only recently at el-Amarna: a necklace with hollow, drop-shaped gold beads and three finger-rings made of gold and steatite (Stevens et al. 2023: 101, 107, fig. 15).

Figure 5. Front view of the golden diadem placed within the mummy bandages on the head of Tutankhamun. Originally worn by the king during his lifetime, its design was modified by adding the vulture head for his burial.

Figure 6. Golden bowl from the Tomb of Psusennes I.



The Third Intermediate Period (1086 – 664 BCE) is dominated by the rich finds from the necropolis of the Tanite kings, including gold masks and elaborate jewelry, as well as gold bowls (fig. 6) and jars (Stierlin 1993: 156), particularly associated with Kings Psusennes I (1056 – 1010 BCE) and Shoshenq II (906 – 881 BCE).

Only a handful of gold statues, such as the solid cast figure of the god Amun (fig. 7) (e.g., Schorsch 2007a: 84-86; Hill 2007; Reeves 2022: 70-71), have been discovered. These are rare examples among the many statues made of gold, silver, and other precious materials that ancient texts suggest once filled temple sanctuaries.

Figure 7. This 17.5-cm-high gold statue shows Amun standing in the traditional pose with left leg forward, cast in solid gold.

Figure 8. Both sides (a and b) of a gold stater depicting: a) a horse and b) a collar(?), the lung-sign signifying "pure gold."

During the reign of the Kushite kings, larger gold nuggets were fashioned into jewelry, showcasing an appreciation for the raw material itself (Gänsicke and Newman 2000: 76; Lacovara and Markowitz 2019: 26-27, fig. 6). The gold staters minted during the rule of Nectanebo II (360 – 343 BCE) are the first Egyptian pharaonic coinage in existence (fig. 8a-b) (e.g., Bolshakov 1992; Faucher, Fischer-Bossert, and Dhennin 2012: 148-150, 168 [pl. I]; Loeben 2014).

In contrast, gold jewelry from Alexandria during the Ptolemaic Period reflects a classical rather than pharaonic style, catering to the tastes of the Hellenistic upper class, albeit with a few adapted Egyptian elements. Notably, the protective snake rings or bracelets, popular for centuries, were made in a variety of shapes (Walker 2000: 151-152; Ogden 1990: fig. 463).

1.2. Electrum

Electrum, also known as "argentian gold," is a naturally occurring or man-made alloy of gold and silver. Pliny the Elder (23/24 – 79 CE) (König ed. 1984) defined electrum as a natural alloy of gold with a silver content of more than 20 percent. Centuries later, Isidore of Seville observed, "it reflects in the sun's ray more clearly than silver or gold," while distinguishing between natural and man-made alloys (translation Barney et al. eds. 2006: 332). The modern standard definition, however, requires a minimum of 25-percent silver.

In ancient Egypt, electrum was understood as a derivative of gold, with its color ranging from golden to yellowish-white depending on its composition. This variability can lead to misidentification when relying solely on visual inspection. A Middle Kingdom (c. 2010 – 1640 BCE) amulet from Abydos, for example, was initially cataloged as silver but was later revealed to be electrum, containing about 40 percent gold (Hayes 1953: 236; Schorsch 2018). However, the known number of electrum objects does not reflect the vast quantities of electrum mentioned in ancient texts. This discrepancy is likely due to the absence or inadequacy of chemical analysis, or our etic perspective on ancient perceptions of this material.

An unprovenanced electrum *sꜣ*-amulet (Andrews 1994: figs. 49d, 64p) resembles a larger counterpart, twice its size, made of silver and electrum and dating to the 11th Dynasty (2130-1990 BCE). The amulet was found on the tattooed body of a woman in Deir el-Bahri, Thebes (Hayes 1953: 162, 230; Schorsch 2001: 59, note 14, pl. VII/3).

Figure 9. A restrung necklace, 46 cm long, probably from the Middle Kingdom, with electrum cowrie-shell beads and various pendants. The cowrie beads contain little spheres that jingle when the necklace is worn.

A necklace from (probably) the Middle Kingdom (fig. 9), reportedly from Thebes, is composed of large cowrie-shaped beads made of electrum (Andrews 1990: 55, pl. 39[a]; 1994: fig. 69; Meeks et al. 2023). It might also, at one time, have been assembled as a girdle and its disparate elements may have come from different objects. A small 12th Dynasty cosmetic container in the likeness of a kneeling girl (British Museum EA 2572) illustrates how such girdles were worn around the hips rather than the waist. Another girdle, comprising 26 scaraboid-shaped electrum beads and dating to the 17th Dynasty (1690 – 1548 BCE; Petrie 1909: 9, pl. XXIX; Maitland, Potter, and Troalen 2022; Troalen, Tate, and Guerra 2023), was recovered from an intact burial group of a woman and child at Qurna, Thebes (Petrie 1909: 6-10, pls. XXII-XXIX), whereas hardly any electrum was found in the tomb of the "three foreign wives" of Thutmose III (Lilyquist 2003).

A fine example from Tutankhamun's tomb is a ritualistic sickle decorated with sheets of gold and electrum (Carter 1933: 143; James 2000: 279). Both metals were also combined in a stemmed drinking cup fashioned in the shape of a flower, found among the belongings of General Wendjebauendjed at Tanis (Stierlin and Ziegler 1987: 174-175).

Figure 10. a) Massive (17 cm) silver adze from Ballas, Tomb 39. b) The *pesesh-kef* amulet, made of silver and meteoritic iron, is the only known artifact from pharaonic Egypt to combine these two metals. c) This utilitarian mirror, likely used by Princess Sithathoryunet in her daily life, showcases exceptional design and craftsmanship, with its reflecting disc made of silver. d) Mirror case shaped like an *ankh* from Tutankhamun's tomb, decorated with gold foil on the exterior and silver foil on the interior.

1.3. Silver

Silver's allure arises from its metallic luster, which bestows a bright whitish sheen when polished—a quality familiar to our modern sensibilities. Its scarcity in Egypt may have contributed to its appeal, as well as its tendency to develop rich colors like satin gray or glossy black over time or when left unpolished. This characteristic aligned well with the ancient Egyptian aesthetic appreciation of metal polychromy, also allowing for colorful combinations with colored stones and glass, thus expanding the creative repertoire of ancient craftsmen. Alloys of gold and silver ranging from 5 to 50 percent gold-content are referred to as "aurian silver" by modern standards (Gale and Stos-Gale 1981: 108; but see Hauptmann 2022: 58). Silver was used to fashion beads as early as the Predynastic Period (Prag 1978: 38-39), retaining its value in Egypt for personal ornaments and cult objects until Roman times (30 BCE – 394 CE). However, larger cast objects, such as a dagger blade from a grave in el-Amra (Randall-MacIver and Mace 1902: 42, pl. VI.1.2; Baumgartel 1960: 9-10, pl. II.1-2), or a silver adze (fig. 10a) found at Ballas, Tomb 39 (Petrie 1917: 28, pl. XXXIII.1), were also made from this precious metal.

Among the few known silver objects from the Old Kingdom, the most notable are the 20 silver bracelets (Reisner 1927: 21; Reisner and Smith 1955: 43-44, fig. 44, pls. 36-37) discovered in the tomb of Hetepheres I.

The tomb of Princess Aasheit from the 11th Dynasty (c. 2130 – 2060 BCE) at Deir el-Bahri contained a *pesesh-kef* amulet formed of a silver head combined with a blade crafted from highly exclusive meteoritic iron, resulting in a rare subtype (fig. 10b) (Brunton 1935: 214, fig. 4).

An increasing number of objects are recorded for the Middle Kingdom. The Theban tomb of Wah, a minor official from the beginning of the 12th Dynasty (1990 – 1809 BCE), contained unexpected silver riches, including a ball-bead necklace (Aldred 1971: 183-184, pl. 22; Schorsch 1995) found between the layers of Wah's mummy wrappings, as well as two fine silver scarabs placed over his wrists (see fig. 27a; Hayes 1953: 308; Schorsch 2001: 59-60, n. 18, pl. VIII/1; Oppenheim 2015). Other silver jewelry has been found at Dahshur (de Morgan 1895, 1903), an elaborate silver mirror was discovered in the Tomb of Sithathoryunet at Lahun (fig. 10c) (Brunton 1920: 26, 36, pl. XI; Müller and Thiem 1999: 89, 122), and a 38.5-cm-long silver model boat, part of a set with the golden boat, was found among the treasures of Queen Ahhotep I (Wachsmann 2022: 279, 283-286, figs. 2a-c).

In Upper Egypt, a unique hoard of foreign tribute, the "Treasure of Tôd" (Bisson de la Roque et al. 1953: pl. XXV; Pierrat and Menu 1994), contained, alongside riches of lapis lazuli and gold, intact and crushed silver vessels, ingots (see also figs. 14a-b), and smaller objects, weighing a total of 8.87 kg. Its dating is uncertain, with suggestions ranging from the 12th Dynasty (1990 – 1809 BCE) to an uncertain time after the Middle Kingdom (Kemp and Merrillees 1980: 290-296).

More Egyptian silver has survived from the New Kingdom onwards. For example, the burial of Thutmose III's three foreign wives included three lidded silver vessels (Lilyquist 2003: 128, nos. 13, 14, 15; 195, figs. 99–102, 263b-265b) and two silver mirrors (Lilyquist 2003: 152, nos. 106, 222, figs. 149, 151, and 107; 222, fig. 150; Hayes 1959: 139, fig. 75; Patch 2005: no. 147). Additionally, a bowl, a small vase, and a strainer made from silver found in the tomb of Kha at Deir el-Medina may have been part of a service to prepare beverages (Ferraris 2018: 133, fig. 157).

Some objects in the tomb of Tutankhamun have been described by scholars as being made of silver. For instance, there is a companion to the gold stick featuring a cast statuette (Desroches Noblecourt 1963: 262-263; Wiese and Brodbeck 2004: 254-255, cat. 56), and a vase shaped like a pomegranate (Carter 1933: 130, pl. XIII; Reeves 2022: 409). There are also silver details on jewelry pieces, as well as silver foils and sheets decorating objects such as the interior of a mirror case (fig. 10d), the pedestal of a perfume box shaped like a double cartouche (Carter 1927:

Figure 11. Rendering of the 3D-model of the newly discovered gilded silver mask from Saqqara before restoration.

90, pl. LXXIV; Reeves 2022: 319), and a sledge carrying a small golden shrine (Wiese and Brodbeck 2004: 260-265, cat. 58; Eaton-Krauss and Graefe 1985). However, apart from the analysis of a trumpet (Manniche 1976: 7-8, pls. V-X, 5-10; Wiese and Brodbeck 2004: 330-331, cat. 82; Othman et al. fc.) and of some details on the golden throne (Broschat, Eckmann, and Mertah 2024: 40-41, 52), a thorough analysis of the composition of these items is lacking, leaving the possibility that some of them could also be electrum or aurian silver.

