Chapter 3

Navigation
now that there are three classes of navigators: those whose voyage goes off well one time and another time not, whose answer is right one time and wrong the next. These do not deserve the title of “master”. In the second class there are the navigators who are known for their practical knowledge and experience. They are skilful and fully conversant with the routes which they have sailed, but after their death they sink into oblivion. The third class is the highest. Whoever belongs to it is famous, masters all operations at sea and writes treatises which people make use of during their lifetime and even later.

Ibn Māʾīd (2nd half of the 9th/15th century)
Introduction

HE relevant research in this field, particularly in the latter half of the 20th century, has established that as early as the middle of the 1st/7th century approximately the Muslims began to attack and conquer islands in the east of the Mediterranean with their own fleets, growing into a formidable sea power within a short time in the southern Mediterranean and later in the entire region of the Mediterranean.\(^1\) That the sea-borne traffic between the Muslims and China also goes back to the 1st/7th century and that it continued to expand throughout the centuries had long been known to research.\(^2\) In his excellent work *L’océan Atlantique musulman*, Christophe Picard explained that the development of Arab-Islamic seafaring in the Atlantic along the ca. 1300 km long strip of coast from Coimbra in the north to Nul (today probably Noun) in the south was very important from the time of the Arab conquest up to the rule of the Almohads (1130-1269). It must, however, be emphasised that these works generally deal with the historical aspect of the seafaring undertaken by Arabs and Muslims in the great basins mentioned, not being concerned with the techniques employed. That is why we know hardly anything now about the seafaring techniques of the Muslims in the Mediterranean and in the Atlantic. By contrast, in the case of the Indian Ocean, we know that navigation was quite well developed, thanks to special research begun in the early 19th century. In the eleventh volume of my *Geschichte des arabischen Schrifttums*, dealing with the *Mathematische Geographie und Kartographie im Islam und ihr Fortleben im Abendland*,\(^3\) I wrote extensively about this navigation and its influence on the nautical knowledge of the Portuguese. Some aspects of this may be mentioned here.

We can almost certainly assume that contacts across the sea between the peoples living along the western and eastern littoral of the Indian Ocean for a long time hugged the coastlines. After some time, however, they must have felt emboldened to cover longer distances across the high seas. We do not know when, how and among which seafarers this happened. Arabic sources permit us to assume that use was made of the rising and setting of certain fixed stars, of the position of the Pole Star and other circumpolar stars for orientation at sea. In the course of development of this system of orientation, sailors began to take their bearings not only on the North Star and Southern Cross, but also on 15 fixed stars whose points of rising and setting are at a distance of ca. 11° 15’ to each other, which led to a division of the circle of the horizon into 32 parts: At a relatively high level of development the awareness emerged that the astronomers and mathematically inclined geographers divided the Earth’s surface northwards and southwards from the equator into 90° each and the longitudes into 360°. This may have led to the desire for a determination of the position on the high seas in degrees, which apparently had hitherto only been estimated in a rough and ready way on the basis of the time elapsed and the distance covered in the time since putting out to sea. In this \([36]\) connection, they must have acquired the astronomical knowledge, known already to the ancient Greeks, that the altitude of the pole (P) at a point (D) on the Earth’s surface (angle HDP) is equal to its latitude (angle ACD).\(^5\)


\(^4\) *Geschichte des arabischen Schrifttums*, vol. 11, pp. 159-319.

\(^5\) F. Sezgin, op. cit., vol. 11, p. 188.
The navigators of the Indian Ocean will have learnt either through their own experience, but more likely from Arab astronomers, that the pole as an abstract point does not coincide with the Pole Star, but that once a day the latter describes around the former an (apparent) circle with a radius of ca. 25', which changes in the course of time, and that while establishing the height of the pole the altitude of the Pole Star has to be taken into account, which is variable because of the rotation. This means that the observed altitude of the Pole Star has to be reduced to the altitude of the celestial pole itself. For this they had at their disposal the method of Arab astronomers, known since the 3rd/9th century, of calculating the true distance of circumpolar stars to the celestial pole by halving the difference between their upper and lower culmination heights as elicited. In contrast to the astronomer, who fulfilled this task mainly by observing and measuring the hour angle between the position of the Pole Star in the meridian and its right ascension or the position of a circumpolar star relative to the meridian, the sailor needed to overcome his problem by observing additional fixed points in the sky. In doing this at first the two stars β and γ were used, which according to the contemporary astronomical view were joined to the Pole Star α in the constellation of Ursa Minor by a fixed link. These two, known as al-Farqadân, made it possible to determine the position of the celestial pole by virtue of their known distances and the positions forming horizontal and vertical lines, which fluctuated jointly. To be on the safe side, though also to facilitate the determination of the position of the celestial pole, seafarers in the Indian Ocean also employed specific times of rising and setting of the twenty-eight lunar stations (manâzîl al-qamar) as an additional aid. The rising of specific lunar stations provided evidence that one of the fixed positions of the two stars β and γ of Ursa Minor relative to the pole is accurate, and they revealed the time when those positions are taken up as part of the apparent diurnal rotation of the firmament, since the lunar stations in the ecliptic follow this apparent diurnal rotation.

