The Antikythera Shipwreck

The technology of
the ship
the cargo
the Mechanism

The present publication on the technology of the ship, the cargo and the Mechanism of the Antikythera shipwreck is offered in connection with the homonymous temporary exhibition held at the National Archaeological Museum, Athens.

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Drawings
Nektaria Roumelioti, Thomas Kotsigiannis, Giannis Nakas

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The Antikythera Shipwreck

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Editors:
Alexandra Christopoulou - Anastasia Gadolou - Polyxeni Bouyia

Translation:
Michael Anthony Fowler, M.A., Columbia University

MINISTRY OF EDUCATIONAL AND
RELIGIOUS AFFAIRS, CULTURE, AND SPORTS
GENERAL SECRETARIAT OF CULTURE
NATIONAL ARCHAEOLOGICAL MUSEUM

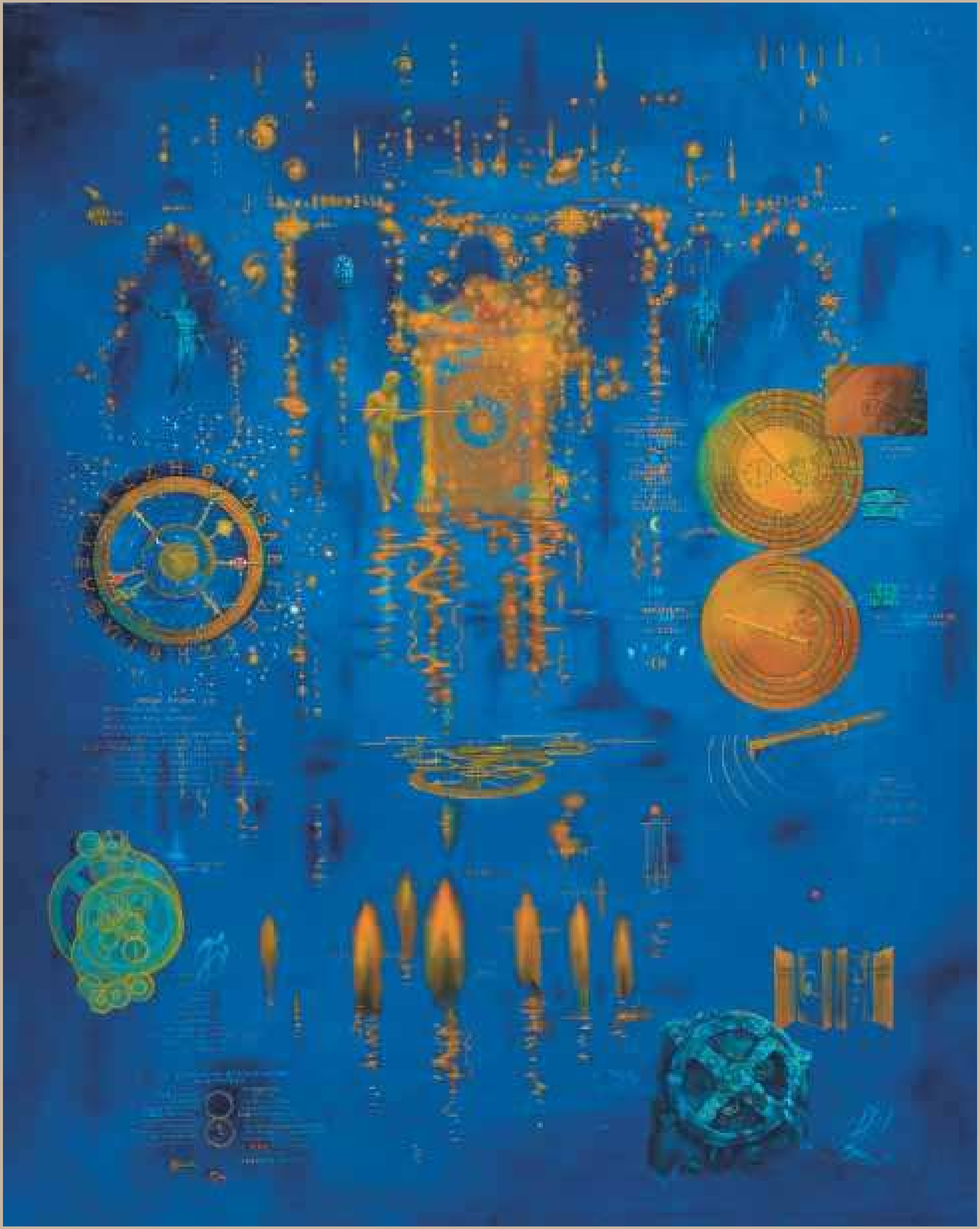
Contents

Hellenes laid the foundation of modern culture; we offered knowledge and innovation to the entire world.

The “Antikythera Mechanism” - predecessor to modern computers - that our ancestors created, together with every other product of our culture, has come to awaken and remind us of the virtues of thinking and acting as a collective mind.

Rediscovering collectivity, innovation, and the good side of our nature is something we all are in need of today more than ever.

MICHAEL TSAMAZ
Chairman & Chief Executive Officer, OTE Group



In antiquity, a systematic treatment was called technology (*τεχνολογία*). The technician (*τεχνολόγος*) wrote about the art of rhetoric and the verb *technologeō* meant "to prescribe as a rule of art". The mythical metallurgists, the Telchinai and the Kouretes, constructed the first statues of the gods, but their ingenuity did not distinguish the good from the bad. The activity of Daedalus, innovator of many tools and technical works, reveals the beneficial yet still destructive side of inventions.

The technology of the ancient Greeks – as experience, practical skill, knowledge, and feedback, as well as a process of making tools or more complex objects – was based on observation of the universe through philosophical reflection. The impact of science on technology from the 6th c. BC onward expanded its applications; the acceleration of technology's progress produced, in turn, the development of science.

The fascinating and unexpected discovery off the island of Antikythera is an ark of technological applications from a time when technical expertise was at its zenith. That is why its study has achieved such wide interdisciplinary attention and continually attracts global interest. The technology gathered there, including the Mechanism, which constitutes one of the most sophisticated examples of ancient technical intelligence, excites equal admiration as the artistry of the objects. The National Archaeological Museum's exhibition of *The Antikythera Shipwreck*, which has been received with enthusiasm by the world community, places this successful coupling of art and technology on display within an evocative atmosphere.

The present handbook was designed to provide the fullest understanding of the exhibits from the standpoint of technology, which is entitled to an equal status to art in the evaluation of each material creation. Warm gratitude is due to the OTE and COSMOTE companies, which are at the cutting edge of technology in the telecommunications sector and funded this publication with great willingness. We believe that the alternative reading of the exhibition, with this handbook as a guide, will increase visitors' enjoyment and benefit through dialogue with the unique archaeological evidence of *The Antikythera Shipwreck*.

The various cultural activities marking the occasion of this archaeological exhibition are part of the vision for a more integrated educational and entertaining experience for potential visitors. Targeted towards all audiences, these activities aim to highlight the beneficial and strategic role in cultural affairs played by the first archaeological museum in our country and among the most important ones worldwide.

DR. GEORGIOS KAKAVAS
Deputy Director of the National Archaeological Museum

Painting by Evi Sarantea-Micha *The Mechanism of Antikythera*.
Chalkis, Greece 2010 (oil on canvas, 1.20 x1m.).

Technology coexists with mankind since when our Paleolithic ancestors struck stones together in order to construct the first tools. From then, all human achievements are works of art in the original sense of the Greek word *technê*, which is a noun deriving from the ancient verb *teuchô*, that is, to create/to construct skillfully, or from the verb *tiktô*. Sculpture and ceramics, mathematics, architecture, and physics are included in fields of art and technology. In awe, humankind realized very early on the greatness of its achievements and humbly imbued them with divinity and myth. In Greek antiquity there were Metis, personification of wisdom, sagacity, and resourcefulness for survival, Hermes, inventor of fire, Hephaestus, patron of metallurgy, Athena, patroness to a variety of artisans, the Muses, the Telchines, the Cyclopes, as well as Prometheus and Daedalus.

Art or technology is essentially the result of the continual advancement of the intelligent human. Every time human achievements appear for the first time, they draw and attract their contemporaries. They then take their place in the developmental ladders of the areas in which they have been recorded, since they become the property of all. In this way, for instance, the ceramic arts developed from handmade Neolithic vases to the intricate red-figure vessels of the Classical period.

The Antikythera Mechanism is no exception, since it incorporates all the preceding knowledge of ancient technology. It is an astonishing technological achievement and has been characterized as 'mankind's first computer'. With this in mind, the present handbook was created. In addition to the Mechanism, i.e., each find from the Antikythera Shipwreck, from the boat itself and its equipment to its precious cargo – marble and bronze statues, glass vessels, gold jewelry, a multitude of clay vases, and bronze couches – presupposes the maturation, enrichment, and development of older techniques or specialized knowledge.

This publication is a further offering to the 'Antikythera Shipwreck' fund and, in connection with the homonymous temporary exhibition, forms part of the actions of both the National Archaeological Museum and expert scientists, who collaborated to produce as complete and timely a public briefing as possible.

We hope that in its pages the unseen side of these artworks as well as the breadth and innovation of ancient Greek technology will be illuminated, and that the offer of ancient Greek thought to the European and global cultures will be appreciated.

We warmly thank OTE and COSMOTE for funding this publication, which, in connection with the scientific catalogue and the small guide published for the exhibition, *The Antikythera Shipwreck. The Ship, the Treasures, the Mechanism*, we believe will contribute considerably to multiple interpretations of the finds from the Wreck and of the Antikythera Mechanism.

DR. ALEXANDRA CHRISTOPOULOU
Head of the Department of Public Relations and
Educational Programmes of the National Archaeological Museum

Fig. 1. Fragments of a red-figure kylix (cup) by the Euergides Painter. From the Athenian Acropolis. 510-500 BC. On the left, sculptors work on a statue of a horse. In the center of the scene, a vase painter seated in front of a potter's wheel decorates a cup. At the right, the metalworker hammers metal by the furnace, while a boy next to him handles the blowpipe. (National Archaeological Museum photographic archive).

The apogee of technology in the Hellenistic period was a continuation and "intensification" – rather than an "explosion" – of related advances. At that time, previous technology ripened, fertilized by developing science, and served the personal ambitions of the Successors of Alexander the Great to exhibit acts and works of a scientific character, while it also responded to the "cosmopolitan" atmosphere of the period.

In this multifaceted florescence of technology, the Antikythera Mechanism was but a logical consequence, all the more since it was not the only artifact that operated with sets of gearwheels.

1. THE ORIGINS OF ANCIENT GREEK TECHNOLOGY

The time has certainly passed by when one would hear the bucolic saying "the ancient Greeks were 'theoreticians' – they did not have technology; the Romans developed technology." However, the Romans themselves said other things: The greatest Latin technical writer, Vitruvius, refers continuously to ancient Greek technology in his classic book *On Architecture*. More than one hundred Greek engineers, architects, scientists, philosophers, and artists parade through the pages of his ten books. Moreover, the distinguished engineer uses several dozen predominantly Greek technical terms – a fact that alone answers the question "who developed and who borrowed technology?"

Today, at any rate, the position of the international literature is very clear: the Greeks were avid technicians. It would be perhaps sufficient here for us to recall the fundamental fact that the Greeks regarded technology as a divine invention (fig. 1): a) with the presence of the craftsmen Cyclops in the divine triad "Titans, Cyclops, One-hundred-handed ones" (Spirit, Art, Nature), b) with the technical nature of one of the twelve Olympian gods, Hephaestus (fig. 2) and c) with the evolved Promethean myth (in Plato's *Protagoras* 321c), in which the divinity decides to save the human race by gifting Prometheus technical wisdom *(ἔντεχνον σοφίαν)*, which derives from Athena (fig. 1).

Fig. 2. Bronze coin with a depiction of Hephaestus. End of the 3rd c. BC. Malaga, Spain. Alpha Bank Numismatic Collection 10783. (Reproduction courtesy of Alpha Bank).

A people who very much linked technology with their religion were engineers.

Ancient Greek technology was developed continuously from the middle of the 2nd millennium BC until the middle of the 4th c. BC. It experienced, however, a marked upsurge during the Hellenistic period, the subject to which this handbook is dedicated. This upsurge itself is of

Fig. 3. Drawing representing the dam and artificial pond at Mycenae. (From Knauss J., *Υστεροελλαδικά Υδραυλικά Έργα. Έρευνες για την Υποδομή Υδραυλικών Έργων Διαχείρισης Υδάτων κατά τη Μυκηναϊκή Περίοδο*, Athens 2002, 66 fig.11. (Reproduction of drawing by N. Roumelioti).

great interest for global history, as the Arabs and Byzantines would copy, sustain, and bring it to the European West. The specific interest of this Hellenistic technological florescence is associated, however, with the origin of the Antikythera Mechanism, which can no longer be considered as an "unbelievable" achievement, but rather as a logical consequence of Hellenistic technology.

2. THE MOST ANCIENT GREEK TECHNOLOGY

Ancient Greek technology had developed already from the appearance of the first Greek tribes in (pre)history, and was continued until the Classical period to such a degree that what followed after Alexander the Great was an acceleration and an extension, not an explosion thereof.

The "Mycenaeans", a merchant people (who sailed the Mediterranean from Palestine to Sardinia), proceeded with tremendous growth in land reclamation projects in order to exploit the few agricultural possibilities of their country's cultivable valleys. They constructed dams (fig. 3) and managed river diversions, for example, the long wall diverting the Kladeos (a tributary of the Alpheios) to Olympia and the earthen dam for the diversion of the Tiryns River (which perilously eroded the walls of Tiryns); these works are preserved even today. The Mycenaeans reclaimed flood-land, the most important being the first complete drainage of Copaïs (ca. 1300 BC).

In the field of construction, humanity would still need 1500 years to build anew a 15-meter wide dome, like the great tholos tombs of Mycenae. Mycenaean metalworking was extremely developed, as demonstrated by their preserved panoplies and swords as well as by their jewelry (systematically exported products).

Their technology, however, seems to culminate in shipbuilding: their famous *penteconter* ("fifty-oared"; a commercial and war ship) is the result of numerous technologies.

The so-called "dark" ages that followed appear, however, to have conserved earlier Greek technology. Two key examples suffice: The extensive Homeric oral epics reflect the Greek passion for technical automation (a) on the level of the gods (automatically moving tripods, robot girls made of metal, etc.) and (b) on the level of the mythic Phaeacians, whose crewless ships led their passenger to the destination "that he had in his mind". In the 8th c. BC emerging from the "dark" ages, the Greeks found themselves paradoxically technologically equipped: the Chalcidians and the Cymaeans who departed Euboea in order to found Cyme in Italy appear to have possessed the following advanced technological knowledge: they built large ships capable of travelling distances of a few thousand kilometers; they dried the marshes of new Cyme; they built renowned temples; meanwhile they proceeded to Pithekoussae (modern Ischia), where they organized a highly specialized metalworking and jewelry industry.

With such evidence, we suggest that Mycenaean technology was continued, unlike other activities closely associated with the dissolved palatial system.

Some researchers associate the cultural blossoming of the 6th c. BC with the birth of science in Ionia and, in particular, with geometry, the mother of the sciences: For instance, the design of the large diversion of the Alis River by Thales, and the surprising geometric precision of the driving from both ends of Eupalinos' tunnel on Samos are explained in this way. The Greeks' admiration for these technical achievements was such that, apart from Herodotos' praise for the projects (1. 70 and 3. 60), Plato himself would characterize Thales as "a wise man" *(ἄνδρα σοφόν)* – not for his contribution to mathematics, but for "works of many and ingenious inventions for the arts [actions]) (*τὰ ἔργα [ἔνθα] πολλαὶ ἐπίνοιαι καὶ εὐμήχανοι εἰς τέχνας [πράξεις]*) (*Republic* 600, a).

For the sake of brevity, it is appropriate here for us to refer to shipbuilding, the product of various technologies: The Greek trireme (a work chiefly of Corinthian engineers, Thucydides 1.13) was widespread in the Mediterranean and was the subject of "orders" of mass shipbuilding, as, for example, in Samos on behalf of the Pharaoh Amasis. Furthermore, there was not a Greek city lacking an extensive water supply network (the Peisistratid one in Athens was 7.5 km), while mineral/metallurgical exploitation in Laurion, conducted on a unique scale in antiquity, was based on a large number of technological innovations.

The quasi-industrial production of metal products in Athens (e.g. owned by the fathers of Demosthenes and of Lysias) indicates also the economic importance of technological development during the Classical period.

It is not by chance, then, that an "idealist" philosopher like Plato expresses respect for artisans (he calls them "*δημιουργοὺς", i.e. creators*), referring to the concept, composition, and harmony of their works (*Gorgias*, 503E, 504A). Aristotle predicated a political utopia upon future technology, when he envisioned that automatic and robotic machines would eliminate slavery (*Politics*, 1253.6, 35). These facts, we note, do not support the prevailing notion that the Classical period witnessed stagnation in technology due to "shifting interests of citizens".

3. HELLENISTIC TECHNOLOGY

History thus entered into the zenith of ancient Greek technology as a continuation of earlier innovations. It was served emblematically by the Greek engineers employed in Alexander's full army mobilization (tunneller, urban planner, hydraulic specialist, etc.).

This is the first example (i.e. the military) of the very positive role that the enlargement of the scale of public affairs would play in the field of technology.

Before attempting to explain the great upsurge in technology from the end of the 4th c. BC until the 1st c. AC, the main technological achievements of this period should be outlined:

3.1. Summary description of technological achievements

a) Technical works

Specialization in major land-reclamation projects, such as that of Lake Ptechai (Euboea), which was the first contracted work in history with a capitalist B.O.T. system (Build-Operate-Transfer). The Ptolemies also dried up a large portion of Lake Mareotis so that Alexandria could be developed.

The bridge with a multi-centered arch at Rhodes (ca. 316 BC) and the corbelled bridge in Eleftherna (middle of the 4th c. BC), prior to the Roman development of the vaulting.

The "lighthouse", a tower up to 120 meters high in Alexandria, most likely with an internal installation for the mechanical lifting of vast quantities of fuel.

Pergamon's four aqueducts that brought 2000 cubic meters of water to the city each day through a triple pipeline and siphons with 15 atm. of pressure.

b) Shipbuilding

The characteristic example is the gigantic ship *Syracusia,* with its massive tonnage, that Hieron sent as a gift to Ptolemy III.

c) Military technology

"Helepolis", the multi-storied, armored, mobile siege tower (40-60 meters in height), with known usage by Dionysius the Elder at Syracuse and by Demetrius Poliorketes.

Invention of catapults with a spring and pressurized air (Ctesibius, 285-222 BC) and the theoretical and experimental research of Philo of Byzantium (ca. 250 BC) on catapults with torsional springs.

d) Machinery

Pumps: Ctesibius' two-stroke piston (fig. 4), the "drum" and "chain" of Philo of Byzantium (to whom the first water-powered chain pump is owed), as well as the Archimedean screw pump.

The huge cranes, with which Archimedes (287-212 BC), from behind the walls of Syracuse, snatched the Romans' giant mobile siege towers and destroyed them.

Automation: The Greeks' dream became a reality – not only the gods had *automata*. Philo of Byzantium and Heron of Alexandria (ca. 1st c. AC) wrote books "On Automation", while Athenaeos (5.198f) describes how the four meter statue of Nysa (270 BC) would stand up, pour a libation, and sit down again, most probably by means of a cam and two gears.

Gearwheels: In roughly the same period, Aristotle refers (*Mechanics* 848a) to the transmission of motion through tangent circular wheels and to their applications. Shortly thereafter, Ctesibius would use gears in his water clock, and Philo's pumps appear to have made similar use of them, just as the odometers later did.

Steam power: Heron's *aeolopile* rotated by means of steam. Even though there is no evidence of its practical application, the transmission of motion from one axle to another by means of a closed chain was already known in Philo's hydraulic pumps. Therefore, it was only a matter of time until rotation, with the aid of steam, was transmitted

Fig. 4. Ctesibius' pump. Collection of the Society of Ancient Greek Technology. Construction D. Kriaris.

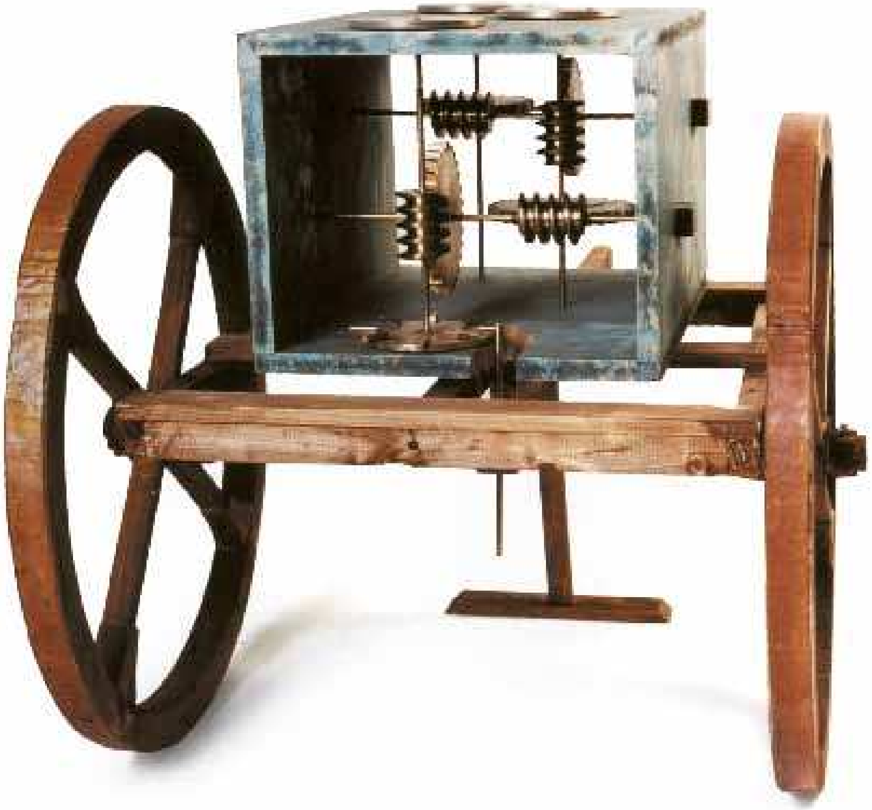


Fig. 5. Heron's odometer. Collection of the Society of Ancient Greek Technology. Construction D. Kriaris.

by means of a chain to a pump. Heron himself himself had already designed the transmission of a wind rotor's circular motion to Ctesibius' two-stroke pump.

e) Agriculture: an indicative example is the olive screw press, an invention of Heron.

f) Metalworking
All metallurgical technologies had already, since the 4th c. BC, reached their peak. Metalworking had at its disposal, then, various alloys for diverse applications, from the production of statues to weaponry, from the manufacturing of well-made domestic utensils to gearwheels. The basic techniques were casting or hammering of metal sheets, but the metal lathe was also utilized.

g) Chemistry
Following the basic principles of chemical transmutation, which had already been introduced by the pre-Socratic philosophers and the Stoics, empirical chemistry of processing metals, precious stones, and dyes of all kinds (through a huge variety of reagents) was initiated by Bolos from Mentes (ca. 200 BC) and culminated in Alexandria, between the 1st c. BC and the 4th c. AC.

h) Scientific instruments
The view that "the concept of technology in service of science in the ancient world was almost completely unknown" is inaccurate. We certainly do not expect an ancient Greek essay detailing technology's "intention" to serve science. However, we have evidence of the production of useful artifacts for scientific measurements.