Fine examples of Ramesside silverwork were found at Tell Basta (ancient Bubastis) (Hayes 1959: 358-360; Simpson 1959; Lilyquist 2012; but see Laube 2023 with new information on the find's context). Additionally, the so-called Gold Tomb in the Valley of the Kings (KV 56) contained, among gold and electrum objects, unusual silver hands (coverings?) and a silver sandal (Daressy 1908: 43-44, 91, 107). In the tombs of Psusennes I and Shoshenq II at Tanis, larger objects such as silver masks or coffins (see fig. 20) were discovered (for color photos see, e.g., Stierlin and Ziegler 1987; Stierlin 1993; Hawass 2023: 284-285; silver finds from Tanis are conveniently listed by Jurman 2015: 51-55, with further literature).

An unprovenanced statuette, possibly depicting a royal woman (Becker, Pilosi, and Schorsch 1994), and a partially gilded silver figure of Amun-Ra (see fig. 26b), are believed to date to the Late Period (664-337/336 BCE) (Russmann ed. 2001; Strudwick 2006: 200-201).

The recent discovery of a mask at Saqqara (fig. 11) (Hussein 2020: 657-658, figs. 21-22) is part of a group of objects made of silver but fully gilded (see, e.g., Cauville 1987, and Gänsicke and Newman 2000 for gilded silver finds from Nubia).

2. Methods of Examination and Scientific Analysis

In Egyptology, the history of ancient Egypt is typically divided into epochs and dynasties. From a metallurgical perspective, important periods of human development are defined by the introduction of the most advanced materials at a given time. These periods include the Copper, Bronze, and Iron Ages,

Figure 12. Various metal-shaping methods as shown in the tomb of Rekhmira.

with their dates varying across different regions of the world. Precious metals such as gold, electrum, and silver were also processed and used, alongside copper; these metals were the first to be worked by humans.

In addition to evaluating archaeological data such as find context and typological details, and using art historical approaches to analyze finds, other methods, such as interpreting pictorial and textual sources, can also be employed. For example, the wall paintings in the Theban tomb of Rekhmira are widely recognized for providing valuable insights into various techniques of metal shaping (fig. 12 and see also fig. 23; Davies: 1943, pl. 55; Drenkhahn 1976: 18-42). Experimental work aims to verify observations or theories (Wunderlich, Lockhoff, and Pernicka 2014; Berger et al. 2021; Rademakers et al. 2021; Verly, Rademakers, and Téreygeol eds. 2019) or identify the *chaînes opératoires* for a technology or technique, or the manufacture of a specific object. A *chaîne opératoire* links technical processes and social interactions, enhancing our understanding of the social context, actions, and ancient cognition involved in the production of an object, as well as the practical aspects of material procurement or production (Faucher 2019; Hauptmann 2022: 19-20; Verly et al. 2021; Odler 2023: 24-30).

The impact of materials and manufacturing processes on societies, particularly their tools and infrastructures, is significant, any innovation carrying considerable economic, social, and cultural implications (Hansen 2020: 275). Consequently, recent research has not only focused on (archaeo-)metallurgical studies (Hauptmann 2022: 2-6; Giardino 2022), which pertain to the techniques used to extract and process metals, but also on chemical investigations. These studies explore the properties and behavior of metallic substances, including their composition, structure, and changes when they interact with other substances. Both fields fall within the realm of archaeological science, known as archaeometry, which applies scientific techniques to analyze archaeological materials and sites (e.g., Pollard et al. 2007; Richards and Britton 2020). This discipline has significantly influenced modern archaeology in general, enriching our understanding of precious metals and specific aspects of ancient Egyptian society in particular. Ideally, methodologies should be non-destructive and/or non-invasive, selected based on the questions to be addressed, and considering any restrictions that may be imposed on certain objects, such as bans on sampling or transportation.

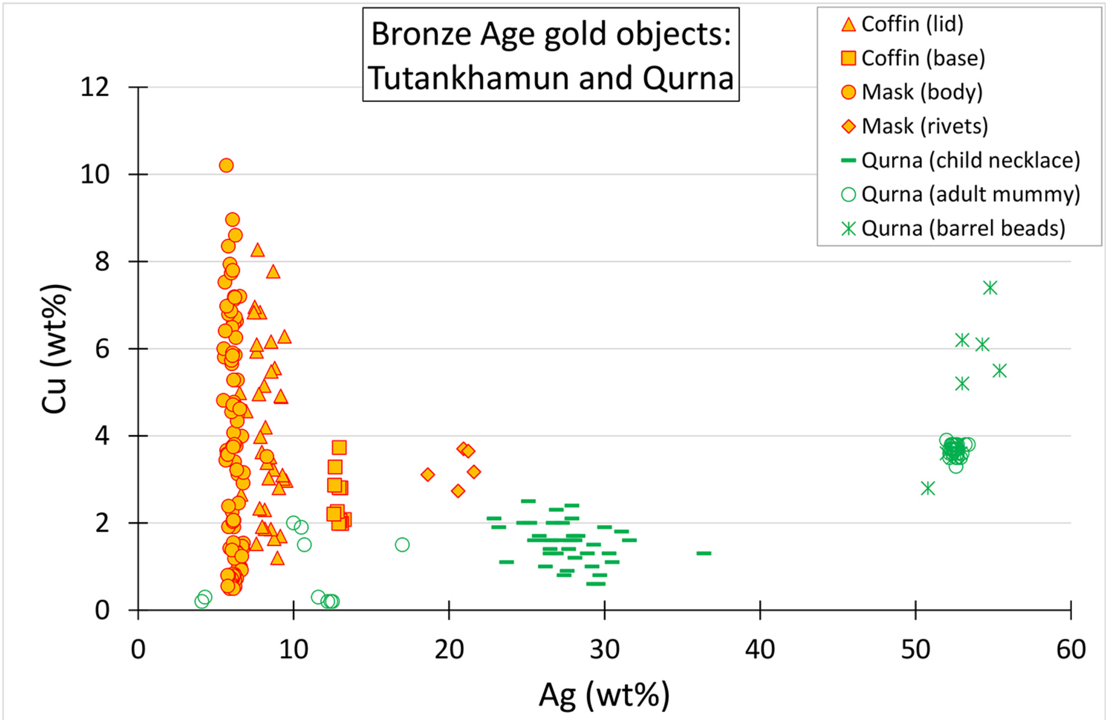


Figure 13. Graph comparing the copper and silver content of different Bronze Age Egyptian assemblages: the gold burial mask and innermost coffin of Tutankhamun and selected jewelry from Qurna. The silver content is considered natural, with higher levels likely indicating freshly mined gold, while lower levels are often found in placer gold. The copper content is most likely due to metallurgical activities such as soldering and recycling.

Chemical data can be used to track and compare the sources of raw materials or the compositions of alloys produced and/or used in specific geographical regions or for particular purposes (fig. 13). They can also be used to identify the reuse of gold (Guerra and Pagès-Camagna 2019: 151) or even individual jewelry components (Maitland et al. 2022: 218). In rare cases, it is possible to attribute gold objects or pieces to a single goldsmith or workshop. While many methods necessitate sampling, the samples taken nowadays are typically very small.

A thorough visual examination of an object and its materials is essential and should be the first step in any investigation. Stereo-microscopes, which allow three-dimensional visualization, are particularly advantageous for this purpose. Additionally, a camera or digital microscope can aid in documenting observations accurately. Metallography, the study of the physical structure and components of metals by means of microscopy, typically involves sampling, careful surface preparation, and enhancing optical contrast to observe microstructural features such as annealing effects, casting defects like inhomogeneity (segregations) or cavities, non-metallic inclusions, corrosion phenomena, or plastic deformation caused by hammering (Scott and Schwab 2019).

Optical Microscopy (OM) and Scanning Electron Microscopy (SEM) can be used to examine samples. SEM can be non-destructive, contingent upon the object's dimensions aligning with the instrument chamber for examination. The SEM produces images by scanning the surface with a focused beam of electrons over a square area (Scott and Schwab 2019: 32-47; Tissot et al. 2015: 77, table 2; Guerra 2023c). Most instruments are equipped with an electron microprobe (EMP) device, providing highly space-resolved chemical information through X-rays emitted from the beam – material interaction (Scott and Schwab 2019: 37-47; Guerra

2023c). Metallographic techniques are also applicable for studying slags (waste products of metallurgical processes) or technical ceramics like crucibles or molds. Additionally, a variety of X-ray methods exist for examining structure or chemical composition.

Radiographic techniques play an important role in non-destructive examination, providing images of internal structures like fractures, ancient restorations, casting defects, or soldering seams. These techniques also yield information on the manufacturing techniques employed (Troalen and Guerra 2023). Furthermore, 3D Computed Tomography provides more detailed information, allowing for the visualization of 3D images and cross-sections. This facilitates a complete optical internal examination of an object, including, for example, the mummy equipment on the fully wrapped body of a deceased person (Saleem, Abd el-Razek Seddik, and el-Halwagy 2023). For particularly thick metal objects, such as metal statues, techniques like Gamma (γ)-ray or Neutron Beam Radiography can prove useful (Festa et al. 2018).

X-ray Fluorescence (XRF) Spectrometry is adept at analyzing the chemical composition of metals and their alloys and is capable of determining a wide range of elements from the periodic table (Troalen et al. 2022; Gänsicke et al. 2023). The use of portable devices (pXRF) has become increasingly common, allowing on-site analysis of objects (Guerra and Pagès-Camagna 2019). However, surface alteration due to corrosion can limit its application to non-destructive analysis of metals, necessitating sampling and/or the removal of corrosion layers. While gold objects are less susceptible to surface alteration and can often be analyzed without any preparatory measures, it is important to note that X-ray fluorescence analysis only penetrates a few microns into the surface. If there is a depleted layer, whether occurring naturally or artificially, and its thickness is unknown, the analysis of just this shallow depth can yield unreliable results, as it may not represent the full composition (Cowell 1977). Therefore, non-destructive accelerator-based techniques like Particle- or Proton-induced X-ray Emission (PIXE) or Particle-induced Gamma Emission (PIGE) are often used for gold analysis (Tissot et al. 2015: 76-78, table 2; Lemasson et al. 2015, 2023).

X-ray Diffractometry (XRD) is used to determine the atomic structure of crystalline materials, like metals, minerals (e.g., pigments), and ceramics, enabling the direct identification of compounds. In the case of metals, XRD can also determine the morphological characteristics of patinas (Ghoniem 2011).

Optical Atomic Emission Spectroscopy (OES) is a technique that relies on the emission of radiation in the near ultraviolet and visible light range, respectively. It was the first instrumental multi-element technique used for the systematic study of ancient metals using flames, arcs, or sparks as excitation sources. Modern instruments use excitation plasma sources, e.g., inductively coupled plasma (ICP), and can quantitatively identify a score of elements at very low concentrations. Samples are typically introduced as a liquid, but laser ablation (LA) techniques can analyze solid samples or objects directly.

