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CHAPTER THREE

Laboratories and Technology: *From Temples to Workshops: Sites of Chemistry in Ancient Civilizations*

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EGYPT

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From the First Dynasty (3150–2925 BCE) onwards, the reunification of the various territories of the Egypt was under the yoke of a royal power and the authority of one or two nominated viziers (Moreno Garcia 2013), whose task was to establish a central administration and to see to the increase of industrial production. At the regional level and from a political and religious point of view, this administration was carried out by nomarchs (provincial administrators) representing the king. The emergence and availability of written texts facilitated the work of these two viziral administrations and ensured overall management of the agricultural resources of the Nile valley. As the Nile Delta was considered a "Gift of the Nile," according to Herodotus (*Hist*. 2: 5; Sall 2005–6), a policy was established imposing the digging of irrigation canals, exemplified by the Mace Head of King Scorpion (Oxford, Ashmolean Museum, inv. no. AN1896.1908.E.3632; Goyon 1982; Menu 1994; Gauthier and Midant-Reynes 1995; Manning 2002). This irrigation limited the recurrent hunger episodes caused by irregular Nile water levels (Vandier 1936).

Administrative centralization from the south to the north of the country made it possible to balance resources and develop an industrial economy in various fields of agriculture. It not only improved the exploitation of mineral resources in the immediate vicinity of the Nile and in the deep desert but also increased the importation of high-value substances and products. (For a general history of Egyptian economy, see Muhs 2016.) In Egypt there was no currency and all transactions were made with monetary equivalents (Daumas 1977; Kemp 2005: 319–26) standardized by a unit of weight and measures, the *deben* (); its value varied more or less with the product weighed, generally 90–91 g, and it was subdivided into 10 *qites* (*qedet*) or 12 *shats*, or in volume as the *heqat* (4.8 l). This mode of exploitation of the country's resources led to a redistributive economy under the aegis of the Pharaonic state providing payments in raw commodities (cereals, meat, fish, wood) or processed materials (bread, beer, wine, salt products, clothing; Koenig 1979–80).

The Egyptian economy was based on the collective production of foodstuffs and on the control of storage and modes of transportation. The improved exploitation of quarries and mines in the surrounding valleys increased the number of expeditions for the supply of materials to meet orders coming from royal or local personalities. (See the information on the quarries of Wadi Hammamat; cf. Couyat and Montet 1912; Goyon 1957; Gasse 1987: 207–18; Gasse 1988.) Overexploitation of mines led to the imposition of drastic bans or even convictions (Meeks 1991: 234). The importation of exotic products through traditional channels and from distant lands to meet the requirements of the temples for various materials that were indispensable for the conduct of their rituals (precious metals and minerals, oleoresins, etc.; Grandet 1994) had to be organized and strictly controlled. Treasury-dependent state warehouses and major and minor temples then became places where raw materials were processed. Cult products requiring specific know-how for the treatment of metals, minerals, and aromatics were produced in specific temples. Despite the fact that several designations relating to the mineral world have been debated (Putter and Karlshausen 1992; Klemm and Klemm 1993), it is possible to define the geography of deposits of raw materials (rocks, precious metals and minerals, soils and dyes, resins, aromatics, and chemicals) in Egypt (see the maps of hard rock resources in Aston et al. 2000: 8–11; Gremilliet and Delangle 2017: 9) and in its bordering deserts and distant lands. The Pharaonic state had the capacity to locate these deposits. Large contingents of quarrymen and miners or even personnel of private enterprises could be sent by a central or provincial administration into these deserts, their security ensured by the military (e.g. Chartier-Raymond n.d.). These expeditions included sailors employed to handle cables and move the stone blocks cut from the mountain and craftsmen. The search for mineral veins in the deserts of the East was done by prospectors named *sementyu* (; *Wb*. III: 135, 18), identifiable by the bundle () they carried on their shoulders at the end of a stick (Yoyotte 1975). According to a scene showing a transport of typical desert products by nomads (Kemp 2007: 317), the idea of a monopoly on desert resources, which would result from the reading of inscriptions relating to major royal expeditions, is disputed. Nonetheless, under the reign of Seti I, based on the idea that gold represented the flesh of the sun, the smuggling of gold nuggets from the mines of Samut was strictly prohibited (Aufrère 2016d). This clearly meant that the Pharaonic state wanted to assert its sovereign rights on the veins.

The two plateaus flanking the Nile valley were the main sources of sedimentary rocks for the building of temples (Aufrère 2001e); limestone of different qualities came from quarries in the region of Gîza (and Masara) and Middle Egypt (Goyon et al. 2004: 142–5), sandstone came from the Gebel Silsila and from many other places (Aston et al. 2000: 54–6; Goyon et al. 2004: 145–6), and sedimentary quartzite came from Gebel el-Ahmar and Aswan (Aston et al. 2000: 16–17, 53–4). Igneous rocks such as granite and granodiorite, destined for the carving of obelisks and columns, came from the Aswan quarries (Aston et al. 2000: 35–7; Goyon et al. 2004: 161–71). Granite and porphyry were respectively exploited in Roman times in *Mons Claudianus* and *Mons Porphyrites* in the Eastern Desert. Anorthosite gneiss or diorite-gabbro (*mentet*), formerly considered as diorite, came from Toshke (Gebel el-Asr) in Lower Nubia (Engelbach 1933; Klemm and Klemm 1993: 423–6; Aston et al. 2000: 30–1). Metamorphic rocks (greywacke, siltstone, shale), for the manufacture of coffins, pyramidions, and small statues, came from the quarries of Wadi Hammamat (Aston et al. 2000: 57–8; Goyon et al. 2004: 173–4). In the first dynasties, minerals such as travertine (or alabaster-calcite), used for the manufacture of large statues and the industrial-scale production of containers such as dishes and jars, came from the Hatnub quarries of Middle Egypt (Putter and Karlshausen 1994: 43–6; Aston et al. 2000: 59–60; Goyon et al. 2004: 172–3).

Although Egypt had abundant supplies of iron ores such as magnetite and hematite (Ogden 2000: 166–8) and sometimes had recourse to meteoritic iron, the Egyptians were not able to master a controlled reduction process (Besançon 1954: 313–14; Gremillet and Delangle 2017: 39). Copper and tin ores and their different alloys (copper-arsenic, copper-tin, copper-zinc; Ogden 2000: 149–61) are well documented in the Eastern Desert, but they were underexploited since copper and tin mainly came from abroad. In contrast, the Eastern Desert and Sinai mines were rich in other minerals such as agate, amethyst carnelian, chrysoprase, chrysocolla, garnet, green feldspar, green and red jasper, malachite, onyx, sard, sardonyx, silicified wood, silver galena, turquoise, various oxides (Aston et al. 2000: 25–30), and particularly bitumen (essential for the preparation of recipes of liturgical ointments; see Chapter. 1, pp. 28–30; Chapter 7, pp. 187–188), found in Gebel el-Zeit (or *Mons Petrolius* of the Romans), the Dead Sea Basin, and the deposits of Syria-Palestine (Serpico and White 2000: 454–6). Antimony came from abroad (Ogden 2000: 149). Aquamarine or beryl (emerald) from the Sikait-Zubara mines (*Mons Smaragdus*; Harrel 2004) or olivine (peridot) from Zabargad Island off the Red Sea coast were used only from Ptolemaic times onwards (Aston et al. 2000: 24–5, 47–8).

Moreover, earths, mineral dyestuffs, and chemicals were processed in local deposits in the Nile valley and its surroundings. This was not case for the red and yellow ochre deposits mentioned in religious texts, for the hematite of Aswan, or for the natron deposits of Wadi el-Natrun, west of the Delta (*Nitria* of the Greeks) and of Elkab (Upper Egypt; Aufrère 1991: 609–37). Natron, used for the dehydration of mummies and the preservation of various foodstuffs, seems to have remained under royal monopoly right through to the Greco-Roman period. There is no archaeological proof attesting to the organization of official expeditions carried out to exploit these resources (see Chapter 6, p. 166). The sea salt coming from the regions of Peluse and Thonis-Herakleion were important for the preservation of meat products.

Aromatics and gum resins – various species of frankincense and myrrh – came from two areas: the plateaus of Southern Arabia and the mountains of the Horn of Africa. Oman frankincense (*Boswellia sacra* Flueckiger, 1867) – the best-quality incense – came from Yemen and Oman. Other species of *Boswellia* came from Yemen and Somalia. The myrrh tree (*Commiphora myrrha*) or basalm tree grew naturally on these plateaus. The method of harvesting of their products varied. Like today, frankincense trees were tapped and the resin collected several times a year. As for myrrh trees, the naturally exuding resin was simply detached from the tree trunk.

Punt was the name given to the region situated on both sides of the Bab el-Mandeb. Recent discoveries have shown that after crossing the Eastern Desert, the Egyptians had access to several harbors on the shores of the Red Sea, from where they could embark for Punt (see Chapter 6, p. 162). Taking advantage of the trade winds, they transported these resinous trees in baskets to acclimatize them gradually and planted them in the Nile valley, as illustrated by scenes depicted in Queen Hatshepsut's (1478–1458 BCE) temple at Deir el-Bahari. Other products, such as styrax resin, balm, and terebinth resin, came from various parts of the Near East (Baum 1994b).

