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Ancient Alexandria as the centre of maritime innovations

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Alexandria's maritime destiny was naturally predetermined by its excellent geographical position at the confluence of the two worlds. It was here that the waters of the Nile mingled with the Sea and here the Egyptian culture, riverine in its origins, mingled with the maritime world of the Greeks. The Ptolemaic dynasty was based on the principles of the thalassocracy that manifested itself in almost every aspect of the Egyptian state and was represented by the legendary Pharos through seventeen centuries.

This article is an attempt to evaluate the contribution of the city to the global development of navigation and seafaring in the ancient world. The Alexandrian traces of some of these inventions currently remain implicit; however, they were equally included in the discussion in hope that future research will bring more light on their origins.

Keywords: Alexandria, marine engineering, ancient seafaring, shipbuilding.

Geography, mathematics, astronomy

The development of geography, mathematics and astronomy had a strong influence on the progress of navigation but with one important reservation. This progress was gradual and it was of no benefit to contemporary mariners who relied on collective memory, common sense geography and so-called mental charts[1]. These simple sailors did not use paper charts or even *peripli*[2] and had only a sounding lead as their most sophisticated instrument[3]. It was the power of observation and deep feeling of the elements, known as 'good seamanship

[1] Arnaud 2012: 118; Arnaud 2014.
[2] The most ancient known examples date to 4th century BC. See Rougé 1975: 24–25; Meyer 1998.
[3] Pomey 1997a: 90 and note 3; Pomey 1997b; Herodotus, Hist. 2. 5: 'For this is the nature of the land of Egypt: firstly, when you approach to it from the sea and are yet a day's run from land, if you then let down a sounding line you will bring up mud and find a depth of eleven fathoms. This shows that the deposit from the land reaches thus far'.

practices'[4], that allowed them successfully finding their way in the open sea[5]. However, with time *peripli* evolved into the modern pilot charts, which contain exhaustive nautical descriptions and directions, while the charts won in reliability thanks to the progress in geography. The astronomy and mathematics were the cornerstones of the celestial navigation and indispensable for route calculation before the advent of GPS[6].

It seems a paradox but Greek geographers before Ptolemy relied on vast knowledge of the seamen while creating their first maps of the inhabited world[7]. Most of them were so-called 'armchair geographers', but that was not the case of the first Alexandrian in the list.

Timosthenes of Rhodes (Τιμοσθένης, fl. 270 BC) was appointed the admiral by Ptolemy II Philadelphus (284–246 BC). His 10-book work *On Harbours* may be classified as a piece of descriptive geography, something unknown to the Greek literature before[8]. The surviving fragments of this work allow suggesting that it was a forerunner of medieval portulans and modern pilot charts. The author much relied not only on the works of his predecessors but on his own naval experience too[9]. Timosthenes proposed a new 12-rhumb (points of compass) version of the windrose with the position of major countries of the oecumene while the classical examples were based on eight winds only (Figure 1)[10].

The work of Timosthenes was cited by many geographers for the centuries to come and, in the first instance, by his contemporary Eratosthenes, designated as the Head of the Library of Alexandria *c*. 245 BC. According to Strabo, Eratosthenes praised Timosthenes 'beyond all the rest, though we find him disagreeing with Timosthenes on most points'[11].

Eratosthenes developed the original method for measuring the circumference of the Earth that allowed him obtaining very precise results. The very term 'geography' was proposed by Eratosthenes and even if his opus reached us only in fragments, some of them show an outstanding insight in many natural processes, some of which concern the maritime world directly. One example will suffice.

Much feared by the seamen, the strait of Messina between Sicily and Italy was at the origin of the legend of Scylla and Charybdis[12]. In its narrowest point the strait is only 1,9 miles

[4] It is quite indicative that the notion of the 'good seamanship' exists in any maritime culture around the world. This notion is independent of the state of the art equipment but relates exclusively to the knowledge, skills of the sailor, and, not the least, his state of consciousness and respect towards the Sea. Cf. 'bonnes habitudes de matelotage' (French), «хорошая морская практика» (Russian). 'On top of these three fundamental qualities — hard work, judgment and humility — seamanship also means constant practice of on-the-water skills'. Ellen Massey Leonard, 'The foundations of good seamanship'. See http://www.oceannavigator.com/Web-Exclusives-2014/The-foundations-of-good-seamanship/ (last consulted: 30.11.2020).

[5] Knowledge of the coast, winds and stars was essential for an ancient navigator. See Pomey 1997a: 89. Choosing the course in relation to the wind's direction was known as 'anemometric compass'. See : Pomey 1997a : 93; Arnaud 2012: 117.

[6] The importance of these sciences for navigators during the Age of Sail is condensed by P. O'Brian in the following paragraph: '...for Captain Aubrey was not only an officer professionally concerned with celestial navigation but also a disinterested astronomer and, although one would never have suspected it from his honest, open face, a mathematician...' 'The Commodore': 83.

[7] Arnaud 2014: 42.

[8] Prontera 2013: 208.

[9] Prontera 2013: 209.

[10] On the windrose of Timosthenes see Prontera 2013: 212 with further references. Timosthenes added two winds to the windrose of Aristotle (Met. 2. 6) — the Libonotus and Euronotus. See also Arnaud 2014: 47, 52 with further references.

[11] Strabo 2. 1. 40. Trans. by H. L. Jones, Loeb Classical Library. 1917.

[12] Homer Od.12.223–259. For the description of the strait in the ancient sources and conditions of ancient navigation see Arnaud 2019: 198–201.