Atomic Absorption Spectroscopy (AAS) is a highly sensitive technique based on optical spectrometry, which measures light absorption. It requires samples to be in solution and permits the determination of only one element at a time due to the need for a specific lamp with a wavelength characteristic of the sought-after element (Hughes, Cowell, and Craddock 1976; Welz and Sperling 1997).

Neutron Activation Analysis (NAA) is an analytical technique that irradiates samples with neutrons to convert elements into artificial isotopes. By measuring radioactive decay, it provides information on a large number of trace elements present in metals. Despite its sensitivity, accuracy, and precision, NAA cannot irradiate certain elements like lead or bismuth.

Of all the spectrometric techniques, Mass Spectrometry (MS) is particularly important because it can resolve atomic weights, enabling the most sensitive detection of the elemental and isotopic composition of metals and their alloys. The samples are usually introduced as solutions (as they were for the ICP-OES), but the size of the samples required can be reduced to a minimum by using a laser ablation technique (LA-ICP-MS), where the sample spots are invisible to the naked eye. Recently, portable instruments for on-site or in-situ laser ablation sampling have been developed (Dussubieux, Golitko, and Gratuze 2016; Merkel et al. 2022; Numrich et al. 2023). Their use will greatly expand the database by allowing the analysis of objects that cannot be sampled in the traditional way, cannot be easily transported to a laboratory, or come from regions where this technology is not yet available.

Multi-Collector Inductively Coupled Plasma Mass Spectrometers (MC-ICP-MS) are used to determine the isotopic ratios of elements like lead. The isotopic composition of lead is the main source of information on the origin of the ores used for ancient metal production, as it is passed unchanged to the metal (and metal slag) during smelting. Thus, if regional reference datasets are available, their isotopic signature can enable the tracing of metal sources (Guerra and Calligaro 2004; Schlosser et al. 2012; Schwab and Willer 2016; Masson-Berghoff et al. 2018; Sowada et al. 2023: 6-8, figs. 4-5, table 5). However, excessive ancient re-melting and reuse of precious metals often obscure the results, making it difficult to identify their origin. (For the most comprehensive overview of new analyses of ancient Egyptian gold jewelry, see Guerra et al. 2023b: 131-475.)

3. Sources, Procurement, and Mining

The establishment of the Egyptian state heralded the onset of the centrally controlled exploitation of metallurgical resources. Expeditions were dispatched to explore and extract raw materials (Eichler 1993; Hikade 2001), especially during the (18th Dynasty) reign of Thutmose III. Provinces were mandated to supply their products to the Egyptian royal court, as depicted in the tomb of Rekhmira, where representatives from Egyptian cities are shown delivering precious metals to the administrative center (fig. 14a). From the reign of Thutmose III onwards, tombs like those of Senenmut, Puimra, Intef, Useramen, Menkheperrasonb, Rekhmira, Meryra, and Nebamun depict both large and small silver ingots carried by Syrians and Minoans/Aegeans (Wachsmann 1987: 6-13, 41-52, 98-99; Rehak 1998: 40). Scenes in the tomb of Rekhmira show the weighing of rings, indicating their use as ingots (fig. 14b) (Davies 1943: 35, pl. LV). Additionally, the tomb of Huya, Overseer of the Treasuries at el-Amarna, records men from the north (Syria and Canaan) presenting gold vessels, stands with rings, and bags of gold as tribute from Nubia (Davies 1905b: 12-13, 19-25, pls. III-XV; see also Davies 1905a: 38-43, pls. XXXVII-XXXIX, XLVII). One such gold ring ingot was found in the Uluburun shipwreck, in a hoard of scrap jewelry (Pulak 2008: 297; Yalçın, Slotta, and Pulak eds. 2005: 528, 611-615, and see fig. 138 for the gold ring). Silver rings and coils have been discovered in hoards, such as the one found at el-Amarna (fig. 15) (e.g., Pendlebury 1931: 236; Frankfort and Pendlebury 1933: 59-61, pl. XLIII [6]; Bell 1986: 147; Gestoso Singer 2013). Some of these objects are small and display decorative (?) patterns, which could cause them to be misidentified as jewelry (Jones 2007: 80; Gestoso Singer 2015: 89).

Metal ingots are frequently listed as "tribute" from foreign countries, although they may have actually been commodities used in trade or "gift-exchange" networks involving powerful kings and elites (Gestoso Singer 2015: 87). Precious metals were transported in a variety of forms, such as powder or small nuggets (sometimes in small bags), and even as finished objects, and they were also brought to Egypt in large quantities as spoils of war. The metals were registered and stored in temple treasuries for later distribution, after which they were allocated for architectural projects (Lacau 1949, 1956) and for the production of prestige goods to be rendered by craftsmen who worked on behalf of the state in workshops associated with temples and palaces. This practice is also exemplified in the tomb of Rekhmira (east

Figure 14a. An official presents gold and silver ingots alongside other valuable commodities (after Davies 1935: pl. XLVII/3).

Figure 14b. The weighing of gold and silver (after Davies 1935: pl. XLVII/3).

Figure 15. A selection of silver objects, discovered in a hoard at el-Amarna, feature geometric patterns on the ends of the coils.

and west wall in the south wing of the transverse hall).

Tomb robbery, a practice dating to the earliest times and well documented in the 20th Dynasty Abbot and Amherst papyri, constituted a third source of metal. The so-called tomb robbery trials report two series of thefts of the tombs of private individuals, queens, and even a 17th Dynasty king in Thebes-West (e.g., Peet 1930; Graefe 1999). Some scholars suggest that during the 21st Dynasty (1086 – 962 BCE), royal tombs were even robbed on the initiative of the state or at least with its acquiescence (Taylor 1992; Jansen-Winkeln 1995; Thijs 2018). Throughout Egyptian history, a significant quantity of precious metal must have been reintroduced into the material cycle through the practice of looting. This reuse should not be underestimated as a source, as it is likely the only logical explanation for the large discrepancies between the quantities of precious metals mentioned in historical texts and the estimated amount of metal mining that was possible (Graefe 1999; Störk 1977).

During New Kingdom reward ceremonies, known as the "Gold of Honor," held at the Window of Appearance, the flow of precious metals into the private sector was institutionalized and its supply maintained (Kemp 1976; Schulman 1988; Brand 2006: 17; Gestoso Singer 2015: 91).

3.1. Gold

The inscription in the tomb of Puimra states "the mountains have opened their hands with gold" (Davies 1922: 89, pl. XXXVI) and ancient texts primarily refer to three different sources: the "Gold of Coptos," used as early as the Predynastic Period; the "Gold of Wawat" during the Middle Kingdom; and the "Gold of Kush" in the New Kingdom (Vercoutter 1959; Vercoutter, Bonnet, and Caneva 1998: 11-28). These sources correspond to the mines situated around Wadi Hammamat and Wadi Abbad in Egypt's Eastern Desert and around Wadi Allaqi and Wadi Cabgaga in what is today the Sudanese Eastern Desert, bordering Egypt (Botros 2004; R. Klemm and D. Klemm 1994; Gundlach 1977; Störk 1977: 725-726; Lucas and Harris 1962: 224-225). The earliest known topographical map from ancient Egypt, the fragmented Turin Papyrus Map (also known as "the Goldmine Papyrus"), from the reign of Ramesses IV, shows a plan of Wadi Hammamat, featuring local geology and

Figure 16. The fragmented so-called "Goldmine Papyrus," the oldest known surviving map from ancient Egypt, depicts Wadi Hammamat on the recto, with several texts on the verso.

details related to the gold-mining settlement there (fig. 16) (Harrell and Brown 1992). Following in the footsteps of the New Kingdom pharaohs, the Ptolemies undertook a series of mining expeditions in the Eastern Desert in search of the precious metal, but gold mining was limited to the area that comprises modern Egypt (Faucher 2018).

Gold extraction, mining, and processing—virtually universal practices—began with the collection of small quantities of alluvial gold as nuggets, sifted from water-washed gravel and sand, often concentrated in the beds of dried-up desert wadis. Larger-scale gold extraction became possible with the development of a more sophisticated panning technique. This involved digging up gold-bearing sands or crushing gold-bearing quartz ore into smaller pieces and grinding it into a fine powder. The denser, and hence heavier, gold particles were then separated from the lighter quartz sands, presumably by washing them in pans (D. Klemm, R. Klemm, and Murr 2001: 653). The use of large sloping or inclined washing tables (fig. 17) allowed for more efficient production (ibid.: 652-653; D. Klemm and R. Klemm 2016). Until at least the New Kingdom, alluvial gold likely remained the main source of gold, until more advanced methods made it possible to mine gold-bearing veins.

Agatharchides of Cnidus, writing around 200 BCE, provided the only contemporary description of the labor-intensive mining process in the Wadi Allaqi region (Woelk 1966). However, it is generally assumed that the operational procedures remained unchanged over millennia: gold-bearing rocks, such as quartzites, were subjected to heat (fire) and then crushed using stone hammers and picks. Subsequently, they were worked in mortars and ground between two stones to create an extremely fine powder suitable for panning. The remark of the nomarch Amenemhat (c. 1965 – 1920 BCE) in which he stated, "I forced their (Nubian) chiefs to wash the gold" (Newberry 1893a: pl. 4) emphasizes that hydro-metallurgical concentration processes were already well established in the Middle Kingdom.

Figure 17. New Kingdom ruins at Wadi Naba, Sudan, with oval stone mills and a central sloping washing table (arrow).

Depictions found in the tomb of the troop commander of traders and gold washer Khay at Saqqara (19th/20th Dyn.; 1302 – 1198 BCE/1198 – 1086 BCE) also offer a brief illustration of the mining process (Martin et al. 2001: 15, 26-27, pl. 11). Subsequently, the gold could be melted and cast into rings or square bars for transport or trade, as evidenced by the hoard from el-Amarna.

During the New Kingdom, extensive settlements developed along gold-bearing wadis, posing resource supply and logistical challenges for their residents, notably those pertaining to firewood (Müller and Thiem 1999: 36-37, 41-42). Consequently, due to the scarcity of water and fuel near most mining sites, it is likely that washing and smelting operations were carried out at stations along the banks of the Nile. However, the transportation of sands would have incurred great expense, and as of yet, no sites have been identified within modern Egyptian territory (for potential Meroitic washing stations, see Vercoutter 1959).

The desire or necessity to control the Nubian gold mines may have been a major factor prompting Middle Kingdom rulers to annex northern Nubia. For example, Quban, probably constructed during the reign of Senusret I (1971 – 1926 BCE), served as a fortress and base for mining operations, becoming one of the more important Egyptian New Kingdom centers in Nubia, overseeing the gold mines of Wadi Allaqi (R. Klemm and D. Klemm 2013: 294-295). Additionally, at Askut, there were "settling basins," possibly also related to gold washing (Smith 1991: 114; the Middle Kingdom fortresses are conveniently summarized by Knoblauch 2019). Other archaeological findings further support the presence of gold-working activities in the area, such as a pot of unprocessed gold-bearing quartz and grinding stones found at Amara West (Papyrus Spencer 1997: 105-106, pl. 81d), the elite burial of the goldsmith Khnummose at Sai (Budka 2017: 77-78; 2018: 185-194; 2019), and the tomb of the gold worker Bak at Soleb (Schiff Giorgini 1971: 311-321, fig. 629).