In the figure which we added here, “the 12th lunar station … is in the descendant. Its ‘guardian’, the 26th lunar station, … is located opposite at 180° in the ascendant. In this constellation the Pole Star reaches its highest culmination. By contrast, the setting of the 26th and the rising of the 12th lunar station point to the fact that the Pole Star is in its lower culmination.”

The determination of the position of the North Pole enabled the sailor not only to measure the height of the pole more precisely and thereby his latitudinal position on the high seas, but also, while sailing

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6 Sezgin, Geschichte des arabischen Schrifttums, op. cit., vol. 11, p. 188–189.
7 Ibid., vol. 11, p. 191–192.
8 Ibid., vol. 10, p. 169
9 Ibid., vol. 11, pp. 189-190.
meridionally, to ascertain the distance traversed in degrees.
This was only one of the factors which made possible a safe passage across the Indian Ocean in all directions and a fairly precise determination of the position at sea. But under a cloudy sky an orientation by the stars or by the sun was not possible. In that case another aid was needed. It was the compass. Our Arabic sources permit us to assume that the compass was known to the Arab sailors in the Indian Ocean by the 10th/16th century, perhaps even by the 7th/13th century. It is very likely that the knowledge of the magnetic needle as a means of orientation reached the Indian Ocean from China. We can take it as certain that the compass served the sailors in the Indian Ocean not only as an aid for orientation, but also for the determination of distances on the high seas and was being used for the compilation and correction of map material before the 10th/16th century, perhaps even in the 7th/13th century. While studying the geography and navigation of the Indian Ocean, we became convinced that the cartographic representation of this area and the work on the longitudes and latitudes required for this had reached a high level by the 9th/15th century. This leads to the question of the determination of longitudinal positions on the high seas, and here we see a fundamental achievement of Arabic-Islamic navigation.

Towards the end of the 19th century, when Wilhelm Tomaszek was able to compile, on the basis of the limited second-hand material then known, so much data about distances and directions that he was able to reconstruct 30 regional maps of the Indian Ocean, he astounded the scholarly world. In his view these data had, however, been obtained “by thousand-fold trial and error”. This fundamental problem of Arab navigation could be solved only after the discovery and thorough study of its specialised works, particularly those by Sulaimān al-Mahrī (early 10th/16th c.).

While referring to the excellent study by Matthias Schramm and to the detailed treatment of the topic in the Geschichte des arabischen Schrifttums, we may here list the methods of Arab navigation which served to determine three kinds of distances by measuring the covered distances on the high seas, measured in Arabic miles (1 mil ≈ 1972 m):

1. Determination of distances parallel to the meridian. Here too the seafarer first of all determines the pole altitude at the point of departure. After covering a certain distance, while maintaining a predetermined course (either according to one of the points of direction of the compass disc, divided into 32 segments, or according to the corresponding point of the rising or setting of one of the fifteen known fixed stars), he determines the pole altitude once again. The resulting difference between the two measurements yields the distance covered in degrees.

2. Determination of distances oblique to the meridian. Here too the seafarer first of all determines the pole altitude at the point of departure. After covering a certain distance, while maintaining a predetermined course (either according to one of the points of direction of the compass disc, divided into 32 segments, or according to the corresponding point of the rising or setting of one of the fifteen known fixed stars), he determines the pole altitude once again. The resulting difference between the two pole altitudes and the course determined at departure gives the navigator one side and one of the two adjacent angles of a right-angled triangle, whose hypotenuse, which has to be calculated trigonometrically, represents the length of the distance traversed.

3. Determination of distances between two places lying on the same geographical latitude, but on op-

10 ibid, vol. 11, p. 198.
12 F. Sezgin, op. cit., vol. 11, pp. 198 ff.
posite coasts. What are involved here are distances running parallel to the Equator. With this type of measurement of distance, which amounts to a determination of longitudinal difference, the problem is solved by a type of triangulation. After the exact determination of the pole altitude at departure the navigator maintains an elicited angle, which is oblique to the meridian, until a certain point is reached where the pole altitude is again measured.

From there he sails at a certain angle opposite to the course followed so far, until he once again reaches the same pole altitude which was registered at departure. With the angles of the course maintained and the elicited difference in pole altitudes, the seafarer simulates two right-angled triangles with a common side, which is constituted by the elicited difference in pole altitudes.