- Measuring time: "water-clocks", (Ctesibius, Archimedes).
- Odometer (like today's taximeters): Vitruvius, Heron (fig. 5).
- Astrolabes of all sorts.
- Precision balances (Aristotle, *Mechanics*)
- Surveying instruments, like the level, dioptra, etc.
- Medical instruments: surgical and orthopedic implements (Andreas, Numphodorus, *et al.*), as well as the special sphygmometer of Herophilus in Alexandria (ca. 300 BC).

- "Globe-making" (*spheropoeia*): simple figurative replicas of the sky with fixed celestial bodies (Cicero, *On the Republic* 14.22) or functional models, like the second planetarium of Archimedes, which Cicero mentions, and the Antikythera Mechanism.

H. Von Staden's view has a place here: "The parallels between Erasistratos' model of the heart and central features of the new Alexandrian mechanical technology are striking" (a reference to the two chambers and the valves of Ctesibius' pump).

i) Artifacts for cultural use

Just as technology served every kind of need that could not be met by physical means, it was logical (especially during the Hellenistic period) that technology would also serve the needs of people in communication and culture in general. It is surprising that, in a significant portion of the current international bibliography, these miraculous technical discoveries are undervalued by ideological characterizations as "amusing contrivances", when they are exceptional technological achievements – even with today's knowledge.

Indicative examples include:

- Athletics: The *hysplex*, the instrument that by means of a torsional spring allowed the racers in the stadium to start at the same time (fig. 6).
- Music: Ctesibius' *Hydraulis*, the musical instrument that functioned with compressed air conducted, by means of keys, to the appropriate pipes.
- Theatre: The seven-minute automatic theatre of Philo and Heron ("The Myth of Nauplius"), which worked without any outside interference, thanks to a highly intricate internal winding of thin rope approximately 100 meters in length.

Fig. 6. Hysplex. Study and construction P. Valavanis. Nemea excavations of Berkeley University (director S. Miller). Exhibition catalogue, *Ancient Greek Technology,* Athens 2002, 28.

Fig. 7. Automatic opening of temple gates. Collection of the Society of Ancient Greek Technology. Construction D. Kalogeropoulos.

- Communication: The hydraulic telegraph of Aeneas Tacticus (Philo, *Compendium of Mechanics* V), and Cleomenes' and Democleitus' *pyrseia*, transmission of a visual signal by means of torches (Polybius, *History* X, 43-47).
- Religion: Automatic opening of temple gates once the believer lit a flame on the outer altar, (Heron, *Pneumatics*, A, 38), achieved thanks to the expansion of heated air (fig. 7).

In spite of the extreme brevity of quoting the several technological achievements of the Hellenistic period, it is obvious that the multitude of artifacts, and, especially, the range of subjects that were served were highly characteristic features of the period.

3.2. Economy and technology in the Hellenistic world

"Economy, a science with which people can increase what is useful to each."

Xenophon, *Oeconomicus*, 6. 4-5

When Philotas, inventor of a water-pump in Alexandria (2nd c. BC), proposed that the authorities "adopt" the machine, he was acting in an economic and technological spirit. Wage labor of citizens (or occasionally of slaves) in ancient Greece, one of the features of modern economics, was observed more in the technical occupations requiring skill. In the homes of the ruling class in Alexandria, it seems that personnel were normally paid in cash. Pliny mentions two Greek essays on beekeeping, one by Aristomachos and another by Philistos. Of interest are the extensive lending activities in Rhodes during its acme. Contrary to the practice of the Classical period, now the names of the great military engineers are made public: Polyeidos, Diades, Charias, Epimachos, Hegetor, Diagnetos, Kallias, and others, many of whom were also authors of (now-lost) books. The financial aspect of their profession is characteristic. Diodoros (14.41.3) writes that Dionysios the Elder attracted engineers by "compelling them with high wages". It is proposed by certain scholars that Ptolemy III, in order to curb the growth of the Pergamene library, prohibited the export of papyrus from Egypt and contributed – unwittingly – to the development of the technology of parchment in Pergamon... What is more, mass organization of pottery workshops is observed (for example, the five kilns concentrated in Macedonian Euia, Polymylos).

These few examples of technical activities with a specialized financial objective ought to be associated also with the broader economic significance of extensive trade of products (in the quasi-unified Hellenistic world), which presupposed their own technologies. Here, commerce in the Seleucid kingdom should indeed be mentioned separately. Still it cannot be argued that the economy of the Hellenistic period had acquired the characteristics of today's economy.

4. ETIOLOGY OF THE TECHNICAL APOGEE

Whither may this florescence of Greek technology in the Hellenistic period be ascribed? A response to this question can be proposed only through logical inferences.

4.1. Reasonable maturation

It has been argued that Hellenistic technology consisted of an "acceleration and an extension" of the ancient Greek technical phenomenon, "and not an explosion". We then traced the continuity of cognate phenomena.

The development and ripening of ancient Greek technology as the centuries passed is reasonable, provided, of course, that the ambient conditions permitted this continual maturation. In fact, the conditions allowed and encouraged ongoing development.

Let us note a further element of this continuation: the numerous scientists and engineers who moved from Greece to Alexandria and Pergamon, sometimes transporting entire libraries along with them as well. There is, then, a living two-fold connection between the old and the new.

4.2. Fertilization by science

An initial positive influence of newborn Greek science on technology was seen already by the 6th c. BC. Plato himself made crystal clear the great potential of this fertilization of technology by science: "For example, if someone were to separate arithmetic, measuring, and weighing from the all the arts, what remained of each would become paltry" (*Philebus*, 55E).

And the perspicacious Vitruvius, three centuries later, would confirm the fortunate wedding of Greek science with technology in writing (1, 1.17-26), "Aristarchos, Philolaos, Archytas, Apollonios, Eratosthenes, Archimedes, and Scopinas have bequeathed to posterity many machines, which were devised and manufactured on the basis of numbers and natural laws" – in other words, on the basis of science.

The productive role of the great libraries of Alexandria, Pergamon, and Antioch has its place precisely here: Knowledge was now exploited in an aggregated fashion, even if T. E. Rihll is accurate in making the (anachronistically demanding) observation that these libraries were not 'public'.

It should also be noted that the same author admires Alexandria, of which the "established reputation as a center for these studies [i.e. science and technology] seems to have served to draw successive generations of students to this city."

Such a broader educational climate made the Hellenistic metropolises greenhouses of scientific and technical development – for the standards of the time, of course. Therefore, we are perhaps justified, for instance, in associating what Strato of Lampsacus wrote about the elasticity of gases with the inventions of Ctesibius' air-powered catapult and with Heron's *aeolopile*. While the arithmetization of music (chiefly by Archytas) rendered the manufacture of stringed musical instruments a simple application of geometry, so too did the knowledge of the Archimedean spiral enable the construction of the eponymously named screw pump. The conception of the helicoidal ore-washeries at Laurion seems to be analogous.

Philo of Byzantium would propose an algebraic formula (of experimental origin) for determining the diameter of the twisted "rope" of the catapult, when the weight of the projectile to be launched is known.

Notwithstanding their unavoidably fragmentary nature, these facts indicate that Hellenistic technology was irrigated to a sufficient degree by science, which was systematically cultivated in the Musaeum of Alexandria.

4.3. The euergetism of the Greek kings

A striking shift in the ways that kings acquired prestige is observed with Alexander's Successors: They all persistently supported the development of letters, science, and technology, established great libraries, and surrounded themselves with scientists.

The Ptolemies, in particular, believed that they would gain fame through new scientific and technical activities. Eratosthenes sought by royal command to measure the meridian arc of the Earth (the famous Syene experiment). Philo (*Ballistics* 50.24-6) notes that technicians in Alexandria possessed rich resources, since their kings loved fame and technology. And the construction alone of the Lighthouse of Alexandria implied the solution of numerous scientific problems, multi-year research, and continuous funding. The man who constructed it, Sostratos of Cnidus, would record the name of the king on the base of the enormous work. The Library and the Museum presupposed initiative and constant royal funding. During the Roman period, when the Library was almost destroyed (J. Caesar, 47 BC, Aurelian 270 AD, the fire of the Serapeum 391 AD - before Omar 641 AD) and the Museum was demolished, the prolific marriage of science and technology became indistinguishable.

4.4. The Cosmopolis

It is assumed that the small scale of the Greek city-states before Alexander the Great was not so conducive to the gathering of scientists, concentration of funds, and unimpeded circulation of goods across borders.

In the Greek world, and for long periods of time, a relaxation of the aforementioned constraints – partly at least – is now seen in an extensive geographic area, which had recognized a common language (*koine*) and a (more or less) common mindset and lifestyle among the ruling classes.

What is more, in this era, many people living in the new atmosphere of the *pax hellenica* appear to have been interested in the "here-and-now" issues of life. Even the scientist and engineer writers of the period were not aristocrats or generals, but rather children of trade practitioners (Ctesibius' father was a barber, Heron's father was a cobbler, etc.).

Finally the great development of chemistry during the Hellenistic period focused on "dyeing", counterfeiting and adulteration of gold, silver, and precious stones (from processed rock crystal), and porphyry. There was a multitudinous clientele with a mind for easy money or at least with a taste for *faux bijoux*. The "Cosmopolis" of the Stoics was perhaps not very far from the reality of the era. Thus, for these reasons, a clear encouragement to develop practical activities and, thereafter, technology makes sense.

The great florescence of technology in the Hellenistic period, particularly from the 3rd to the 2nd c. BC, is explained by the combination of the four factors outlined above.

5. A REASONABLY FORESEEABLE ARTIFACT: THE ANTIKYTHERA MECHANISM

In this blossoming of every sector of technology the production of a planetarium, like the Antikythera Mechanism, is, then, a reasonably foreseeable artifact.

The knowledge, materials, and skills required in order for the production of this Mechanism to be feasible in the 2nd c. BC will be presented below.

- Astronomical knowledge, which the Mechanism incorporates, was all known to the Greeks before the middle of the 2nd cent. BC (Meton, Autolycus, Hipparchus, and others). This was the main prerequisite.
- Euclidean geometry and the contents of Aristotle's *Mechanical Problems* were sufficient for the engineering design of the instrument.
- From a metalworking perspective, while the "alloys" (bronzes) were well known for centuries, like the production of sheets and discs (with hammering or casting), the manual cutting of teeth could be carried out with the use of a template (made of papyrus, for instance).
- Knowledge of the operation of gearwheel sets was sufficient not only from the pertinent paragraphs of the *Mechanical Problems* (848a), but also from reasonably imputed earlier applications of gearwheels:

  a) by Ctesibius in his water-clock

  b) by the Alexandrian doctors Andreas and Nymphodoros (end of the 3rd c. BC) in equipment for orthopedics,

  c) by Archimedes, first, in launching a ship by means of a worm gear (Athenaeos, *Deipnosophists*, 5.206e), and, second, in his planetarium, as Cicero describes in detail (*On the Republic*, 14.22), mentioning, "with rotation it was possible to observe various orbits [of celestial bodies] with unequal speeds and disparate motions".

When, in the 1st c. BC, Vitruvius (10.9) described his odometer (with a complex system of gearwheels) he assumed that the technique of gears was familiar to all.

For all these reasons, the Antikythera Mechanism thus embodies knowledge and techniques that were, in fact, available to the Greeks earlier than the middle of the 2nd c. BC – a period during which, as we have seen, Hellenistic technology was at its apogee.

THEODOSIOS P. TASSIOS

In the years 75-50 BC, when the loaded commercial ship sank off Antikythera, the political, economic, and social situation was particularly fluid. Because of Roman expansion, strong Hellenistic centers, such as the Seleucid and Ptolemaic kingdoms, were in turmoil and/or were diminishing, while important stations in the production and distribution of utilitarian and luxury goods, like the Syro-Palestinian coast and Rhodes, were dealt critical blows. Even the tax haven of Delos, where Roman merchants and bankers predominantly operated, was closed in 69 BC. The Roman Republic itself was being ravaged by a civil war conducted by ambitious generals and aristocrats, until the triumph of Octavius Augustus in 27 BC.

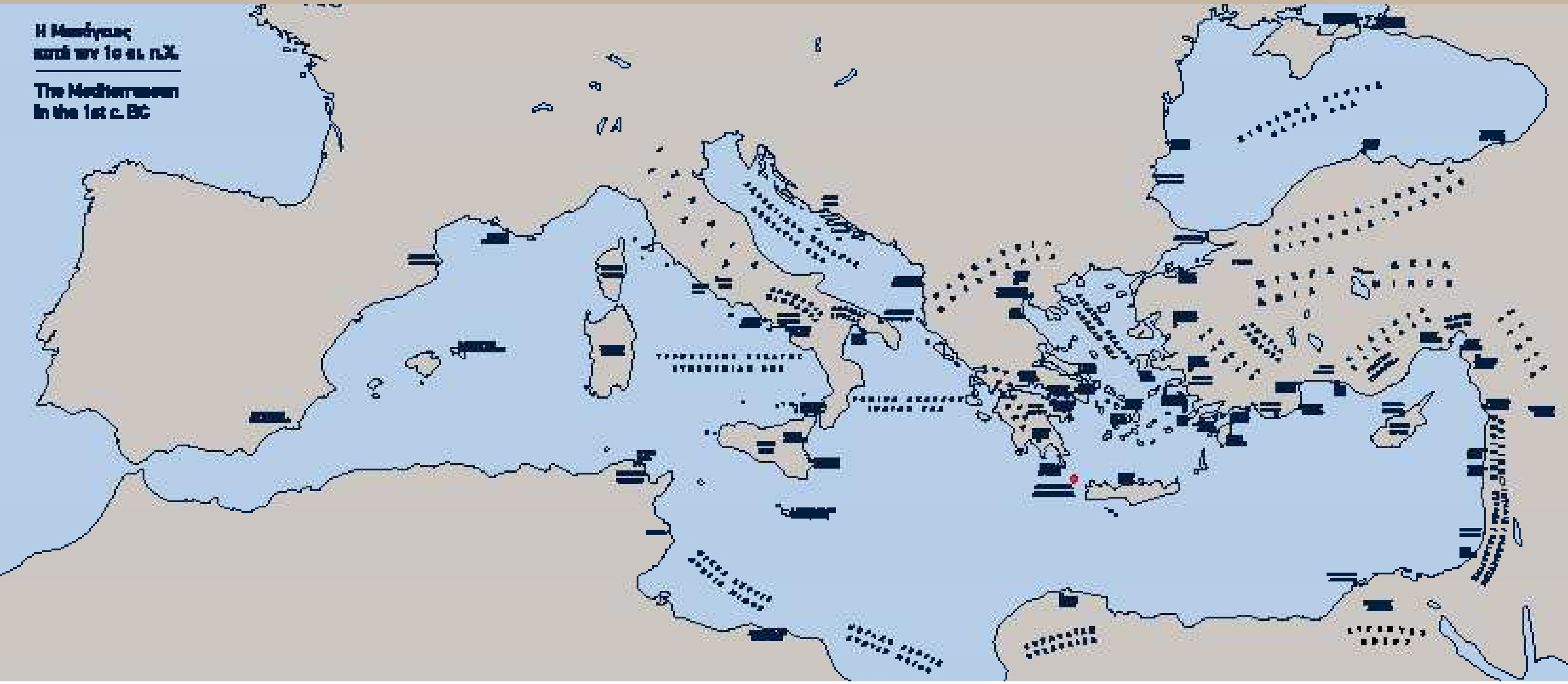
Taking advantage of military victories and effective diplomacy, Roman merchants and entrepreneurs competed with their counterparts in Greece and the Near East. The spread of amphorae for the transport of wine, foodstuffs, and other substances reflects conflicting interests. The Roman ruling class' desire for luxury items – textiles, jewelry, utensils of glass and precious metals, silk, perfumes – from the Near and Far East contributed to the increase in seaborne transport of products and in necessary commercial fleet. A consequence of this was the greatest number of shipwrecks with respect to earlier periods.

In the mania for luxury items, works of Greek art were destined to be acquired. During the 1st c. BC, their use for the decoration of private residences became widespread. Acquired from plunder or purchase, they were transported to the port of Puteoli (Pozzuoli) in the Bay of Naples in order to be carried on to villas in Campania, Latium, Etruria, or in Sicily. The inability to meet the demand on the part of the individuals for artistic works from the spoils of the Roman war machine triggered the then unprecedented practice of trading them; indeed, the production of copies, unrestrained transformations, as well as of works inspired by older periods was already flourishing. Orders for Greek artworks, as they were recorded in the letters of the Roman politician, orator, and philosopher Cicero (106-43 BC), could have led to the chartering of the ship that sunk off Antikyhera.

The intensification of trade, the abundant supply of familiar and new materials, and the increase of constructions (often large scale), rendered technology – long-supported by the scientific finds – necessary for various applications.

Technology presupposes mathematics, observation, and philosophical inquiry. Its representatives were erudite and versatile personalities who engaged in philosophy, physics, mathematics, and engineering, since specialized knowledge was required for technological improvements. Ancient Greek technology peaked during in the 1st c. BC in Rhodes and Alexandria. The chosen solutions contributed to the visibility of the Hellenistic monarchs or of the city-states. Rhodes, an ideal place for astronomical observations, attracted the great astronomers Hipparchus and Poseidonius. A center of astronomical discoveries was by far Alexandria, with its famous *Museum* and *Library*, where, in addition to the collection of copies or originals of manuscripts from all over the world, there was an astronomical observatory. The representatives of the Alexandrian school were distinguished for their scholarship and diverse interests, as well as for their great technical skills. It is noteworthy that leading physicists and engineers from Alexandria also came from the lower classes.

The beginning of topographical and astronomical instruments of the Hellenistic period was based on the expansion of art and science of measurement, which was connected with geometry and measurement of physical magnitudes (body weight and time). It is a reasonable theory that Archimedes used gears to launch his ships and Planetaria. The idea that interlocking gears could mechanically express mathematical actions and replicate bodily movements made it possible to record



Η Μεσόγειος κατά τον 1ο αι. π.Χ.

The Mediterranean in the 1st c. BC

distances with an odometer on land and with a dromometer at sea, to produce devices that predicted astronomical phenomena, like the Antikythera Mechanism, and to create automatic machines supported by mechanical systems with programmed movements, like the *automata* of Heron.

Even the production of objects for everyday use, like clay, metal, or glass vases, furniture, sculpture, jewelry, and specialty tools, required assimilation of technological knowledge. When a technique, like that of blown glass, facilitated production by reducing required time and effort and rendered all its products affordable to everyone, a turnover in the market was warranted.

If the dialectic relationship between technology and science in the Roman period had not deteriorated and if the Library of Alexandria (47 BC) and, with it, all the material culture had not been destroyed, things would have taken a different turn.

POLYXENI BOUYIA

Fig. 1. National Archaeological Museum. Part of the first gallery of the temporary exhibition, The Antikythera Shipwreck. The ship, the treasures, the Mechanism (photo by Eir. Miari).

The ship: The ship that wrecked off Antikythera in the second quarter of the 1st c. BC was a freighter (anc. ὁλκάς) with an estimated capacity of 300 tons, judging from its sturdy construction, equipment, and cargo.

The vessel was bound for the Roman port of Puteoli in the Bay of Naples. Falling victim to a storm with easterly or northeasterly winds, it sank off the east coast of Antikythera. This fact suggests an Eastern Aegean origin of the voyage. Given the type and composition of the cargo, there are three likely candidates for the ship's place of loading: Delos, a port free of taxes on transit goods and a prime base of Italian merchants and bankers with its thriving market of luxury and exotic items; Pergamon, on account of its cultivation of neoclassicism, and, finally, Ephesos, in light of certain vases (amphorae, lamps) and numismatic finds, of which the vast majority were issued by these two East Greek cities.

The cargo: The goods transported by the ship provide important testimony for the circulation of sculptures, jewelry, vases, utensils, and coins during the Late Hellenistic period; however, the discovery of the Mechanism makes this ancient shipwreck one of a kind. Investigations under the supervision of the Archaeological Service, with the assistance of sponge divers from Symi and the Greek Royal Navy in 1900/1901, and with the support of Jean-Yves Cousteau's oceanographic vessel *Calypso* in 1976, retrieved part of the cargo.

The most impressive part of the cargo so far uncovered is the sculpture: a) original bronze statues of the "Antikythera Youth" and the "Philosopher", along with fragmentary limbs of other statues and attributes (lyre, swords, crest); b) five classicizing bronze statuettes; c) statues (36 in total based on the torsos) of Parian marble, larger than life-size, life-size, and less than life-size, which depicted gods, heroes, and mortals and were copies or variations of famous works from Classical antiquity, classicizing creations, works recalling productions of the Early and High Hellenistic periods, and originals of the Late Hellenistic period.

The ship carried at least three bronze couches-beds (*klinai-anaklintra*), a number of vessels made of copper, led, and tin, two small bowls and two conical bowls of silver, three gold earrings with pendant cupids, a gold man's ring, two gold pouches with precious stones like those with which necklaces were decorated. The twenty salvaged glass vessels offer a complete sample of Syro-Palestinian and perhaps Egyptian

Fig. 2. National Archaeological Museum. The opening of the second gallery of the temporary exhibition, The Antikythera Shipwreck. The ship, the treasures, the Mechanism (photo by Eir. Miari).