As all manufacturing sectors were under state control, a rationalization of the manufacturing processes was imposed to obtain mass production. This was true for the mastery of ceramics techniques, reflected by the imposing ceramic decoration of aristocratic tombs in the Old Kingdom. The tombs of the common people contained only a basic piece of funerary furniture. The shape of the coffin was often indicative of their content: the number and richness of tombs in archaeological layers is a relative indication of the living conditions of the population.

The demand for standardized ceramic pots necessitated the rationalization of production, the distribution of food resources, and the organization of a society with common norms for all. For example, the evolution of norms in bread-making can be determined by the shapes of bread molds, indicating that there were several types of molds and which mold was most in demand. This mold was then used to meet the ever-increasing demand. The same observation applied to coiled-clay handmade beer jars, water jugs, and plates until the Middle Kingdom. A rudimentary hand-operated potter's wheel was then invented, making it possible to manufacture objects with thinner and lighter walls. Spinning the potter's wheel with the feet appeared much later, allowing the manufacture of larger containers (Bourriau et al. 2000).

The study of multiple kilns found in the fortified city of Qila' el-Dabba, where the palace of governors of the Oasis of Dakhla was located, show that the Egyptians had mastered the firing techniques required for the production of ceramics. These kilns were used not only to meet the daily needs of the palace but also to make the funerary furniture for the mastabas (monumental bench tombs) of dignitaries. The reproduction of an experimental kiln made of raw bricks by researchers of the French Oriental Institute in Egypt has shown that a sufficiently high temperature could be reached using only desert scrub as fuel, since wood resources were not readily available (Soukiassian et al. 1990; Bourriau et al. 2000: 123).

The manufacture of papyrus (*Cyperus papyrus*), a kind of sedge (Leach-Tait 2000: 227–31), was developed very early, perhaps even before the Third Dynasty (2790–2625 BCE). This became generally known when rolls of virgin papyrus ready for use were discovered in the tomb of Hemaka. The Nile Delta contained many large fields where papyrus grew, especially at the mouths of branches of the Nile, in areas where, according to Pliny, the depth of water did not exceed two cubits. It is said that each region produced a different quality of papyrus. Scenes of the harvesting and transportation of bundled stems of papyrus are attested in tombs of the Old Kingdom and Middle Kingdom (Leach-Tait 2000: 231–6). According to the iconography, these bundles were mainly intended to build light boats made of vegetal stems (Vandier 1969: 446–510; Leach-Tait 2000: 235) and to make mats and furniture. Information on the manufacturing stages of papyrus itself was never given, probably because such highly skillful craftsmanship remained a trade secret until the Ptolemaic and Roman periods, when it became a state monopoly. Most of the papyrus was for exportation to Mediterranean countries. The etymology of the word papyrus – *Pa-per-aa* "That-of-the-Palace" – indicates that under the native dynasties its manufacturing process was under the control of the Pharaonic state, which saw to its distribution according to the needs of the administration and clergy. The *Zeno papyrus* (third century BCE) indicates that the papyrus fields were systematically set on fire before and after flooding to stimulate the regeneration of young shoots (Lewis 1974; Brink and Achgan-Dako 2012: 129–34). Greek papyri indicate that papyrus was processed in farmhouses in producing areas. Pliny (*Nat. Hist.* XIII 69–89), after Theophrastus, gives the best description of the manufacturing process of papyrus. Their rough edges having been removed, the fibers of the papyrus were used to make ropes, mats, nets, and seats.

The Egyptians understood how to take advantage of these properties of papyrus to manufacture a good writing surface. After the harvest, the process started by peeling the triangular-shaped stems, chopping them into pieces of equal length, cutting them into thin slices, placing the slices in two layers (one horizontal and the other vertical), pounding the crossed slices with a mallet to make the fibers adhere, and then smoothing the surface. The papyrus manufactories needed to be close to the production areas because the material degraded quickly (it dried within forty-eight hours), losing the adhesive properties of its sap. For this reason, the size of papyrus formats was limited. The various formats obtained, as mentioned by Pliny, made it possible to recognize various qualities of papyrus, from the highest (the *hieratic* paper, intended for the administration and religious texts) to the lowest (the *emporitic*, wrapping paper; Leach and Tait 2000: 236–8).

The documentation available – texts written on papyrus or architectural and archaeological remains – makes it possible to affirm that the major temples and the funerary temples were places of storage and of production of different products to meet the daily requirements of the people and of the clergy for liturgical celebrations. In the New Kingdom, the vaulted mud stores found in the Temples of Millions of Years – royal funerary temples on the west bank of Thebes – testified to their storage capacity. These enclosures also contained butcheries, bakeries, and various other workshops.

The supply of these products was ensured by the Pharaonic state, as shown by donations listed in the thirtieth year of the reign of King Ramses III (1186–1154 BCE; see Chapter 6, p. 164). These lists appear in the *Great Harris Papyrus* (British Museum, inv. no. EA9999, 43). For contemporaries, this document evoked royal gifts made to major temples (Thebes, Heliopolis, and Memphis) and to several minor temples in Upper Egypt. The different uses of precious and basic metals, specifying their quantities in units of weight (*deben* or *qite*), of precious minerals with information on their origin, of different species of wood (Baum 1988), and of many types of fabrics were given. There were lists of utilities, cereals, meat and poultry, varieties of bread, beverages, oil, honey, fruits, and vegetables. Aromatics and chemicals (pitch, bitumen, natron, salt) and a multitude of small objects (beetles, seals) and tools, imported from different geographical areas – Egypt, Punt, the so-called God's Land, Kush, and the Oasis – were also listed.

All these products were stored in places originally called "White-House" (*per-hedj*; i.e. treasury). From the Middle Kingdom onwards, on the basis of the primacy of silver over gold in ancient times, they were called "Double Houses-of-Silver-and-Gold" (). Some of these treasuries were made of solid stone constructions – material that connoted their religious role – such as that of Thutmosis I (1504–1492 BCE), discovered in Karnak-North (Jacquet 1994), which met both utilitarian and religious needs. Around it there were workshops managed by a staff supervised by the clergy. The excavations of this building show that baking was one of its activities, meaning that the word "treasury" was used in the broad sense of "store." Conical bivalve ovens (100 cm in diameter) opening at the top, found in excavations in the vicinity of this structure, were used to bake flat, round loaves placed on the heated walls. Rectangular-shaped ovens to preheat ceramic bread pans were also found. The furnaces were fed with vegetable waste. The temperature required in the ovens was kept even by placing ceramic shards on the opening. The silos were not far from the ovens (Jacquet 1994: 141–4).

There were few workshops outside the temples. A raw brick structure adjoining the temple of Dendara, previously identified as a sanatorium due to the presence of tuns made of waterproof cement, has recently been reinterpreted as being a

FIGURE 3.1 Procession of metals and mineral bearers. Treasure D'. Dendara temple. © Sydney H. Aufrère.

FIGURE 3.2 *Tinctorium* (dyeing workshop), South-East Dendara temple. © Sydney H. Aufrère.

dyeing workshop (*tinctorium*; Cauville 2005; Cauville and Ali 2015: 264–5). It was a production unit where dyes were made. The linen and wool came from outside, probably from the agricultural fields around the temple, and were dyed to make sacred fabrics for the goddess – fabrics that had to be protected from natural light. It was a place where the dyers worked using techniques described in extracts of texts found in the so-called New Year House of this temple.

Information on dyeing is, however, rather scarce, especially in the case of woad, where the leaves undergo a transformation process of grinding, drying, and fermentation until the moment when the dye material, called agranate (in French *agranat*; the agranate is made of blackish aggregates), is obtained (Vogelsang-Eastwood 2000: 278). The dye is immersed in water and produces a greenish–yellow alkaline medium. The linen is immersed in this bath and, after being removed from it, it oxidizes in the air and turns blue. A similar process is used for wool. This process is much longer, using urine for biting, and it also requires time and heat (Hurry 1930; Ailliaud 1990).

The Egyptian corpus gives details on this dyeing process in a text: "The blue color of lapis lazuli fabric of the goddess Lapis-lazuli is obtained with the help of woad (*der-neken*; *Isatis tinctoria*), diluted in the agitated water of the river until the process, which the ancestors mention yields the (same) color (as that of) flax flowers" (*Dendara* IV: 109 ult.-110, 2; Goyon 1980: 33).

Indeed, the blue of the flax flower is similar to that of woad. The dyeing process was considered a trade secret and details of the entire dyeing process were not available. Other texts mentioned the chemical reactions taking place during the fermentation of the froth resulting from the bath of the red cloth (*ines*), which, paradoxically speaking, allowed the dyers to obtain the green color (*wadj*) under certain specific conditions (*Dendara* IV 109,10–11, *Edfou* I 388,5–6; Goyon 1980: 26). The root of the alkanet (*nesty*; *Alkanna tinctoria*) – a Mediterranean plant (attested near Alexandria) – was used in antiquity to dye fat. Egypt used it to give the sacred *medjet* ointment () a red color for a symbolic reason (Loret 1930: 23–8).