The Ptolemies improved the efficiency of grinding and ore processing by combining concave-shaped millstones with semicircular, two-lugged millstones that were manually moved across the grinding surface (D. Klemm, R. Klemm, and Murr 2001: 655, fig. 17). A subsequent innovation was the importation of Roman quern technology, introducing the use of a round mill (D. Klemm, R. Klemm, and Murr 2001: 656-657, fig. 19; D. Klemm and R. Klemm 2016).

3.2. Electrum

Natural gold alloys with high silver content, primarily occurring in the Upper Nile Valley, are often mistaken for electrum (Botros 2015; Guerra 2023a: 7-8, fig. 1.5). The extraction of natural electrum alloys follows the same principles as those for gold extraction, but electrum can also be produced artificially by mixing silver with a gold alloy.

Once more, we confront the inconsistency between the abundance of electrum described in ancient literature and the limited number of electrum artifacts identified. For example, Osorkon I's (941 – 906 BCE) recorded donation of approximately 416 tons of precious metals to various temples included about 25 tons of gold, 209 tons of electrum, and 182 tons of silver. Remarkably, the list, though incomplete, also includes a sphinx made of four tons of electrum. While the ratios and quantities of these metals (particularly concerning Hatshepsut's two obelisks: Desroches Noblecourt 1951; L. Gabolde and M. Gabolde 2015: 88-89) may not accurately reflect reality, the scarcity of evidence and our vague understanding of the exact definition of electrum in pharaonic Egypt suggest that a range of gold alloys broader and more diverse than the currently accepted definition of the metal might have been regarded as electrum. The reuse and blending of precious metals into a compositional range beyond the contemporary definition of electrum alloys may further contribute to the metal's ambiguous status. Thus, it is important to acknowledge here the limited nature of our understanding.

3.3. Silver

Egypt lacks known mineralogical sources of silver, suggesting that much of the silver must have been imported from neighboring countries. Records in the royal annals from the reign of 4th Dynasty King Sneferu (c. 2613 – 2589 BCE) already mention silver as an imported commodity, although its exact origins are not preserved (Strudwick 2005: 66). A recent study of early bracelets from the tomb of Hetepheres suggests that the silver may have originated from the Cyclades or the Lavrion mines in Attica (Sowada et al. 2023).

The late 6th Dynasty (2350 – 2200 BCE) biographic inscription of Iny, possibly from Saqqara, lists the importation of silver through the trading hub of Byblos in Lebanon (Marcolin and Espinel 2001). For approximately a millennium subsequent to the 6th Dynasty, silver acquisition primarily occurred through trade or as tribute from conquests in Western Asia (Lucas 1928: 319; Gale and Stos-Gale 1981: 104). For example, in the 18th Dynasty "Annals of Thutmose III," silver rings are mentioned three times, twice as part of the tribute from Syria and once from Babylon (Wachsmann 1987: 53).

While silver in Egypt could have been extracted from argentiferous galena (lead glance), local sources possess a very low and therefore insufficient silver content to support this hypothesis. Analyses of Egyptian silver artifacts also fail to support the origin of silver from galena deposits (Gale and Stos-Fertner 1978; Stos-Fertner and Gale 1979; Stos-Gale and Gale 1981; for the production of silver in ancient times, see Craddock 2014).

Gold grains sourced from the mines at Wadi Hammamat have been found to contain significant amounts of silver, with levels reaching up to 44 weight-percent (Osman, Kucha, and Piestrzyński 2000). However, these mines could not have been a source of silver in pharaonic Egypt, since the knowledge of how to separate silver from gold (parting) was not present in Egypt until sometime between the seventh to fifth centuries BCE.

A proper series of alloys extends from silver and aurian silver, to electrum, to gold.

4. Workshops and Gold- and Silversmith Techniques

Publications documenting excavated pharaonic workshop structures are scarce and the limited archaeological evidence often makes it difficult to distinguish metalworking activities from other high-temperature industries (Hodgkinson 2018: 136-137). Finds providing evidence for precious-metal working are virtually non-existent. However, rare exceptions include the discovery of small quantities of gold sheets—suggesting their decorative use—in various workshops at Qantir, although it is likely that they were produced elsewhere (Prell 2011: 231, 235, note 1274, plan 23). Other examples include limestone molds used for jewelry casting or for pressing/chasing gold foil into shapes. At el-Amarna one such mold featured a fish motif (fig. 18a). While not precisely matching, a finished gold foil similarly shaped like a fish (fig. 18b) was also discovered (Kemp 2012: 284-285, figs. 8.8-8.9). Similar molds were also made of wood (Bulsink 2015: 32-33, fig. III.2). For the first evidence of technical ceramics used to process precious metals at el-Amarna, see Rademakers (fc.). Moreover, Petrie identified a silver working area in the ancient Greek settlement of Naukratis (Petrie 1886: pl. XLI; Masson 2015: 84; Masson-Berghoff et al. 2018: 319, fig. 2).

The techniques, skills, and tools required to work the various precious metals into objects are so similar that distinguishing between their workshops, if such distinctions were ever made, would prove difficult. However, given the relatively similar melting points of gold and bronze alloys and the comparable working methods for both metals, technical-scientific studies, coupled with interpretations of the abundant depictions of gold and other metalworking activities found in Theban tombs, paint a rather precise picture of the evolution of techniques and procedures for precious-metal working in ancient Egypt.

Depictions of various metalworking techniques date back as early as the Old Kingdom (e.g., Davies 1902: 10, pls. 10, 19, 24). Over time, details in these depictions reveal technological innovations, such as the

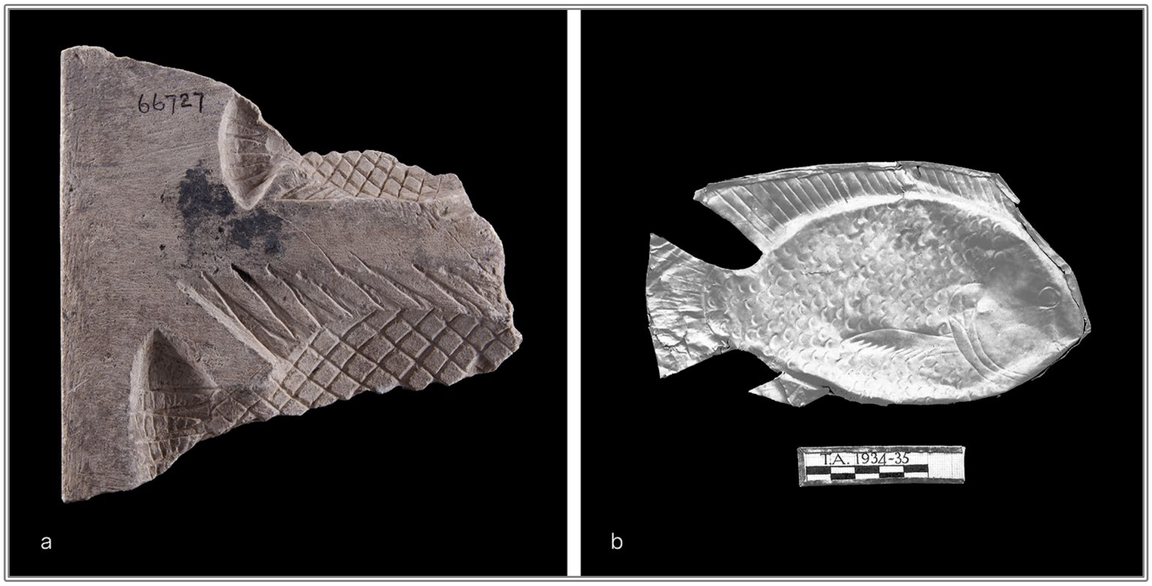


Figure 18. a) Limestone mold with fish motif. The metals used in the molding are unknown. b) A three-dimensional fish made of two gold sheets.

Figure 19. a) Detail of the gilded fingernails on the statue of Pepy I. b) Wooden statue of Amenhotep III featuring a temple band and remnants of the lost uraeus highlighted in gold (over gesso).

introduction of bellows alongside blowpipes to supply the necessary oxygen for the fire—a practice observed from the New Kingdom onwards (see fig. 23; Drenkhahn 1976: 30; metalworking depictions are conveniently summarized and discussed in a comprehensive overview by Quirke 2023: 57-67).

The "language of artists" (Quirke 2018) and the professional titles associated with the goldsmith's trade (Quirke 2004; 2023: 37-45; tables 2.6-2.7, 2.9, 2.11, fig. 2.7; for copper, see Eccleston 2007 and Odler 2023: 67-96) also provide us with valuable information on the structure of workshops, production processes, and the division of labor. Some individuals in this field are even identified by name (Ward 1982: 99, no. 824; Quirke 2023: 45-57, tables 2.12-2.16, figs. 2.9- 2.14).

Both hot- and cold-working techniques may be used in shaping, joining, and decorating metals. Predynastic finds of precious metals in Egypt were primarily made of small sheets, forged (cold) from metal nuggets that were rolled into beads and rings.

The production of many objects, as well as the metal plating of artifacts, required the casting of numerous ingots, which were then hammered into sheets and foils of varying thicknesses.

The forging of precious metals is a cold forming technique in which metal sheets are "kneaded" (Armbruster 2000: 91) between a hammer and anvil to attain the desired shape. Egyptian wall paintings generally show the use of fist-sized, unshafted stone hammers for this purpose (see fig. 12, bottom right). Forging flat sheets of uniform thickness is a challenging task that demands great skill and effort, despite the monotonously repetitive nature of the work. Working the thinner sheets into foils is even more challenging; however, anciently, gold beaters did not necessarily need expertise in other goldsmithing techniques. Many objects were decorated with precious metal foils, used for techniques like gilding or silvering. Notable examples include the furniture of Queen Hetepheres; the life-size copper statue of Pepy I, the earliest such example known (fig. 19a) (Quibell and Green 1902: 27; Eckmann and Shafik 2005: 50, color figs. 18-19, 22-24); the coffins of Kha and his wife Merit (Ferraris 2018); a wooden figure of Amenhotep III (fig. 19b) (Fazzini et al. 1989: cat. No 44); and the small, golden (gilded) shrine on a silvered sledge from the tomb of Tutankhamun. These metals are often referred to, albeit inaccurately by today's standards, as metal leaf, typically with a thickness of no more than 0.1 μm in modern usage. As a practical rule of thumb, modern metal leaf exhibits a degree of translucency when transmitting light, whereas foil does not; metal sheets are strong enough to support their own weight.