Fig. 3. National Archaeological Museum. Part of the second gallery of the temporary exhibition, The Antikythera Shipwreck. The ship, the treasures, the Mechanism (photo by Eir. Miari).

production in this material. The 29 commercial amphorae with pointed toes for transporting liquid and solid products come from Rhodes, Kos, Ephesos (Nikandros Group), and the Adriatic coast (Lamboglia 2). It seems, however, that many more lie at the site of the shipwreck. Since these types of amphorae are dated to the 2nd quarter of the 1st c. BC, it is assumed that they contained wine from the vicinity of where they were manufactured, without excluding other content as well as secondary usage for the Italian representatives thereof. The fine, red-slipped ceramic tableware from the shipwreck (plates and hemispherical bowls), apparently imitations of precious metal vessels, were intended for the symposia of the Roman upper class, which had been charmed by the luxury of the Hellenistic East. Among the 47 lagynoi, the majority of those with large dimensions were for the transport of wine, just like the amphorae. Those with a white ground were used as tableware. The lagynoi with band decoration were cheaper substitutes. It is very likely that they belonged to the cargo.

Conversely, the black-glazed plates and bowls (mostly of the so-called Megarian type) and the plain jug-pitchers and lekythoi rather served those on board. Greek inscriptions indicate that at least some of them were Greek speakers.

Only one of the 10 lamps bears traces of combustion and on the basis of other shipwrecks it is possible that they were intended for lighting during the voyage. Two "feeder" jugs would facilitate in filling lamps with oil. A manual rotary grinder, a grindstone, and a basin-formed vessel must also have served the crew. The unguentaria for aromatic oils, resin, or incense and the two-handled pot-shaped vessels for products packaged in small quantities cannot be assigned to the ship's cargo or equipment.

Most of the 36 silver cistophoric coins were issued in Pergamon, while only four were struck in Ephesos. Of the 48 bronze coins, three Sicilian ones, issued 187-170 BC, and three from Asia Minor minted 250-210 BC and 70-60 BC have been identified. Considering that the reduced-weight cistophoroi had greater value in the territory of the Attalid kingdom and that bronze coins from Cnidus and Ephesus were used for everyday transactions in the place of their issue or in international commercial ports (such as Delos), it seems that Ephesus must have been one of the ship's final stops.

The Mechanism: The Mechanism, a creation of the latter half of the 2nd c. BC, comprises gearwheels, axles, dials, and pointers, constructed from sheets of copper with low tin content (bronze alloy). It was protected by a wooden frame and metal plates on the front and back.

Its technology, which references the successors of Archimedes and the School of Poseidonius in Rhodes and is based on knowledge of the Hellenistic period (astronomical constants, mechanical design, and use of epicyclic gearwheels), testifies to ancient Greek astronomical, mathematical, and mechanical genius in the mid 2nd cent. BC. With a multitude of applications – as an instrument of scientific research and instruction, as a means of predicting eclipses and the date, and possibly as an astrological and navigational aid – the Mechanism was desirable to many. In instances of cities being sacked, it was by far the preferred loot.

Fig. 4. National Archaeological Museum. The last section of the second gallery and part of the third gallery of the temporary exhibition, The Antikythera Shipwreck. The ship, the treasures, the Mechanism (photo by Eir. Miari).

The Antikythera Mechanism is the most precious relic of ancient technology; it echoes the philosophical, generally geocentric, view of the world and of its creation on behalf of ancient Greek intellectuals, who advanced mathematics and physics as tools for comprehending the universe.

POLYXENI BOUYIA

The ship's construction and equipment

Reconstruction of a commercial ship
(Drawing by N. Roumelioti).

The salvaged physical remains of the ship that sank off Antikythera are minimal, and it was not possible to map the wreck at a depth of 52 meters. Sections of the stern and the bow have not been identified. The ship was constructed in accordance with the "shell-first" method, which was predominant in the Mediterranean world from the 4th until the 1st c. BC.

Following this system, unlike later practice, the construction was based on a longitudinal formation, with the placement of the planks parallel to the keel, at both ends of which were attached the posts of the bow and the stern (fig. 1). Management of the width, length, height, and distribution of the mortises and tenons in the joining of successive rows of planks guaranteed cohesion and stability. After the joining of two adjacent planks, transverse holes were drilled at the height of the tenons for the insertion of wooden pegs (treenails) (fig. 2). When the shell had been erected to a given height, the frames were affixed to its interior, beginning with the floor timbers and followed by the half

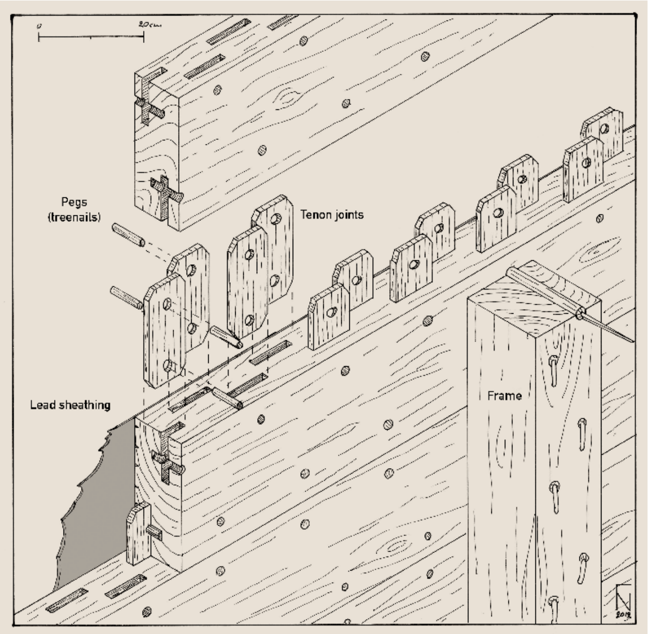


Fig. 2. Planking from the ship sank off Antikythera showing pegged mortise –and- tenon joints (Drawing by Y. Nakas).

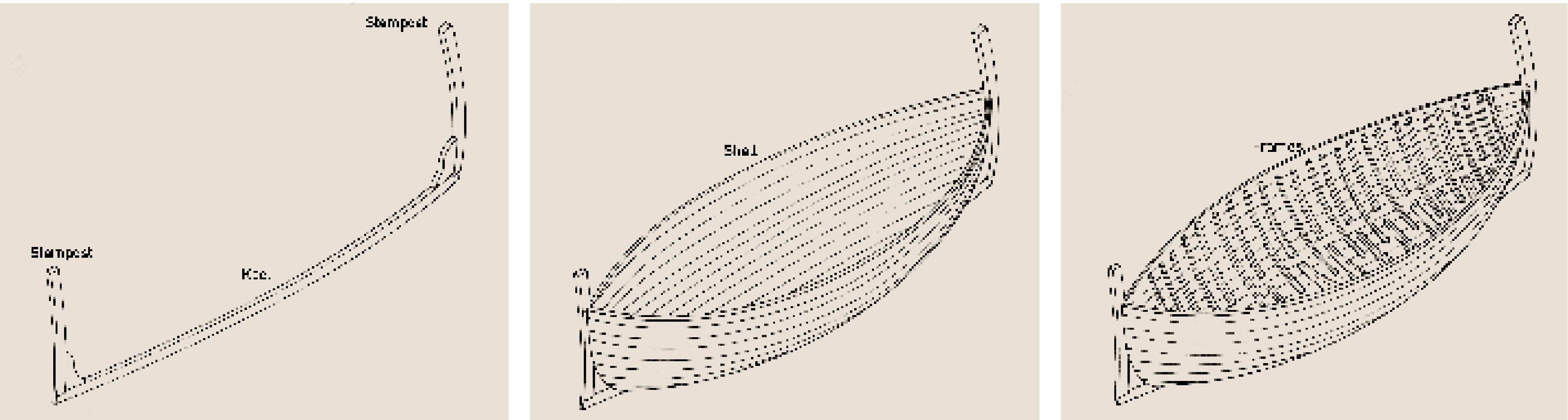


Fig. 1. Longitudinal assemblage of an ancient ship according to the "shell-first technique" (Drawing by Y. Nakas).

Fig. 4. Weights (?). NAM X26783-26785. First half of 1st c. BC.

Fig. 5. Fragment of metal sheathing. NAM X19015. First half of 1st c. BC.

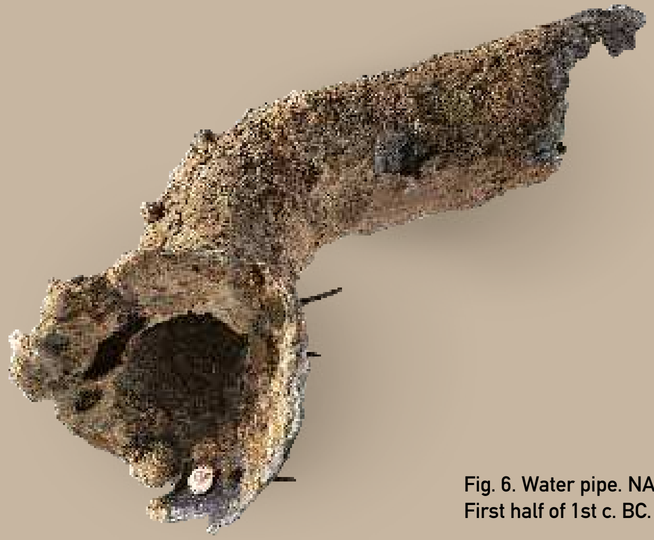


Fig. 6. Water pipe. NAM X19014. First half of 1st c. BC.

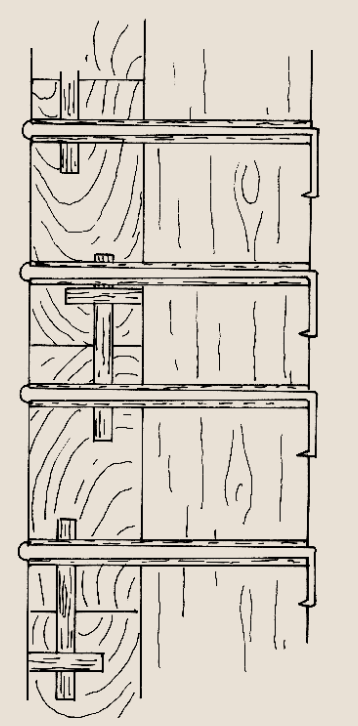


Fig. 3. Attachment of frames (half frames and futtocks) to the shell's planking (hull) (Drawing by Y. Nakas).

frames and the futtocks (fig. 3). For their attachment, wooden pegs were inserted into circular holes that penetrated the frames and the planking. Next, copper nails were driven along the axis of the wooden pegs.

The shell of the wrecked ship had only one series of planks. The tenons and the wooden pegs are of oak, while the planks were cut from elm. In ancient construction of wooden ships the use of elm was limited. According to Theophrastus, fir, pine, and cedar were suitable for naval and commercial ships, while oak and beech could be utilized for parts.

The ship's hull was waterproofed on the exterior with thin lead sheets situated below the waterline (fig. 5). This lining, which insulated the wood from the deleterious effects of marine microorganisms like the mollusk *teredo navalis* (a marine borer), was common in the Hellenistic period and disappeared at the end of the 1st c. AC. The lead sheets followed the contours of the vessel and were secured with the help of small bronze nails hammered in a regular order over a textile, animal skin, or tree leaves dipped in resin or pitch. These latter materials rendered the wood water resistant.

Fragments of lead pipes (fig. 6) lifted from the wreck are interpreted as the remains of a pump for bailing water from the ship. The evacuation of water from the hull was accomplished by the movement of two vertical wheels, one on the deck and one on the bottom of the hull, with the aid of a rope fitted at intervals with wooden discs. When the operator rotated the upper wheel with a crank, the movement transferred through the rope to the lower wheel, which was submerged in the water to be extracted, and transmitted it through a pipe to a lead collector tank on the deck (fig. 7). Lead pipes at the base of the ship removed its content. Occasionally, the pipes also emerged below the deck. This infrastructure drew upon knowledge from the pumps of Ctesibius (285-222 BC) and the helical screw of Archimedes (241-220 BC).

Corinthian roof tiles from the wreck strengthen the theory that there existed a roofed space on the ship's deck, which most likely served for the preparation of food, and/or for covering the openings to the cargo hold.

The ship could have had at least five large anchors. The counterbalancing weights have been identified as weights or devices destined for automatically lowering the sail (fig. 4). The fact that sounding weights for investigating the nature and depth of the seafloor (anc. Gr. *katapeirateriai*) were preserved is particularly important and a telling indication of the ship's size and its seaborne destination (fig. 8). There were nails protruding from the base of the sounding weights that, when pressed into the seafloor, aided in sampling. The weight was a vital tool for safe navigation. Although its discovery is connected with marine operations and Greek colonization during the 8th and 7th c. BC, eighty-two percent of *katapeirateriai* are dated from the mid-2nd cent. BC to the 2nd c. AC, that is, the peak period of seaborne commerce.

Cargo ships from the time of the Antikythera Shipwreck bore a rectangular sail attached to a central mast and a horizontal boom, a triangular sail at the top of the mast, and an auxiliary side sail.

POLYXENI BOUYIA

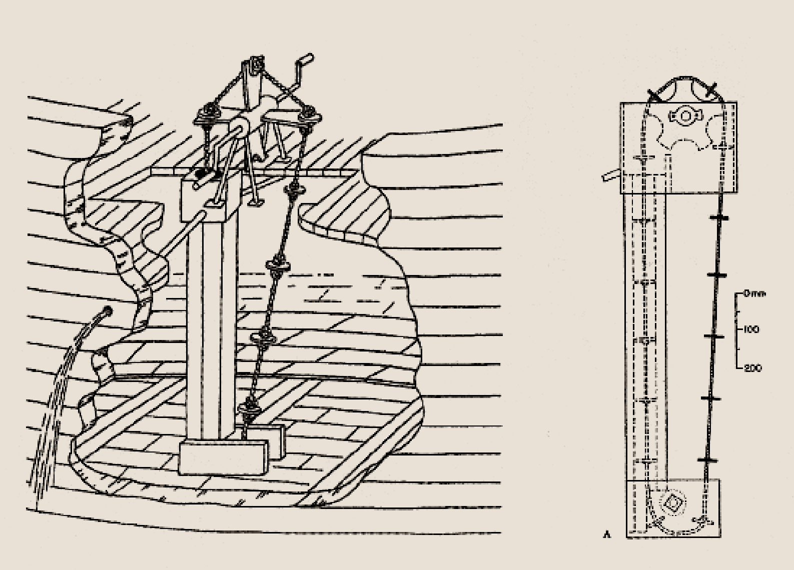


Fig. 7. Reconstructions of bilge pumps based on finds from wrecks. (Drawing from F. Foerster Laures, *Τρόπις* 1/1985, 44).

Fig. 8. Sounding weight. NAM X19013. First half of 1st c. BC.

Sculpture

The marble statues raised from the Antikythera Shipwreck exhibit many interesting technical details of their manufacture.

Several of these statues were not made, as usual, from a mass of marble, but from two pieces that were joined together with flat, smooth contact surfaces and with dowels in between. In addition, the projecting parts of the figures – such as heads (fig. 1), hands, as well as smaller parts like elements of dress, the top of the head, etc. – also consist of separate pieces of marble. This technique is fully justified, if one considers that all sculpture from the wreck is of Parian marble, a material not always easily extractable in large volumes.

Representative of the aforementioned construction method is the splendid seated statue of Zeus (fig. 2), made of two pieces joined at the abdomen, as well as larger than life-size statues of Odysseus (NAM 5745) and of Achilles (?) (NAM 5746), which belong to statue groups with "Homeric themes", also constructed from two marble pieces of roughly commensurate size. The former statue is pieced together at the small of the back and the latter at the buttocks.

The technique of constructing parts from separate pieces of marble was already a widespread sculptural practice by the Archaic period. Heads, inserted in cavities at the base of the neck (fig. 1), and forearm attachments, which were fitted to the arms, are the most frequent cases. The fitting of pieces was achieved with quadrilateral sockets that received wooden tenons or metal dowels, which survive in no case. In the sculptures from Antikythera, no grooves with molten lead have been detected, a fact that compels us to think that only strong mortars and adhesives were utilized for the assembly. External metal joints are seldom, and it seems that they are associ-

**Fig. 1. Detail of attachment of the horse's head to the neck of the statue.
NAM 5747. Early 1st c. BC.**

ated with fractures in the marble that resulted during the carving. The Π-shaped iron clamp, situated vertically on the backside of the torso of a statue of Hermes (NAM 2774), over the left buttock (fig. 3), must be due to such a cause. Its bed, colored red from rust, retains the remains of lead that covered the join.

The three horse statues from the Antikythera Shipwreck (cf. NAM 15536) had separately worked and attached heads (fig. 1). For fitting them to the body, an oval reception cavity, coarsely hewn with a point, was opened at the neck. On the upper part of the cavity an anathyrosis (i.e. a smooth band around the edges) was configured for the best fit of the two pieces. The presence of a socket on the bottom of the cavity indicates the craftsman's intention to make the join even sounder. The relief bridle encircling the neck conceals from the outside the junction of the two pieces (fig. 1). In the case of the hand (NAM 15562), the attachable forearm was fitted into a square socket, while incisions around it created the necessary rough contact surface. Mortars and adhesives would have ensured a strong bond. Shortage of material necessitated the similar attachment of a small part of the top of the head in a statue of a young wrestler (NAM 2773), as well as of the helmet in the statue of a warrior (NAM 15534).

In certain instances, the fitting of the attachable parts is achieved with circular holes that would have received round wooden dowels. The forearm attached to the now welded right hand (NAM 15555) was fit into the upper arm in the same manner. The now mended ball of the sandaled left foot in a seated statue of Zeus (fig. 2) was also joined in the same way. The small circular hole, as on the curved fragment of a garment (NAM 15561), is for the metal dowel that fit the piece to the statue's shoulder or thigh.

Fig. 2. Seated statue of Zeus constructed from two pieces. NAM 5743. Early 1st c. BC.

Another characteristic construction detail are the large props that guaranteed secure support for statues on their bases, as well as smaller struts that joined the hands with the torso and legs. Bronze statues, of course, did not employ struts in order to stand on their bases, except internally, under the feet. However, in copying – that is, the transference of bronze works to marble – the use of struts was required. Supports, placed at appropriate points,

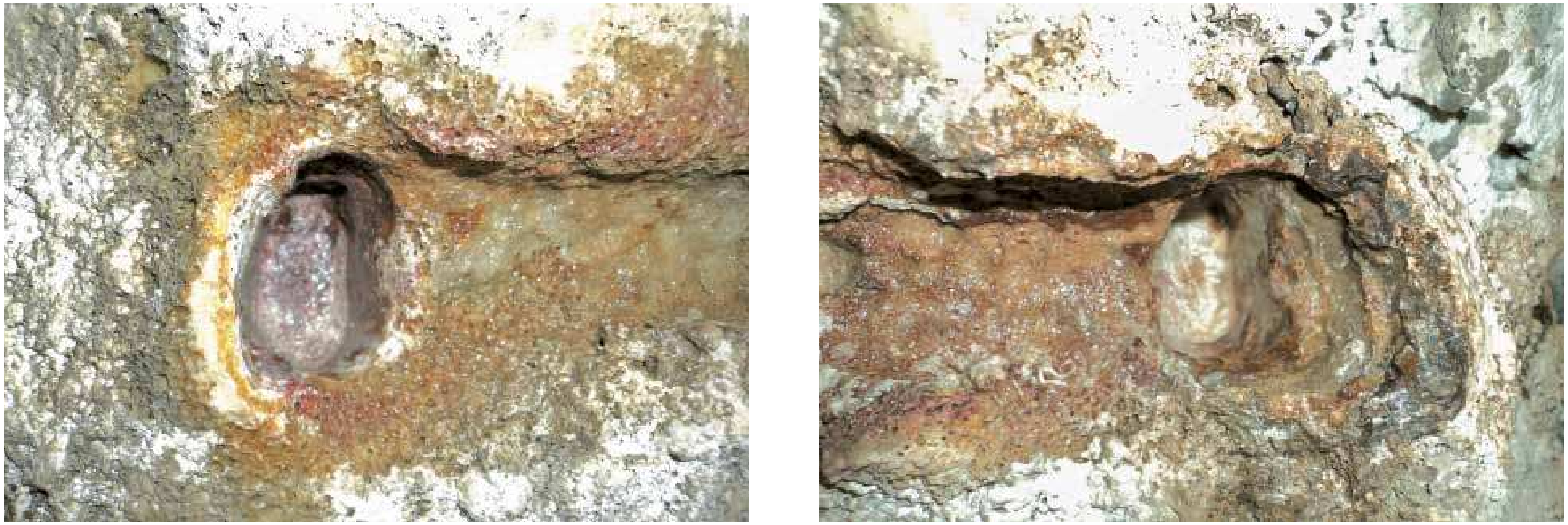


Fig. 3. Bed of vertical Π-shaped metal clamp preserved on the back of the torso of the statue of Hermes. NAM 2774.

generally next to the lower leg of standing statues, had various simple forms, such as columns or tree trunks, like that in the statue of Heracles of the Farnese type (fig. 4), or had more complex ones, such as the tripod that buttresses the statue of Apollo (fig. 5). In the statue of Hermes of the Richelieu type (NAM 2774), the god's mantle, which extends down to the plinth, was innovatively employed as a support.

Also necessary in marble sculptures were struts supporting projecting parts, for example, hands, which were not in danger of breaking off in bronzes. The elements that prevented breakage, relatively short in length and quadrilateral or circular in cross-section, are called by the foreign term "puntelli" (struts). From very early on, however, research found that the puntelli in sculptures from the Antikythera Shipwreck did not indicate that they were copied from bronze prototypes. Struts ensured, first of all, safe loading and transport of the statues aboard the ship. Today, we know that the marble sculptures contained in the cargo of the ill-fated vessel constituted a bulk order to some Greek sculptural workshop in the beginning of the 1st c. BC, and were bound for Italy. It is likely that some of the puntelli would have been carved away when the works arrived at their final destination.

Nevertheless, puntelli were not "bothersome" additions to marble statues and copies of the Roman period. The Romans certainly had become so accustomed to them that they left them intact, perhaps fearing that their removal would cause irreparable damage to the sculptures.