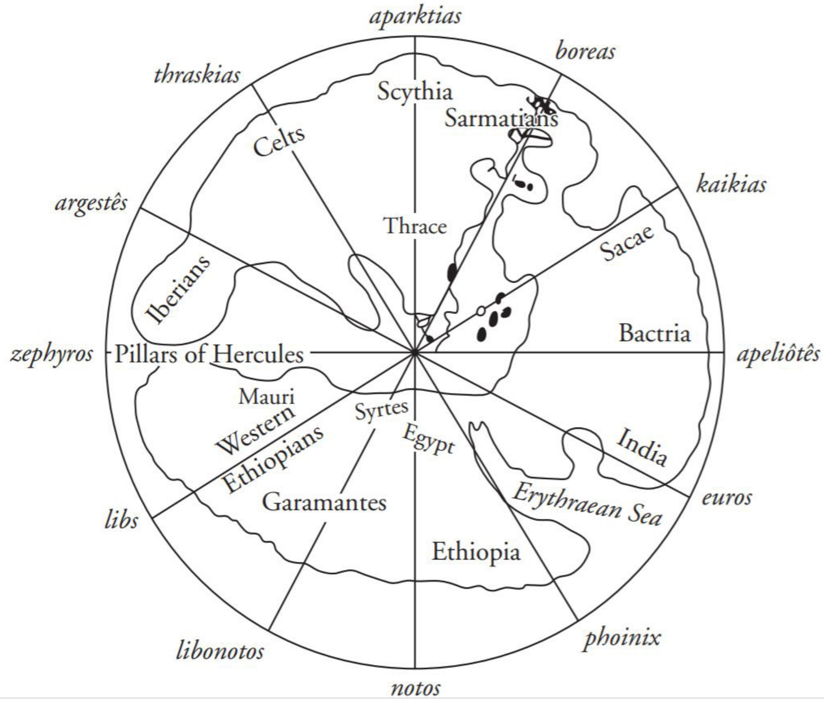

Figure 1. Twelve-rhumb windrose of Timosthenes (*c*. 270 BC). From Prontera 2013: fig. 14.2 (after Miller 1898)

(3,1 km) wide and according to modern measurements the current reaches here the speed of 5–5,5 knots[13] which equals to 2,6–2,8 m/s[14]. Eratosthenes was the first to propose the correct explanation for the origin of this tidal current caused both by the difference in sea level between the Tyrrhenian and Ionian Seas and to the phases of the Moon[15].

[13] Bignami, Salusti 1990: 107, 113, fig.11.

[14] Arnaud gives a figure of 7 knots (3.6 m/s) and even more as the maximum speed. Arnaud 2019: 200.

[15] Strabo 1. 3. 11: 'And Eratosthenes says that this is the reason why the narrow straits have strong currents, and in particular the strait of Sicily, which, he declares, behaves in a manner similar to the flow and the ebb of the ocean; for the current changes twice within the course of every day and night, and like the ocean, it floods twice a day and falls twice a day. Now corresponding to the flood-tide, he continues, is the current that runs down from the Tyrrhenian Sea to the Sicilian Sea as though from a higher water-level — and indeed this is called the 'descending' current — and this current corresponds to the flood-tides in that it begins at the time of the rising and the setting of the moon, and it stops when the moon attains either meridian, namely, the meridian above the earth or that below the earth; on the other hand, corresponding to the ebb-tide is the return-current — and this is called the 'ascending' current — which begins when the moon attains either meridian, just as the ebbs do, and stops when the moon attains the points of her rising and setting'. Trans. H.L. Jones, Loeb Classical Library 1917. Further discussion may be found in Aujac 1998.

Eratosthenes made another breakthrough in the field of cartography when he applied a system of parallels and meridians: *i. e.* the coordinate grid that is used in any modern chart. His astronomical achievements also included the measurement of the distance from the Earth to the Sun.

Another geographer — Agatharchides (Greek Ἀγαθαρχίδης, fl. 2nd century BC) — accomplished in Alexandria his study *On the Erythraean Sea* (Περί της ερυθράς θαλάσσης)[16]. Besides the apparent advances in geography, the Alexandrians extended the trade routes of the Empire as far as India[17].

The development of astronomy was extremely important for the mariners and Alexandrian scientists made a considerable progress in this field.

How one can determine the position of a ship in the open sea, once all landmarks are gone? Anemometric compass identifying the position of the ship in relation to the wind's direction, supposed to be stable for each season[18], was helpful but very rough. To the same, much later method of dead reckoning, based on the measurements of the ship's course and speed, was subject to significant errors of approximation and was very imprecise for long voyages.

Thus, the observations of the sun and of the stars during the night time were vital. The constellation of the Bear was the most important for navigators of the northern hemisphere. Initially they just observed the position of the Pole star[19] in reference to the ship. Later, different celestial navigation instruments were used to measure the altitude of the stars, the planets and the Moon. These instruments progressed from a simple cross-staff, kamal and quadrant to mariner's astrolabe[20], octant, and sextant. The improvement of tools and methods permitted achieving a sufficient precision of the so-called 'latitude sailing' that was already known to the Ancient Greeks[21]. The appearance of the precise marine chronometers towards the middle of the 18th century solved the problem of finding the longitude[22].

A constellation of eminent mathematicians and astronomers worked in Alexandria and we shall probably never know all the names[23]. As in case of geography, their achievements were not for the immediate benefit of navigation, however, they were essential for its progress. Euclid was called the father of geometry[24], indispensable for the navigators of the future, while Claudius Ptolemy made important advances in trigonometry, geography and cosmology representing the culminating achievements of Greco-Roman science[25].

Heron of Alexandria invented the first steam engine and although its smoking descendants would once bring to a close the Age of Sail, something the current author much deplores,

[16] See Thompson, Buraselis 2013: 17.

[17] Eudoxus and pilot Hippalus. See Habicht 2013 The *Periplus Maris Erythraei* (middle of the 1st century AD) was written by the Egyptian Greek. See Schoff 1912: 6.

[18] Arnaud 2012: 117.

[19] Arnaud 2014: 49. Arnaud remarks that in Antiquity the β Ursae Minoris was the closest star to the North Pole.

[20] See Castro et al. 2020.

[21] Pomey 1997a: 90.

[22] Gould 1921: 257–260.

[23] Euclid of Alexandria (Εὐκλείδης — fl. 300 BC), Conon of Samos (Κόνων ὁ Σάμιος — *c*. 280–220 BC), Apollonius of Perga (Ἀπολλώνιος ὁ Περγαῖος — late 3rd — early 2nd century BC), Timocharis of Alexandria (Τιμόχαρις — *c*. 320–260 BC), Aristyllus (Ἀρίστυλλος — fl. *c*. 261 BC), Heron of Alexandria (Ἥρων ὁ Ἀλεξανδρεύς — *c*. 10–70 AD), Claudius Ptolemy (Κλαύδιος Πτολεμαῖος — *c*. 100–170 AD), Diophantus (Διόφαντος ὁ Ἀλεξανδρεύς *c*. 201–215 AD — *c*. 285–299 AD), Pappus of Alexandria (Πάππος ὁ Ἀλεξανδρεύς — *c*. 290–350 AD), Theon of Alexandria (Θέων ὁ Ἀλεξανδρεύς — *c*. 335–405 AD), Hypatia (Ὑπατία — *c*. 350–370 BC — 415 BC). See Lloyd 1984; Duarte Gamas 2013.