The foils and sheets could be fixed using glues, and often the sheets were additionally hammered or pressed into channels scored into the surface of objects. They could also be glued onto an additional layer of gesso, as seen on the remains of the pleated kilt of the copper statue of Pepy I (Eckmann and Shafik 2005: figs. 18-19), sometimes combined with a layer of textile (see, e.g., Markowitz, Lacovara, and Hatchfield 1997). In Egyptology, the term "gesso" is a vague, general designation, typically comprising calcium carbonate or calcium sulfate mixed with an organic binder (Hatchfield and Newman 1991). Although in Egypt this material is primarily associated with wooden or other non-metallic bases (e.g., Rifai and el Hadidi 2010: 18; Abdrabou et al. 2019: 14-15; Broschat, Eckmann, and Mertah 2024), it has also been documented for gilding copper alloy or bronze items (Lucas and Harris 1962: 32; Oddy 1981: 77, fig. 3; Oddy, Pearce, and Green 1988).

The thickness of gold sheets or foils ranges between 1 μm and 50 μm (e.g., Berthelot 1901: 160-161; 1906: 22; Nicholson 1979: 162; James 1972: 41; Hatchfield and Newman 1991: 31, table 1; Rifai and el Hadidi 2010: 21; Abdrabou et al. 2018: 553-564; Abdrabou et. al. 2019: 14-15), with gold beaters able to produce foils and sheets measuring at least 57 cm x 52 cm during the time of Tutankhamun (Broschat and Eckmann eds. 2022: 70, note 131). Scenes from the tomb of Baqt III, at Beni Hassan, show the gilding of various types of objects (Newberry 1893b: 47, pl. 4; Darque-Ceretti et al. 2011).

Thicker sheets and ingots were fashioned into jewelry, bowls, and vessels, and particularly large objects like Tutankhamun's burial mask or the silver coffins of Psusennes I and Shoshenq II (fig. 20), usually composed of multiple pieces (Broschat and Eckmann eds. 2022: 85-87; Eckmann, Broschat, and Hardwick 2023: 42-44). This process involved raising or sinking the metal, as well as the use of various tools and techniques.

Unlike forging, metals could also be shaped by chasing, for instance, to create relief decoration. This process involved reshaping the metal by first placing blunt chisels and/or

Figure 20. The silver Horus coffin of Shoshenq II.

Figure 21. a) Putty or chaser's pitch used for the chasing of a *repoussé* work featuring the positive imprint of the king and his spouse. b) *Repoussé* work in silver: fragment of a bowl attributed to General Djehuti. c) *Repoussé* work in gold; detail of the animal fight scene on the scabbard of Tutankhamun's golden dagger.

various punches on the surface of the working piece and then molding it with repeated blows of a driving hammer. Putties, easily heated masses that harden when cooled but can still be shaped by applying pressure, were useful for securing sheets or working pieces in place during the working process (fig. 21a) (e.g., Hackbeil 2012: 270, cat. 47). A raised motif (*repoussé*) was worked into the metal mainly from the back, although some areas needed to be alternately lowered again from the front.

Most shaping processes require intermediate annealing (heating the working piece to several hundred degrees; Brepohl 2001: 164). This causes the deformed crystal structure to recrystallize and the metal structure to recede, while retaining the shape already achieved. It prevents the metal from becoming brittle due to plastic deformation and keeps it pliable and easily malleable.

The use of this technique can be seen, for example, in scenes depicting metalworking in the tomb of Wepemnefret at Giza (5th Dynasty, 2480 – 2349 BCE), as suggested by the command "Boil that" and the statement "It is hard" (Hassan 1936: 192-193, fig. 219; Drenkhahn 1976: 33). Similar scenes include those in the tomb of Tiy at Saqqara (Montet 1925: 284-285) and in the tomb of Khety at Beni Hassan (Newberry 1893a: pl. 14; Wild 1966: pls. 66, 71).

In *repoussé* pieces, blunt chisels and punches were used not only for chasing well-defined contours but also for intricately embellishing motifs with delicate details and patterns. For instance, a line could be drawn by moving a

Figure 22 a) Filigree and granulation on the golden dagger of Tutankhamun, with the wire displaying clear signs of being twisted from a small strip or sheet of gold. b) The necklace for the small amulet of Isis is made from wires. c and d) Some of the loops used to attach the medallion of Khnumit have rather straight lines along the wires, suggesting they were made by folding or rolling.

punch along an imaginary line and repeatedly striking it with a hammer, while decorative punches were driven (punched) into the metal with a single blow, resulting in an embossed negative impression of the punch tip.

The combination of these processes produced complex reliefs. Examples from the New Kingdom include a decorated silver bowl (fig. 21b) attributed to General Djehuti (1479 – 1425 BCE) (Lilyquist 1988: 5, 16-17, 22-38, no. 17, figs. 28-54), and an animal fight scene on the scabbard of Tutankhamun's golden dagger (fig. 21c). These techniques displace and compact the metal but do not remove any material.

In engraving, the metal is removed locally, partially by grinding (Broschat et al. 2022: 9, fig. 8) or by using sharp chisels to cut small chips out of surfaces (Broschat 2024: 81-83). With rare exceptions, engraving was not widely used before the first century BCE, when iron processing allowed for the production of effective tools for that purpose (see also Ogden 2023: 95-96).

Figure 23. Casting activities from the tomb of Rekhmira (after Davies 1935: pl. XXIII).

Narrow strips of sheet metal or foil were essential components of Egyptian goldwork, being processed into wires using various techniques. Wire production has been extensively discussed (Williams 1924: 39-44; Carroll 1970, 1972; Oddy 1977, 1987, 2004), with a basic distinction between wires made by hammering square rods into a rounder shape and those made by rolling or twisting thin metal strips or rods. The latter are recognizable by the thin lines that run diagonally along the wires. Rare examples also show signs of being strip-drawn (Oddy 1977; Troalen et al. 2009: 117-118; Guerra and Pagès-Camagna 2019: 146, fig. 4). Wires, made into small rings or loops, were used to connect individual parts of an object (Troalen et al. 2009: 117-118, fig. 6) and crafted into elaborate chains or delicate filigree works (fig. 22a-d).

In addition to producing rings and ingots from the raw materials for transportation, melting and casting were also important aspects of secondary processing (Schorsch 2007b: 188-199; Leusch et al. 2015; Ogden 1982: 71-88; Loeben, Raue, and Wallenstein eds. 2014). Nearly all depictions of gold- and other metalworking operations feature these techniques (fig. 23) (see, e.g., Scheel 1985: 117-177).

Apart from using open molds, primarily for creating blanks that could be further worked into an object, or bivalve molds for simpler shapes like rings, various lost-wax casting (*cire perdue*) techniques (e.g., Roeder 1933; Schorsch 1988; Bianchi 2014; Fitzenreiter et al. eds. 2014; Fitzenreiter, Willer, and Auenmüller eds. 2016) were used in manufacturing, for example, figurative objects (Roeder 1956; Tiribilli 2018). A set of molds and semi-finished products serve to illustrate these processes (Fitzenreiter, Willer, and Auenmüller eds. 2016). The stela of the Overseer of Artisans Irtisen may allude to this technique and imply the transfer of expertise from father to son (Fitzenreiter 2019; Fischer-Elfert 2002).

The primary distinctions in the range of lost-wax casting techniques depend on whether the object is intended to be solid or hollow. For instance, to cast a solid metal statuette, a wax model is made and then encased in clay (or another molding material), with at least one aperture to allow the (melted) wax to flow out of the mold as it heats up. Hot metal is then poured into the resulting hollow mold. Complex shapes require additional openings, such as funnels, to ensure complete filling of undercut areas and/or to allow air to escape from the mold. Once the metal has cooled, the molds must be destroyed to extract the objects. Nevertheless, creating several wax models of the same type still enables efficient mass production.

To make hollow statues and objects, a core is added to the mold. In this instance, the wax

Figure 24. a) Stick from Tutankhamun's tomb, meticulously decorated with filigree, granulation, and inlays. b) Cylinder bead showing granulation in a zigzag pattern, with many small granules lost due to damage or wear. c) Star(fish)-shaped pendants on a necklace from Khnumit, made using wires and granules in open work. Some granules melted due to excessive heat during soldering, others were lost.

is modeled onto a core that roughly matches the shape of the object but is reduced by the intended wall thickness. Depending on the shape, a few or many small spacers ("chaplets") must be added to the core to hold it in place against the mold after the wax melts away. The subsequent casting process remains the same. After the metal has cooled, the cores are typically removed through (for example) an opening at the base, although this is not always the case. Additional metal inserts may need to be fixed in the remaining openings after the spacers are removed, depending on the material they are made of, such as ceramic. If the spacers are made of the same metal as the object, this is not necessary, but in both cases, the metal spacers or inserts may remain recognizable on the surface of an object, depending on the finishing work (Schorsch and Frantz 1997 – 1998; Hill and Schorsch 2005: 170-175, figs. 13b, 15, 16-18, 20).

The variety of natural alloys available in Egypt suggests that goldsmiths were skilled in distinguishing between them based on their sensory and aesthetic characteristics, as well as their physical properties (e.g., melting points, hardness). Melting and mixing techniques also enabled them to create custom artificial alloys tailored to these properties (Rehren et al. 2022a: 158-159, 162, 168, figs. 111-113) or to achieve a metal of a different color (Saeger and Rodies 1977; Guerra 2023b; Guerra, Martinón-Torres, and Quirke 2023: 228-232).

Documented in Egypt since at least the Middle Kingdom, the widespread use of hard solders, usually gold-copper alloys in the form of pallions (small pellet-like pieces), facilitated the creation of material bonds between separate gold parts of an object (Roberts 1973; Schorsch 1995; Tate et al. 2009; Troalen, Tate, and Guerra 2014; Lemasson et al. 2015; Troalen and Guerra 2016; Guerra and Pagès-Camagna 2019). These solders act as fillers (see, e.g., Guerra and Meeks 2023: 284-285, figs. 8.41-8.43) and must have a lower melting point than the metals they join. To assemble more complex objects, alloys with higher melting temperatures must be used first, with subsequent soldering performed using lower-melting compositions to prevent the de-soldering of already closed joints.

Material bonds could also be achieved through colloidal soldering, using copper-bearing minerals or copper salts mixed with a binder or glue and applied to the connecting parts. When subjected to a charcoal fire, these substances are reduced to metallic copper, which alloys with and diffuses into the adjoining gold parts, creating the bond. This technique leaves the metal parts attached to each other without any filling effect; in some cases, slightly reddish hues may appear on the metal surfaces.

Colloidal soldering was mainly used to fix small gold wires (filigree) and spheres (granulation) onto the surfaces of an object (fig. 24a-b; also see fig. 28a-b) or to create open-work granulation and filigree (fig. 24c; also see fig. 21c), typically for joints not subjected to significant stress (Wolters 1981; Ogden 2000: 165; Troalen et al. 2009: 117, fig. 5; Broschat et al. 2022: 18-19, 35, figs. 21-23, 25, 28-30a+b, 32-35, 45, 46).