Madder dye (*ipa*; *Rubia tinctorum*), extracted from the roots and rhizomes of the plant (Vogelsang-Eastwood 2000: 279), was used by tanners (Loret 1930: 28–32) and also to dye wool. Its dyeing properties were described in the *Satire of Trades* (IV 5–7) because this dye had the color of blood. But the text also connected it to another product (*behu*), giving it a pungent smell. *Behu* was probably used as a mordant. The same kind of smell is produced when vinegar is poured onto iron (see Chapter 2, p. 61) to obtain madder in modern recipes. That said, the main mordant used by the Egyptians was alum (*ibenu*; see Chapter 6, p. 166).

The false safflower (*katj*; *Carthamus tinctorum* L., 1753), harvested in Egypt (Loret 1892: 66, 141; Vogelsang-Eastwood 2000: 279) from the Twelfth Dynasty onwards (1991–1785 BCE), makes it possible to obtain, in successive juices, yellow to orange-red by virtue of oxidation. Yellow would be associated with the gold of the goddess Hathor and red with the morning color of the goddess Isis-Sirius. Sometimes the essence of mandrake (a yellow fruit) was used to symbolically add solar light. Archaeological data show that other dyes, such as henna (*Lawsonia inermis*), could be used (Vogelsang-Eastwood 2000: 279). The use of Polish cochineal dye (*Porphyrophora polonica*) is attested to from first century CE onwards, but snail purple (murex) was not known (Vogler 2013). It is possible that the dyeing workshop of Dendara was made of two parts, one dedicated to a *tinctorium* per se, and the other to a *laboratory*, because the two were, so it seems, closely associated.

According to Egyptian texts, it is clear that several Greco-Roman temples of the Nile valley had rooms considered as so-called laboratories (*is*) for the conservation of recipes, techniques, and scenes of offerings. For the priests, these "laboratories" evoked the world of perfumes, another the *tinctorium*, where fabrics were dyed, and yet another the so-called "treasury" where precious metals and minerals were kept safe. The Mansion-of-Gold or goldsmith workshop evoked all that concerned the designing of jewels specially made to adorn the gods according to rituals.

The importance of these places varied with the location of the temple. The most important laboratory, in terms of amount of textual information available, was that of Edfu, on the walls of which very detailed recipes used to satisfy the gods during liturgies are still found. These texts, including lists of aromatics (at the temples of Edfu, Dendara, and Atripe), enabled the safekeeping of the traditional names of all products used by the Egyptians, the majority of which were of foreign origin. The two treasuries of Dendara provided a complete record of the geographical origin of all imported metals and precious minerals from abroad. But as far as the Mansion-of-Gold or goldsmith workshop is concerned, the one in Dendara is quite unique, inasmuch as it describes all the traditions related to silversmithing practiced in Memphis, a place known for its craftsmanship.

MESOPOTAMIA

Cale Johnson

Urbanization and the large-scale storage economies that developed in Mesopotamia in the fourth millennium BCE laid the necessary social groundwork and economic basis both for specialized craftsmen, who no longer needed to provide their own food, and for urban elites that valued their technological innovations. Rather than individual genius, it was the ongoing support of the state and its rulers for small groups of specialists, engaged with the development of new administrative technologies, such as cuneiform writing, or alternatively the creation of new ways of manufacturing and decorating votive and other high-value goods, that led to significant technical advances throughout Mesopotamian history. The most important processes of standardization and mass production took place in the fields of pottery production and cuneiform writing in the fourth millennium BCE. The pottery of the Ubaid period (ca. 6500–3800 BCE), first found in Eridu, but subsequently aligned with the pre-Uruk-period levels in the city of Uruk, for example, was famous for its elaborate decoration, likely produced on a tournette or slow wheel, while the very different Uruk-period (ca. 3800–3000 BCE) pottery was undecorated and produced on a simple fast wheel (the kick wheel only appears much later; see Petrie 2012: 285). Nissen (1989) argues that the increasingly standardized vessels, mass production, and the abandonment of decoration were direct results of this new fast wheel and that these developments followed from the increased specialization and professionalization of Uruk-period ceramic production centers. The ubiquitous beveled-rim bowl was of a far lower quality than other wares, but was mass produced on a previously unheard of scale (Potts 1997: 150–3).

The earliest cuneiform writing, part of a longer developmental sequence involving plain tokens inside of clay bullae and purely numerical tablets, used the new standardized ceramic vessels as prototypes for a number of the earliest cuneiform signs. Iconic images of these vessels were used to represent the vessels themselves as well as a number of different types of both elite and nonelite foodstuffs. The beveled-rim bowl served as the prototype for the cuneiform sign GAR, which could stand for "bread" (corresponding to later Sum. ninda) or, in combination with the sign for "mouth," yield a sign meaning "to consume, to use up" (Sum. gu_7); likewise, higher-quality vessels such as UKKIN and $SILA_3$ were used to identify the elite goods that they normally contained, such as beer and dairy fats, as well as the foodstuffs that were typically associated with them, such as meat and fish (see Johnson 2015 for an overview). In the context of these storage-based urban societies, the relationship between rations, the more-or-less standardized vessels that were associated with the rations, and the bookkeeping mechanisms that were used to track these vessels served as a paradigm for the development of many other domains of economic and technical practice in ancient Mesopotamia, such as the administrative techniques for documenting the use of raw materials in technical workshops.

The most important lexical lists from the Late Uruk period (ca. 3300–3000 BCE) were largely concerned with managing the specialists who operated these workshops, as well as the raw materials they required and the finished goods they produced (see Nissen et al. 1993 for a user-friendly introduction). In contrast to Egypt, we have few images of craft or industrial activity from Mesopotamia, but what we lack in visual representations is more than made up for by the most elaborate bookkeeping procedures for craft and industrial production of any society in antiquity. In the Ur III period (ca. 2112–2004 BCE), where the documentation is extensive and extraordinarily detailed, both raw materials and labor were consigned to a supervisor, who was responsible for meeting specific production goals, and the actual labor performed, quantified in terms of fixed ratios of labor to finished products, was then deducted from the overall consignment of worker time (Englund 1991). The minutiae of these calculations, including varying rates of performance for specific materials and end products and allocations of workers' days off for different age and gender categories, represent the epitome of workshop management and, in fact, the activity of many workshops can be reconstructed from the Ur III textual record alone (see generally Paoletti 2016b). Three studies of purely textual remains have played a leading role in understanding technical practice in ancient Mesopotamian society: (a) Neumann's synthesis (1993) of the Ur III records dealing with raw material inputs and the resulting craft products in five Mesopotamian cities; (b) Heimpel's work (1998; 2009) on "industrial parks" in Girsu and Garshana; and (c) Van De Mieroop's study (1987) of the Isin craft archive from the subsequent Isin-Larsa period (ca. 2004–1763 BCE). Of these, Heimpel's focus on an industrial park in Girsu, where rest houses, animal-fattening, and ship-building centers were collocated with prisons, providing a labor source (Heimpel 1998), and a decade later a project involving "the construction of a ring wall, a triple complex of the food processing facilities brewery, kitchen and flour mill, a double complex of *textile mill and craftsmen's house* (Sum. e_2 uš.bar u_3 e_2 gašam.e.ne), and the rebuilding of residences" (Heimpel 2009: 123, my emphasis) provide us with a comprehensive picture of the physical and administrative situation in which palace-funded workshops existed.

Heimpel argues for a parallel set of technical professions at Garshana and at Ur, the most famous craft center in the Ur III period, "located in the city of the principal royal residence and featur[ing] a port where luxury goods from the Persian Gulf and Arabian Sea arrived" (2009: 157). As Moorey (1994: 15), among others, has emphasized, the key text for making sense of centers of craft production such as these is UET 3, 1498, an inventory of both raw materials and finished products kept in either the "storehouse" or "treasury" (Sum. e_2.kišib$_3$.ba) or the "big warehouse" (Sum. ga$_2$.nun mah). Centralized "workshops" (Sum. e_2.giš.kin.ti) like these typically dealt with the production and decoration of luxury items for temples and the palace, as well as the extensive bookkeeping of raw materials and finished goods, while the mundane production of agricultural implements and the like (and presumably the preparation of processed raw materials such as metals) was carried out elsewhere (Neumann's *Schmeidewerkstätten*). Raw materials, especially metals, were carefully weighed before being distributed to specific craftsmen, and the finished product was also weighed, allowing for the calculation of "its (loss) consumed by fire" (Sum. izi gu$_7$.bi) and "its waste" (Sum. za$_3$.bar.bi). These practices, in combination with multiple copies of inspections (Sum. gurum$_2$ ak) and regular tabulations of the workforce, allowed a full overview of the raw materials and the labor involved. At Ur, eight distinct workshops are mentioned, each beginning with "house of" (Sum. e_2): the "sculptor" (Sum. tibira), the "goldsmith" (Sum. ku$_3$.dim$_2$), the "stonecutter" (Sum. zadim), the "carpenter" (Sum. nagar), the "metalworker" (Sum. simug), the "leatherworker" (Sum. ašgab), the "felt-maker" (Sum. tug$_2$.du$_8$), and the "reed-worker" (Sum. ad.kub$_4$). These different workshops were supervised by a "chief administrator" (Sum. šabra) and a small team of scribes. At Garshana, a shorter list of workshops is found (Heimpel 2009: 161), including that of the "carpenter" (Sum. nagar), the "metalworker" (Sum. simug), the "leatherworker" (Sum. ašgab), the "felt-maker" (Sum. tug$_2$.du$_8$), and the "reed-worker" (Sum. ad.kub$_4$).