[24] Nuno Silva, Pinto 2013.

[25] Toomer 1970.

he must be credited for this outstanding achievement[26]. Alexandrian school maintained scientific contacts with the other parts of Hellenistic world[27]. Archimedes, for example, most probably came to Alexandria[28] and he was in correspondence with Eratosthenes and other Alexandrian scientists[29]. It is a small wonder that Alexandrian scientific school had enormous influence on Roman scientists[30].

Tragic death of Hypatia, the last scientist of the Greek school of Alexandria, marks the coming of the new era. It may seem that the city was doomed to abandonment, desolation and decline[31] but as we shall see later, the Byzantine age probably saw some important achievements in shipbuilding.

Marine engineering

The plan of the port structures of the Great Harbour was sophisticated and 'well-conceived'[32], however, it may not be considered as something new. The hydraulic concrete which was discovered in the submerged structures of the Great Harbour, as well as the remains of one-mission barges, probably date to the Imperial period and the same building procedures were used in Caesarea Maritima[33].

It would be interesting to consider the construction of the great breakwater enclosing the other port of Alexandria — that of *Eunostos*. These impressive remains were studied by a French engineer G. Jondet at the dawn of the 20th century[34]. Today this concession belongs to the Centre for Egyptological Studies of the Russian Academy of Sciences (CES RAS). Unfortunately, this is a military area and the archaeological work here is difficult. During the recent project of land reclamation the remains of the breakwater were buried under the thousands of tons of sediment. Currently the team of CES RAS explores the roadstead of *Eunostos* where ancient anchors and anchor stocks belonging to large merchant ships were found (Figure 2)[35].

Thus, for marine engineering, we should turn to the structure that dominated the Alexandrian landscape — the Pharos lighthouse. This impressive tour of about 120 m high[36] well corresponded to the grandiose scale of the Ptolemaic Empire and gave name to all lighthouses in the Romance languages[37]. The construction of the Pharos probably included many innova-

[26] An *aeolipyle*, also known as a Heron's engine. For Heron's experiments with the steam see Woodcroft 1851: 68, 72, 100—104.

[27] Lloyd 1984.

[28] Di Pasquale 2010: 294, 297; Duarte Gamas 2013: 324.

[29] For example, Ἀρχιμήδους Περί τῶν μηχανικῶν θεωρημάτων πρὸς ῾Ερατοσθένην ῾έφοδος. Ἀρχιμήδης ῾Ερατοσθένει εὖπράττειν. See Bragastini 2010.

[30] See Bakhouche 1998.

[31] See Duarte Gamas 2013: 329.; Fraser 1993.

[32] Strabo 17.1.9-10. For the topography of the Great Harbour see Goddio 1998 de Graauw 1998; Goddio, Fabre 2010; Belov 2015.

[33] Oleson, Brandon, Hohlfelder 2011: 114–115.

[34] Jondet 1916; Jondet 1921.

[35] Belova et al. 2019.

[36] Thiersch 1909: fig. 4; an estimate between 103–118 m is suggested in McKenzie 2007: 42. Some authors estimate the height of Pharos to be from 120 to 140 m, see Pfrommer 1999: 11.

[37] For etymology of the word 'Pharos' see Breccia 1914: 91; Georgiadès 1978 : 23–25. Cf French — *phare*, Italian and Spanish — *faro*, Portuguese — *farol*. However, the idea of a beacon and a lighthouse appeared at the dawn of navigation. Homer *Il*. 375: 'And as when forth ower the sea there appeareth to seamen the gleam of blazing fire, and it burneth high up in the mountains in a lonely steading — but sore against their will the storm-winds bear them over the teeming deep afar from their friends; even so from the shield of Achilles went up a gleam to heaven, from that shield [380] fair and richly-dight'. Trans. by A. T. Murray, London, William Heinemann Ltd. 1924. See Stevenson 1850: 2–8.

Figure 2. A limestone stock of the Greek type from a wooden anchor at the time of its discovery. Roadstead of *Eunostos*. Dimensions: 231×35×17 cm. No later than the 4th century BC. Weight of the stock — around 320 kg. Photo: CES RAS © Sergei Ivanov

tions taking in consideration its height and that it was built on a small island[38]. The study of archaeological remains of the Pharos may be found elsewhere[39] and the following paragraph is devoted exclusively to the maritime function of this building. The Pharos was the world's first specialized building of this kind[40] and 'one of the world's longest-serving functional monuments' being used for 17 centuries[41].

[38] Strabo 17. 1. 6: 'Besides the narrowness of the passage, there are rocks, some under water, others rising above it, which at all times increase the violence of the waves rolling in upon them from the open sea. This extremity itself of the island is a rock, washed by the sea on all sides, with a tower upon it of the same name as the island, admirably constructed of white marble, with several stories. Sostratus of Cnidus, a friend of the kings, erected it for the safety of mariners, as the inscription imports'. Trans. Hamilton, H. C. T. London. 1903.

[39] For the study of the remains of the Pharos see Jondet 1916; Frost 1975; Grimal 1997; Empereur 1998b; Empereur 2002; Hairy 2003; Abdelaziz,et al. 2016; Abdelaziz, Elsayed 2019.

[40] McGrail 2001: 49.

[41] Empereur 1998a: 86.

The landmarks always were, and remain, of primary importance for the blue water sailing. However, the coast of Egypt was very low[42]. In the region of Alexandria there were only two acceptable landmarks — the hills of Sarapeion and Paneion[43]. Those hills were not high and could serve as the alignments for entry into the harbor but they were of little use for a good landfall[44]. Under these conditions the Pharos lighthouse was an excellent solution and this was widely admitted by classical authors. The attempts to estimate the visibility of the lighthouse are numerous but there is a considerable discrepancy between them. Following calculation is an attempt to bring together a reliable physical formula, additional geographical considerations and a bit of maritime experience.