Particularly striking among the sculptures from the wreck are the thick, cylindrical puntelli that underpinned the bellies of the horse statues (cf. NAM 15536) to the plinth of the quadriga, as with the prop that is still preserved today on the large section of the plinth of a horse statue (NAM 5749). The puntello that connects the lifted hoof (NAM 15554) of a horse's foreleg to the plinth is elongated and quadrilateral in cross-section. Similarly quadrilateral are the puntelli that join the right knee and the left hip of a statue of a wrestler (NAM 2773) to the plinth, the hands of Homeric heroes (NAM 5745 and NAM 5746) with the statues' torsos, as well as that which connects the lower legs of a statue of Hermes (NAM 2774). Finally, the fine puntelli that bridged the distance between the fingers of the hands of some statues, such as the fragment (NAM 15550) and the statue (NAM 2773), could be characterized as tiny "masterpieces".

The low orthogonal bases with depressions on the upper side for the inset of the statues' plinths are also included in the technical aspects of marble statues from the Antikythera Shipwreck. These bases enable us to conclude that the statues were loaded upright in the ship's hold. This made the transport more secure. One of the six bases retrieved from the deep has been assigned to the statue of Hermes (NAM 2774).

We observe another technical characteristic in the statue of a young wrestler from the wreck (NAM 2773), particularly on his excellently preserved right side: an intense polishing of the torso, which is a typical feature of the Late Hellenistic and, chiefly, the Roman pe-

Fig. 4. Statue of Heracles of the Farnese type with support in the form of a tree trunk. NAM 5742. Early 1st c. BC.

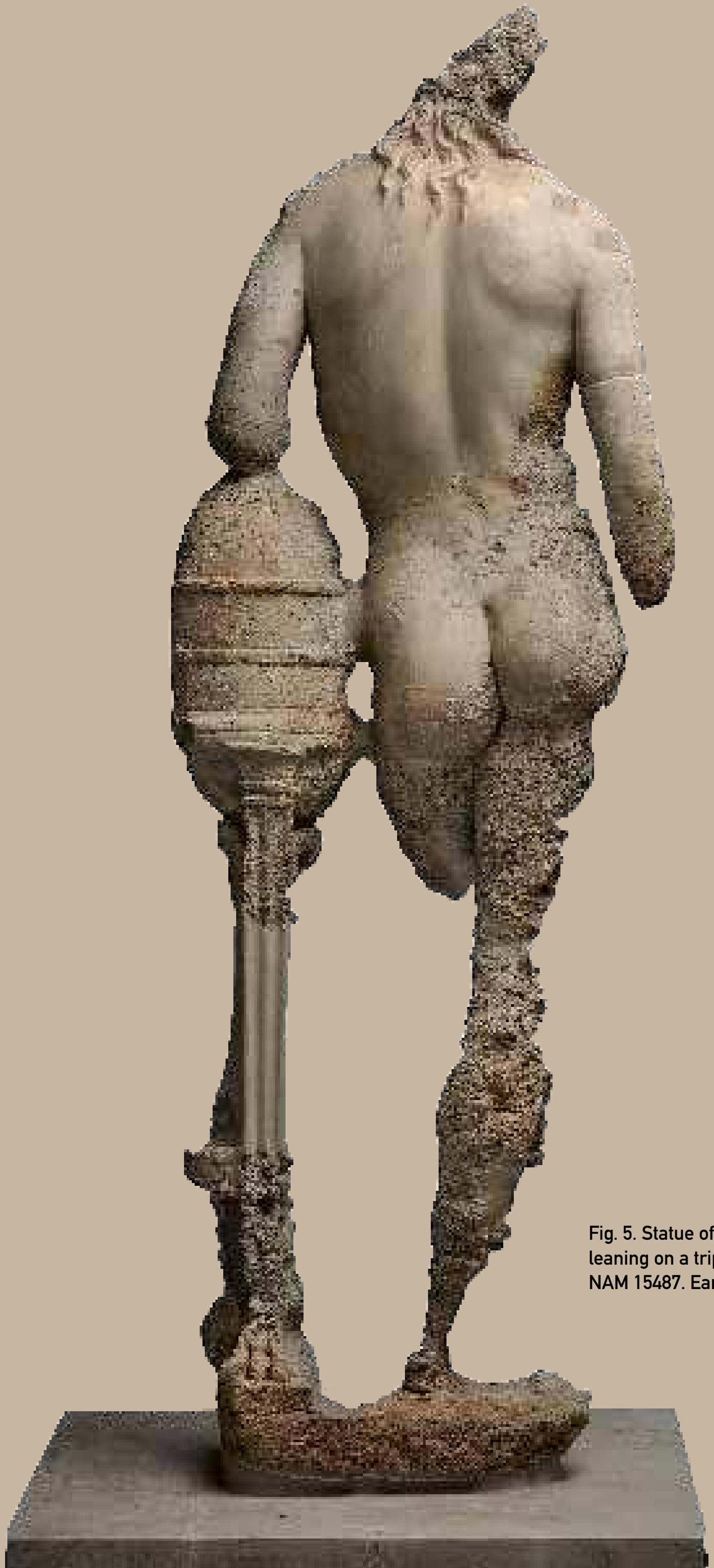


Fig. 5. Statue of Apollo leaning on a tripod.
NAM 15487. Early 1st c. BC.

riod. The polished marble surface, achieved with wax, was an artistic means that served to render the texture of human flesh; at the same time, it was indicative of the taste of Roman buyers. It was also a common feature of Renaissance and later glyptic of the 18th and 19th c., which knew Greek works of Classical antiquity almost entirely through polished Roman copies.

STONE UTENSILS AND ARTIFACTS

The idea of two contiguous millstones moving in a palindromic fashion with the help of a metal handle to grind cereals for the production of flour dates back to the 5th c. BC. The representative example was the quern of the "Olynthus type", which was in use until the Late Hellenistic period.

Around the beginning of the 1st c. BC or a little thereafter, the manual rotary mill, which was composed of two tangent, then cylindrical millstones seems to have been introduced in agricultural technology; the mill consisted of two stones: a) the *onos* (*catillus*), the upper stone, and b) the *myle* (*meta*). The hand mill, essentially the *onos* – insofar as it was the only stone that rotated, moved around a vertical iron axle that passed through the middle of the *onos* and was mounted on the center of the convex *myle* (*meta*), which remained stationary. The grain for grinding was passed through a perforation, the "eye", bored through the center of the *onos*. In order to prevent the seeds from scattering outside the mill, a shallow funnel was formed with walls that were slightly inclined toward the hole on the upper surface of the *onos*. Abrasive stones were always utilized for the construction of millstones, in order that the coarse surface of the material increased friction, thereby facilitating the grinding. The ability to adjust the distance

Fig. 6a-b. Manually operated quern, consisting of a pair of millstones. NAM 15556, 15563. Early 1st c. BC.

between the concave *onos* and the convex *myle* allowed, moreover, total control of the milled product, which could thus range from more coarsely to more finely ground.

In the hand-powered mill (fig. 6a-b) from the Antikythera Shipwreck, the *onos* is slightly concave on its lower surface – that is, on the grinding surface – so that it would set perfectly on the convex *myle*. Rotary movement was enabled by a wooden or metal handle, which was situated vertically on the special slot-socket on the outside of the *onos*' narrow side. Molten lead for securing the handle to the hand mill from the Antikythera Shipwreck was poured into a small hole on the upper surface of the *onos*.

Doidykes or *aletribanoi*, as grinders of small dimension were called, were intended for mashing vegetables and pulverizing pigments and minerals in a mortar. *Doidykes* in the shape of a human finger, found from the 5th c. BC until the Roman period, are not connected with agricultural activities.

The traces of red color detected on the grinding surface of the grinder (fig. 7) from the Antikythera Shipwreck, together with the chemical analysis, which was conducted on the red coloring matter found in an amorphous stone from the wreck and which indicates that it is cinnabar (mercuric sulfide), strongly suggests that the Antikythera grinder was used to pulverize this pigment. They were usually used in combination with shallow basin-like vessels, like the one retrieved from the shipwreck (fig. 8). This common household vessel, unchanged in shape from the Archaic to the Roman imperial period, was known as a mortar (*mortarium*/*θυεία, θυία*).

ELENA VLACHOGIANNI

Fig. 7. Grindstone in the shape of a finger. NAM 31055. 2nd-1st c. BC.

Fig. 8. Shallow basin-like vessel. NAM 15557. 2nd-1st c. BC.

Bronze working

The earliest of the bronze objects retrieved from the shipwreck date to the 4th c. BC, while the latest ones were created around 100 BC. Hammering and casting were the methods of producing statues and vessels from copper alloys. Hammering was the oldest process. Lost-wax casting became common from the 6th c. BC. Ancient written testimony ascribes the first casting of hollow statues to the Samian sculptors and architects Rhoikos and Theodoros.

Bronze statues and statuettes

In the Hellenistic period, bronzes of significant scale were first cast in sections and then their components were assembled, as stated by Philo of Byzantium in *On the Seven Wonders* 4. In this way, flaws were limited and easily corrected. In the "Antikythera Youth", divisions are attested at the level of the nipples, on the upper arms, above the buttocks, and across the middle of the thighs (fig. 1). The head, the mouth, and the front of the left foot have also been cast separately. The statue of the "Philosopher" was also cast in pieces, as shown by the related signs of attachment (fig. 6). Attributes of the bronzes, such as the lyre or the sheathed swords, were independently produced in one piece. The parts of the male statuettes as well as of a female wearing a heavy robe (*peplophoros*) have also been pieced together. Small works were usually produced in molds and were, therefore, solid cast.

Workshops were temporary installations organized for a specific project and were dismantled upon its completion (fig. 5). Apart from those on the fringes of cities, foundries were also found in the vicin-

Fig. 1. The "Antikythera Youth". NAM X 13396. 340-330 BC.

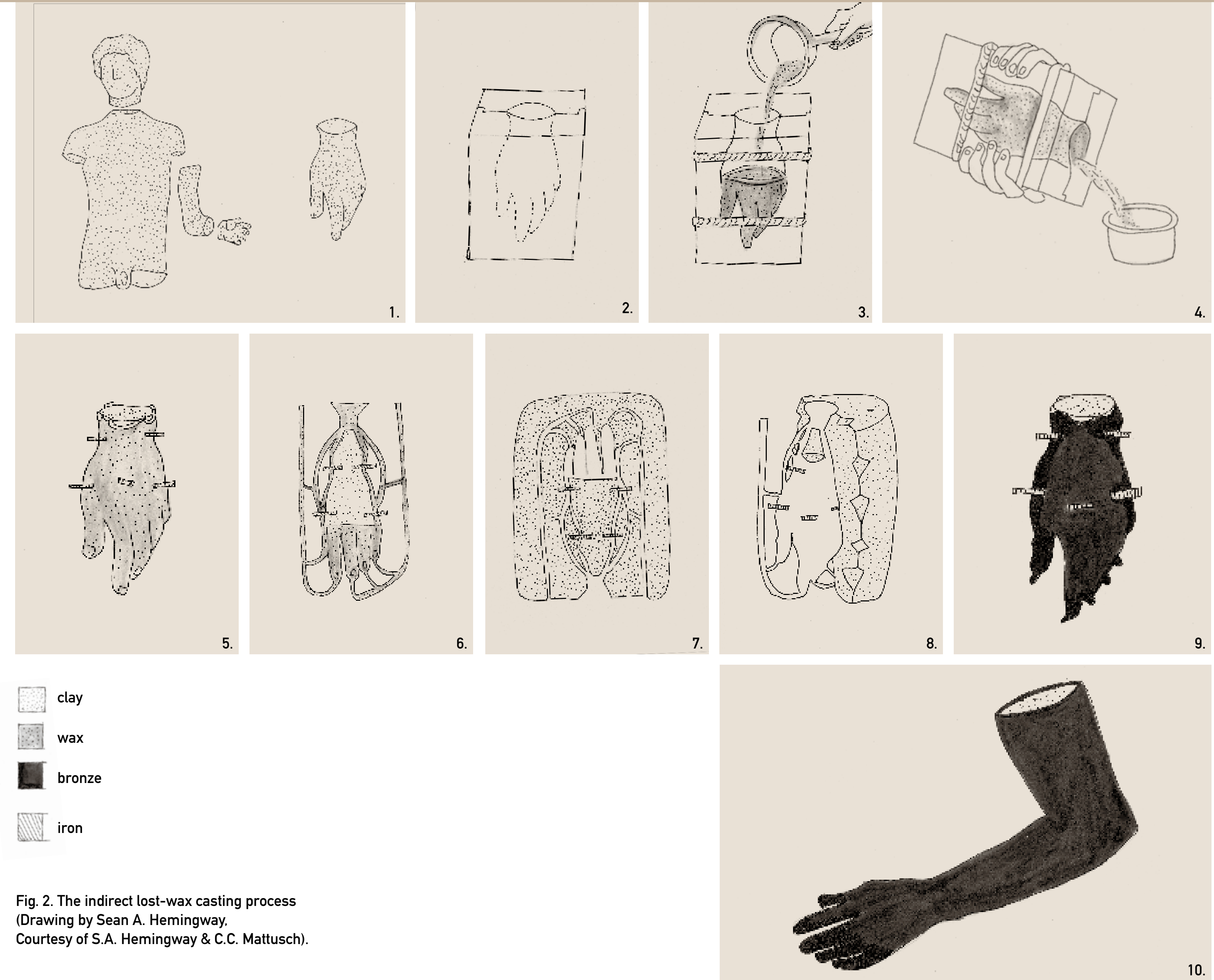


Fig. 2. The indirect lost-wax casting process
(Drawing by Sean A. Hemingway,
Courtesy of S.A. Hemingway & C.C. Mattusch).

Fig. 3. Left foot from a statue. NAM X 15093. 2nd c. BC (?)

Fig. 4. Right foot of a male statue wearing a sandal. NAM X 15115. 225-200 BC.

ity of sanctuaries. Alloys may betray the provenance of bronzes or facilitate their attribution to certain production centers. Copper was the major component of alloys, in combination with tin (bronze) or zinc (brass). Cobalt, antimony, nickel, silver, and gold have also been traced in small quantities in various ancient statues.

The core of the work with its general features – a full size model – was made, mainly of clay. Whereas details were initially carved on a beeswax layer of varying thickness placed over it (direct method), from the middle of the fourth century BC an innovation was introduced: master molds were taken from the original clay model and were fit together in groups of manageable sizes (indirect method) (fig. 2). These master molds were assembled to make segments of the work. Each group of master molds was then coated with beeswax in order to produce a wax model. After the removal of the master molds, surface details, individual features, variation in stance, and symbols were carved on the model, eventually requiring extra wax in certain places. Liquid clay was poured into the void of the wax model to create a solid core. Iron rods served as an armature and iron pins (chaplets) secured both the wax model and the clay core. An attached network of a wax funnel and channels was used to introduce the molten bronze and to remove the gases. Two layers of clay (investment) – the inner of finer texture than the outer one – covered the wax model. Only the funnel for pouring in the metal and the ends of the gas channels were left exposed. Inside the casting pit, the wax burnt out and was replaced by the molten metal at a temperature of 1,100° C. The metal was poured in through the funnel and was distributed throughout the network of channels. After retrieval from the pit and the cooling of the segment of the work, the investment and most of clay core were removed.

A molten copper alloy enabled the joining of parts (fig. 5), filling in of casting holes (fig. 3), or the restoration of imperfections and the repair of cracks. In order to solder the head of the "Philosopher" (fig. 6) to his body, the head was held upside down, as drips of molten bronze behind the beard indicate. Repairing flaws on this part of the statue was possible by means of small rectangular patches. Lead, which has a lower melting point, was generally used as a solder, for internal reinforcement (fig. 4), and for mounting sculptures to their bases. At the end of the process, the surface of the bronze was polished.

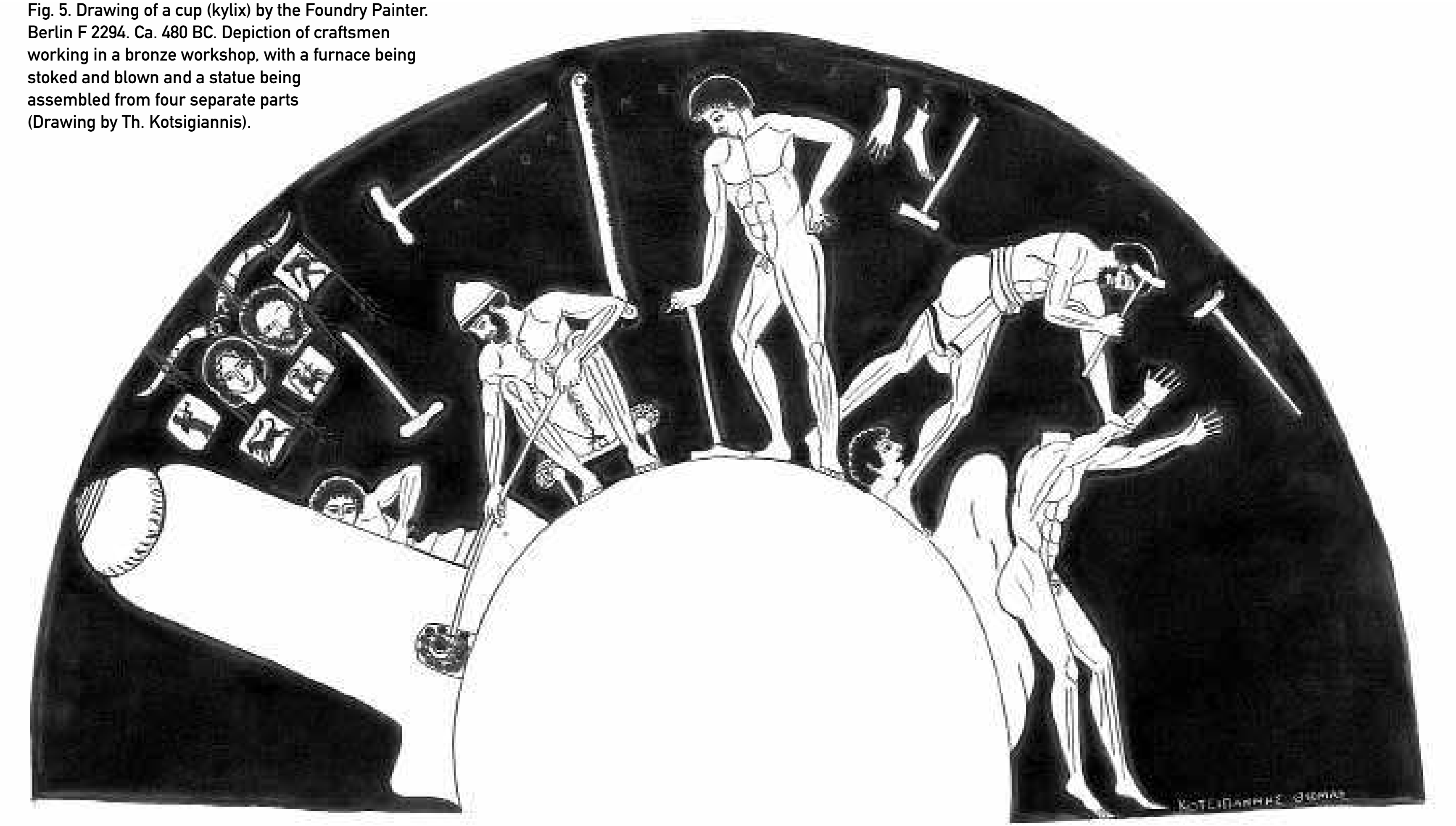


Fig. 5. Drawing of a cup (kylix) by the Foundry Painter. Berlin F 2294. Ca. 480 BC. Depiction of craftsmen working in a bronze workshop, with a furnace being stoked and blown and a statue being assembled from four separate parts (Drawing by Th. Kotsigiannis).

Eyelashes were cut in a thin band and inserted around the eye socket. Bone or white stones were used for the visible part of the eyeball, stones or glass for irises and pupils. They were fixed into place with resinous materials. The "Youth" (fig. 1), the "Philosopher" (fig. 6), and the statuettes of athletes are characteristic of this practice. According to Diodorus Siculus 4.76, Daedalus was the first to use inlaid eyes and to present statues in moving positions. In other cases, the details of eyes were merely carved on to the wax model. Occasionally, the mouth was cast separately. A band of red copper was applied on the lips and on the nipples of nude statues, while occasionally silver emphasized the teeth and fingernails. The "Youth" had inserted teeth and nipples (fig. 1). The male statuettes from the shipwreck were provided with inlaid eyes, lips, and nipples; the genitals were probably inserted into one of them.

It is noteworthy that a statuette of an ephebe on a stone base could rotate (fig. 7). The wind-up key set into the hole of the cylindrical base transferred movement by means of a dowel to the rotation mechanism.

Bronze statues were mounted on their bases with abundant use of lead under their feet, so that they could be securely fixed into the respective socket carved into their stone bases (fig. 4). It is reasonable to argue that molten lead was poured through the front of the feet or the second toe, since they were often cast separately. The massive lead dowels under the soles of some of the bronze statues from the shipwreck are considered to be indicative of the fact that these particular bronzes were mounted before they were included in the cargo of the ship. Another theory, however, postulates that the

Fig. 6. Head of a "Philosopher" statue. NAM X 13400. Ca 230 BC.

lead dowels were added in the initial phase of the bronze's assembly and that they were heated when they were inserted into the socket of the base.

Thin walls, which reduced weight and production costs, are a technological advancement. They are attested in the statue of the "Philosopher" and the hand of another statue from the same group.

It has been proposed that the black patina on parts of the "Youth" is due to its exposure to seawater or to the chemicals employed to clean and to improve its corroded surface. According to other scholars, the black patina on statues of the Classical period or on classicizing works of the Late Hellenistic and Roman periods was a deliberate attempt to render an impression of antiquity.

Production by means of master molds facilitated the reproduction of a work with variations after a single model. In applying this rapid method, bronze artists catered to the increasing demand of rich families in the Greek East and the Roman Republic during the 2nd and the 1st c. BC.

POLYXENI BOUYIA

Fig. 7. Statuette of an ephebe. NAM X 18957. Late 2nd c. BC.

Fig. 8. Jug (*prochous*). NAM X 18937. Late 2nd - early 1st c. BC.