Unlike the metalworkers, who also required pyrotechnic installations of course, potters are not included in these lists of different craftsmen, and the "potter's house" (Sum. e_2 bahar$_2$.ra) in both Ur and Garshana seems to have been located at a different site. As Heimpel (2009: 162) reiterates, this lines up nicely with archaeological evidence from sites like Larsa and Maškan-šapir, where the pottery kilns were located outside of the city center. In spite of its seemingly anomalous position within Ur III craft production, since it is not included in these production centers, like most other dependent laborers (Sum. guruš), potters typically worked year-round for the state in specialized workshops, and their rate of production was measured in terms of fixed equivalences of workdays: the well-known Umma pottery workshop, for example, produced in a single year more than 60,000 one-liter vessels, functionally equivalent to the Late Uruk beveled-rim bowl, each valued at 0.066 workdays. This suggests that a single worker was expected to produce fifteen of these vessels in a single day (Dahl 2010, *pace* Steinkeller 1996).

In spite of extensive textual records and numerous excavations, relatively few technical workshops can be securely identified in the Mesopotamian archaeological record. One of the biggest problems is definitional: many workshops are hypothesized on the basis of finished objects that share features or the isolated presence of an oven or kiln. It is best, therefore, to briefly reiterate Tosi's diagnostic features for identifying workshops: (a) fixed installations for processing raw materials (e.g. kilns and furnaces); (b) specific working tools; (c) residues or wasters; (d) raw material in a convenient form; (e) concentrations of finished commodities; and (f) materials for recycling (1984). The application of these criteria, especially the co-occurrence of pyrotechnic installations and debris from the manufacturing process, has resulted in many "workshops" described in the secondary literature being removed from the classification. The most famous example is the workshop associated with the Larsa Goldsmith's Hoard, discredited by Bjorkman in 1993, as well as the reevaluations of numerous sites in Moorey's extensive work (Moorey 1985: 36–7).

Recognized key sites are surveyed and briefly described in the standard handbooks (Moorey 1994; Potts 1997) and more recently in Morandi Boncossi's (2016) entry on "Werkstatt – Archäologisch" in the *Reallexikon der Assyriologie*. Important pottery workshops have been identified in Tell Abada and Yarim Tepe (Ubaid period), Abu Salabikh (Uruk and Early Dynastic periods), Umm al-Hafriyat, Qatna, and Tell Sabi Abyad (in the second millennium BCE). Duistermaat's *The Pots and Potters of Assyria* (2008) offers a particularly well-considered study of the potter's workshop in Middle Assyrian Tell Sabi Abyad and represents an important point of departure for future work, answering Moorey's lament (1994: 146) that "no coherently published potter's workplace in Mesopotamia" had been published at the time he was writing in the mid-1990s. Metalworking workshops have been identified in Arslantepe and Degirmentepe in prehistoric eastern Anatolia and at numerous sites in the Iran plateau (see Weeks 2012: 301–3 for an overview), Tell edh-Dhiba'i in the early second millennium BCE (Al-Gailani 1965; Davey 1983; see below), and more recently in Late Bronze Age Qatna (Iamori 2015). Glassmaking workshops, which obviously appeared later, are reviewed in detail in these same publications, with particular focus on the glassmaking workshops at the "Mitannian Palace" at Tell Brak and the workshop that Mallowan identified "on the south side of room 47 [of the Burnt Palace]," where he found "traces of kilns and glassmaker's kit, including one specimen of sealing wax red glass, probably from a crucible" (Mallowan 1966: 209–10). Even if the literary quality of Mallowan's report cannot be surpassed, the most important identified glassmaking workshop is almost certainly the one identified by Oates and coworkers at Tell Brak. Henderson's (2012) recent monographic treatment of the origins of glass provides an excellent description of the finds of glass themselves (and the scientific analyses carried out on them), but only rarely hints at the presence of workshops. One of the few instances is at Tell Brak, where he refers to "possible direct evidence of glassworking" (Oates et al. 1997: 86). But he states that the evidence "does not, however, in itself constitute evidence of primary glass manufacture from raw materials at Tell Brak" (Henderson 2012: 140). Even if we cannot locate bona fide production sites in Late Bronze Age Syria, it is fairly clear that "the Hurrian Kingdom of Mitanni was responsible for the great leap forward in glass production" through their development of "large furnaces that could reach temperatures of c. 1150–1200° C," which in turn allowed for the development of core-forming in the sixteenth century BCE (Henderson 2012: 144).

The primary terminologies for kilns and furnaces (as well as other types of pyrotechnic installations, both domestic and specialized) in the languages of Mesopotamia, particularly in the lexical list tradition, were surveyed by Armas Salonen in 1964; the key terms for our purposes here are Akk. *kūru* and Akk. *utūnu*. These are, not incidentally, the same two terms that appear in the mid-second-millennium BCE glassmaking texts: the *utūnu* "kiln" figures in the less sophisticated technique involving week-long baking of glass in molds, while the *kūru* "furnace" appears in the more advanced recipes for making artificial precious stones. (This latter term, viz. *kūru*, also serves as an exceedingly rare qualification for these artificially created stones; e.g. *ûqnu kūri* "lapis of, viz. from, the furnace.") The corresponding Sumerian terms, strictly speaking, are Sum. udun = Akk. *utūnu* and Sum. dinig = Akk. *kūru*, but this leaves the more common term for kiln or furnace in older Sumerian texts, namely Sum. gir_4 (or gir_4.mah), out of the picture. The lexical tradition equates Sum. gir_4 with Akk. *kīru* (not to be confused with *kūru*), and clearly both *utūnu* and *kīru* are Sumerian loanwords in Akkadian, but it is tempting, nonetheless, to suggest that Akk. *kūru* derives from Sum. gir_4 as well (suggested by Salonen 1964: 118), even though it is not directly supported by the lexical tradition or the standard dictionaries. In texts from the third millennium BCE, Sum. gir_4 simply means "oven" and is used to bake bread and cook meat, but particularly in second- and first-millennium BCE sources, after the introduction of Akk. *tinūru* (equivalent to Arabic *tannur*) and similar terminology, Sum. gir_4 generally refers to a "furnace" used in the production of metal, glass, and similar materials.

The overall correctness of Salonen's identification of Sum. udun with "kiln" and Sum. gir_4 with "furnace" is largely confirmed by the qualifications and components associated with these two terms in the lexical tradition, although Salonen consistently translates Sum. udun with "Ofen" and gir_4 with "Brenn-/Schmelzöfen" (both contrasted with "Backöfen" for Akk. *tinūru*). Kilns are often qualified by professional designations such as the "kiln" (Sum. udun) of the "potter" (Sum. bahar) or of the "brewer" (Sum. lu_2 $^{kaš}kurun_2$.na), or the roasting of the particular type of material such as "sourdough" (for beer-making; Sum. bappir) or "dried fermented mash" (Sum. titab). In contrast, Sum. gir_4, particularly in second- and first-millennium BCE sources, serves as the point of reference for a number of terms that describe parts of the furnace such as the "chamber" (Sum. daggan = Akk. *takkannu*), the "peephole" (Akk. *ḫayyāṭu*), and/or the "vent" (Sum. igi = Akk. *īnu*) and the bellows (Sum. $bun_{1/2}$ = Akk. *nappāḫu*), all of which occur almost exclusively with Sum. gir_4, rather than Sum. udun, in the lexical lists. Only some of these terms from the lexical tradition reappear in the late glassmaking texts, and, in particular, a more complex Akkadian terminology for crucibles and related elements for holding or enclosing the crucible such as the saggar is found in the late glassmaking texts, including terms like Akk. *imgurru*, *dabtu*, *ḫaragu*, and *maṣādu* (Oppenheim 1970: 69–74).