The true horizon depends on atmospheric conditions and other factors but mainly on the position of the eye of an observer above the sea level. The distance of the visible horizon D (expressed in international, or 'statute', miles[45]) is calculated as $D \approx 1{,}34\ h^{1/2}$, where *h* is the height of the observer in feet[46].

This equation takes into consideration the effects of the atmospheric refraction which can be considerable[47]. According to this formula, an observer standing on the ground may see for 5,1 km at best. The figure will be approximately the same for the fire beacon set on the beach. The calculations change drastically in case of a lighthouse. For an observer on top of the Pharos (about 115 m above the ground) the true horizon was situated at approximately 42 km.

However, a tall ship may be perceived from even greater distance due to the curvature of the Earth. Thus, an observer first perceives a top of a mast while the ship itself is still 'hull down' (Figure 3).

The mast of a small Greek merchantman like Kyrenia (*c*. 325–315 BC) was estimated to be about 10,5 high[48] while the mast of a Greek trireme was probably close to 15 m[49].

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[42] Diodorus 1. 31. 2–5: 'The voyage along the coast of this sea is exceedingly long, and any landing is especially difficult; for from Paraetonium in Libya as far as Iopê in Coele-Syria, a voyage along the coast of some five thousand stades, there is not to be found a safe harbour except Pharos. And, apart from these considerations, a sandbank extends along practically the whole length of Egypt, not discernible to any who approach without previous experience of these waters. Consequently those who think that they have escaped the peril of the sea, and in their ignorance turn with gladness towards the shore, suffer unexpected shipwreck when their vessels suddenly run aground; and now and then mariners who cannot see land in time because the country lies so low are cast ashore before they realize it, some of them on marshy and swampy places and others on a desert region'. Trans. by C. H. Oldfather. Loeb Classical Library, Volume I: Books 1–2. 34. Cambridge, 1933. Strabo 17. 1. 6: 'For as the coast on each side is low and without harbours, with reefs and shallows, an elevated and conspicuous mark was required to enable navigators coming in from the open sea to direct their course exactly to the entrance of the harbour'. The *Geography* of Strabo. George Bell & Sons. London, 1903.

[43] Georgiadès 1978 : 21.

[44] Belov 2015: 58.

[45] International (statute) mile = 1,609344 km.

[46] French 1982: 798.

[47] Actually, due to refraction an observer sees further because the light, that is travelling horizontally, is refracted downward. It may increase the visible horizon distance up to 9 %. See French 1982: 798.

[48] Katzev, Katzev 1985: 173.

[49] Classic sources are silent as per the heights of the masts of the Greek ships — Morrison et al. 2000: 175. The replica of the Athenian trireme Olympias had a mast 13 m high (estimated by the author from the general arrangement drawings of Olympias in ibid. p. 270, fig.80). The estimate of 15 m for the mast of the trireme is proposed in Georgiadès 1978 : 110. The mast belonging to a ship 30–35 m long that was found in Olbia in Sardinia (1st century AD) was probably about 12–15 m tall — see Riccardi 2002. The mast of the 5th century AD Wreck D about in the Black Sea was estimated to stand 11–12 m high while the vessel was about 12 m long. See Ballard et al. 2001: 219.

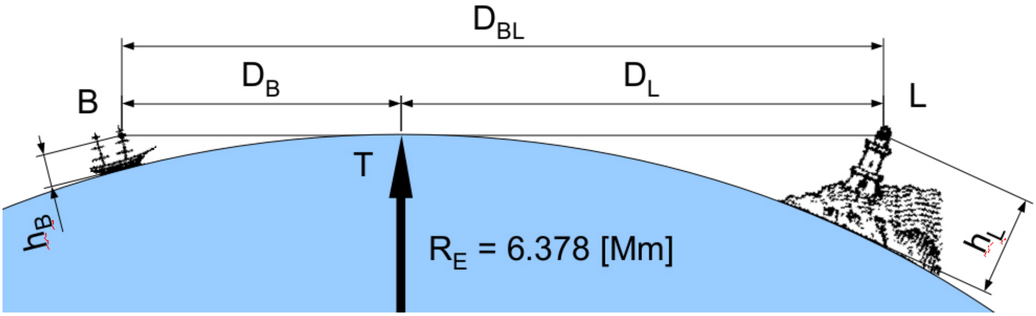

Figure 3. Calculation of theoretical distance at which a ship could have been seen from the top of the Pharos. After: Efa / Wikimedia Commons

According to the formula above, an observer positioned on the mast truck of the trireme could see for 15 km. However, practice shows that this figure is somewhat too low and under favorable atmospheric conditions an observer can detect objects at a distance of 18,5 km[50]. Therefore, in daylight hours and in good weather conditions masts of a ship were detectable from Pharos at a distance of about 57–60 km. The platform for the night fire[51] was about 100 m above the sea level and thus the distance to true horizon was reduced. However, the visibility of a bright light when looking from a ship coming from a lightless sea was surely even better than during the daytime. The figure given by Flavius Josephus (300 stadia or about 55,5 km) corresponds well with the above calculations[52] and confirms great efficiency of Pharos for the mariners.

The descriptions of the mirror on the top of the Pharos that is found in some Arab sources are too fanciful and it is preferable to leave them aside[53].

[50] As a lookout on the bowsprit cap of the replica of the French frigate L'Hermione (1779), the author had occasions of reporting objects 10 nautical miles away (distance verified by the radar). The height above the water was about 8 m. The same figure is given in Morrison, Williams 1968: 258. 'A man at the top of Olympias's mast can just see the deck of a similar ship over the horizon on a dear day (neglecting refraction of light) at a range of 10 miles'.

[51] Pliny Nat. 5. 34.