Middle Kingdom cylinder amulets (see fig. 24b; Andrews 1990: 173, fig. 155a; Müller and Thiem 1999: 98, 100, figs. 191-193) already feature granulation, which involves adding details and creating surface reliefs using the small metal spheres, known as "granules" (Wolters 1981; Nestler and Formigi 2004).

Granules were usually made by melting small pieces of sheet metal or wire on charcoal, causing surface tension to shape them into small spheres. If necessary, they were then sorted by size, a process that may have involved sieving with various sieve apertures. Granules were commonly arranged in geometric patterns, such as triangles, diamonds, or zigzags, as well as small hieroglyphs and/or figurative and floral motifs (see figs. 22a, 24a-b).

Undeniably, pharaonic Egypt aspired to create a colorful universe in both life and afterlife, the penchant for polychromy evident in ancient Egyptian texts, representations, and archaeological findings (e.g., Petrie 1914: pl. XlVIII; Eschweiler 1994: 249-250; Müller-Winkler 1987; Andrews 1994: 100-106; Dubiel 2008: 59-64, 179-189). Each color had a special value within the Egyptian system of relationships, capable of evoking "the idea of divine beauty in a coded language" (Aufrère 2001: 158). For this reason, precious metals were often combined with colored stone inlays and so-called Egyptian faience, and from the New Kingdom onward, also with glass. These inlays were set in prefabricated recesses in the metal (fig. 25a) or in small cells (*cloisons*) made by soldering small strips of metal in the shape of the detail onto a base plate (fig. 25b; see also figs. 5, 9, and 24a), thus creating the compartments for the inlays. Both techniques are commonly referred to as *cloisonné*, although the former is actually closer to *champlevé*. Both terms are problematic as they technically refer to the use of enamel, which is a type of powdered glass melted directly into recesses or cells. However, this hot-working technique was not common in pre-Ptolemaic Egypt (Teeter 1981; Andrews

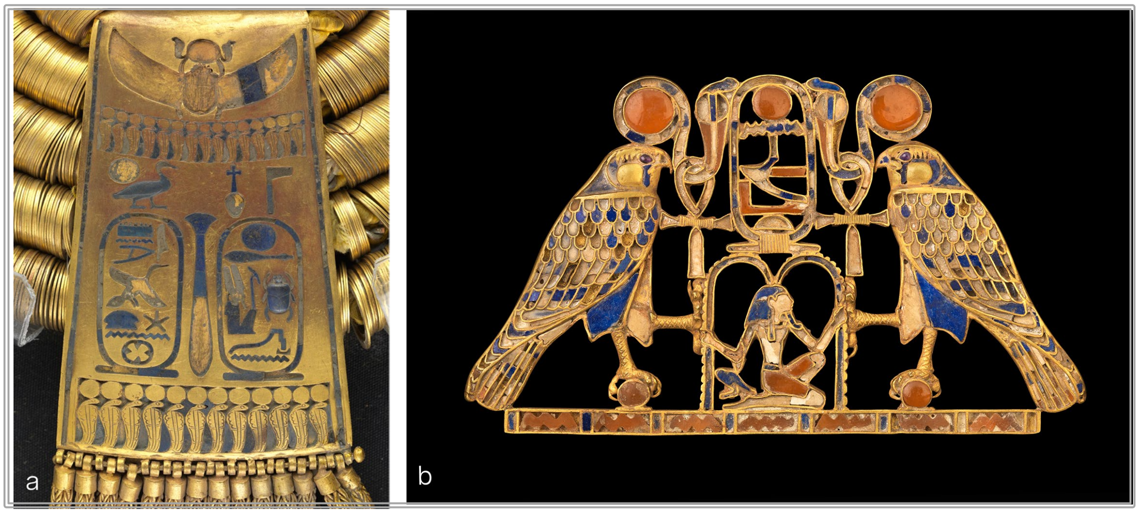


Figure 25. a) Detail from the collar of Psusennes I, with inlays set into recesses in the gold. b) Detail of Sithathoryunet's pectoral, showing small strips of gold soldered vertically onto a base gold sheet to create cells for the colored inlays.

Figure 26. a) This bracelet is crafted in the style of *opus interrasile*, an open-work technique where details are cut out of a metal sheet. However, due to the use of different alloys, the small figures and amulets had to be individually produced and then soldered onto the adjacent gold bands.

Figure 26. b) This 24-cm-high, partially gilded silver statue was found in the Temple of Amun at Karnak.

Figure 27. a) The combination of highly polished silver and brightly shining electrum seems to hinder the readability of the inscription on this scarab from the tomb of Wah, suggesting that the silver was originally intended to have a dark gray satin sheen to enhance the contrast. b) A crocodile figure featuring sparkling gold details and scales.

1990: 82; Müller and Thiem 1999: 153; Ogden 2000: 166). Details and inscriptions were also often highlighted in color, as seen on the back of Tutankhamun's burial mask, where the chased signs were once filled with Egyptian Blue pigment (Broschat and Eckmann 2022: 201, fig. 79).

Metal polychromy, the intentional combination of metal alloys of different colors, "exploits the decorative, colouristic and symbolic values of gold and silver" (Schorsch 2001: 58; La Niece et al. 2002), as demonstrated in an unprovenanced bangle made of these metals (fig. 26a) (Andrews 1990: 55, pl. 39b) or in much of the jewelry found in Tutankhamun's tomb (Schorsch 2001: 63-70; for the use of gold alloys with different colors see Guerra 2023b). On small silver statuettes like that of Amun-Ra, gilding typically highlights and embellishes clothing, headdresses, or insignia (fig. 26b). A small number of finds, like the recently found mask from Saqqara (see fig. 11), were made of silver that was completely gilded; another example is the allegorical representation of a falcon-headed god with "silver bones, golden flesh, and hair of lapis lazuli," where the body parts were made from silver that was once also gilded (Hill and Schorsch 2021). A similar feature can be observed on a pectoral (Lacovara 1990; Newman 1990), where the remaining visible parts of the silver strips used to create the cloisons were gilded. In other examples, these strips were made from gold and soldered onto a silver plate (Schorsch 2001: 60-61). In all these cases, the silver remained concealed. Strictly speaking, this should be regarded as "invisible" or "clandestine" metal polychromy, although its meaning and intended purpose are not yet fully understood, and the applicability of the aforementioned magical-religious associations is not certain.

One of the silver scarabs from the tomb of Wah bears an inscription on its wings, elaborately made by inlaying electrum into the surface (fig. 27a), making it the earliest known example of damascene, i.e., the inlaying of different metals into one another (Aldred 1971: 183-184, pl. 21; Schorsch 2001: 59-60, note 18, pl. VIII/1). During the Late Middle Kingdom, various iterations of this technique were also used to inlay precious metals into objects of patinated black copper (*ḥmt km* or *bjꜣ km*; described as *Corinthium aes* in the Ptolemaic and Roman Periods), exemplified by a 12th Dynasty statuette of a crocodile (fig. 27b) inlaid with electrum (Schoske 1995: 50-51, fig. 51; Giumlia-Mair 1996, 1997, 2020; Giumlia-Mair and Quirke 1997: 98, pl. IXa; for more general information, see Giumlia-Mair and Craddock 1993).

An interesting color phenomenon is Egyptian Red Gold, which mostly results from corrosion, leading to the formation of a thin film of silver-gold sulfide minerals on the

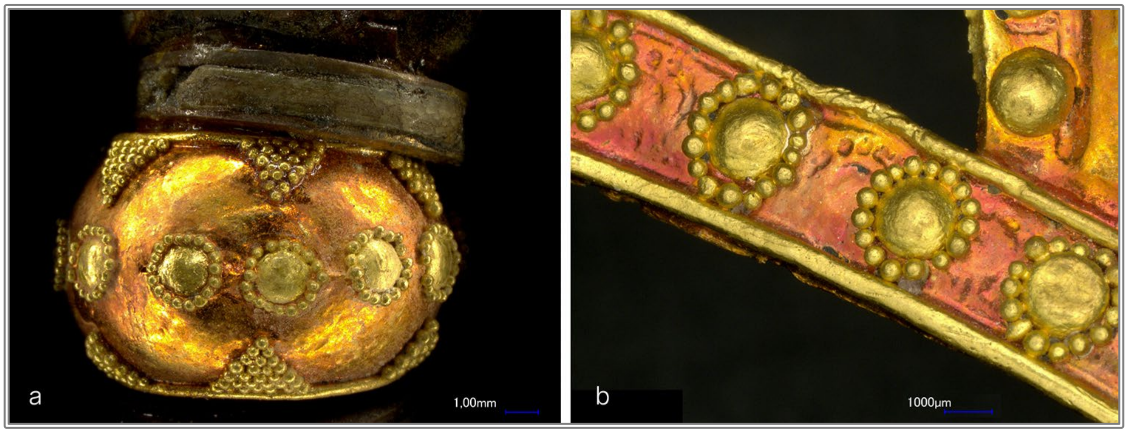


Figure 28. a) A small gold bead with granulation on an earring, accentuated by the pink sheen of the base gold. b) Detail of one of the plaques from Tutankhamun's tomb, showing a shift from pink to cherry-red as the reddish layer thickens. The higher the uniformity of the spheres and the greater the number of granules, the more the objects appeal to modern eyes in terms of quality and aesthetics.

surface of gold (Lucas 1927; Frantz and Schorsch 1990; Rifai and el Hadidi 2010: 21-23; Abdrabou et al. 2018: 559-560; 2022: 47; Tissot and Guerra 2023). On Tutankhamun's shrines, for example, the arrangement of gold foils (composed of differing alloys) in a tile-like pattern is easily recognizable by the varying fortuitous discolorations (see, e.g., Piankoff 1955: pls. 23, 37, 39).

Egyptian Red Gold differs greatly from what is known as Pink Gold (or Purple Gold), which is primarily found among the belongings of Tutankhamun, with a few exceptions (Schorsch 2001: 67, note 74). It is the result of deliberate and sophisticated color manipulation, typically employed in combination with granulation (fig. 28a-b). Experimental work has shown that this effect can be achieved by adding iron to small quantities of molten gold (Wood 1934; see also Plenderleith and Werner 1971: 215-216; Frantz and Schorsch 1990: 147, note 12). However, the process is not yet fully understood. The resulting reddish layers can vary in thickness from very thin, resembling patination, to significantly thick, even separating from the gold in some cases.

The process of cupellation, typically used in metallurgy and refining, serves to separate an alloy into its constituent base metals and gold and/or silver, thereby increasing the values of the precious metals present in the alloy (Pernicka, Rehren, and Schmitt-Strecker 1998). This procedure is exemplified in the extraction of silver from lead ores (Wood, Hsu, and Bell 2021).