The linguistic contrast between "kiln" (Sum. udun) and "furnace" (Sum. gir_4) does not line up in any simple way with the archaeological and technological record; each of these Sumerian logograms enters the writing system at different points in history, and there is no one-to-one relationship between these Sumerian logograms and the proto-cuneiform signs that depict ovens or kilns. The southern Mesopotamian alluvium may not have been at the forefront of copper smelting technology in the Uruk period (ca. 3800–3300 BCE), and so we also have to factor in the possibility that iconic depictions of metallurgy in proto-cuneiform writing may not correspond to contemporary metallurgical practice in fourth-millennium BCE Iran. Furnaces begin to be used at the end of the fourth millennium BCE in Proto-Elamite-period Iran, but the crucible may still have played a central role in metallurgy in Late Uruk-period Mesopotamia (see the complementary overviews of metallurgical processes and archaeological contexts in Weeks 2012; Weeks 2013), so we will be largely concerned here with pottery kilns. The iconic forms of two proto-cuneiform signs (ca. 3300 BCE), namely MAH_a and AD_a, were probably modeled on two distinct types of kiln.

Although any attempt to correlate proto-cuneiform signs with fourth-millennium BCE kiln designs is necessarily fraught, the vertical and curved profile of the MAH_a sign can be equated with the type of two-chambered domed design attributed to the "protoliterate pottery kiln from Chogha Mish" on the basis of a dozen or so parallels from both Mesopotamia and Iran (Figures 3.2 and 3.3; Alizadeh 1985; see the recent survey in Streily 2000 as well). In contrast, the horizontal configuration of the AD_a sign corresponds well to the type of horizontal kiln that became increasingly common in the Early Dynastic period. As Moorey explains:

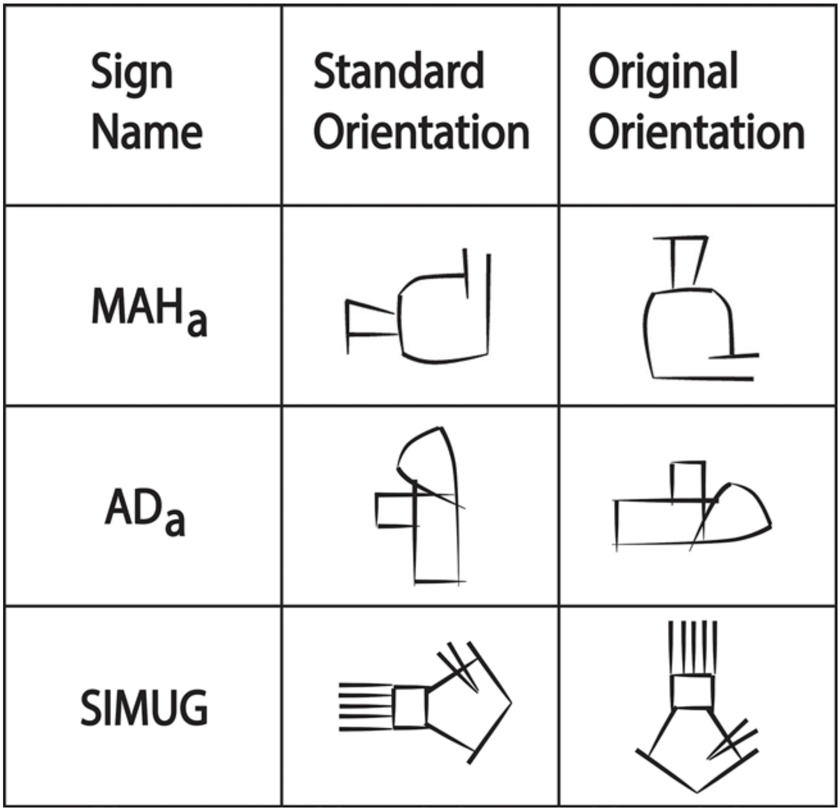

FIGURE 3.3 The proto-cuneiform signs representing ovens and kilns: MAH_a, AD_a, and SIMUG. Drawing by the author, after signs drawn by R.K. Englund.

> In a horizontal kiln the firing chamber and the fuel pit are at opposite ends of the rectangular space. The heat produced near the entrance is drawn by one or more chimneys on top of the firing chamber; in such kilns there is no refractory grid, heavy supports or vaulted roof as found in vertical kilns.
> (Moorey 1994: 157)

When both signs are rotated 90° to the right, into their original orientation, the opening to both kilns is on the right and both also have a flue on top, but MAH_a has a tall, rounded chamber, while AD_a has a boxlike, horizontal chamber. Thus, in all likelihood, the proto-cuneiform signs MAH_a and AD_a represent two different types of kiln – vertical and horizontal, respectively. In the subsequent Early Dynastic period (ca. 2900–2400 BCE), contemporary with the increasing use of horizontal kilns, the AD sign is combined with $ŠU_2$ or U to form GIR_4, which is first attested in the Archaic Ur corpus (ca. 2900 BCE),

FIGURE 3.4 Photograph of a two-chambered oven from Abu Salabikh. Courtesy of J.N. Postgate.

although centuries later, in the ED III period, AD often still functions alone as the logogram for "oven," presumably gir$_x$(AD).

The first attestations of Sum. udun only occur at the end of the third millennium BCE, and the new orthography of Sum. udun (namely U.MUHALDIM) is presumably modeled on the orthography of Sum. gir$_4$ (U.AD), with MUHALDIM (meaning "cook" in Sumerian) replacing the sign AD within the new logogram, presumably in order to differentiate an oven for cooking food (Sum. udun) from a kiln for baking pottery or other nonculinary practices (Sum. gir$_4$).

Although Moorey identifies a few early examples of crucibles, he goes on to say that "furnace development is a subject for which there is very little hard evidence from the ancient Near East" (Moorey 1994: 243). Craddock provides a clear developmental sequence for furnaces and crucibles on the basis of archaeological work in the Levant, which has served as the primary context for defining metallurgical developments until recently. Central to Craddock's account is the use of crucibles, directly heated by piled-on charcoal, and blowpipes (without a distinct "furnace" in the earliest phases). As Craddock puts it:

> … in common with other Bronze Age metalworking centres, the absence of recognizable furnace fragments or of the clay bellow pipes, the tuyeres, with the crucibles, does imply that there were no specific furnace structures or bellows at this stage in pyrotechnic development.
>
> (Craddock 2000: 157)

Likewise in the fifth- and fourth-millennium BCE smelting sites in Iran (see Thornton 2009 and Weeks 2013 for illuminating surveys of this material as well as a critique of the "Levantine paradigm"), the earliest evidence for copper smelting involved crucibles rather than furnaces. The proto-cuneiform sign SIMUG, which comes to mean "metalworker" later on in Sumerian, "appears to show the plan of a smelting furnace with attached blow pipes or tuyère" according to Moorey (1994: 243), but in light of the fact that the sign SIMUG much more closely resembles a crucible than a furnace (alongside the likelihood that southern Mesopotamian metallurgy was probably focused on crucible rather than furnace technologies), we should now amend Moorey's statement: SIMUG is probably a representation of a crucible with its blowpipes, although the lid or flue in the middle of the sign (with fire coming out of the top) remains problematic.

Other than the frequently discussed shift from a "slow wheel" (or "tournette") to a "fast wheel" in the Uruk period and its role in the emergence of mass-produced pottery (Nissen 1988: 46–7; Potts 1997: 161), one of the most important archaeological finds in the ancient Near East is the set of copper-working tools that were recovered from the Isin-Larsa-period workshop at Tell edh-Dhiba'i, just outside Baghdad (Al-Gailani 1965; Davey 1983). Davey (1983) describes and offers illustrations of (a) baked clay pot bellows, (b) crucibles, (c) a mold for casting a pin, (d) a baked clay model ax-head, (e) a baked clay ladle, (f) a fragment of tuyère, and (g) small round dishes (Moorey 1994: 268). The most important aspect of this set of tools, as Davey demonstrates, is that the form of the crucibles from Isin-Larsa-period Tell edh-Dhiba'i precisely matches the form (and likely the production process as well) in the depiction of smelting from the tomb of Mereruka in Saqqara, Egypt. Davey describes the process as follows:

> Adopting the practice illustrated in the Egyptian Old Kingdom tomb reliefs, a plug is placed at the entrance of the crucible and it is kept in place until the material is ready to pour. When that occurs, the charcoal is quickly pushed aside and the plug removed so that the metal can quickly flow into the pre-heated mould.
>
> (Davey 1983: 182)

The key difference between the depiction from the Egyptian tomb and the set of equipment found at Tell edh-Dhiba'i is the presence of pot bellows and a tuyère in the latter. These items suggest that, even if direct work on the crucible was still practiced, it was carried out in a much more carefully appointed pyrotechnic installation, with pot bellows replacing a team of workers equipped with blowpipes.