[52] Joseph. BJ 4. 10. 5: 'The haven also of Alexandria is not entered by the mariners without difficulty, even in times of peace; for the passage inward is narrow, and full of rocks that lie under the water, which oblige the mariners to turn from a straight direction: its left side is blocked up by works made by men's hands on both sides; on its right side lies the island called Pharus, which is situated just before the entrance, and supports a very great tower, that affords the sight of a fire to such as sail within three hundred furlongs of it, that ships may cast anchor a great way off in the night time, by reason of the difficulty of sailing nearer. About this island are built very great piers, the handiwork of men, against which, when the sea dashes itself, and its waves are broken against those boundaries, the navigation becomes very troublesome, and the entrance through so narrow a passage is rendered dangerous; yet is the haven itself, when you are got into it, a very safe one, and of thirty furlongs in largeness; into which is brought what the country wants in order to its happiness, as also what abundance the country affords more than it wants itself is hence distributed into all the habitable earth'. Trans. by W. Whiston. Auburn and Buffalo, John E. Beardsley. 1895.

[53] These sources are briefly considered, for example, in Behrens-Abouseif 2006.

Shipbuilding

An eminent researcher of ancient shipbuilding Lucien Basch said that 'the great port of Alexandria was the ideal place to serve as a laboratory of new naval experiments'[54].

Strabo mentions several shipyards (τὰ νεώρια) in Alexandria[55] but nothing remains of them in archaeological record[56]. However, an interesting case of local repair, apparently at one of those shipyards, was studied during the excavations of a Roman ship from the Great Harbour by *L'Institut Européen d'Archéologie Sous-Marine* (IEASM)[57]. This freighter was about 30 m long and it sunk between the end of the 1st century BC and the 1st century AD. The ship was mainly built of imported species of wood like pine and elm. One of its stern floor timbers was cut of sycamore fig (*Ficus sycomorus*). The fastenings of this floor timber witness a replacement of a broken piece (Figure 4)[58].

From written sources we know of the giant ships that were launched from Alexandrian shipyards. Textual evidence is not substantial to study their constructional details but this capacity of building giant vessels is important, as it testifies to the great skill of the shipbuilders and excellent wood supply. Philopator's *tesseraconteres*[59], pleasure Nilotic barges[60] and a grain carrier *Isis*[61] were all built in Alexandria while *Syracusia* (*Alexandris*), the progeny of Archimedes, closed its days in the royal port of cape Lochias[62].

However, deep innovations in shipbuilding with possible Alexandrian origins may be only guessed. One of them is the transition from a shell-based to skeleton-based technique of construction, otherwise called 'shell-first' and 'frame-first' technique[63]. The shell-first technique is far more ancient and implies that the construction of the outer hull precedes that of the internal structural members[64]. The frame-first technique, on the contrary, means that the framing of the ship is built first and the construction of the planking follows it. Transition from shell-first to frame-first construction method was of great importance for navigation. The geometrical control of the hull's shape, achieved by a new method, allowed building ships much faster and using the shipbuilding materials more efficiently, saving both 'time and timber'[65]. However, the transition was not a linear process and depended on many factors. It lasted for about a millennium and had multiple geographical roots[66]. One of these roots, although hypothetical for the time being, brings us to Egypt. The architype for this root is represented by Dor 2001/1 shipwreck from the Tantura lagoon in Israel[67]. This shipwreck is dated to the beginning of the 6th century AD[68]. The middle section of the ship was characterized by 'flat and

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[54] Basch 2001: 63. In original: '...le grand port d'Alexandrie était l'endroit idéal pour constituer un laboratoire d'expériences navales nouvelles'.

[55] Strabo 17. 1. 9–10.

[56] It is interesting to note that the coast of the bay of Anfushi remains an area of the shipyards till our days. Perhaps, it is a remnant of the shipyards of the port of Kibotos. See Georgiadès 1978: 23.

[57] Sandrin et al. 2013.

[58] Sandrin et al. 2013: 51–52.

[59] Athenaeus V.203e, Plutarch Demetr. 43: 4. See Casson 1980; Meijer, Sleeswyk 1994; Williams 2004:65.

[60] Athenaeus 5.203–206. See Thompson 2013.

[61] Lucian Navig. 5, 7–10. See Casson 1950; Casson 1971: 186–188; Pomey 2009: 520–530.

[62] Salviat 1987; Meijer, Sleeswyk 1996; Turfa, Steinmayer 1999; Pomey, Tchernia 2006: 89–97; Pomey 2009: 516–519.

[63] For the history of the question with relevant literature see Pomey et al. 2012: 235–237.

[64] Pomey 2004: 28: 'Just as the absence of homogenous skeleton associated with planking perfectly linked in all its parts implies a shell structural context, the presence of perfectly integrated framework associated with planking in which the strakes are independent of each other reflects a skeletal structural concept'.

[65] Steffy 1994: 84–85.

[66] Pomey et al. 2012: 236, 301–308.

[67] For references see Pomey et al. 2012: 260.

[68] Pomey et. al. 2012: 261.

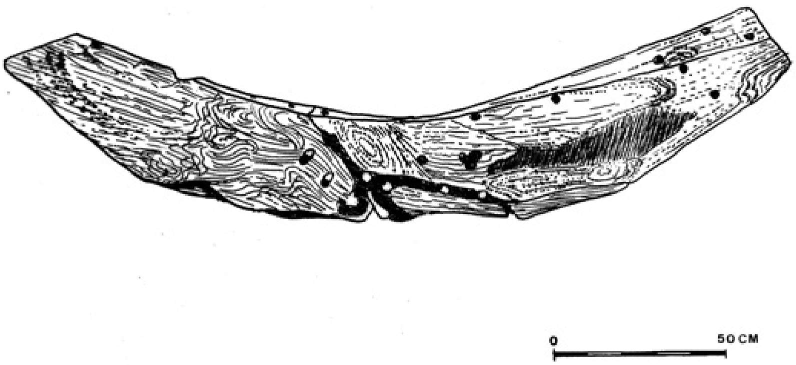

Figure 4. Photo and drawing of the floor timber No. 19 from Antirhodos island shipwreck (end of the 1st century BC — 1st century AD). Dimensions 230×35×35 cm, Sycamore fig (*Ficus sycomorus*). Photo/drawing: © IEASM