An important innovation in metal refining was the development of cementation processes, which, particularly in the case of gold alloys, separate the silver (and base metals) from the gold (Ramage, Craddock, and Cowell 2000; Craddock, Guerra, andCowell 2005; Berger et al. 2021). Their early use has been discussed based on textual evidence (Forbes 1965: 173-174; Notton 1974; Hauptmann 2022: 327), but until further evidence emerges, we must assume that the separation or refining of gold was not invented until the seventh century BCE in Lydia, Western Anatolia (Ramage, Craddock, and Cowell 2000; Craddock, Guerra, and Cowell 2005). Late Bronze Age gold objects with very low silver content are known, but they are presumably due to the exploitation of Neogene deposits (Guerra and Rehren 2009; Nixon, Rehren, and Guerra 2011).

Another radical improvement occurred with the importation of mercury gilding from East Asia. Also known as fire-gilding, this process involves applying an amalgam, a mixture of gold and mercury, onto a metal surface. The mercury is then evaporated by heat, leaving a film of gold on the metal. In Roman times, it became the most common method of gilding silver or copper alloys in the Mediterranean world and remained so until the early modern period (Lins and Oddy 1975; Oddy 1981, 1991).

5. Value and Perception

The various interpretations of the term "value" and the various perspectives of "perception" become apparent when comparing a bar of gold to a sacred relic or to the cherished knick-knacks in one's childhood treasure box. However, the exact delineation between economic or "monetary" and socio-religious values, and the meanings of precious metals in ancient Egyptian society, is only vaguely understood.

Ancient texts suggest that the distinction between gold, electrum, and silver evolved gradually (conveniently summarized from Harris 1961: 32-50 by Schorsch 2001: 56). Initially, a single word, *nbw*, was used interchangeably for gold, silver, and electrum until the early 4th Dynasty. Subsequently, it exclusively referred to gold until the New Kingdom, when specifications regarding origin (e.g., *nbw n ḫꜣs.t*, "gold of the desert"), form (e.g., *nbw m ḳnḳn*, "gold in lumps"), color (e.g., *nbw wꜣḏ*, "fresh or green gold"), or the quality of a batch (*nbw nfr*, "the good/pure gold") were added (see also Bulsink 2015: 22-23).

These specifications highlight a distinction between various qualities, yet it remains unclear whether and how this distinction relates to, or results from, value assignments at the time. Sparse references in the letters of the Kassite King Kadašman-Enlil II (c. 1263 - 1255 BCE) and his successor Burna-Buriaš II point to gold alloys of "lesser quality" (Moran 1992: 66-68 [EA 3], 73-78 [EA 7], 82-84 [EA 10]), but it is debatable whether this reflects the Egyptian perspective on their social and/or economic value.

From the 5th Dynasty onwards, electrum alloys were referred to as *ḏꜥmw*, a term that gradually lost its meaning during the New Kingdom when other criteria and terms were used to make distinctions. Metallurgically, this term likely denotes the most commonly used natural gold alloys in early ancient Egypt, potentially explaining the complexity of reconciling our modern metal definitions with the ancient classification and perception of precious metals. However, scenes in the tomb of the official Puimra suggest that about a hundred years before the Kassite kings complained about the quality of Egyptian gold, Puimra might have known how to calculate the gold and silver content of electrum (Pommerening 2007).

Initially, there was no distinct Egyptian word for silver. However, in the 4th Dynasty, the term *nbw ḥḏ*, meaning "white gold" or "colorless precious metal" was established. It was abbreviated to *ḥḏ* by the 5th Dynasty, when *ḏꜥmw* was introduced to denote silvery gold alloys like electrum (Gardiner 1927: 492, 576, 586, 591; Sherratt 2018: 98). The use of the same determinative, commonly referred to as a collar (Gardiner Sign List S12), in their names suggests that precious metals were perceived as variations of the same basic substance. Lepsius had already suggested that the sign did not represent a necklace but rather a type of bag/pouch or folded cloth from which water used to wash gold would dribble out (Lepsius 1872: 31). Aufrère picked up and endorsed this idea, suggesting that it could also be a gold-washing table/frame covered with cloth (Aufrère 1991: 353-354).

Silver must have been highly valued in ancient Egypt and consequently preceded gold in commodity lists until the Middle Kingdom (Harris 1961: 32-33, 41-42). The gold-to-silver ratio remained relatively stable at 2:1 during the New Kingdom (Černý 1954). It became the standard material for a unit of value by the first millennium BCE (Lucas and Harris 1962: 247; Jurman 2015: 60), although it competed with gold, which was also the primary standard of exchange at various times (Moreno García 2016: 21; Muhs 2016: 75-76).

Precious metals were not coined in Egypt before the fourth century BCE (see fig. 8a-b). However, they served as a medium of ex-

Figure 29. Facsimile of a scene from the New Year festival in the tomb of Panehsy (TT 16) depicting a procession from the gold-decorated temple of Amun.

change and were used to determine value, weighted according to the weight standards of ***dbn*** and *ḳdt* (Rossi 2007; Lepsius 1872: 40-43, 45, 51; Harris 1961: 41-42; Janssen 1975: 101-111; Černý 1954: 904-906). In the Annals of Thutmose III, ingots and sheets of copper, as well as ***dbn*** and ***ḳdt*** units of lead, along with gold, silver, and bronze scrap are mentioned in the list of "offerings" from Isy/Asy (probably Cyprus) and "benevolent gifts" from Retenu (in Upper Syria), attesting to the existence of various metal units (Redford 2003: 82, 247, 250).

Silver bowls from the fourth century BCE feature their weight inscribed in Demotic script, indicating their metal value (Lansing 1938: 199-200, fig. 1; Vleeming 2001: 7). However, it is also plausible that these inscriptions served as a guide for weighting their possible contents.

Beyond their value for trade and exchange, precious metals are "spectacularly impractical" in the sense that, due to their being too soft, they cannot be fashioned into functionally useful objects like tools or weapons. This characteristic renders them luxury materials in the truest sense—"something desirable but not indispensable"—reserved "for gods, kings, and lesser mortals to show off and hoard" (Sherratt 2018: 97-98).

We are acquainted with the "Gold of Honor" bestowed by the pharaoh upon his subordinates, especially officers, officials, expedition leaders, and members of the royal house (Müller and Thiem 1999: 142; Binder 2008). We have knowledge of the so-called House of Gold, where, contrary to its designation, not only gold but other materials were worked and stored (von Lieven 2007), and we are familiar with the king who rode in a chariot made of gold towards the rising sun (Lichtheim 1976: 32). We also recognize that architectural elements such as doorjambs, columns, and parts of wall decorations, as depicted in a scene (fig. 29) from the 19th Dynasty tomb of Panehsy at Thebes (Wilkinson and Hill 1983: 145), were decorated with gold. Moreover, obelisks were either made of or covered with precious metals, contributing to the country's splendor (see e.g., Davies 1922: 97, pls. XXXIX; L. Gabolde and M. Gabolde 2015: 89). However, jewelers and architects were not merely concerned with displaying wealth and/or elitist ostentation. Rather, they sought "the vital, unchanging, and eternally youthful contribution" (Daumas 1956: 17) of the divine metal, which was often invisible to the lay public.

Because of gold's resistance to corrosion, which makes it immune to the effects of time, the ancient Egyptians regarded it as close to the divine. They primarily associated gold with the sun and solar deities, and the concept of rebirth (Aufrère 1991: 353-406). Understandably, when the status of the pharaohs— positioned between deity and mortal—was threatened by death and decay, the rulers' bodies were secured in golden caskets, with almost everything around them gilded. Even in Roman times, the bodies (or parts) of mummies were considered the "flesh of the Gods" and gilded (Ikram and Dodson 1998: 130).

Tomb inscriptions, known as the "Addresses to the Living," served as warnings to potential intruders about the negative consequences of their actions in both this world and the hereafter (e.g., Müller 1975; Edel 1984), reflecting the prevalence and social condemnation of tomb robberies. However, by the end of the New Kingdom, the Egyptian state's high demand for gold seems nevertheless to have been met by the treasures deposited in the tombs (Taylor 1992).

On the other hand, due to its pale hue, silver (and possibly most electrum) was associated with the moon (in contrast to the golden sun) and linked to the god Thoth. It was used to fashion items showcasing the lunar disc and associated with ceremonial purity, as well as the bones of the gods (Aufrère 1991: 409-423; Lacovara and Markowitz 2001: 287). The components of these metals evoked an evolutionary stage occurring at night as the sun traversed the underworld.

Hence, to possess or govern minerals and metals, like the pharaohs, was to wield power over the gods, or at least a "strong power of divine suggestion" (Aufrère 1997: 113). Given their divine nature, minerals and metals represented an integral part of the gods themselves "from the point of view of the metaphor, which was elaborated to the point that the gods were represented in precious materials" (Aufrère 1997: 114; on the limits of this metaphor, see Hill and Schorsch 2021).

At least, this is what we may imagine when endeavoring to adopt an emic perspective, seeking to perceive these precious metals and objects through the lens of the ancient processors and/or recipients.

Bibliographic Notes

Only a few books provide comprehensive coverage of precious metals in ancient Egypt, but two stand out as valuable resources for those interested in exploring this subject further. One of the foremost studies in this field is authored by Guerra, Martinón-Torres, and Quirke (2023), providing a voluminous discussion of various topics related to gold, including recent analytical investigations of different objects and groups of finds, and Andreas Hauptmann's book (2022) provides an extensive overview of archaeometallurgy, including other metals. Mary Malainey (2012) and Mark Pollard et al. (2007) offer valuable insights into analytical techniques and methods. Classics on jewelry and other gold- and silversmith's work include publications by Cyril Aldred (1971), Carol Andrews (1990), and Alix Wilkinson (1971). For a focus on materials, refer to Alfred Lucas and John Raymond Harris (1962) and Jack Ogden (2000). For mining and mining sites in Egypt refer to Rosemarie and Dietrich Klemm (2013). Johannes Auenmüller (2020) provides a convenient overview of the organization of gold mining and mining sites during the New Kingdom. The substantial use of precious metals in pharaonic architecture, though not sufficiently tangible in this article (and generally), merits special consideration due to the lack of preservation of these metals and their subsequent invisibility. Pierre Lacau (1949, 1956) and Luc and Marc Gabolde (2015) provide intriguing overviews of this topic, supported by numerous literary sources. For a recent comparison of gold and silver values over almost three millennia, see James Ross and Leigh Bettenay (2023): While the text contains additional references, presented as examples, the extensive literature on precious metals and objects in Egypt is intentionally streamlined to ensure readability; however, the selected literature includes both primary and secondary sources, consistently referenced throughout, facilitating a seamless progression to more in-depth studies.

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Figure 1. Gold spoon from a child's tomb at Hierakonpolis, 8.5 cm long, the Fitzwilliam Museum (E.5.1900). (Photograph © The Fitzwilliam Museum, University of Cambridge.)