We have focused here on workshops, installations, and tools that can be included in specific technical processes with certainty, either because they are specified as such in textual sources or because the preponderance of Tosi's

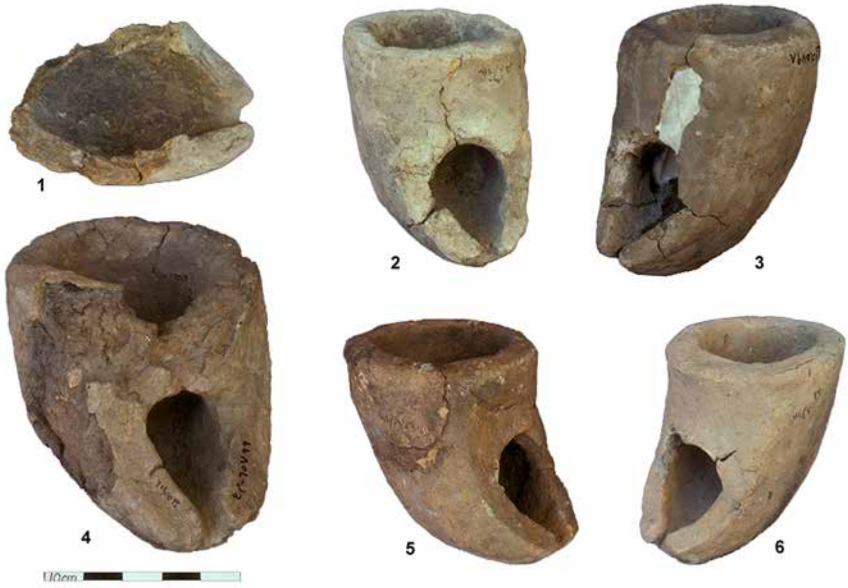

FIGURE 3.5 Tools from Tell edh-Dhiba'i. Photograph © C.J. Davey.

criteria makes it clear that they were involved in specific technical processes. Many other tools could easily have had their primary use in food preparation, for example, and only occasionally found their way into some kind of chemical practice: the various bowls, funnels, steamers, sieves, strainers, and the like, carefully surveyed and described by Ellison (1984), were always primarily used for food preparation, but could of course be repurposed for other uses (see Faivre 2009 and Michel 2012 for recent surveys of vessel use). This idea was the basis for Levey's erroneous suggestion (1960) that distillation was already being carried out at Tepe Gawra in the middle of the fourth millennium BCE. In the absence of clear contextual evidence of some kind, arguments based exclusively on the "possible" use of relatively simple decontextualized vessels must be ruled out. The counterexamples, even if their operation and significance still eludes us, are the so-called "Parthian galvanic cells" consisting of a "clay jar, a cylinder made from copper sheet and an iron rod" (Eggert 1995), which König (1938) suggested were used for electroplating (Keyser 1993 surveys the different theories, ranging from electroplating – actually invented in Birmingham in 1839 – to medicinal uses), but whatever their function, the internal complexity of these mechanisms precludes the possibility that they are repurposed kitchenware. And as Eggert reassures us, "as is always the case in experimental archaeology, successful experiments can only show a supposed ancient technique to be possible, but never by themselves that it was, in fact, applied" (1995: 14).

GRECO-ROMAN WORLD

Matteo Martelli

There is no ancient term for either a chemical or an alchemical laboratory. The word *chymeion*, which one can read in early modern treatises on alchemy, was probably introduced by Andreas Libavius in the second edition of his handbook *Alchymia* (1601). The term *laboratorium* too is late: absent in classical texts, it started to be used in medieval sources, and only by the mid-sixteenth century had it assumed a more specifically alchemical nuance. On the other hand, we do have the ancient Greek term *ergastērion* (ἐργαστήριον), which could refer either to a workshop or to a shop of different craftsmen, from butchers to perfumers, from bakers to smiths (Martelli 2011).

Despite the lack of a specifically alchemical connotation, the general term *ergastērion* could also apply to working spaces where ancient chemical arts were practiced. Indeed, it could refer – along with more specific names such as *bapheion* “dyer’s workshop” (or *porphyreion*, if specialized in purple dyeing), *hyelourgeion* “glassmakers’ workshop,” or *chrysochoeion* “goldsmith’s workshop” – to the workshops of various craftsmen active in those technical areas that attracted the attention of the earliest alchemical authors. These craftsmen carried out their activities by using customized sets of tools and devices, which necessarily varied in accordance with the specific needs of their areas of expertise.

Dyers’ workshops were usually equipped with dyeing vats, furnaces, water supplies (e.g. basins or fountains), and various types of vessels, which were necessary to prepare the dyestuff and to use it to treat fabrics and cloths. These workshops could be either independent buildings or part of the house, as it is possible to infer from some contracts for leasing or selling *ergastēria* preserved in Geek papyri. For instance, a sale contract of dyers’ workshops (*baphika ergastēria*) equipped with a leaden pot and an earthenware cask is preserved by *P.Oxy*. XIV 1648 (second century CE). Archaeological evidence confirms the presence of dyeing workshops in Late Roman Egypt. In this period, various rooms of the Egyptian temple of Repit at Athribis were reused as working spaces (Müller 2015: 188). Here, a dyers’ workshop was excavated by Flinders Petrie, who discovered a cistern and many vats in a raised bench: “these vats,” Petrie writes (1908: 11), “are lined with cement and deeply stained. Most of them are black blue with indigo, and some are red.” Six dyeing workshops have been excavated in Pompeii as well. Usually parts of larger houses, they are recognizable by high furnaces over which large lead cauldrons have been installed (Flohr 2013b: 60–2; Lowe 2016). In four workshops, sets of cauldrons of different sizes were discovered. The largest cauldron was probably used for the pretreatment of wool with alum and other mordanting substances, which allowed dyes (such as madder) to be fixed to the fibers. Indeed, lists of mordanting substances capable of fixing colors are included in the chemical papyrus of Leiden (e.g. § 92 in Halleux 1981: 106), and they are very similar to the lists of astringent drugs provided by medical texts, such as Galen's *On the Capacities of Simple Drugs* (I 34 = XI 440–1 Kühn) or *On the Method of Healing* (III 5 = X 199 Kühn). The smaller cauldrons were then used for dyeing. Cauldrons consisted of lead kettles slotted into a surrounding structure made of bricks and lime mortar. Experimental archaeology has shown that lead represented an unusual choice due to its physical properties. It is, in fact, heavy (and kettles were usually filled with ca. 90 litres of dyeing liquid), malleable, and with a low melting point. When heated, it could change its shape, thus making the apparatus somewhat fragile: evidence of "lead creep" has been detected in the kettles unearthed in Pompeii. However, unlike other metals that affected the different stages of the process, lead appeared from modern replications to act as an inert material that had no effect on the results of the mordanting and dyeing procedures. Moreover, it certainly helped to keep the temperature constant during the processes (Hopkins 2008; Puybaret et al. 2008; Kania et al. 2018).

Archaeological sources provide us with little precise information on early perfume technology, especially for the centuries that precede the end of the Hellenistic period. Recent excavations in Cyprus have unearthed a large installation from the mid-second millennium BCE for the production of perfumes in the area of Pyrgos. Here new evidence has been examined that might point to a very early use of distillation. A rich set of vessels has been discovered, which experimental archaeologists have reconstructed in the shape of various distillation devices for the production of essential oils and perfumes (Belgiorno 2017). In the framework of these experimental reconstructions, the controversial interpretation that Martin Levey (1955; 1960) proposed for the Tepe Gawra channel-rimmed pot found in Iraq (fourth millennium BCE) as an apparatus for distillation was reconsidered. Analogous vessels, dating to the mid-second millennium BCE, were found in Cyprus and Spišský Stvrtok (Slovakia), and replicas of these devices have been used in experiments for distilling scented waters (Belgiorno 2018).

These findings would antedate by ca. 1,500 years the discovery of alembics, whose earliest descriptions in Greco-Roman textual sources date to the first centuries CE (see below). Indeed, Greco-Roman classical texts devoted to the production of perfumes (primarily Theophrastus' *On Odors* and Pliny's *Natural History*, XIII 1–26) never mention distillation among the technologies employed in the field. Aromatics were simply added to different kinds of oil (mainly olive oil) and boiled together, a procedure confirmed by archaeology. For instance, in the Hellenistic perfume shops excavated in Delos and Paestum, archaeologists discovered furnaces, large marble mortars, and stone press beds. Each press bed has neatly carved circular channels converging on an outlet groove: this facilitated the collection of the oil produced by a vertical edge press that originally rested on the stone bed (Brun 2000). Vertical edge presses are actually depicted in frescos of Pompeii (House of the Vettii; see Figure 3.6) and Herculaneum (Casa dei Cervi); they consisted of a wooden structure with different rows of wedges set one upon the other, which were used to compress the olive paste (or other fruits and seeds) that was produced after crushing olives in mortars (Mattingly 1990; Brun 2000). In his *Mechanics*, only extant in Arabic translation (Nix and Schmidt 1900: 102–3), Hero of Alexandria (mid-first century CE?) explains that these edge presses were particularly suitable for extracting fine oils for perfumes.