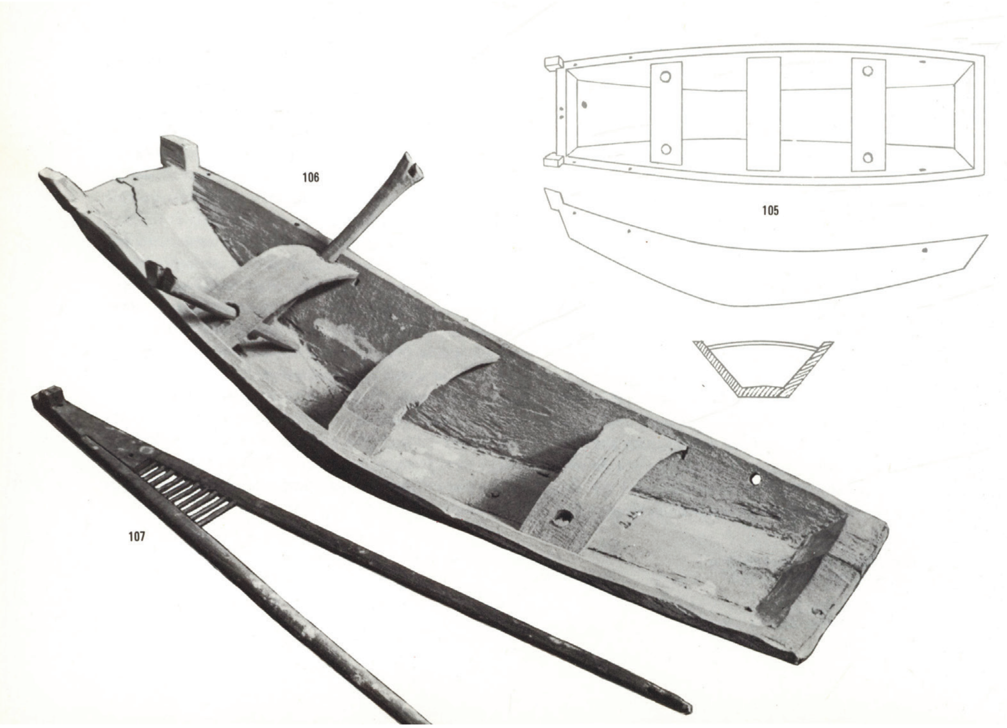

Figure 5. Model from the tomb of Neith, wife of Pepy II (end of the 6th Dynasty, *c*. 2278–2184 BC). Cairo CG 4882. From Landström 1970: 40, figs. 105–107

horizontal frames, a hard chine and oblique sides — three characteristics of a pure 'box-shaped' master-frame[69]. This frame-based construction was not of local origin and its genesis remains unknown[70]. The Nilotic origins for this type were first suggested by Basch[71]. In support of his hypothesis the author cites several Old Kingdom models showing typically riverine, so-called 'triptych', type of construction (Figures 5 and 6). The hull of this type consisted of the flat-bottom that formed a hard chine with the sides and transom fore and aft[72].

Furthermore, the Ptolemaic written sources mention the Nilotic freighter called the 'kybaia'[73]. The name implies that the boat was 'boxlike' and it was probably represented on the Nile mosaic from Praeneste (*c*. 100 BC) (Figure 7)[74]. A type called 'mareotike', mentioned in a document dated to 87–86 BC, was undoubtedly endemic to the lake Mareotis[75].

Although it is difficult to link ancient Egyptian vessels with the later Arab tradition, both show the same constructive adaptations to the shallow-water environment. Thus, traditional

[69] Pomey et al. 2012: 303.

[70] Rieth 2008: 66–67.

[71] Communication between L. Basch and E. Rieth, July 2007. See Rieth 2008: 57.

[72] Basch 2008: 73–74. For 'triptych' construction see Beaudouin 2000: 41; Rieth 2008: 62–64.

[73] Casson 1971: 166–167; Arnaud 2015: 15–16.

[74] Basch 2008: 74; Pomey 2015: 161–164. This type is last mentioned in the 1st century BC. See Casson 1971: 167. There existed a smaller version of the ship called the 'kybaidion'.

[75] Arnaud 2015: 18.

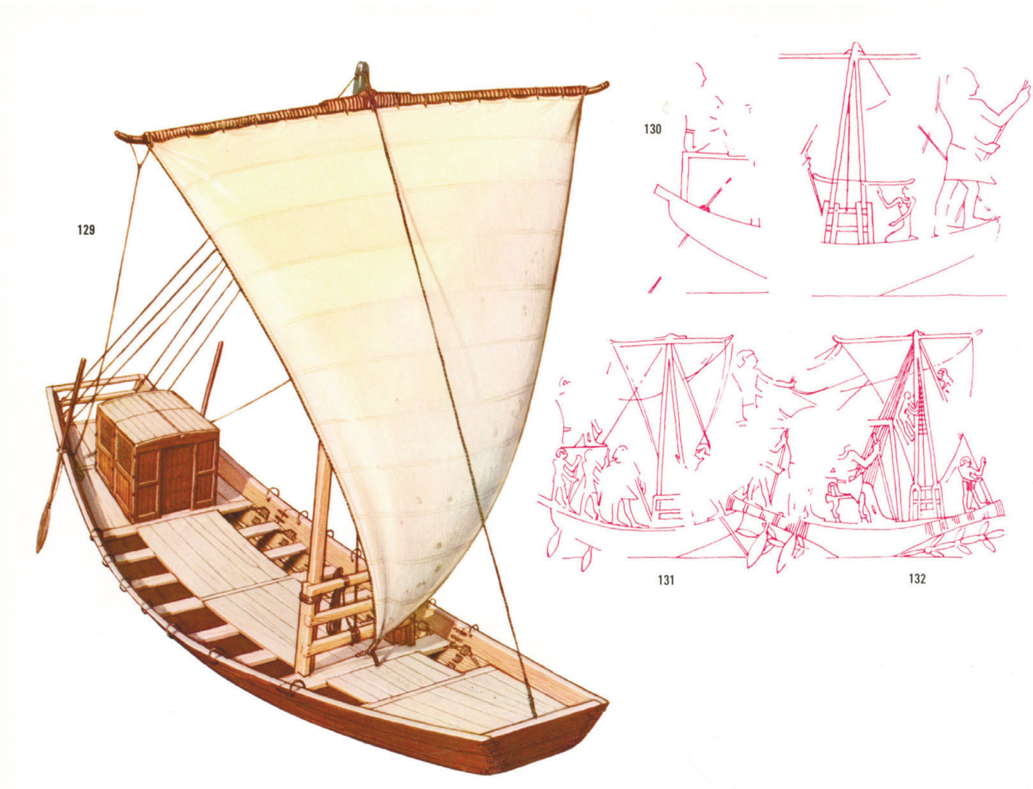

Figure 6. Reconstruction based on a model dated to the 6th Dynasty (2345–2181 BC),
Cairo CG 56395. From Landström 1970: 47, fig.129