Vases

Cast parts of bronze vases, serially produced, are preserved among the finds of the shipwreck. They belong to jugs, buckets, or basins. A shell could have been a cover for the fill hole of a lamp. The bodies of these vessels, hammered either at room temperature or after firing, have almost disintegrated in the marine environment.

The biconical jug (X18937, fig. 8) was widespread in Italy during the second and first centuries BC. This type of vase has been recognized in the remains of two more specimens from the shipwreck on the basis of their handles, which have parallels on Delos. The rim of a bucket with a dotted floral decoration refers to Campanian workshops (X 18939α-γ, fig. 9). The rectangular frame it exhibits is probably a manufacturer's stamp.

Tin vases, like the two miniature jugs, the lamp, and the miniature kyathos are generally scarce (X 15109α-β, X 18938, X 18978, fig. 10).

Fig. 9. Parts of a jar (*kados*). NAM X 18939α-γ.
Late 2nd - early 1st c. BC.

Open lamps appeared on Sardinia in the Archaic period, and their use was later disseminated. The single lead vessel is a pyxis missing its lid (X 26786, fig. 11).

Arguments about the provenance of the metal vessels from the shipwreck, which aim at understanding their technology or function, should take into consideration the remaining finds as well as the fact that the retrieved material does not represent the total cargo. Provision of the ship's outfit was possible upon arrival in a port. The Sicilian bronze coins allude to some kind of transaction in Italian territory. On the other hand, the cargo came from the Eastern Mediterranean. If the metal vessels were part of the cargo, they were either imported in a major market – like Delos or Ephesos – or were locally made in imitation of Italian prototypes.

Furthermore, during that time, metal craftsmen from the Syro-Palestinian coast were active on Delos alongside their Greek colleagues, who were encountered in all the traditional centers of bronze working.

POLYXENI BOUYIA

Fig. 11. Lead pyxis. NAM X 26786. Late 2nd - early 1st c. BC.

Fig. 10. Miniature wine jug (*oinochoe*) and a tin lamp. X 15109α-β, X 18978. 2nd-1st c. BC.

The couches
(*klinai*)

The underwater research of 1900-1901 and 1976 in the vicinity of the Antikythera shipwreck brought to light parts of the wooden frames of *klinai-anaklintra* (beds-couches). The variations that are observed with regard to the type, dimensions, construction technique, as well as the corrosion of the individual metal parts indicates the existence in the ship's cargo of at least three wooden *klinai* with bronze revetment dating from the 2nd to the first half of the 1st century BC (fig. 1).

Although fragments of the wooden frames are little preserved in connection with metal components, the fragments nevertheless represent the three main parts of the couches. That is, there are surviving parts from the ornamental ends of the headrests (*fulcra*), the side rails, and the bases of the legs.

Microscopic and macroscopic examination of the wood showed that the discrete parts of the *klinai* were constructed from various timbers. On the upper parts – for example, the ends of the headrests – the narrow-leafed ash (*Fraxinus*) was utilized, while in the lower parts – for example, on the bases of the legs – chestnut (*Dios balanus*, 'Euboian nut') was employed. The side rails are made of walnut ('Persian nut'). This variation particularly attests to the experience of the carpenter, who seems to have been familiar with the mechanical properties of each timber, for instance, its durability as well as its degree of workability.

Extant pieces of the wooden frame from the lateral ends of the headrests follow the general shape of the metal revetment and form a rim around the perimeter for the fitting of bronze attachments. The metal and wooden parts were assembled with bronze bolts (rivets), as is indicated by existing holes and partially preserved bolts. Traces of the marks from the carpenter's tools, an adze or a large chisel, are preserved in various places on the wooden surface of the surviving parts (fig. 2).

The conserved wooden parts from the couches' legs correspond only to the lower rectangular part of the base with convex and concave molding and an overlying square element. These components follow the general shape of the metal revetment. The wooden legs would have been constructed on a lathe, as is necessary for the type of rich decoration with overlying bell-shaped attachments found in the shipwreck. Although lathed legs were produced by carpenters since the late 6th century BC, only from the 3rd century BC were they embellished with metal revetment. Traces of tool marks from a chisel as well as a larger woodworking implement – perhaps an adze – are visible in places on the wood's surface.

However, an important technical variation is observed on the wooden bases. In almost all the surviving examples, the front face is plane and uniform. On a single example, near the middle of the front side there is a groove dovetailed in cross section for joining the base with another wooden part (fig. 3). This element implies that the legs on the short sides of at least one *kline* were joined together with a horizontal bar.

Three fragments from the couches' wooden side rails are preserved. Two of them also retain their metal revetment, as mentioned above, while a third conserves only traces thereof (NAM X 18929). The wooden side rails are rectangular; three of their sides – the upper, lower, and outer – are still extant.

Fig. 1. Reconstruction of a couch (*kline*) and fragments of couches (*klinai*). Temporary exhibition of the Antikythera shipwreck. The ship, the treasures, the Mechanism. National Archaeological Museum (Photo by Eir. Miari).

Fig. 2. Wood from the inner part of a fulcrum from the headrest of a *kline*. NAM X 15099. 150-100 BC.

Fig. 3. Part of the wooden frame of the base of a couch leg. NAM X 18923. 2nd-early 1st c. BC.

The shaping of the rails' edges in two surviving instances is interesting, although there is not enough preserved to permit a final evaluation. Instead, there are corner pieces of varying dimensions, which perhaps demonstrate that these parts come from different *klinai*. It is also certain that the edges did not bear metal revetment. On one rail (NAM X 18925), two edges are widened in the form of projecting bands serving perhaps for better application of the metal revetment to the rest of the rail, or for slotting in the other wooden part, or the two edges served both purposes. The other part of the side rail (NAM X 18929) exhibits different shaping on two of its edges, a feature more indicative of their various uses. One end is widened in the form of a band protruding 0.004m, as in the previous example, possibly for the better application of the metal revetment. However, the surface at the other end tapers to a plane that is 0.016m lower, perhaps indicating that this part was slotted into a mortise.

Decorative side ends of headrests (*fulcra*) and fragments of others, bases of the legs, and pieces from the side rails comprise the couches' metal attachments. All the metal parts are made of bronze, an alloy of copper and tin. In these instances, the content of copper ranges from 78.70 to 85.2 percent and tin from 12.0 to 13.8 percent. The metal components were cast in molds.

The decorative side ends of headrests (*fulcra)* (NAM X 15098-X 15101) (fig. 4) consist of an inclined S-shaped wooden frame, which bore a zoomorphic figure on the finial and an anthropomorphic or zoomorphic protome on its lower side. Three different molds were certainly used in their construction, one for each main part of the headrest: frame, metal protome, and the finial figure. The figures at the two ends were fitted into slots placed around the perimeter of the corresponding part of the headrest's metal frame.

The bronze bases of the couches' legs (NAM X 18922-X 18924) (fig. 5) are elaborately decorated and consist, depending on the case, of two or three cast parts for which an equivalent number of molds were used (fig. 7). The base consists of a rectangular component decorated with concave and convex molding and terminates in an almost square top. The front side of the lower part is flat. It bears a square element on the upper surface, to which a bell-shaped component is attached.

Traces of adhesion on the parts that belong to the couches' legs, both on the metal and the wood, are completely absent. It seems

Fig. 4. ***Fulcrum*** **from the headrest of a** ***kline*****.**
NAM X 15099. 150-100 BC.

Fig. 5. Base of the leg of a *kline*.
NAM X 18922. 2nd-early 1st c. BC.

Fig. 6. Part of a side rail from a couch.
NAM X 18925. 2nd-early 1st c. BC.

that the metal revetment was simply fitted to the wooden frame of the leg. The upper diameter of the base's upper bronze bell-shaped component has a clearly smaller mounting surface, suggesting the existence of a rod – likely wooden but perhaps iron –, which functioned as a tenon joining together the parts of the wooden leg as well as the individual metal components of the leg. It is worth mentioning that a central iron rod is used in couches of the subsequent period for the joining of the separate parts of the leg.

Little information is gleaned about the couches' rectangular side rails (NAM X 18925, X 18929, X 18968) (fig. 6), since only fragmentary parts thereof are preserved. It is certain, however, that they were wooden and bore bronze revetment that covered the outer, upper, and lower surfaces of the wooden frame. The revetment was fastened to the wood with bronze bolts (rivets) affixed to one of the two sides that run parallel to the ground (most likely on the upper side), penetrating the wooden rail and terminating at the opposite side. The outer side of the revetment occasionally bore relief decoration: a meander in one instance from Antikythera. It remains unclear whether the metal revetment decorated the entire length of the four sides of the couches or covered just their ends.

The high cost of metal, the difficult method of processing it, and the "challenging" production of bronze components for the *kline (fig. 7)* – which required experienced and capable bronze smiths – and the inability of making substantial repairs to the metal object in the event of human error seems to render necessary the manufacture of the couch's metal parts first and then the carving of the wooden parts that would have been attached to the bronze. The fact that couch parts bearing a wooden frame with its metal revetment were retrieved as a single mass due to corrosion and marine deposits – as, for example, the side ends of the headrests and the already attached bronze revetment on the wooden frame – shows that the couches were assembled by the time they were loaded onto the ship.

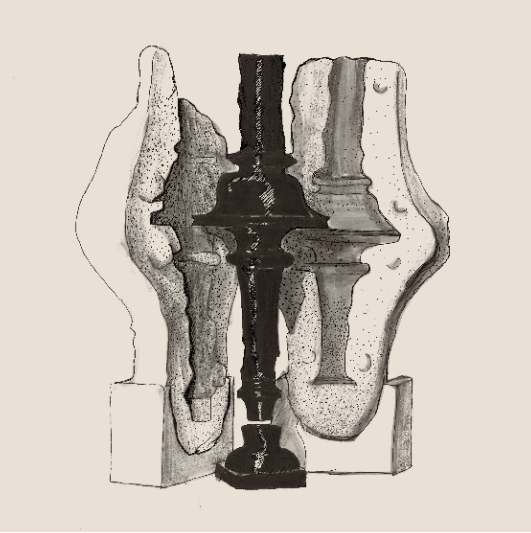


Fig. 7. Mold for the construction of the bronze legs of a couch. (Pl. Chatsidakis, Δήλος, 273, 433, fig. 457. Delos Museum B18619, B18620) (Reproduction of drawing by N. Roumelioti).

NOMIKI PALAIOKRASSA

[The microscopic and macroscopic examination of the wood was conducted by Mr. Panagiotis Kavouras, Head of the Laboratory of Anatomy and Wood Technology at the Institute of Mediterranean Forest Ecosystems and Technology of Forest Products at the National Agricultural Research Foundation].

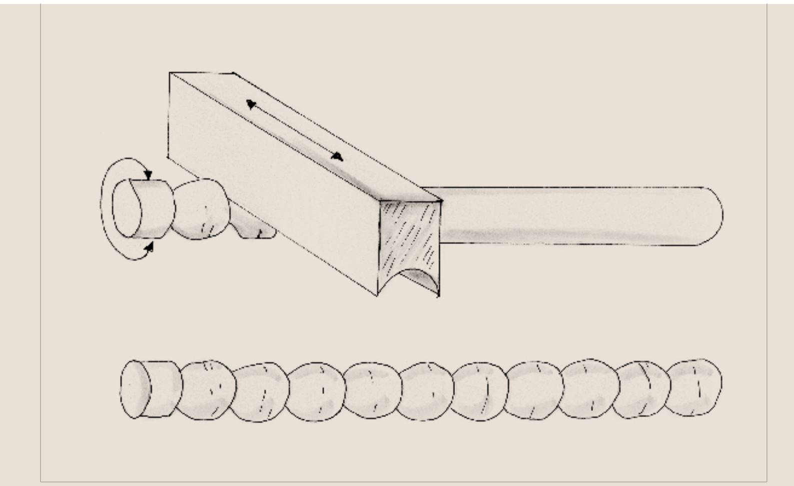
Gold - and silver working

Fig. 1. Pair of earrings and a single earring.
Gold, pearls, garnet, emeralds or prase.
NAM Xp. 1579, 1579a and NAM Xp. 1646. 2nd- 1st c. BC.

Included in the cargo retrieved from the shipwreck are a small number of pieces of gold jewelry (three earrings with pendants, a ring, and two settings with inlaid stone), two calyx bowls, and two conical cups made of silver.

The gold jewelry

Gold is found in veins within silicic minerals like quartz. As the minerals erode, gold flakes are detached; with rainwater, they end up in riverbeds, whence they are collected by their familiar separation from the sand. Gold jewelry is divided according to their manner of production, into forged and cast works. As the casting of gold with the lost-wax method was costly, due to the process as well as to loss of material, cast pieces of jewelry were tiny (rings, small pendants). Artisans created gold jewelry mostly out of hammered sheets of suitable thickness and decorated them with various techniques (for example, repoussé, engraving, granulation, filigree). The granulation technique is based on the capacity of gold to be transformed into small spheres when minute amounts are melted. Using these spheres, artisans ornamented the surfaces of the jewelry with diverse designs and configurations. Wire was very important in the fabrication and decoration of gold jewelry (fig. 2). Extremely fine wire was created out of a very thin and flat band of gold, which the artisan first twisted and then rolled between two wooden plates, in order to make it uniformly thick and smooth. Wire of varying thickness could be utilized either in the manufacture of chains – plain or plaited – or in filigree decoration (fig. 3). The filigree technique was accomplished by soldering to the surface systems of wires in different forms (plain, twisted, granulated, etc.) to form myriad patterns (fig. 4). The use of semi-precious stones in the decoration of jew-



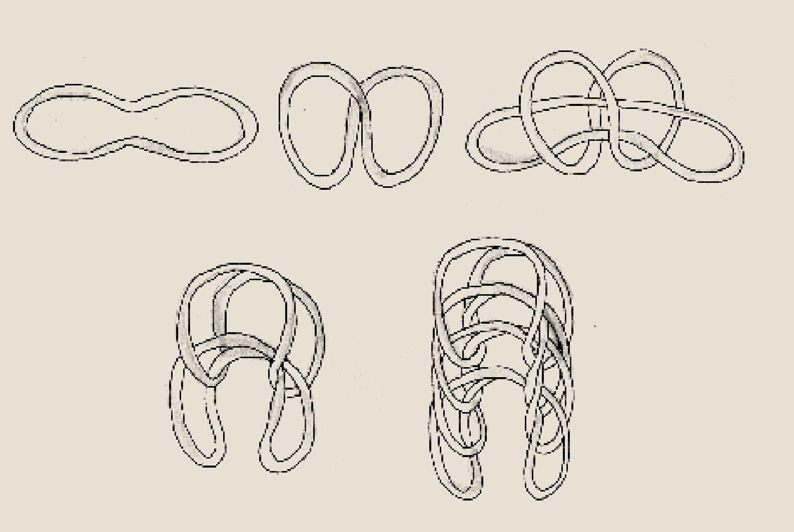


Fig. 2. Working the wire with a special tool to create a specific design on its surface (Reproduction of drawing by N. Roumelioti).

Fig. 3. Single loop-in-loop chain and double loop-in-loop chain (Reproduction of drawing by N. Roumelioti).

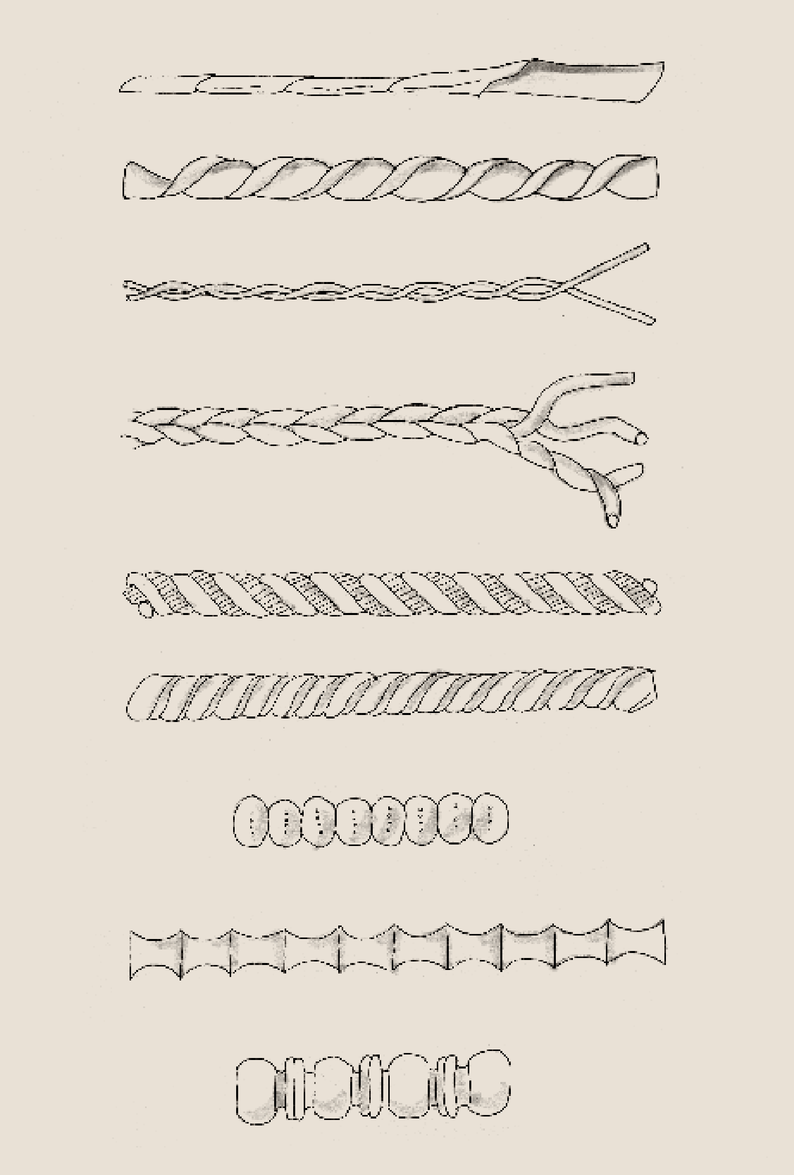


Fig. 4. Various kinds of decorative wires (Reproduction of drawing by N. Roumelioti).

elry was particularly limited until the Hellenistic period, which saw the influx of large quantities of precious and semi-precious stones from the East and a change in the aesthetics of making pure gold jewelry. In fact, Pliny 37.12 associates the enthusiasm for precious stones and pearls with Pompey's triumph (63 BC). To solder different decorative parts and elements on to gold jewelry, the artisan would have to use a eutectic (i.e. fusible) alloy, perhaps silver or bronze, which had a lower melting point than that of gold and melted upon heating, resulting in the bonding of the gold surfaces.

The gold jewelry from the shipwreck was constructed with a combination of various techniques. Despite their fragmentary nature, the three earrings (fig. 1) are counted among the most beautiful and representative Late Hellenistic (2nd-1st c. BC) samples of jewelry decorated with precious stones. The earrings consist of a forged ellipsoid plaque, suspension hook, and pendants in the form of Eros. Each plaque bears three superposed settings that enclosed stones: in the better preserved of the pair, emerald or prase bordered by two garnets with convex exposed surfaces (*cabochon*) in smaller settings. In the case of the single earring, a gold sheet with granulated edges separates its settings, while twisted wire was employed in the pair. The settings were decorated on their oval periphery with small pearls (16 or 20 depending on the case) attached with small pins to settings in one case, and to loop settings made of very thin sheets in the other case. The suspension hook, which is bonded to the backside, bifurcates at the bottom, to form two hinge-like rings, through which a tiny pin with pearls at its ends passes; this pin is for the suspension of the Eros. The two preserved Erotes are miniature masterpieces, of which one plays a kithara and the other raises a box mirror. Their compact forms were constructed with the lost-wax technique. Their wings and the mirror were also cast and soldered to the figurines. Details were rendered with engraving. It appears that in the pair of earrings, the Erotes were making contrasting movements. These earrings, works of the latter half of the 2nd c. or the beginning of the 1st c. BC, belong to the same group as the finds from Delos and Palaeocastro in Thessaly. Some scholars ascribe them to Syrian workshops, while others consider them as works of goldsmiths, with influences from the Black Sea and Ptolemaic workshops of Egypt.

The romboid lamella setting (fig. 5) with inlaid emerald or prase (ancient *πράσιος*), convex on its exposed surface (*cabochon*), should be an element of the central composition of a valuable precious stone necklace from the 1st c. BC, which was held together by gold cords and chains.

The oval-shaped bezel from the latter half of the 2nd-1st c. BC is made of a hammered gold sheet and decorated with granulation on its rim and outer wall (fig. 6). From a typological view, the setting recalls the exquisite rings from the 2nd c. BC, which usually have a triple hoop and bezel attached by means of components in the form of hearts and other shapes. Their settings bear inlaid semi-precious stones or floral compositions of polychrome enameled gold leaves covered by a convex crystal. The production of these rings is sought in Alexandria or Tarentum, without excluding Antioch or even Rome. The absence of any sign of the attachment of a hoop as well as the system of sheets and wires on the setting's backside suggests secondary use in a sumptuous necklace with attached precious stones inlaid in settings.

The ring (fig. 7), perhaps a male adornment, is constructed from a thick gold sheet that is hollow on the inside. Its uniform shape consists of a

Fig. 5. Setting with inlaid stone. Gold and emerald or prase. NAM Xp. 1642. 1st c. BC.

Fig. 6. Gold bezel setting. Made of hammered gold sheet. Decorated with granulation. NAM Xp. 1643. 2nd- 1st c. BC.

Fig. 7. Finger ring. Gold. NAM Xp. 1645. 2nd- 1st c. BC.

Fig. 8. Small bowls. Silver. Cast.
NAM Xp. 1647, NAM Xp. 1648. 2nd- 1st c. BC.

hoop that is flat on the inner surface and rounded on the outer, and of a continuous raised shoulder that converges to form an oval bezel. The now-missing ring stone, made of semi-precious stone or glass paste, would have been secured in place with some type of adhesive, traces of which are well preserved in the cavity of the hoop. Rings of this type, dated to the 2nd and 1st c. BC, have been found in Eretria, Delos, Patra, and Tarentum.