Furnaces were also critical tools in many fields of ancient craftsmanship. For instance, in reconstructing the history of ancient glassmaking, scholars have stressed how the introduction of a new kind of furnace (along with other tools, such as iron blowing pipes) played a vital role in the development of glassblowing (Stern 1999). Probably discovered along the Syro-Palestinian coast, this new technique of shaping molten glass by blowing into it through iron pipes was perfected in Italy. Here, during the Roman period, glassmakers introduced a novel glassblowing furnace equipped with a closed heat chamber into which the pipe entered horizontally. In this way, glass was not simply heated in the side turned to the fire, but hot air surrounded it, thus allowing the glass to expand evenly (Stern 1999: 446).

FIGURE 3.6 House of the Vettii, Pompeii. Frieze depicting cupids working in a perfumery. Photograph by De Agostini/Getty Images.

Like glass, various metallic ores can be melted. Metallic ores were often treated in workshops next to mines, in installments that hosted different kinds of furnaces. Litharge, for instance, was a by-product of the cupellation of silver–lead ores (or argentiferous galena; see Chapter 2, p. 78). At Laurium, archaeologists found *tubuli* (cones) of litharge that had been lifted with bars (Halleux 1975: 75; Healy 1999: 320–2).

Another interesting case study is the mineral medicine called *pompholyx*, which was produced by burning copper ores. Galen (*On the Capacities of Simple Drugs*, IX 3.25 = XII 234,3–12 Kühn) specifies that in Cyprus some furnaces were designed to transform cadmia into *pompholyx*. A more detailed description of these furnaces is provided in a long passage by Dioscorides, which is worth quoting in full (V 75):

> It (i.e. *pompholyx*) is made this way: in a building of two chambers a flue is built and at the upper chamber a hole is made of equivalent dimensions as the flue opening from the parts above. The wall of the chamber close to the flue is bore through with a small hole level to the melting pot to receive the bellows. The chamber has also a door of proper size built by the craftsman to get in and out.
>
> Attached to this building is another room wherein are the bellows and where the bellows blower works. So, coals are placed in the furnace and lit, then the attending craftsman sprinkles the calamine finely crushed from stations above the top of the furnace and the helper does the same and at the same time throws continuously coal until all the charge is consumed.
>
> For as it burns, the part that is thin and that is composed of light particles is borne to the upper story and settles on its walls and ceiling; then it solidifies and becomes at first like bubbles that rise from rushing waters; then, as more particles are added, it becomes like fleeces of wool (transl. by Beck 2011: 363–4).

Along with this complex structure described by Dioscorides, other furnaces were used to collect the fumes of mineral ores. Vitruvius (*On Architecture*, VII 8.2) explains that, in a workshop (*in officina*) next to a mine for cinnabar, chunks of the minerals were thrown into furnaces and dried, to get rid of their moisture: the fumes that rose from them (i.e. mercury) precipitated on the floor of the furnaces. A special device for extracting mercury from cinnabar is also described by Pliny the Elder (*NH* XXXIII 123) and Dioscorides (V 95.1), who used a different terminology referring to its parts. An iron spoon containing cinnabar was put in a clay vessel (called *patina* by Pliny and *lopas* by Dioscorides), which was covered by a convex lid (a *calix* according to Pliny) or a upside-down vessel that Dioscorides calls *ambix* (ἄμβιξ): this term was then rendered in Arabic as *al-'inbīq* (with *'inbīq* as simple transcription of the Greek *ambix*), from which our "alembic" derives. The device was constantly heated, and the moisture (*sudor*/*hymor* in Pliny's words) or soot (*aithalē* in Dioscorides' words) that condensed on the lid became mercury when scraped off.

Scholars usually agree in interpreting these passages as one of the earliest accounts of a sublimation technique that exploits the low boiling point of mercury (356°C): cinnabar reacts with the iron in the spoon, thus liberating mercury that evaporates and condenses on the colder surface of the upper vessel. As mentioned by Healy (1999: 343), the remains of condensers dating to the Greco-Roman period have been found in Ladik, an area containing many cinnabar mines in Anatolia. Various scholars argue that similar rudimental apparatus were developed and improved by Greco-Egyptian alchemists: they (a) separated the lower container and the upper pot (or condenser) by a pipe and (b) added to the upper pot a tube (or, in some cases, two or three tubes) with a digestion vessel (Taylor 1945: 186–7; Forbes 1970: 16–24).

According to the Egyptian alchemist Zosimos of Panopolis (*Authentic Memoires*, VII 2 in Mertens 1995: 23), Maria the Jewess described how to assemble various alchemical devices, such as alembics for the production of "sulfur waters," the *kērotakis*, and various kinds of furnaces. Moreover, the cooking apparatus called bain-marie (*bagnomaria* or *Marienbad*; i.e. a water bath) is usually associated with her name (Lippmann 1913: 185–200; Forbes 1970: 24); the expression is common in Latin medieval sources (*balneum Mariae*), but never used in Greek alchemical texts, although a similar device for cooking food (with different vessels slotted into one another) is already described in classical writings, such as Hippocrates's *On Diseases* (III 17.17 = VII 160 Littré = Potter 1980: 98). This tool was then called *diplōma* ("double vessel") in the works of later medical authors, such as Dioscorides' *De materia medica* (II 77), Galen's *On the Composition of Medicines According to Places* (XIII 23 and 36–7 Kühn), and the sixth-century CE medical encyclopedia by Aetius of Amida (books I 122,2 and 123,2; IV 196,73 Olivieri). The use of cooking tools in alchemical practices, indeed, is well documented in the works of Greco-Egyptian alchemists. For instance, Zosimos saw a particular device used to steam poultry in the kitchen of his wealthy pupil Theosebeia (*Authentic Memoires*, VIII 1 in Mertens 1995: 26–7). After discussing this equipment with the chef in charge of the kitchen, Zosimos decided to take the Jewish alchemical books from Theosebeia's library and look for the description of a similar device designed to treat arsenic ores with sulfur's vapors (Mertens 1995: clxii–clxiii; Dufault 2019: 119–22).

A treatise *On Furnaces* is also attributed to Maria the Jewess in alchemical sources (Festugière 1944: 365), but it has not been preserved in Byzantine manuscripts. Various passages from her works, however, are quoted by Zosimos, who records Maria's description of a three-arm still (or *tribikos* in Greek; *Authentic Memoires*, III 1 in Mertens 1995: 14–5):

> I shall describe to you the *tribikos*. For so is named the apparatus constructed from copper and described by Maria, the transmitter of the art. For she says as follows: "Make three tubes of ductile copper a little thicker than that of a

> pastry-cook's copper frying pan: their length should be about a cubit and a half. Make three such tubes and also make a wide still-head (copper vessel, *chalkeion*) of a handbreadth width and an opening proportioned to the still-head. The three tubes should have their openings adapted like a nail to the neck of a light receiver … . Towards the bottom of the still-head are three holes adjusted to the tubes, and when these are fitted, they are soldered in place, the one above receiving the vapour in a different fashion. Then setting the still-head upon the earthen pan (*lopas*) containing the sulphur, and luting the joints with flour paste, place at the ends of the tubes glass flasks, large and strong so that they may not break with the heat of the water, heat that comes with the distillate." Here is the figure.
>
> (transl. by Taylor 1945: 190, slightly modified)

This detailed description of a still – which interestingly includes a comparison with a cooking tool (a frying pan) – is followed by a second description of an alembic only equipped with one tube, a device that, in all likelihood, should be ascribed to Maria the Jewess as well. Both descriptions refer to drawings of the devices, which are likely to have complemented Zosimos' original text. The Byzantine manuscripts do include some images of these stills, which also include captions referring to their different parts. As one can infer from the images in Figure 3.7, the terminology used only partially matches Zosimos' descriptions of the devices.

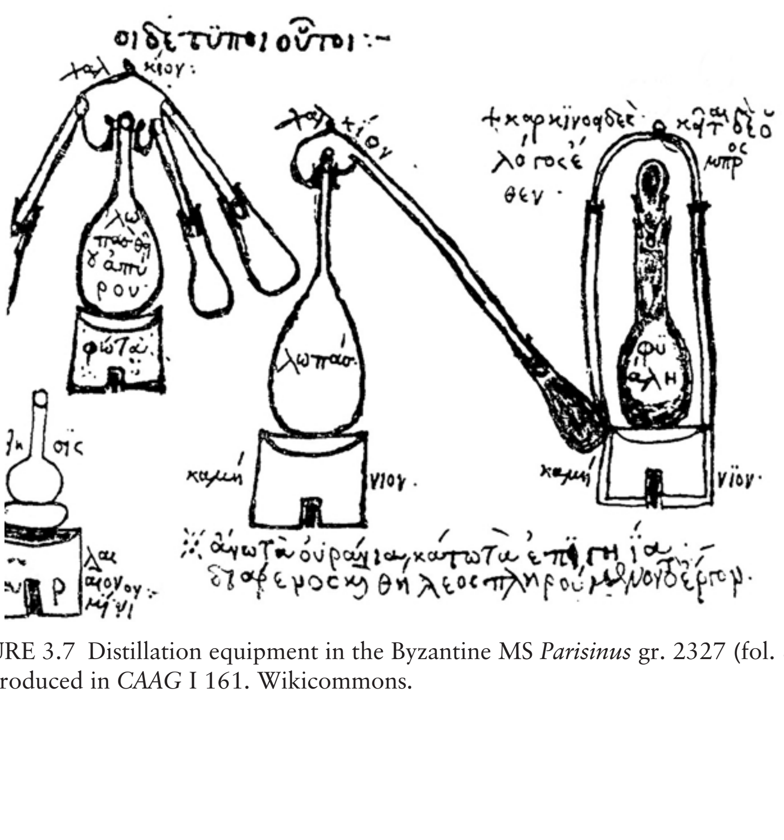

FIGURE 3.7 Distillation equipment in the Byzantine MS *Parisinus* gr. 2327 (fol. 81v) – reproduced in *CAAG* I 161. Wikicommons.