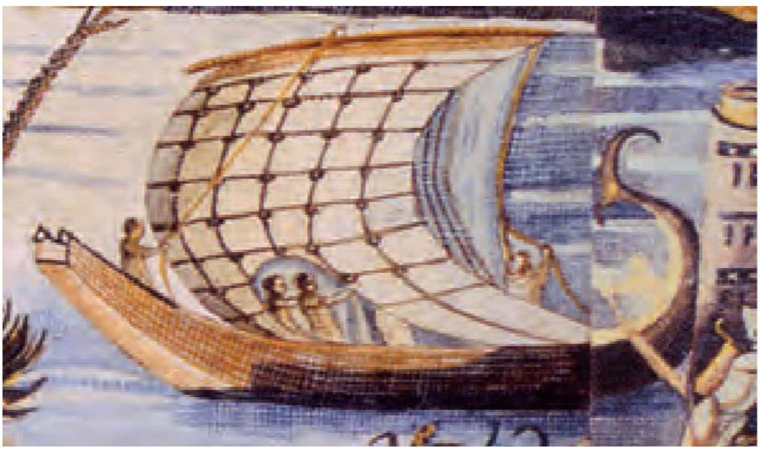

Figure 7. One of the boats represented on the Nile mosaic from Praeneste (*c*. 100 BC). Possibly the 'kybaia'

Figure 8. Caulking the boat in the 19th century Egypt. The Thomas Cook Archive. Photo: W. W. Todd

Arab boats like 'lokkafa' of the lake Borollos or 'zahreyya' of the lake Manzala are flat-bottomed boats with a sharp turn of the bilge (hard chine)[76].

High diversity of types of Nilotic ships in Dynastic[77] and Ptolemaic times[78], ideal position between the river and sea, ethnographic parallels — all these factors allow suggesting Alexandria as the most probable place of origin for the archetype of the Eastern riverine root in transition from shell-first to frame-first type of construction. First suggested by L. Basch, the hypothesis is now supported by many researchers[79]. We may hope that future underwater excavations in Alexandria may furnish the missing archaeological proofs.

In its turn the frame-first type of construction allowed application of caulking for ensuring watertightness of the hull (Figure 8). During this process the waterproof material is driven into the seams of the planking. In case of more archaic shell-first shipbuilding technique this not was possible because the strength of the hull relied much on the tenons of the planking and caulking would much weaken these joints[80]. L. Basch made an extensive research on

[76] Collet, Pomey 2015; Gaubert, Henein 2015. Description of more types may be found in Koutkat et al. 2017.
[77] 89 types of vessels, most of which were Nilotic, are cited in Jones 1988.
[78] Arnaud 2015.
[79] Basch 2008: 77; Rieth 2008: 67; Pomey et al. 2012: 261, 308; Pomey 2017: 21.
[80] Gianfrotta, Pomey 1981: 262; Bass 1982: 72; Basch 1986: 187; Basch 2015: 228.

the origins of the caulking [81]. Relying on the material from the existing shipwrecks, documentary evidence and etymology, he concludes that the appearance of caulking technique is related to the frame-first type of construction [82]. The earliest document mentioning *kalaphatos* (καλαφάτος) — caulker — is dated to the period 578–613 AD. It comes from Egypt, from the juridical archives written in Greek and discovered in Syene (modern Aswan) [83]. These documents precede the conquest of Egypt by Arabs in year 642 [84]. As we have seen above, the Dor 2001/1 shipwreck is one of the earliest specimens of frame-first type of construction and the hull of this boat was caulked [85]. Basch thus suggests that the conception of the type represented by Dor 2001/1 ship probably belongs to Alexandrian shipwrights [86].

The third important invention in the field of shipbuilding that may be linked to Alexandria is the Latin rig [87]. This rig consists of a triangular sail set on a long and inclined yard. It is closely linked to the settee rig although there exist a minor difference between them [88]. The lateen/settee rig first appeared in the Eastern Mediterranean and was adopted towards the 5th century AD [89]. The Lateen rig may originate in the square rig, the brailed square rig being possible intermediate stage [90]. The Latin rig was not superior to the square rig nor for the ability of sailing into the wind, neither for the speed [91]. However, its invention was an important step in the development of maritime technology as it has expanded the diversity of rigging types [92].

The main evidence for ancient lateen/settee rig comes from iconography. The earliest representation of the settee sail is known from the Kelenderis mosaic in Turkey that is dated to the 5th–6th centuries AD [93]. However, the earliest image of the pure Latin rig comes from Egypt, from the monastery of Kellia, *c.* 80 km of Alexandria (Figure 9). This representation is dated to 600–630 AD [94]. Possibly more ancient graffiti from Alexandria is difficult to date with precision (Figure 10) [95]. It was discovered in the hypogeum No. 2 of Anfushi dating to the 3rd century AD [96].

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[81] Basch 1986; Basch 2008: 77–79; Basch 2015. The etymological origins of the words related to caulking that were proposed by the author in his earlier paper (1986) were reconsidered in his subsequent publications.

[82] Basch 1986: 194.

[83] Papyrus p.lond.5.1737=HGV P.Lond. 5 1737= Trismegistos 19750, see Basch 2008: 78. The term may have Indian origin. See Basch 2015: 231–232.

[84] Basch 2008: 78; Basch 2015: 229.

[85] Kahanov, Mor 2014: 42, 45, 51, 63.

[86] Basch 2015: 232.

[87] According to convincing theory by I. C. Campbell (Campbell 1995) there could be three independent inventions of Latin rig in different geographical zones: the Mediterranean, the Indian Ocean and the Pacific Ocean, each bearing its own distinction in rigging prototypes.