The silver vessels

The handleless silver bowls (fig. 8) emulate common yet beloved Hellenistic ceramic tableware used for serving foods in small quantities. Their calyx-shaped bodies and ring bases were cast separately and subsequently soldered together. Conical cups without a base are known in Hellenistic pottery from the 3rd c. BC. Silver cups of this type, known as *mastoi*, are a characteristic product of Hellenistic silver working and are widespread in the 2nd and 1st c. BC, from Parthia to the Iberian Peninsula. The two conical cups from the shipwreck (fig. 9) were manufactured on a lathe out of two superimposed and fused sheets of the same alloy, however of different thicknesses; the sheets were then forged. It is noteworthy that both of these types of silver vessels have glass counterparts in the ship's cargo, as their shapes and materials were ideal for drinking vessels.

ELISABETH STASSINOPOULOU

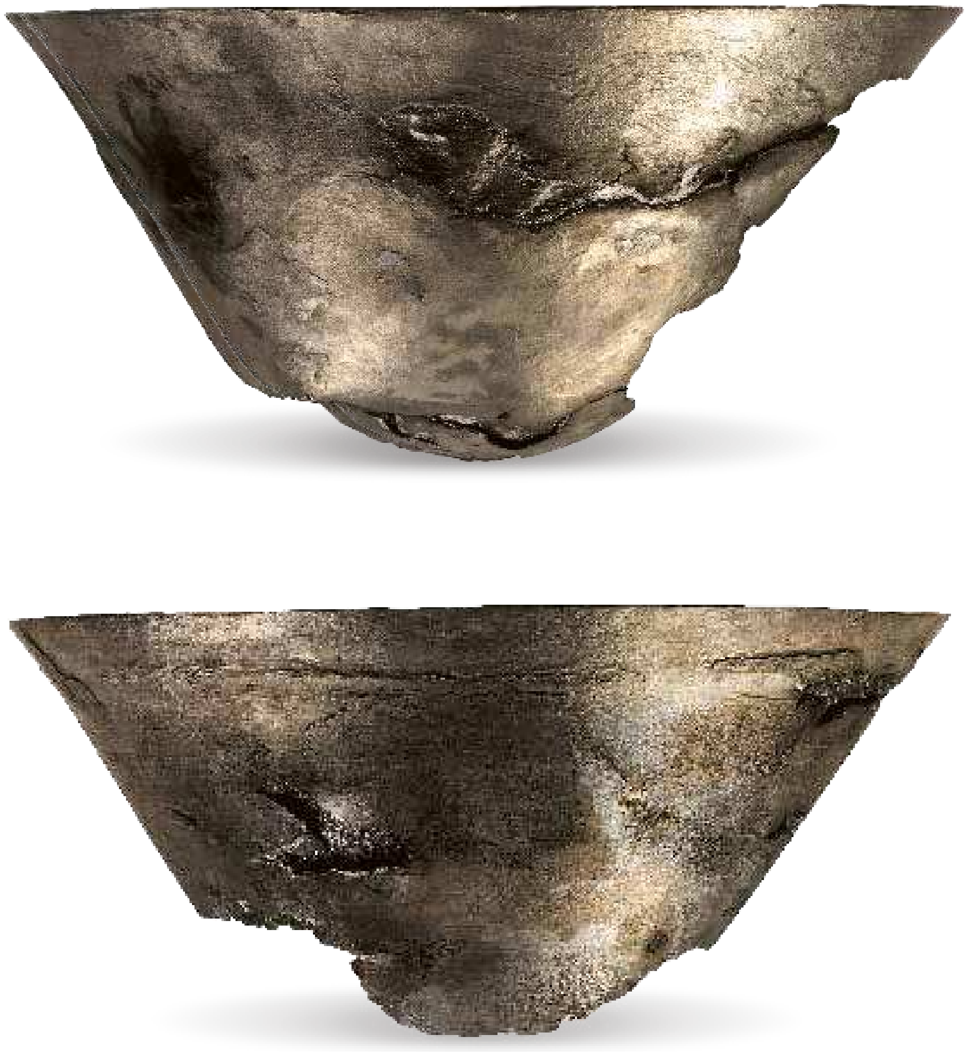


Fig. 9. Conical cups. Silver. Dual-wall technique. Forged.
NAM Xp. 1649, NAM Xp. 1650. 2nd- 1st c. BC.

Glass working

Fig. 1. Lobed bowl. NAM 23714. 1st half of 1st c. BC.

The twenty retrieved monochrome and polychrome vessels, preserved whole or fragmentary and dated to the 1st c. BC, comprise a unique archaeological assemblage that represents the most famous and impressive glass techniques of the Hellenistic period.

A blue alabastron (fig. 2) is a late example of the core forming technique, one of the oldest glassworking methods, with which unguentaria were manufactured in the Mediterranean already by the 7th/6th c. BC. In this technique (fig. 3), the vessel was shaped around a core (made of sand and iron oxides) that was placed at the end of a metal rod. A molten glass trail was wound around the core or crushed glass was applied to it, melting as the rod was inserted into the opening of the glass furnace. Next, the vessel was decorated with glass trails wound around it, which formed zigzags, garlands, or feathering; they were embedded into its surface by marvering (rolling on a stone surface). Finally, the base, handle, and rim were created separately and attached to the vessel.

Three fragmentary bowls (NAM 23709, 23710, 23711) were made by casting, a manufacturing technique employed already from early antiquity. One of the bowls still has one of its two tripartite handles, which were either created inside a mold with the rest of the vessel or were formed separately and then attached to the vessel's body.

A green-blue bowl decorated with leafy olive branches shooting up from the mouth of stylized vase (fig. 4) is of exceptional rarity and beauty. Perhaps it was created in a mold and decorated thereafter with cold cutting (i.e. removal of glass from its surface). However, it has also been suggested that the vessel was manufactured with

Fig. 2. Alabastron. NAM 23726. 1st half of 1st c. BC.

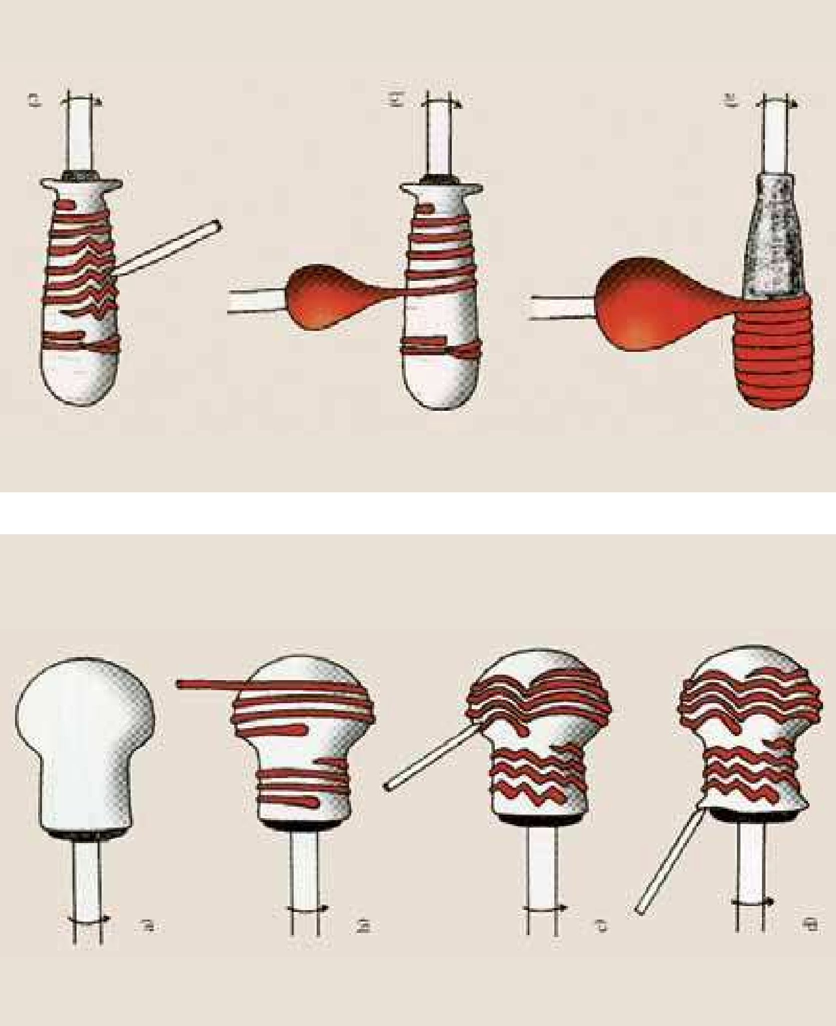


Fig. 3. Core forming technique. After R.S. Bianchi (ed.), *Reflections on Ancient Glass from the Borowski Collection*, Mainz 2002, 28 fig. 11 and 27 fig. 8.

rotary pressing in a mold (on which the shallow design had been incised while the mold was still damp), a hypothesis that is corroborated by the rotary scratches discernible on the vessel's interior. According to the latter view, after the pressing, the decoration was most likely highlighted with short, cut grooves. Rotary pressing, a technique that was applied toward the end of the Classical period in the manufacture of luxurious colorless and polychrome glass vessels, consists of pressing molten glass with a plunger into a concave mold or on to a convex former mold, which was turned on a potter's wheel.

A golden brown lobed bowl (fig. 1), decorated with 16 lanceolate leaves alternating with 16 protruding lobes and an eight-petalled rosette on the base, is the largest of the vessels found in the shipwreck. Lobed bowls, which around the end of the 3rd c. BC succeeded vessels bearing "almond-shaped" relief protrusions, were manufactured by casting (i.e. with the use of a mold) or with rotary pressing (formation with pressing in a mold mounted on a revolving potter's wheel) of transparent colorless or colored glass. The protruding lobes are due to cavities that had been dug into the mold while it was still damp, whereas the grooves, the vegetal decoration, and the ornamentation on the bottom were executed after firing. But since the vegetal decoration appears to be in relief in relation to the surface of the Antikythera bowl, it is likely that either the decoration was also incised in the mold while it was still damp, or that during the polishing and cutting of the vessel the body of each leaf was isolated by excision and then decorated.

Among the drinking vessels, a grooved conical bowl (fig. 5) and a fragmentary fluted bowl (NAM 23715) stand out; these were types of vases associated with Syro-Palestinian glass production and found for the first time in the 2nd c. BC. Grooved bowls, with internal or external grooved decoration, often under the rim, were made by rotary pressing on a former mold that rotated on a potter's wheel or by simple sagging of a blank (prefabricated glass disc) that was heated over a convex former mold. Sagging is a technique that appeared in the Hellenistic period and was employed for the manufacturing of luxurious open form vessels, not only over convex former molds, but also within concave molds. Fluted bowls, characterized by shallow, vertical grooves on the body, were created with rotary pressing and then their decoration was cut.

The most impressive group of glass vessels that were found in the Antikythera shipwreck is that of the multicolor vessels formed with the mosaic technique, developed especially during the end of the High Hellenistic period. The group comprises vessels preserved intact or in fragments: six mosaic bowls (fig. 6), four network mosaic bowls, as well as one striped mosaic bowl (fig. 7). A common characteristic among them is the existence of a base modeled from a separate glass ring. The key components in the manufacture of

Fig. 4. Bowl. NAM 23712. 1st half of 1st c. BC.
Fig. 5. Conical grooved bowl. NAM 23713. Early 1st c. BC.

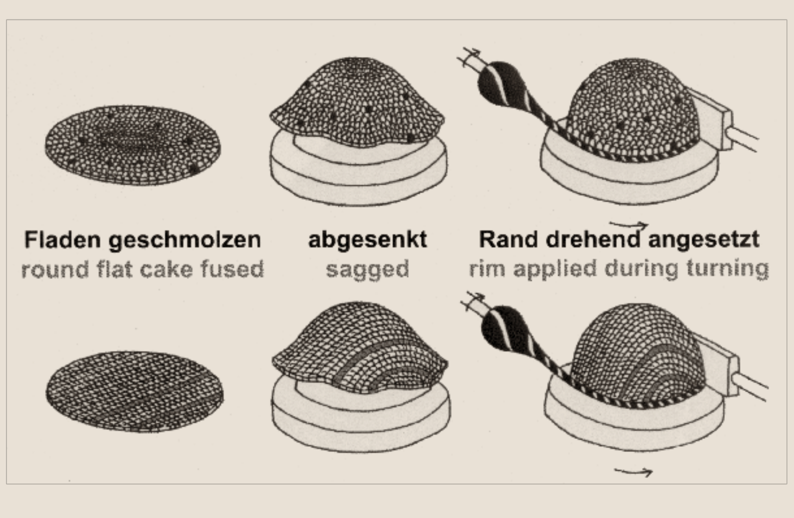
mosaic glass are cane sections, i.e. transverse pieces of one or more composite mosaic cones (resulting from the fusion of a set of simple glass rods), which formed a polychrome pattern visible in cross-section. These cane sections were assembled and melted in the furnace at a high temperature in order to create a disc-shaped blank. Often, monochrome pieces of glass or sections of glass trails were also melted with the cane sections. Next, this "disc" was placed over a convex former mold, which had the desired shape of the vessel being manufactured; then it was reintroduced into the furnace. With the heating of the disc-shaped blank, the glass sagged under its own weight, covering the mold and taking its shape (fig. 8). Network mosaic bowls were invented, along with the mosaic variety, at the end of the 3rd c. BC most likely in Alexandrian workshops, and were manufactured with twisted trails of glass wound in a spiral around a convex former mold that was spinning on a potter's wheel (fig. 9). Finally, striped mosaic bowls, which also appeared in Egypt shortly thereafter, at the end of the 2nd c. BC, could have been manufactured in the same way as the mosaic variety: glass trails were formed into elongated bands lined with colorless glass and, then, were assembled and melted in the furnace at a high temperature, in order to create a disc-shaped blank. The "disc" was then placed over a convex former mold and heated within the furnace so that it would sag under its own weight,

Fig. 6. Mosaic bowl. NAM 23718. 2nd quarter of the 1st c. BC.
Fig. 7. Striped mosaic bowl. NAM 23723. 2nd quarter of the 1st c. BC.

covering the mold and taking its shape. It is also possible, however, that the glass trails were placed on a disc-shaped blank of colorless glass, which then began to sag. The presence of such a colorless layer is evident in the striped bowl from the shipwreck.

Without a doubt, the glass vessels from the Antikythera Shipwreck were part of the ship's cargo and, as important commercial goods, were destined for the markets of Rome. Their high aesthetic value makes them an ideal luxury item, which satisfied the Romans' need to decorate their private spaces with products characteristic of Hellenistic opulence.

CHRISTINA AVRONIDAKI



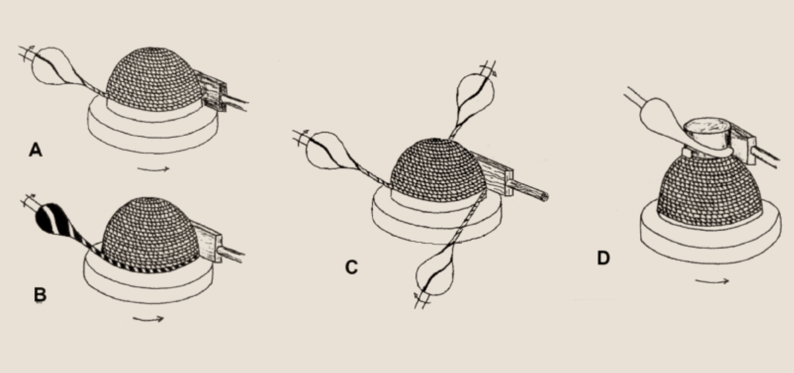


Fig. 8. Manufacturing technique of mosaic bowls. After R. Lierke, *Die nichtgeblasenen antiken Glasgefässe - ihre Herstellung von den Anfängen bis zu den Luxusgläsern der Römer. The Non-blown Ancient Glass Vessels - their Manufacturing from the Beginning to the Luxury Glasses of the Romans*, Offenbach/Main 2009, 41.

Fig. 9. Technique of manufacturing network mosaic bowls with spiral decoration. After R. Lierke, *Die nicht-geblasenen antiken Glasgefässe - ihre Herstellung von den Anfängen bis zu den Luxusgläsern der Römer. The Non-blown Ancient Glass Vessels - their Manufacturing from the Beginning to the Luxury Glasses of the Romans*, Offenbach/Main 2009, 40.

Pottery

Fig. 1. Red-slipped hemispherical cup and red-slipped plate.
NAM 30654 and NAM 30634. 1st c. BC.

Ceramics of a great diversity of types and categories, which were integrated into the daily life of every ancient civilization, can be studied through several themes, such as their production, diffusion, and use. Vases can also be studied in terms of their formation and technique.

The pottery transported by the ship that wrecked at Antikythera in the second quarter of the 1st c. BC consists of various categories. Different workshops are represented, indicating their place of origin, while the uses of the ceramic products vary.

The greatest quantity of pottery had a commercial character and was part of the ship's valuable cargo. The red-slipped plates and the hemispherical cups of the Eastern Sigillata A type (NAM 30624-30632, 30634-30654, 30660) account for part of the luxurious cargo of the ship, as these vessels most likely were intended for the feasts of wealthy Romans (fig. 1). If they didn't purchased them in Ephesus or in a market of luxury goods at Delos before its decline in 69 BC, they could have been procured in their littoral production centers in Cyprus, Cicilia, and the valley of the Orontes River. Indeed, if these are associated with Cicero's *rhosica vasa* and Athenaeus' *ῥωσικὸν κέραμον*, as has recently been proposed, then the city of Rhos(s)os, on the southern coast of the Bay of Issos and the harbor of Antioch, is a likely place for this particular transaction.

Present also were vases for the transport of products, like the lagynoi (NAM 30680-30684, 30701-30705, 30713-30715, 3-718-30730, 30759-30762 and 30771-30775) and the transport amphorae, in the case of which the commodity is the content and not the vessel itself.

The transport amphorae (fig. 2), the vase that is more connected with ancient shipwrecks, is a storage container, with some specific characteristics: the pointed toe was used for interlocking the upper layer of amphorae with the lowest, so that the storage of the containers in the ship's hull was secure and the possibilities of the cargo's displacement during the journey were reduced. They were used principally for the transport of liquids, such as wine and oil, but also for the transport of solid products.

At the Antikythera Shipwreck, at least four different types of transport amphorae have been identified and all of them are dated to the first half of the 1st c. B.C. These amphorae are mainly from Rhodes (NAM 27996, 27997, 31046) and Kos (NAM 28003, 30994, 30999), important wine producing areas, as well as from Ephesus (NAM 30993, 30998, 30997, "Nikandros Group") and from the coast of the Adriatic Sea (Lamboglia 2 type) (NAM 28004). The amphorae from Rhodes, Kos, and Ephesus were probably part of the cargo of the ship and the amphorae of the Lamboglia 2 type was probably used by the crew for the storage of wine or water.

Vases that have been identified as utilitarian are associated either with specific crewmembers on board the ship, like the two skyphoi (NAM 30708, 30709) bearing incised inscriptions indicating at least a few members of the Greek-speaking crew, or with activities that occurred during the voyage, such as at least the one (fig. 3) of the nine lamps that have been retrieved from the shipwreck with evident use for lighting. The two filter jugs (NAM 30769, 30770) likely facilitated the filling of lamps with oil.

Production

Potting clay, an essential component in the production of earthenware, is a product of soil erosion. The clay's composition is one of the criteria for recognizing the different categories of pottery and workshops. The extraction of the clay took place mainly in open, extensive pits and occasionally in subterranean galleries. The next stage involved removing foreign matter from the clay in order to create a pliable mass out of which vases would be formed on the potter's wheel.

The technique of producing wheel-made pottery begins to spread to the Eastern Mediterranean around 3000 BC. Ancient potter's wheels,

Fig. 2. Transport amphorae. 1st c. BC.

Fig. 3. Lamp with traces of burning. NAM 30620. 1st c. BC.

made of wood, stone, or terra cotta, were hand rotated; a requirement for their operation was that they be "centered" unobstructed by means of a hollow internal support cylinder, usually made of wood (fig. 4). Wide use of wooden, foot-powered potter's wheels is attested from the 2nd c. BC. The first form in which vases were produced was simply cylindrical in shape and almost identical to one another (fig. 5). During this phase, the first artistic feature (propeller-shaped motif) was formed on the lower surface of vases while they were being detached from the slowly rotating wheel with the use of a plain thread. After they dried, the finishing started again on the potter's wheel with the aid of clay wedges. The next step was the attachment of separately made parts of the vase, chiefly the handles but also certain decorative elements, mainly reliefs.

Almost all the vessels that have been retrieved from the Antikythera Shipwreck, exclusive of the Megarian bowls and perhaps the wide-diameter red-slipped tableware plates, were produced in the aforementioned manner.

The Megarian bowls represent the technique of producing entire vessels with patterns in relief. Matrices in raised relief are used for the creation of the molds, as metalworkers used for the production of metal vases. As for the wide-diameter red-slipped tableware plates, it has been suggested that they were produced in workshops characterized by a high degree of standardization and were also made in part with the use of molds (fig. 6).

Decoration

Once they had passed all the stages on the potter's wheel, vessels were smoothed carefully with a wet piece of leather and then decoration began (fig. 7).

The vessels from the Antikythera Shipwreck were either undecorated, or had a white ground (some lagynoi), a slip that was nothing more than properly prepared clay that acquired different color gradations with appropriate firing conditions in the kiln, or, finally, were soaked in a dilute solution of clay resulting in some differentiation in color on their surfaces. Some lamps carry relief decoration made with the use of molds (EAM 30616-30618, 30623), while the red- and black-slipped tableware bear stamped decoration. This particular manner of decoration is achieved by pressing small stamps with fine ornamental motifs, mostly vegetal, into the unfired clay. The red-slipped plates from the shipwreck and, to a lesser extent, the bowls bear at the center of their inner surfaces small grooved circles or impressed rosettes and an ornament of five impressed flowers or leaves arranged in a circle and surrounded by multiple, concentric circles in a "roulette" pattern.

Firing (baking)

Baking was the last stage in the production of clay vessels. The ancient kiln was an aboveground cist oven, with fire rising from below (fig. 8). They consisted of a chamber dug into the earth with a feed line for the fire and an above-ground vaulted chamber with a circular plan, in which the unbaked vases were stacked one on top of the other for firing. The clay floor dividing the two spaces was perforated in order to let the flames rise amidst the vases. An opening in the roof, which could be closed as desired with a plate, facilitated the evacuation of smoke and the entry of oxygen. One or two small holes on the sides, which closed easily, allowed the potter to check the temperature by the color of the flames and the progress of the firing with test ceramics pulled from the chamber. The baking was completed in three sequential stages.