Figure 2. The gold-headed falcon standard of Pepi I, the Egyptian Museum in Cairo (CG 14717 and 52701, the head and crown respectively; SR 8263 and TR 8/2/15/3). (Photograph by Peter Windszus, Deutsches Archäologisches Institut, Abteilung Kairo.)

Figure 3. Leopard-head girdle of Sithathoryunet, circumference of 81 cm, the Metropolitan Museum of Art (MMA 16.1.6-.15). (Photograph: Purchase, Rogers Fund, and Henry Walters Gift, 1916.)

Figure 4. Necklace with three large golden flies from the tomb of Ahhotep at Dra Abu el-Naga, the Egyptian Museum in Cairo (JE 4694) (temporarily at the Luxor Museum). (Photograph by Sandro Vannini.)

Figure 5. Front view of the golden diadem placed within the mummy bandages on the head of Tutankhamun. Originally worn by the king during his lifetime, its design was modified by adding the vulture head for his burial, the Egyptian Museum in Cairo (JE 60684). (Photograph by Christian Eckmann, Leibniz-Zentrum für Archäologie, courtesy of the Egyptian Museum in Cairo.)

Figure 6. Golden bowl from the Tomb of Psusennes I, the Egyptian Museum in Cairo (JE 85897). (Photograph by Sandro Vannini.)

Figure 7. This 17.5-cm-high gold statue shows Amun standing in the traditional pose with left leg forward, cast in solid gold, the Metropolitan Museum of Art (MMA 26.7.1412). (Photograph: Purchase, Edward S. Harkness Gift, 1926.)

Figure 8. Both sides (a and b) of a gold stater depicting: a) a horse and b) a collar(?), the lung-sign signifying "pure gold," Museum August Kestner (1930.141). (Photographs by Christian Tepper, © Museum August Kestner, Hannover, Germany.)

Figure 9. A restrung necklace (British Museum EA 3077), 46 cm long, probably from the Middle Kingdom, with electrum cowrie-shell beads and various pendants. The cowrie beads contain little spheres that jingle when the necklace is worn. (Photograph © The Trustees of the British Museum.)

Figure 10. a) Massive (17 cm) silver adze from Ballas, Tomb 39, now in the Petrie Museum of Egyptian Archaeology (LDUCE-UC5477). (Photograph courtesy of The Petrie Museum of Egyptian Archaeology, UCL.) b) The *pesesh-kef* amulet, made of silver and meteoritic iron, is the only known artifact from pharaonic Egypt to combine these two metals, the Egyptian Museum in Cairo (JE 47314). (Photograph by Christian Eckmann, Leibniz-Zentrum für Archäologie.) c) This utilitarian mirror, likely used by Princess Sithathoryunet in her daily life, showcases exceptional design and craftsmanship, with its reflecting disc made of silver, the Egyptian Museum in Cairo (JE 44920). (Photograph by Sandro Vannini.) d) Mirror case shaped like an *ankh* from Tutankhamun's tomb, decorated with gold foil on the exterior and silver foil on the interior, the Egyptian Museum in Cairo (JE 62349). (Photograph by Sandro Vannini.)

Figure 11. Rendering of the 3D-model of the newly discovered gilded silver mask from Saqqara before restoration. Saqqara 19754, currently in the Egyptian Museum in Cairo. (Image © Matthias Lang and Philippe Kluge, Bonn Center for Digital Humanities.)

Figure 12. Various metal-shaping methods as shown in the tomb of Rekhmira. (Drawing by Michael Ober, Leibniz-Zentrum für Archäologie, after Davies 1935: pl. XXIII.)

Figure 13. Graph comparing the copper and silver content of different Bronze Age Egyptian assemblages: the gold burial mask and innermost coffin of Tutankhamun and selected jewelry from Qurna. The silver content is considered natural, with higher levels likely indicating freshly mined gold, while lower levels are often found in placer gold. The copper content is most likely due to metallurgical activities such as soldering and recycling. Data from Rehren et al. (2022 a, b) and Troalen, Tate, and Guerra (2023: 320-321, table 9.1). (Graph by Thilo Rehren.)

Figure 14a. An official presents gold and silver ingots alongside other valuable commodities. (Drawing by Michael Ober, Leibniz-Zentrum für Archäologie, after Davies 1935: pl. XLVII/3.)

Figure 14b. The weighing of gold and silver. (Drawing by Michael Ober, Leibniz-Zentrum für Archäologie, after Davies 1935: pl. XLVII/3.)

Figure 15. A selection of silver objects, discovered in a hoard at el-Amarna, feature geometric patterns on the ends of the coils, the British Museum (EA 68503). (Photograph © The Trustees of the British Museum.)

Figure 16. The fragmented so-called "Goldmine Papyrus," the oldest known surviving map from ancient Egypt, depicts Wadi Hammamat on the recto, with several texts on the verso, Museo Egizio, Turin (1879+1969+1899+2083/174+2083/182). (© Photograph by Federico Taverni/Museo Egizio.)

Figure 17. New Kingdom ruins at Wadi Naba, Sudan, with oval stone mills and a central sloping washing table (arrow). Referenced from D. Klemm and R. Klemm (2016: 533, fig. 6185). (Photograph courtesy of Rosemarie Klemm.)

Figure 18. a) Limestone mold with fish motif. The metals used in the molding are unknown. Egyptian Museum in Cairo (JE 66727). (Photograph by the author, courtesy of the Egyptian Museum in Cairo.) b) A three-dimensional fish made of two gold sheets, the Egyptian Museum in Cairo (JE 64982). (Photograph courtesy of The Egypt Exploration Society.)

Figure 19. a) Detail of the gilded fingernails on the statue of Pepy I, the Egyptian Museum in Cairo (JE 33034). (Photograph by Peter Windzus © DAI Cairo.) b) Wooden statue of Amenhotep III featuring a temple band and remnants of the lost uraeus highlighted in gold (over gesso), the Brooklyn Museum (48.28). (Photograph: Charles Edwin Wilbour Fund.)

Figure 20. The silver Horus coffin of Shoshenq II, the Egyptian Museum in Cairo (JE 72154). (Photograph by Sandro Vannini.)

Figure 21. a) Putty or chaser's pitch used for the chasing of a *repoussé* work featuring the positive imprint of the king and his spouse, Ägyptisches Museum und Papyrussammlung (ÄM 21684). (Photograph by Sandra Steiß © Ägyptisches Museum und Papyrussammlung; Ägyptisches Museum, Staatliche Museen zu Berlin – Preußischer Kulturbesitz.) b) *Repoussé* work in silver: fragment of a bowl attributed to General Djehuti, the Louvre Museum (E4886). (Photograph by Christian Décamps © Musée du Louvre, distributed by RMN – Grand Palais.) c) *Repoussé* work in gold; detail of the animal fight scene on the scabbard of Tutankhamun's golden dagger, the Egyptian Museum in Cairo (JE 61584). (Photograph by Christian Eckmann, Leibniz-Zentrum für Archäologie, courtesy of the Egyptian Museum in Cairo.)

Figure 22 a) Filigree and granulation on the golden dagger of Tutankhamun, with the wire displaying clear signs of being twisted from a small strip or sheet of gold, the Egyptian Museum in Cairo (JE 61584). (Photograph by Christian Eckmann, Leibniz-Zentrum für Archäologie, courtesy of the Egyptian Museum in Cairo.) b) The necklace for the small amulet of Isis is made from wires, the Egyptian Museum in Cairo (JE 87716). (Photograph by Sandro Vannini.) c and d) Some of the loops used to attach the medallion of Khnumit have rather straight lines along the wires, suggesting they were made by folding or rolling, the Egyptian Museum in Cairo (JE 52972). (Photographs by Christian Eckmann, Leibniz-Zentrum für Archäologie, courtesy of the Egyptian Museum in Cairo.)

Figure 23. Casting activities from the tomb of Rekhmira. (Drawing by Michael Ober, Leibniz-Zentrum für Archäologie, after Davies 1935: pl. XXIII.)

Figure 24. a) Stick from Tutankhamun's tomb, meticulously decorated with filigree, granulation, and inlays, the Egyptian Museum in Cairo (JE 61673). (Photograph by Erno Endenburg and André Veldmeijer.) b) Cylinder bead showing granulation in a zigzag pattern, with many small granules lost due to damage or wear, the Brooklyn Museum (48.28). (Photograph courtesy of the Charles Edwin Wilbour Fund, 37.701E.) c) Star(fish)-shaped pendants on a necklace from Khnumit, made using wires and granules in open work. Some granules melted due to excessive heat during soldering, while others were lost, the Egyptian Museum in Cairo (JE 31126). (Photograph by Sandro Vannini.)

Figure 25. a) Detail from the collar of Psusennes I, with inlays set into recesses in the gold, the Egyptian Museum in Cairo (JE 85752). b) Detail of Sithathoryunet's pectoral, showing small strips of gold soldered vertically onto a base gold sheet to create cells for the colored inlays, the Egyptian Museum in Cairo (JE 44922). (Photographs by Sandro Vannini.)

Figure 26. a) This bracelet (British Museum EA 24787) is crafted in the style of *opus interrasile*, an open-work technique where details are cut out of a metal sheet. However, due to the use of different alloys, the small figures and amulets had to be individually produced and then soldered onto the adjacent gold bands. b) This 24-cm-high, partially gilded silver statue (the British Museum EA 60006) was found in the Temple of Amun at Karnak. (Photographs © The Trustees of the British Museum.)

Figure 27. a) The combination of highly polished silver and brightly shining electrum seems to hinder the readability of the inscription on this scarab from the tomb of Wah, suggesting that the silver was originally intended to have a dark gray satin sheen to enhance the contrast, the Metropolitan Museum of Art (MMA 40.3.12). (Photograph by Rogers Fund and Edward S. Harkness Gift, 1940.) b) A crocodile figure featuring sparkling gold details and scales, Staatliches Museum Ägyptischer Kunst (ÄS 6080). (Photograph by Marianne Franke, © Staatliches Museum Ägyptischer Kunst, München.)

Figure 28. a) A small gold bead with granulation on an earring, accentuated by the pink sheen of the base gold, the Egyptian Museum in Cairo (JE 61972). b) Detail of one of the plaques from Tutankhamun's tomb, showing a shift from pink to cherry-red as the reddish layer thickens, the Egyptian Museum in Cairo (JE 61984). The higher the uniformity of the spheres and the greater the number of granules, the more the objects appeal to modern eyes in terms of quality and aesthetics. (Photographs by Christian Eckmann, Leibniz-Zentrum für Archäologie, courtesy of the Egyptian Museum in Cairo.)

Figure 29. Facsimile of a scene from the New Year festival in the tomb of Panehsy (TT 16) depicting a procession from the gold-decorated temple of Amun. (Photograph by Charles K. Wilkinson: Metropolitan Museum of Art 30.4.6; facsimile by Charles K. Wilkinson, Rogers Fund, 1930.)