The actual use of similar alembics is not evident in early alchemical texts, which often refer to the production of sulfur water, whose recipe, however, has no mention of distillation or distillatory devices, at least in the version transmitted by the Leiden Papyrus (§ 87; see Chapter 2, p. 80). In other passages, Zosimos describes how to distill eggs in order to produce alchemical dyeing waters (*Authentic Memoires*, IX in Mertens 1995: 30–3). Moreover, scholars have argued that these stills could have been used to distill alcohol during the first centuries CE; that is, long before the period in which the earliest medieval recipes describing similar procedures were compiled (twelfth century CE). Hermann Diels (1913) had the above-discussed alchemical alembics in mind when he tried to interpret a reference to flammable wine he found in the early third-century CE treatise *Refutation of all Heresies* attributed to Hippolytus of Rome (IV 33.2). He speculated that alcohol could have been produced if wine was slowly heated in devices such as the alembics described in Greco-Egyptian alchemical literature. A tantalizing passage from Pseudo-Hippolytus prescribes the boiling of "seafoam" (salt?) with sweet wine (simply referred to as *glyky*, lit. "sweet," in the recipe) to produce an easily flammable liquid that, if poured upon the head (in the context of a gnostic baptism), does not burn. Diels' hypothesis was firmly criticized by Lippmann in a series of papers (collected in Lippmann 1923), where he emphasized, among other points, that sophisticated cooling methods were necessary to isolate alcohol. Even though more recent laboratory tests seem to confirm that distillation of aqueous ethanol can be performed with Hellenistic stills (Butler and Needham 1980), the scattered information provided by ancient sources – recently collected and analyzed by Anne Wilson (1984: 46–9, 56–64), who supports Diels' hypothesis – makes it difficult to solve the problem.

On the other hand, ancient alembics were certainly used to distill liquid substances, as one can infer from Pseudo-Democritus' description of a still as recorded in the fourth-century CE commentary on Pseudo-Democritus' work by the alchemist Synesius (Martelli 2013: 128–31; see also Taylor 1930: 195–7; Martelli 2011: 301–5). Various "bodies" are mixed with mercury and distilled in an apparatus, whose parts are referred in a quite different terminology to Maria's alembic: in particular, the head of the still is described as a glass vessel having a breast-shaped protuberance – a *mastarion* in Greek. This word, a diminutive form of *mastos* ("breast"), represents a technical term implying an analogy between the female body and the shape of the instrument.

An increasing specialization of alchemical vocabulary is also recognizable in the use of the word *kērotakis*, a term related to a second category of alchemical instruments. A similar device was probably described by Maria the Jewess (see Zosimos, *Authentic Memoires*, VII 2 in Mertens 1995: 23), and scholars usually agree in tracing back the *kērotakis* to the palette of ancient painters (*CAAG* II 250,4s.). They melted wax colors on a small metal shovel, which was heated over a vessel containing hot charcoal (*CAAG* I 144; Forbes 1970: 25–6; Mertens 1995: cxxx). In the alchemical texts, the same shovel (actually a metallic leaf) was probably heated and treated with dyeing substances in order to change its color: the word *kērotakis*, in fact, seems to refer both to the leaf itself (*CAAG* II 102,20, 146,13, 169,12–13) and to the specific instrument used to treat it.

On the basis of Zosimos' writings (*Authentic Memoires*, VII 4–6 in Mertens 1995: 24–5) and of the images preserved by the Byzantine manuscripts (Taylor 1930: 132–4; Mertens 1995: 246–51), scholars have tried to reconstruct a specific device composed by different parts slotted together (see Figure 3.8): the instrument could probably have either a cylindrical or a spherical shape. A lower vessel contained the source of heat (Figure 3.8A), while a volatile substance was put into a second vessel (Figure 3.8B) – very often made of glass – fitted to the first one. On the top of the second vessel alchemists placed the metallic leaf (Figure 3.8C), which was covered by a glass cup (Figure 3.8D). Most scholars agree that the metallic leaf was transformed by the vapor of the

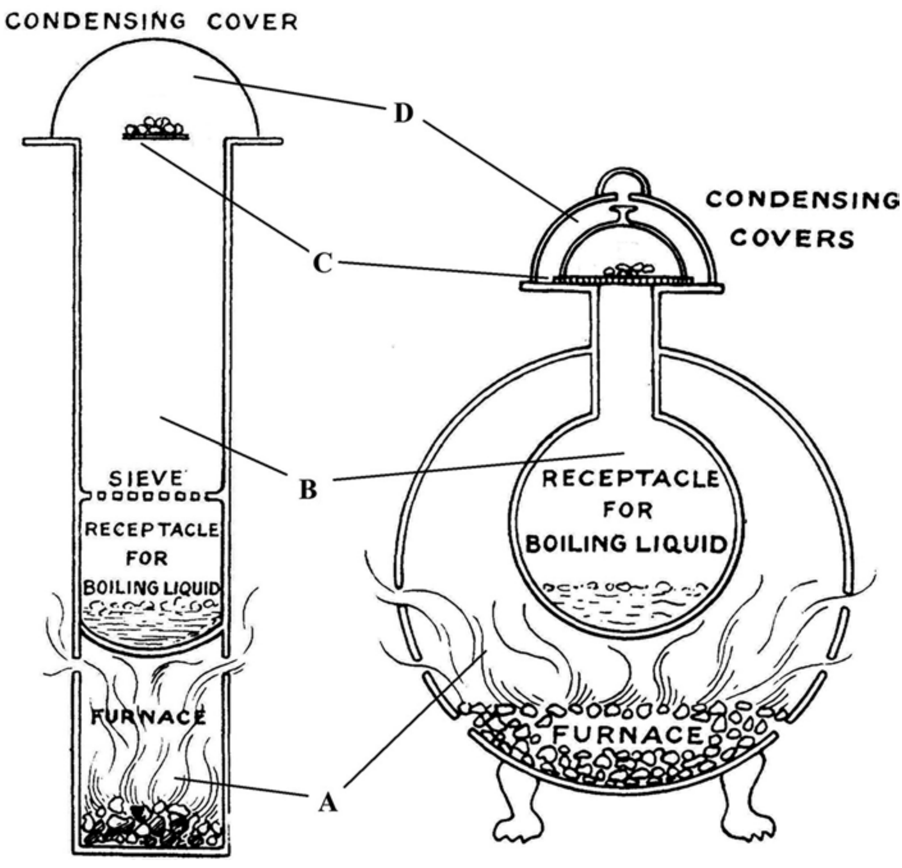

FIGURE 3.8 Two types of *kērotakis* (from Taylor 1930).

volatile substances that were put in the central container (Taylor 1930: 133–7; Mertens 1995: cxxx–clii); in other cases, some reactive chemicals applied to the leaf itself could cause the color changes (*CAAG* II 146,13f.).

CONCLUSIONS

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The innovations introduced in chemical apparatus and experimental practice by the ancient civilizations created most of the instruments and devices that were used in early modern laboratories. These remarkable achievements were the result of a slow accumulation of improvements that were adapted to stable technical routines of experimentation. This evolution was possible thanks to the importance that the chemical arts acquired in both the Egyptian and Mesopotamian civilizations, where they were under the authority of the political and religious powers. In Egypt, the exploitation of many mineral resources and chemical processes occurred in the areas surrounding the Nile valley. Being under the control of the state, the actual manufacture of chemical commodities was performed by qualified craftsman and was often kept secret. Although archaeological findings are few, the remaining evidence suggests that important chemical workshops were mostly situated in the temples until the Greco-Roman period.

In Mesopotamia too, the state and its rulers supported the emergence of specialists in the chemical manufacture of valuable commodities that, in several cases, were produced in specialized workshops supervised by chief administrators and scribes. Archaeological remains have shown the evolution of kilns, furnaces, crucibles, and other tools.

In the Greco-Roman world, the appearance of several terms to denote workshops devoted to the chemical arts illustrated an unprecedented specialization, especially in dyeing, pharmacology, mining, cosmetics, and glassmaking. Consequently, a variety of new instruments and apparatus was introduced. Archaeological findings have been recently interpreted as evidence of the existence of distillatory techniques. The reference to the first treatise on furnaces, attributed to the alchemist Mary the Jewess, revealed specialized literature on the making of chemical devices.