With a constant supply of fire after eight or nine hours, the temperature reached around 940- 950^{0}C. The vases were fired, turning red, an effect of the ferrous clay coming into contact with the oxygen entering the two openings (the hole in the roof and the feed line). When the baking reached this point, the potter fed the fire green branches in order to create smoke, and closed the two openings. At a temperature around 900^{0}C, and with the carbon monoxide from the smoke, the atmosphere inside the kiln was converted from an oxidized into an oxygen-reduced one, thereby blackening the vases completely. At that time, the potter reopened the hole in the roof and the feed line in order to let the air cir-

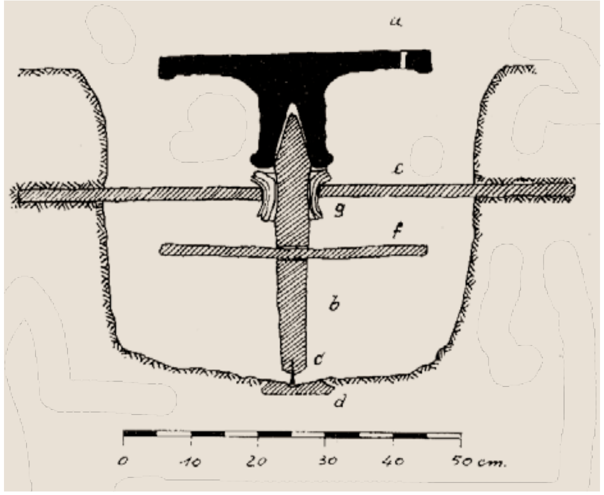


Fig. 4. Potter's wheel. 7th c. BC (Reproduction R. Hampe, *Ein kretische Töpferscheibe*, fig. 1).

Fig. 5. Potter works a mass of clay on tray of a potter's wheel, which is turned by a young boy. From a black-figure miniature kylix in the manner of the Centaur Painter. Kalsroue. Badisches Landesmuseum, no. 67/90. From Etruria. 540-530 BC (Drawing by Th. Kotsigiannis).

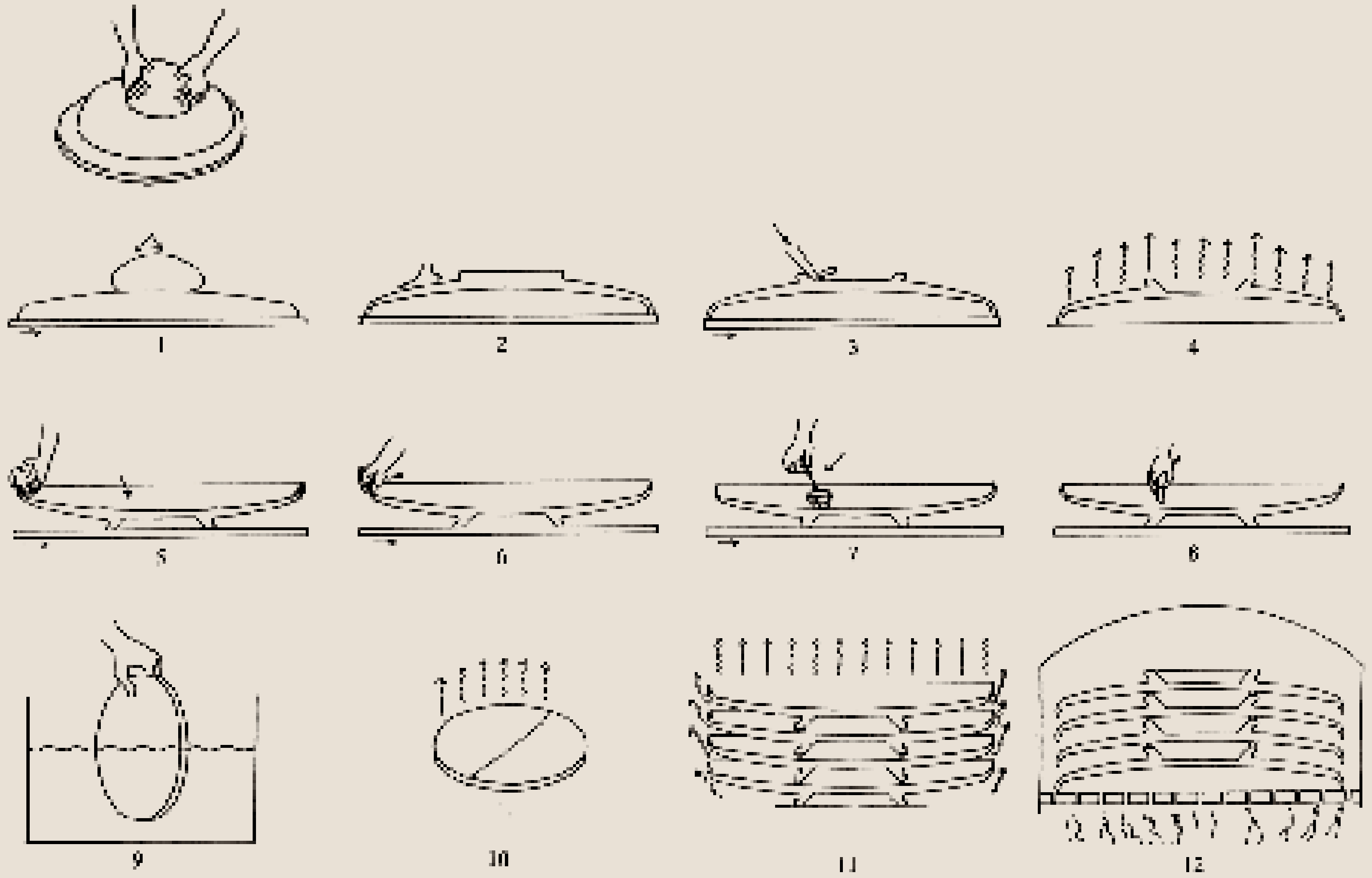


Fig. 6. Manufacturing process of ESA wide plates. From H. Meyza, *Early Eastern Sigillata A from Paphos, Cyprus. Πρακτικά Ε΄ Επιστημονικής Συνάντησης για την Ελληνιστική Κεραμεική*, Athens 2000, 238, fig. 1.

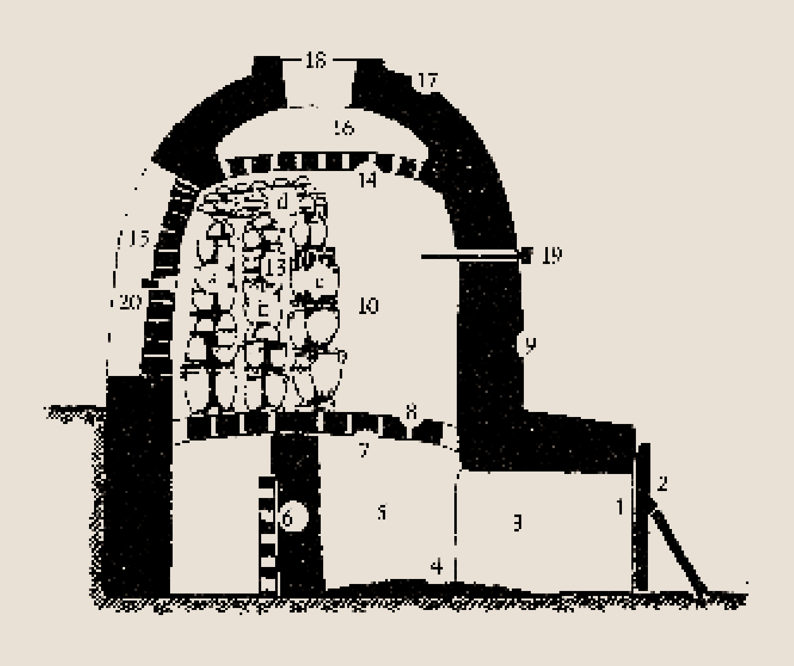


Fig. 7. A young painter involved in the decoration of a vase. From a red-figure kalpis of the Leningrad Painter. Milan. Private Collection. From Ruvo. 470-460 BC (Drawing by Th. Kotsigiannis).

Fig. 8. Ancient pottery kiln (Reconstruction Winter, *Antike Glantzonkeramik*, fig. 9).

culate and the kiln cool. The oxygen entering the chamber re-oxidized the areas of the clay that were not covered with "glaze", and restored their red color. The "glaze" retains, however, its glossy black color, since it contained alkali, the molecules of which, after fusing at high temperatures between 900^0 and 950^0C, sealed the pores of the vases and prevented oxygen from penetrating and affecting them.

Although pottery is one of the less impressive finds from the wreck, its construction presupposed highly qualified craftsmen as well as knowledge, and reflects the specific technical skills of the ancient world. Moreover, the clay, a material especially accessible and inexpensive, enabled all cultures to create works of art comparable to these of precious materials but also to develop their artistic skills, making pottery one of the most vital industries.

ANASTASIA GADOLOU


RIS
ARIM

Coinage

Fig. 1. Pergamon, silver cistophoric tetradrachm, date of issue: 85-76 BC. Athens Numismatic Museum, ΒΠ 707: 19.024/2.

The silver and bronze coins from the Antikythera Shipwreck have been dated to the period from the second half of the 3rd to the 1st c. BC (fig. 1). With respect to their manufacture, they are products of a simple technique that was used since the late 7th or early 6th c. BC in connection to mass production of money in the form of coinage under the auspices of official authorities. This was an important technological advancement for both evaluating goods and services and conducting transactions. They were made by striking metal discs, the flans or blanks, between two dies bearing designs impressed on them. This manufacturing technique was employed in the great majority of ancient coins, since on occasion only coins of a particular shape or significantly large size were cast.

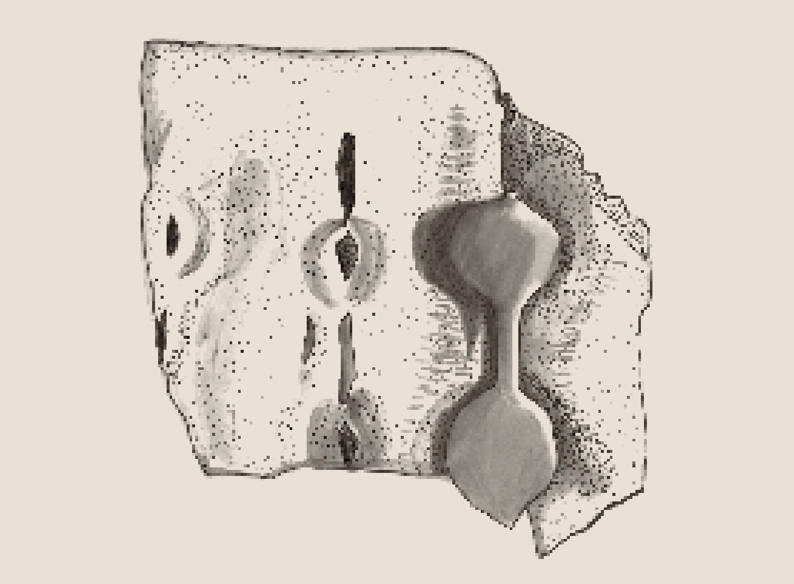
Information on coin-making technology in antiquity by the method of striking or hammering derives from observing the actual coin specimens, a restricted number of certain tools preserved from different periods, few related depictions, as well as cases where similar practices have been recorded in modern times. It was mostly a simple method that involved few tools managed by limited personnel. The basic tools included a furnace for heating the flans, tongs for handling hot flans, scales for weighting, a pair of dies – the obverse die and the reverse one attached on a punch -, an anvil to keep the obverse die fixed and a hammer for striking the punch. Some of these tools are depicted on the reverse of a Roman Republican denarius dated to 46 BC (fig. 2).

The procedure of coin-making did not require permanent facilities. The need to use a special permanent building must have arisen only when there was a large and constant numismatic output. A most characteristic example has been the mint of Athens, which operated on the eastern edge at the south side of the Agora from the end of the 5th to the end of the 1st c. BC. It measured 27x38 m, with rooms of different sizes surrounding an outer courtyard.

The making of dies: Dies were made either of iron or bronze. Upon their surfaces, expert engravers inscribed in intaglio the types and legends that were to be impressed on the two sides of each flan, using small wedges, gravers of various sizes, and possibly a drill. It is a technique closely related to the engraving method of carved gemstones, which developed centuries before the invention of coinage. It is quite plausible that the same artists engraved both dies for striking coins and gemstones. There were actually some who signed their creations by incorporating their names or initials in the design. Since the engraving was executed by hand, dies bearing the same design differed in details. When there was need to issue large amounts of coins, many similar dies were likely made at a faster rate by using the practice of the positive die or patrix (hubbing). In these cases, a die was made of metal with the design in relief. Then, the design was impressed in intaglio upon the heated face of the die-blank and the engravers worked the details on each die by hand.

The making of flans or blanks: The value of each coin was determined by its metal composition, size, and weight. For this reason, when producing a coin series it was extremely significant that flans were prepared according to specified requirements. They were made of gold, silver, bronze or their alloys in workshops where metal ovens were operating. Flans were produced by either casting the metal in stone or clay molds (fig. 3) or cutting metal cylindrical bars (fig. 4). Occasionally, in order to both save time and limit the

Fig. 2. Roman Republic, denarius, date of issue: 46 BC (moneyer: T. Carisius). Classical Numismatic Group, Auction 90 (23/05/2012), no. 1367.



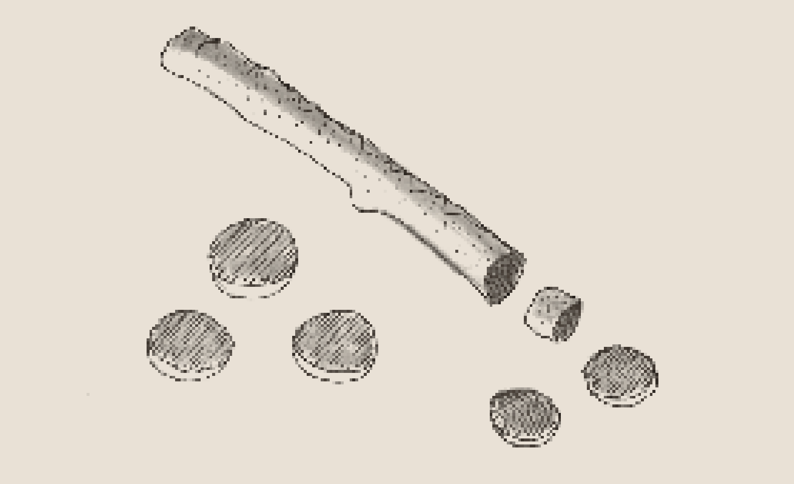


Fig. 3. Mold for casting flans and pair of flans linked by a runner, from Paphos, 2nd-1st c. BC (Reproduction of drawing by N. Roumelioti).

Fig. 4. Metal bar and flans, from Pella, 2nd c. BC (Reproduction of drawing by N. Roumelioti).

cost of their production, earlier coins were used as flans. The shape and thickness of the flans varied through time and depended on their manufacture method and the trends in style of each period. During the Hellenistic period, flans were less thick and bigger in diameter than in preceding times. These features are observed on all the cistophoric tetradrachms of the hoard discovered in the shipwreck (fig. 1).

A variety of mold shapes was used for making cast flans. The latter were produced individually by casting the metal in open molds that had circular deepenings which were not attached to one another. This technique may have been more preferable in making flans of precious metals in order to ensure the necessary precision in weight. Flans could also be made in pairs or groups in molds that had depressions connected to each other by channels. In this method, flans were attached with thin strips that were then cut off. Traces thereof can be seen on the find from Paphos in Cyprus (fig. 3) as well as on coins that still retain parts of the runners.

The striking process: Craftsmen usually heated up the flans to make them relatively soft and then transferred them with a tong and placed them one-by-one on the obverse die that was attached to the anvil. They then put the punch die on the flan and while holding it with one hand they hammered it with the other. In this way, the designs of both dies were impressed on the two faces of the flan thus making it into a coin (fig. 5). On the occasion when flans were struck without having been heated first, the procedure was certainly easier while placing them between the dies. However, more strength and perhaps more attempts were required in order to get the flans impressed to satisfaction. The operation of a mint is depicted on the obverse of a bronze coin of Paestum in South Italy,

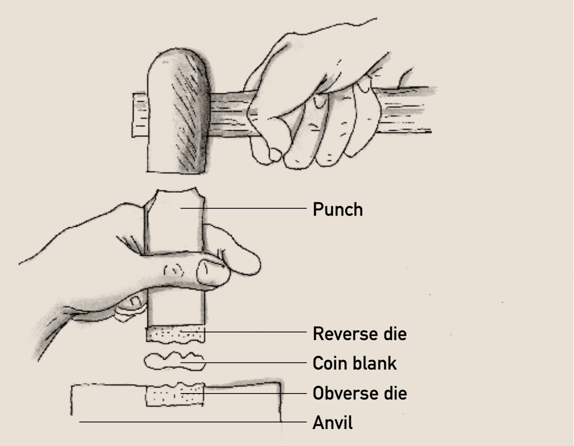


Fig. 5. Representation of striking ancient coins (Reproduction of drawing by N. Roumelioti).

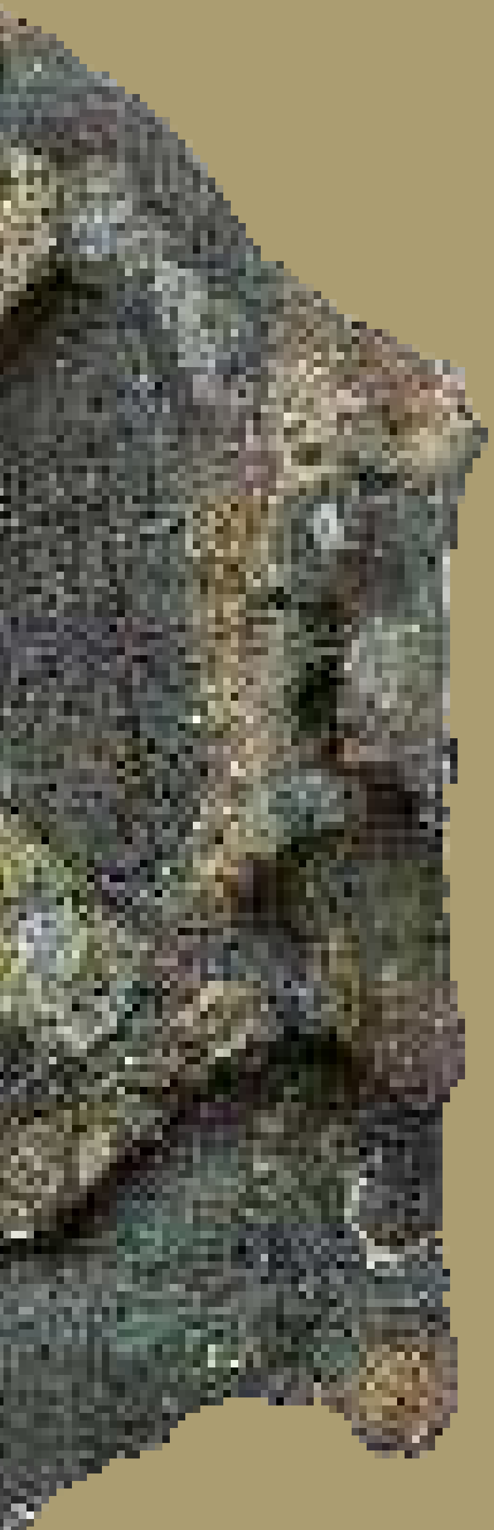
Fig. 6. Paestum, semis, date of issue: early 1st c. BC. *Numismatica Ars Classica*, Auction 27 (12/05/2004), no. 41.

where two craftsmen are shown while striking coins (fig. 6). It is one of the earliest relevant representations dated to the early 1st c. BC, i.e. the same period when most of the coins from the shipwreck were issued.

Since the striking was done by hand, the free reverse die could be placed in many different positions as opposed to the secured obverse die. As a result, in many cases the orientation of the obverse and reverse of each coin within a series could be quite random. Still, during the Hellenistic period an attempt to have a fixed relation between the axes of the designs on both coin faces became quite obvious. Both designs are frequently depicted vertically on a 360^0 position and occasionally one of them reversed on an 180^0 orientation. This feature has been also observed in the shipwreck coins where, regardless of metal or place of issue, most of them bear both designs along a 360^0 position and the remaining ones along the slightly differentiated orientations of 330^0 or 30^0. This widespread practice suggests that dies must have born certain indicators, in the form of incisions or similar marks that helped the craftsmen to precisely place both dies on the preferred position.

The number of coins produced by a single die is not known. Based on both the existing scarce valid data and the modern experimental techniques, an average output of each die reached a few hundreds. The output of each die greatly varied depending on the metal and the size of flans, the quality of the die, as well as the expertise of the mint craftsmen. By constant use, dies were gradually worn out, broken, and damaged beyond repair. Given that the obverse dies were securely attached to the anvil and thus better protected, they lasted longer than the reverse dies which were fixed at the end of the movable punch and were directly struck by the hammer. This may be the most important reason for the very few ancient dies recovered until now.