[88] The sail of the settee rig has its bow corner cut off, giving it a quadrilateral shape, while the sail of the lateen rig is triangular.

[89] Pomey 2006: 329; Whitewright 2008: 199–200; Whitewright 2009.

[90] Hypothesis first suggested in Bowen 1953 and supported, among other works, in Casson 1966; Casson 1971: 276–277; Basch 1997; Pomey 1997a. However, according to another theory this adoption did not follow a unilinear model that would mean that the lateen/settee rig appeared independently of the square rig. See Whitewright 2008: 152, 166, 194, 200–201; Whitewright 2018.

[91] Whitewright 2008: 142.; Whitewright 2011.

[92] The importance of Latin rig for the ships of the Age of Discovery seems to be overestimated and it is hardly can be considered as the ancestor of the fore-and-aft rig. See Campbell 1995: 19–23.

[93] Friedman, Zoroglu 2006; Pomey 2006; Whitewright 2008: 110.

[94] Basch 1991; Basch 1997; Basch 2001; Whitewright 2008: 118, 146, 153, 155–156.

[95] Whitewright 2008: 157–158.

[96] Basch 1987: 480, fig. 1084.

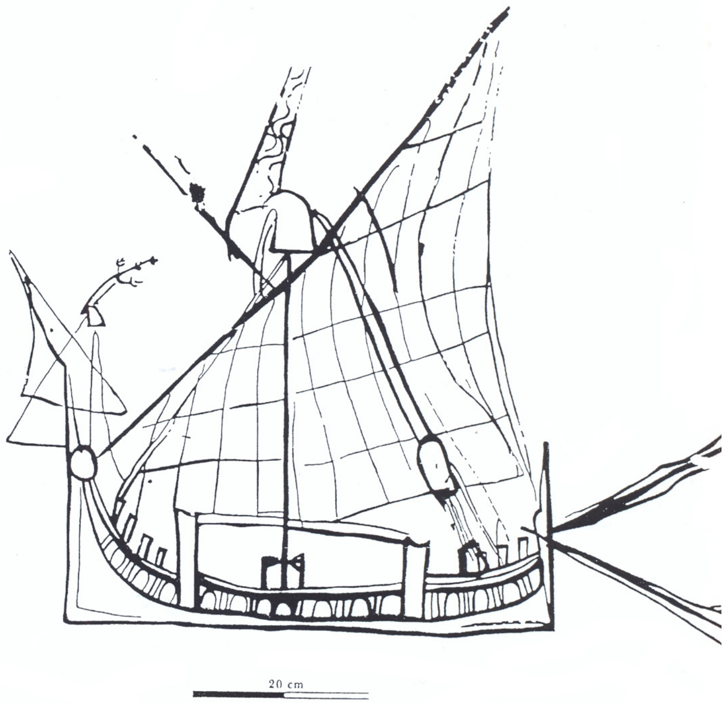

Figure 9. Graffiti from the monastery of Kellia (80 km south-east of Alexandria).
600–630 AD. After Basch 2001: fig.1

Figure 10. Graffiti of a ship (date uncertain, possibly 1st century BC)
from the hypogeum No. 2 of Anfushy, Alexandria (3rd century BC). Photo by the author

Moreover, it was recently shown that a formula proposed in a text attributed to Heron of Alexandria for a calculation of sail's surface refers to a triangular sail[97]. Unfortunately, the authorship and date of this fragment remain uncertain[98].

During the long history of Ancient Egyptian navigation, the experiments with the rigging were not a rarity and the first loose-footed sails could well appear in Egypt[99]. Starting from the 5th century AD the lateen/settee rig gradually replaced the square rig in the Mediterranean[100]. Apparently this change was determined by the same economic reasons that influenced the appearance of the frame-first technique in shipbuilding by the 5th century AD[101]. It was suggested that the evolution of the rigging goes along with the changes in hull construction techniques[102]. The new method of building ships as per the frame-first technique allowed using the wood resources more frugally and diminishing the time and costs of construction. The same is true for the simplification of the Latin rig in comparison to the square one[103].

According to the hypothesis that was developed above, one of the roots of the transition from shell-first to frame-first technique may well be linked to Alexandria. Summing up the iconographic evidence for the Latin sail and indirect considerations, Basch said that 'everything suggests that the frame-first type of construction and the Latin sail, both of them being non-Arab innovations of the end of the Byzantine era, were born in Alexandria'[104].

Conclusions

Ancient Alexandria's exceptional position on the confluence of the two worlds, the pharaonic civilization on the Nile and the sea-born cultures of the Mediterranean, made the city a major node of ancient science, culture and trade. Melting together, these traditions resulted in a great number of important new technologies that were born in the 'cosmopolis'[105] of Alexandria. Many of them were connected to the sea. Some of these inventions are undeniable but others still remain obscure and we may hope that future archaeological research in Alexandria will bring more light on this question.

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[97] Stereometrica 2, 48-49. See Pomey 2017: 19–21.
[98] Pomey 2017: 21.
[99] Belov 2019.
[100] Whitewright 2008: 216.
[101] Whitewright 2008: 174, 213.
[102] Whitewright 2008: 174.
[103] Whitewright 2008: 217.
[104] Basch 2008: 74–75.
[105] Agut-Labordère 2019.

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Развитие мореплавания и древняя Александрия

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Особое значение Александрии для развития древнего мореплавания было обусловлено ее исключительно выгодным географическим положением. Город вырос в месте соприкосновения двух водных миров — древнеегипетской цивилизации долины Нила и древнегреческой цивилизации Средиземноморья. В течение трех столетий династия Птолемеев основывала свою деятельность на принципах талассократии. Символом последней стал Фаросский маяк, который 17 столетий помогал кораблям всей ойкумены находить путь к гавани Александрии. В данной статье предпринята попытка оценить вклад древней Александрии в развитие мирового кораблестроения и навигации. Александрийское происхождение некоторых рассмотренных новшеств в области мореплавания остается гипотетическим. Таким образом, верность этих предположений может быть подтверждена или опровергнута новым археологическим материалом и будущими изысканиями.

Ключевые слова: Александрия, Александрийская школа, древнее мореплавание, древнее кораблестроение, древние порты.

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