PANAGIOTIS TSELEKAS



The Antikythera Mechanism

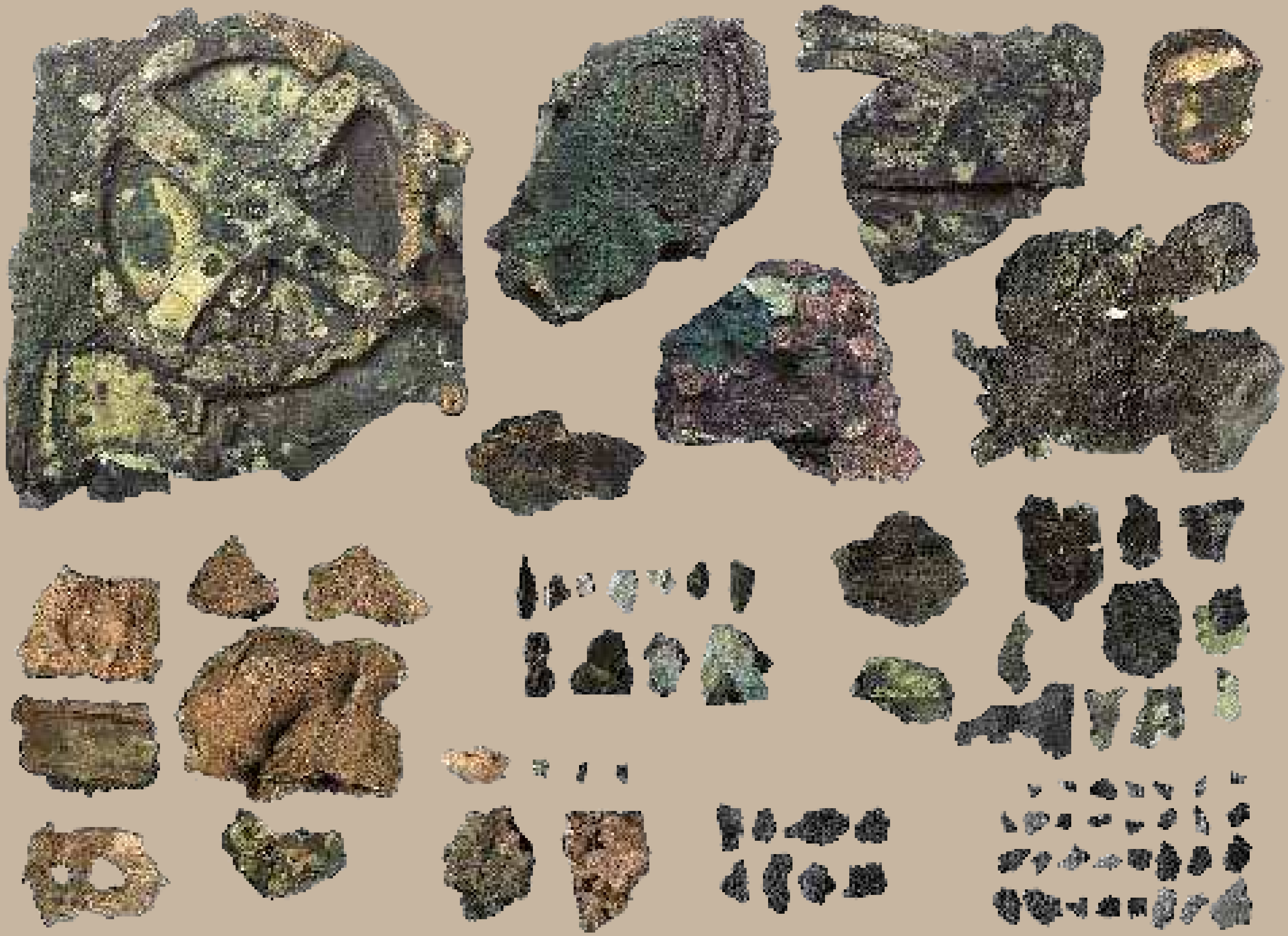


Fig. 1. The Antikythera Mechanism fragments A-G and 1-75. Second half of the 2nd c. BC.

The Antikythera Mechanism, as it is conventionally called, a superb object kept in the National Archaeological Museum in Athens (X 15087, fig. 1), has been ascribed since its discovery to the class of astronomical instruments: Some of the functions attributed to it are those of the astrolabe, planetarium, and navigation tool. Its construction dates to the second half of the 2nd cent. BC. Over a century of research has now established that it is the oldest known astronomical and calendric calculator, the "World's First Computer".

The nature of the Mechanism

The Mechanism consisted of mechanical parts: at least 30 gear wheels as well as dials, axles, and indicators. The exact position of the 82 surviving fragments of the original instrument (A-G and 1-75, fig. 1) and the complete structure are still a matter of intensive research. The mechanical parts were mounted and protected within a wooden housing and bore metal plates on its front and back. The similarities shared with more contemporary machines of analogous function are apparent.

Chemical analyses of smaller fragments showed that at least three different alloys containing variable amounts of copper, tin, and lead were used in its manufacture. In any case, it is reasonable to expect considerable variation of the constituent elements of an alloy from point to point. Higher tin content in the alloy increased mechanical durability as well as facilitated the casting. The hardness of the alloy was achieved by means of cold working and final or multiple annealing. Bronze sheets were used to produce hammered artifacts, while by the 4th c., the disks of folded mirrors were being cast. The gear wheels of the Mechanism must have been formed out of such sheets by sawing, filing, and planishing. In the case of production by direct casting in clay molds, filing of their peripheries could be accomplished by means of a metal lathe, known since the 4th c. BC. The geometrical division of the gear wheels perhaps relied on a suitable template or on trial-and-error methods. Cutting of gears on a bronze disk required a compass, a fine-edged chisel, and a hammer. The Antikythera Mechanism's teeth are not very precise in their division and cutting, but this fact did not seem to have affected its function.

A century of research

The Mechanism has been recognized as an astronomical device since its first published description. The first experts to study it (1902-1934) were two Greek archaeologists (I. Svoronos, V. Staïs), a historian (K. Rados), and officers of the Greek Royal Navy (P. Rediades, I. Theophanides). Both Svoronos and Staïs guessed that it was an astrolabe. The German philologist A. Rehm, who studied the mechanical elements and inscriptions on the plates, called it a "planetarium". Theofanides was the first to build a mechanical likeness of the Mechanism, and wrote several articles about his findings, arguing that it was a navigation tool.

During the period 1953-1974, the historian of science Derek J. de Solla Price examined the internal structure of the Mechanism's fragments with the aid of radiographs made by the physicist Ch. Karakalos, and created a second reconstruction. De Solla Price concluded that the object was a calendric calculator. His conclusions, presented in two seminal publications (1959, 1974), were fundamental for subsequent research. Consensus was then reached about the artifact's use: it was a mechanical calculating device that combined calendars with astronomical phenomena. From 1990 onwards, the fragments were subjected to x-ray linear tomography (professor of computer's sciene A.G. Bromley, and historian of mechanism M.T. Wright) and were later examined

Fig. 2. Fragment 19. The three main circles of astronomical terms are shown in the highlighted area.

with the techniques of three-dimensional surface imaging and X-ray computed tomography (Antikythera Mechanism Research Project). This research resulted in the reading of additional inscriptions and the production of new models.

The "key" to the inscriptions

Parts of Greek inscriptions on bronze fragments from the Antikythera Shipwreck, now at the National Archaeological Museum, led to the identification of this exceptional device in May 1902. Astronomical terms such as "OF THE SUN", "RAY", and "APHRODITE" were discerned on some of the fragments. They are incised on many of the fragments' surfaces as well as on two plaques, which probably covered two sides of the Mechanism. These inscriptions seem to have functioned as an "accompanying manual", an idea that the first researchers advanced already in the early 20th century. Putting these inscriptions into the context of ancient astronomical knowledge, in conjunction with examination of the remaining mechanical parts (gears, axles, dials, parts which moved the indicators, etc.) enables current researchers to demonstrate with enough confidence the calendric and astronomical functions of the device. As a significant portion of the Mechanism is not preserved, the investigation of certain additional functions relies to a large extent on the interpretation of the inscriptions.

Already from the first decades of the 20th century, as the cleaning of the fragments progressed and more inscriptions were discovered – like numbers related to known astronomical periods and words with specific astronomical meaning –, it became obvious that one was dealing with an extremely sophisticated astronomical instrument. Four numbers in total, which were the "key" to the mystery, had been inscribed on two small fragments of the Mechanism. These numbers refer to astronomical periods known in antiquity: On fragment 19 (fig. 2), the Greek number Iota Theta (19 years, the Metonic cycle in solar years), the number Omicron Sigma (=76 years, the Calippic cycle), and the number Sigma Kappa Gama (=223 lunar months, the Saros cycle); on fragment E, the Greek number Sigma Lambda Epsilon (=235 months, that is the Metonic cycle in lunar months). The latter inscription indicates that the dial is divided into 235 parts. In order to elucidate the role of these numbers it is necessary to understand the meaning of the related ancient astronomical periods.

The Metonic cycle lasted 19 years, as its ancient name (*enneadekateris*) suggests. The period from one new moon to the next is called a "lunar month" or "synodic". The problem with the calendars is that a full year (for example, that from one spring equinox to the next, about 365 days later) does not contain a whole number of lunar months and, thus, the dates deviate as time goes on. Starting at the spring equinox in 432 BC, the Athenian astronomer Meton proposed the solution to this problem by introducing a calendar based on a period of 19 years, which coincides with 235 lunar months. Even today, the calculation of the date of Easter, which is a moveable feast in our solar calendar and is based on the phases of the moon, is made using the Metonic cycle.

The Calippic cycle is due to the Ionian astronomer Calippos, who, about a century after Meton, further improved the coincidence between the periods of the Sun and the Moon by observing that four Metonic cycles (4 x 19 = 76 years, minus one day) result in a better approximation to the equivalent period of lunar months.

Whoever deals with the periods of the Sun and the Moon, however, will certainly at some point observe that the important phenomenon of eclipses also present certain periodicities. Ancient astronomers had noted the Saros and Exeligmos cycles by observing that every 223 lunar months (6,585 and 1/3 days, that is, every 18 years) solar and lunar eclipses repeat, but not exactly at the same coordinates. This period of time does not contain a whole number of days, a fact which results in the shifting of recurrent eclipses by eight hours, or 120° longitudinally. Ancient astronomers had also observed that a triple temporal period – that is, 669 lunar months – contains a whole number of days and named this period the "Exeligmos cycle". The Saros cycle was called the "periodic cycle" by Ptolemy, however, in 1691, E. Halley renamed it the "Saros cycle", based on a Hellenized Babylonian word that was likely misused to indicate a period of time. Yet, the misnomer is well known to modern astronomers, professionals and amateurs alike.

However, the numbers 235 and 223 were not the only inscriptions; as is demonstrated by the recent studies based on tomographies, there were two spirals inscribed into the back side of the Mechanism: the upper and lower spirals are subdivided into 235 and 223 sections, respectively, each one of which corresponds to a lunar month. One of the two dials on the inside of the upper spiral runs the Mechanism's only cycle that did not have an astronomical significance: the four years of the Olympiad. The number 76 in the inscriptions suggests that there would also have been a dial for the Callipic cycle, which is hypothetically placed within the upper spiral. The 223 months of the lower dial are a full Saros period. A smaller dial inside the spiral runs in a circle divided into three sections. This spiral corresponds to the Exeligmos cycle, which contains three Saros cycles.

In addition to these numbers, some words had a specific meaning, like, for instance, the name of the planet Aphrodite (Venus), inscribed both on the front and back covers of the Mechanism. The planetary functions are more or less obvious due to the repetition of the word "stationary point" on the longest preserved inscription, that on fragment G, which probably was part of the front cover of the Mechanism. The reading of this word in 1905 by A. Rehm was made possible by a small piece that was later reassembled to fragment G. In recent tomographic data, this word was read in several places by the Antikythera Mechanism Research Project's philologist, A. Tselikas. This term directly refers to the orbits of the planets as observed from Earth.

The Mechanism's functional principles

Calculating the position of celestial bodies always had a special significance for the organization of human life. Today, electronic computers

Fig. 3. Gearing diagram of the Antikythera Mechanism (Aristotle University of Thessaloniki. K. Efstathiou, G. Seiradakis, M. Anastasiou, A. Basiakoulis, M. Efstathiou, P. Boutbaras).

and special software are used to determine – for a given date and observation point – the location and phases of the Moon and the visible constellations, as well as to predict eclipses and to find the correlation among various calendars by means of which humanity has, for centuries, recorded astronomical phenomena. Certain of these functions can also be accomplished with the use of devices with moving mechanical parts, gear wheels, and indicators without, however, attaining the same accuracy and speed of modern computers.

How is it possible for gear wheels to express mathematic ratios related to astronomical periods? A simple example: If a one-hundred-toothed gear intermeshes with a fifty-toothed gear, the second will rotate with half the period – in other words, twice as fast. When the larger gear completes one rotation, the smaller one has revolved twice in the opposite direction. With the appropriate combination of gear wheels, rotations can be multiplied and divided in order to correspond to astronomical periods. The selection of the number of teeth on the Mechanism's wheels was made by its original designer in order to assimilate the Metonic and Saros periods as well as the apparent variable motion of the Moon (fig. 3).

Mechanisms related to astronomy are the astrolabes (for calculating the time as well as the rising and setting of stars), extremely complex astronomical clocks (which, along with the hour, display astronomical phenomena), planetaria, etc.

The Antikythera Mechanism is the most famous and most ancient of such instruments, in which rotation with the use of a hand-powered crank moves simultaneously all the indicators by means of the gears and axles connecting them. Thus, by selecting a date on the frontal 365-day dial (with the possibility of an extra leap day every four years), the remaining indicators would provide all available astronomical information concerning this specific date. Alternatively, the user can place an indicator on an astronomical phenomenon and then see when it will occur (or has occurred in the past). For instance, the user can directly check the correspondence between the solar and lunar calendar, the position and phase of the moon, and the eclipses that may occur for a given day of the selected lunar month.

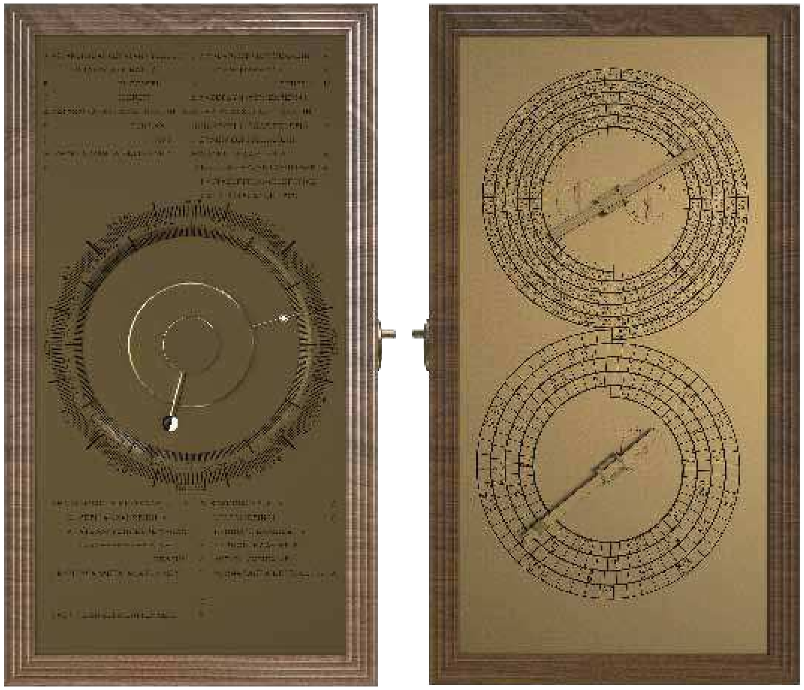


Fig. 4-5. The front and back views and dials of the Antikythera Mechanism according to the scientific results of the Antikythera Research Project (2008).

The true type font "Antikythera" used for the inscriptions was designed by the Aristotle University of Thessaloniki, according to the inscriptions on the mechanical parts of the Mechanism.

The functions of the Mechanism

The Mechanism has on its front side two concentric dials on the edge of a large disk (fig. 4). The months of the Egyptian Calendar were inscribed in Greek on the outer dial, following the preference of the astronomers of the Hellenistic period. Each year had twelve 30-day months, supplemented by the five extra *epagomenai* days, which totalled 365 days and allowed the possibility of an extra leap day every four years. The inner dial corresponded to the Zodiac with the Greek names for its signs and index letters in alphabetical order that referred to the observations of the *Parapegma*. The *Parapegma* was an astral calendar that followed the risings and settings of the stars and constellations in the annual cycle. It was associated with the Zodiac scale by means of index letters.

Indicators moved across the front dial: the Sun indicator showed the motion of the Sun across the Zodiac, the Moon indicator, a rotating half-white and half–black ball, probably displayed the lunar phase. The Moon indicator revolved around the Zodiac at a variable speed that reproduced the Moon's apparent motion. This is the most remarkable function of the Antikythera Mechanism, which was possible by means of an astonishing epicyclical system of gears. Let us examine the details of this system: Price, like Rehm almost seven decades earlier, proposed that the Mechanism contained epicyclical gears, that is, gears that rotated on axles, which were themselves situated on other gears. This was a key step in the history of technology. Epicyclical gears enable the addition and subtraction (not only multiplication and division) of rotational ratios. In Western technology, the next known example of epicyclical gears appears about 16 centuries later. The "input" gear of two epicyclical gears has a pin on it, which slides in a slot on the "output" gear. Thus, the two gears rotate on slightly different axles separated by a distance of about 1mm. The result is that, while the input gear turns at a constant speed, the rotation speed of the output gear varies from slower to faster (and vice versa). This device is exactly what is needed to depict the observable variation of the speed of the moon's rotation, according to the most advanced theory of the era, attributed to Hipparchos of Rhodes.

In addition to the Sun and the Moon, the front side may have reproduced the then contemporary Greek "Cosmos", by including indicators for all five planets known in antiquity (Mercury, Venus, Mars, Jupiter, and Saturn), perhaps with the use of more epicyclical systems.

Two spirals with 235 and 223 subdivisions dominate the backside. (fig. 5). The upper dial is a full Metonic calendar with 235 months of 29 and

Fig. 6. The model of Aristotle University of Thessaloniki (construction K. Eustathiou).

30 days for the 19 years of the Metonic period. The names of the months pertain to Corinth or one of its colonies. This is deduced from the fact that the names and the sequence of the twelve months in the calendars of ancient Greek cities were not the same everywhere. Variations and similarities from city to city often reflect various relations among them, like, for instance, the bond between a metropolis and its colony. The Metonic calendar of the "Corinthian type" on the Antikythera Mechanism is akin to many calendars of Corinthian colonies in the Western Greek world.

The Callipic dial for the 76 years of the Callipic period (4x19=4 Metonic periods) is conjecturally placed within the upper dial. An indicator of the Olympiad, divided into quadrants corresponding to its four years, is found on the opposite side. The names of the most important Panhellenic games, like those at Nemea, Isthmia, Delphi, Dodona, and Olympia, are inscribed around the dial. Some took place every two years, others every four.

The Saros indicator rotates on the lower back dial, around the 223 months of this period. Incised symbols on some of the 223 subdivisions refer to possible eclipses. The ligatures (groups of symbols) correspond to the type of eclipse ("H" for the Sun, "Σ" for the Moon), the hour it will occur, and whether it is expected to happen during the day ("HM") or at night ("NY"). Within the Saros dial is another dial divided into three sections, that of the Exeligmos, a triple Saros cycle of 669 lunar months. It records how many hours (8 or 16) should be added to the ones marked by the ligatures in order to predict the hour of the eclipse during the specific period of the Saros: no addition for the first period, 8 ("H") for the second, 16 "(IC") for the third. After the third period, we return to the first period and to the hour indicated by the ligatures.

Modern models of the Mechanism

Thanks to the detailed description of the Mechanism's functions, many recent models have been produced and are still being made. Some of these models are even operational. In the same spirit of the handmade workmanship of the original, M. Wright constructed a model based on his own examination of the Mechanism's fragments, completed with the late A. Bromley, as well as partly on published data. Wright used screws instead of rivets in some instances for ease of maintenance.

At the same time, K. Efstathiou designed and constructed a replica at the Aristotle University of Thessaloniki (fig. 6) that did not include planetary mechanisms, since his reconstruction was based exclusively on data established and published by the Antikythera Mechanism Research Project. A specially designed true type font was employed for the inscriptions.

The results of the Antikythera Mechanism Research Project have also been used by other researchers of ancient technology and skilled craftsmen in order to create physical or digital models. M. Buttet, Director of Research and Development at the Swiss watchmaker Hublot, designed a watch that includes the functions of the Antikythera Mechanism *en miniature*. Additional modern functions are supported by a tourbillon which makes one rotation every 60 seconds. This watch, a donation by Hublot to the National Archaeological Museum, closes the exhibition on the Antikythera shipwreck as an ultramodern homage to the predecessor of all modern mechanisms with gears.

YANIS BITSAKIS

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ABBREVIATIONS

NAM National Archaeological Museum

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Fragment A of the Antikythera Mechanism. NAM X 15087. Second half of 2nd c. BC.

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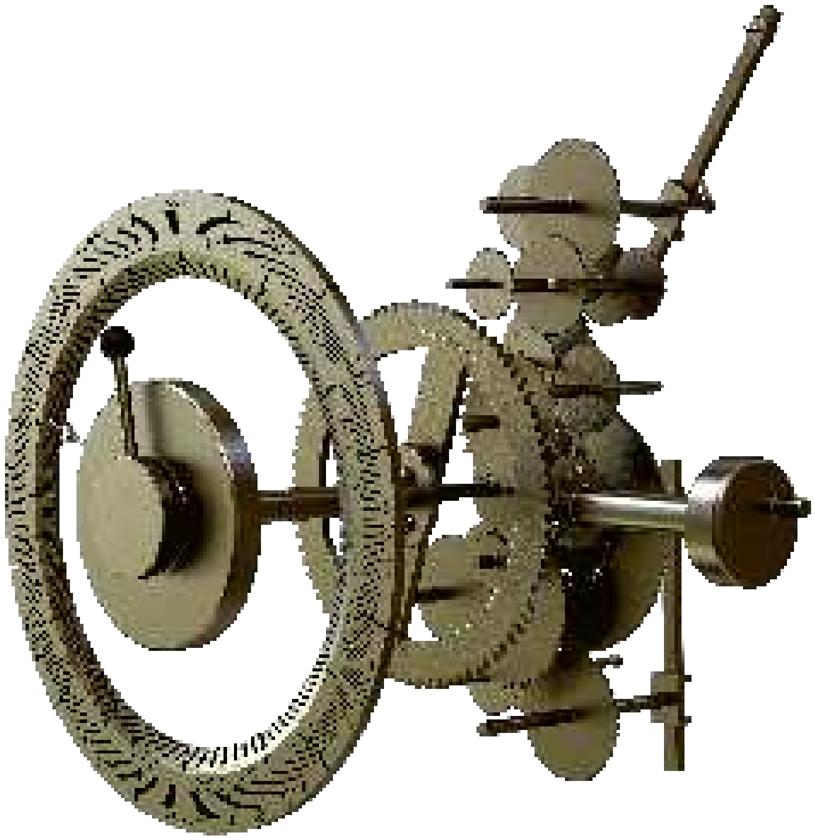
NAM X 15087. Second half of the 2nd c. BC.



3D representation of the gearing inside the Antikythera Mechanism
(Graphics by M. Buttet, Hublot).

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