![Diagram of navigation](image)

AC = first course
CD = difference in pole altitudes
CB = second course
AB = distance to be measured

The seafarer could repeat this triangulation as many times as he wished. We may add here that among the navigators of the Indian Ocean the custom became established of stating distances by using a measure of length called *zām*, which corresponded to 23,851 metres or 4.77 new Portuguese leguas. This measure of length was one eighth of the distance that could be covered by ship in a day and night, implying a voyage of three hours, as our Arabic sources state. From this we can conclude that the ships in the Indian Ocean could cover a distance of ca. 190 km per day (i.e. a mean speed of almost 5 knots) and took ca. 32 days for the voyage between East Africa and Sumatra along the Equator (ca. 57° = 6330 km).

To make this overview intelligible, it is also necessary to mention the measure of the arc, the *išba‘*, which literally means “thumb’s width”, and which was used by the navigators of the Indian Ocean. This measure, whose practical usefulness cannot be denied may have been known before Arabic astronomy became known, perhaps even before the appearance of the Arab navigators in the Indian Ocean. The *išba‘* is a part of a circle divided into 22 or 210 degrees. According to the first division, one *išba‘* is equal to 1°36′26″, according to the second 1°2′51″.

After these introductory explanations, we may cite here the two classic examples of Arab navigation in the Indian Ocean to illustrate the method of measuring distances on the high seas which are parallel

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14 v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 11, p. 201
15 ibid, vol. 11, p. 194.
to the Equator. The first example “involves three places in the Gulf of Bengal which form an equilateral triangle with the latitudes given (twice 11 1/2° = 22°18’ and once 11 1/2° = 23°09’). The size of the two (identical) base angles is given according to the position of the places facing the rising or setting point of a fixed star, which is 22°30’ according to the corresponding 11th or 23rd point of the compass rose”:

\[ \angle HAC = \angle HBC = 22°30' \]

The second example refers to the Arabian Sea. It says: ‘There are two courses, [one] between Aden [5 1/2° = 12°] and Anf al-Hinizira at 4 1/2° [= 10° 18’] at the rising of the Suhail [Canopus, α Argus] and [the other] between Aden and al-Maskan, also at 4 1/2° at the setting of the Himārān (the two donkeys, α and β Centauri). The distance determined between the two places [Anf al-Ḥinizira and al-Maskan] is 10 zām.’

\[ \angle CAB = 56°15' \]
(based on the 20th point of the compass rose).
\[ \angle ABC = 67°30' \]
(based on the 15th point of the compass rose).
\[ \angle ACB = 56°15' = \angle CAB. \]

Despite the deviations of the latitudes from today’s values, the distance determined, viz. 10 zām = 283.56 km, seems to correspond approximately to the value of the modern map (45°50’ - 43°37’ = 2°13’). The Arab navigators “preserve for us fairly long tables for short and long distances in the Indian Ocean in the corresponding chapters of their books. When compared with today’s values their data prove largely to be very good, sometimes relatively good, and sometimes, where they refer to less frequented areas, to be erroneous. Yet on the whole, together with the latitudes and the directions given, they reveal [40] a mathematical record of the Indian Ocean which accords astonishingly closely with reality … In the fourth chapter of his Minhāq al-fāhir Sulaimān-al-Mahri gives us clear information about the question of how far the mathematical record of the configuration of the Indian Ocean had progressed in the Arab-Islamic world and how successfully the seafarers operated with their measurement of distances. There, in a section exclusively devoted to distances between the east coast of Africa and Sumatra – Java, he lists 60 distances between headlands, gulfs, islands and ports in the Indian Ocean which are located on the same geographical latitudes. Over 60 years ago G. Ferrand pointed to the importance of the materials provided by Sulaimān al-Mahri on the (transoceanic) distances between the East African coast and Java – Sumatra. Unfortunately his comment was ignored, as far as I can see, by historians of geography and cartography, with the exception of H. Grosset-Grange.”

“Under no circumstances does the extraordinarily great significance of this table by Sulaimān al-Mahri for the history of geography depend simply on what was indicated by G. Ferrand. The table really only comes into its own when its data are compared with today’s coordinates. The comparison is scarcely impaired by the fact that not all the ancient names can be identified in a modern atlas. Even without place names we would have been able to carry out a comparison, since al-Mahri recorded distances between corresponding latitudes at opposing points of the African and the Sumatran-Javanese coasts. If we convert the sums given by Sulaimān al-Mahri from zāms … into degrees, we arrive at the values in the following table:’

\[ \text{∠ C AB = 56°15'} \]
\[ \text{∠ A BC = 67°30'} \]
\[ \text{∠ A CB = 56°15'} = \text{∠ CAB.} \]

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18 ibid, vol. 11, p. 215.
[41] “The largest divergence (-7°20’) seems too large to us nowadays; the second largest ones (1°22’ and 1°21’), also at first glance, spoil the high quality of the other, more correct values. However, the precision we are dealing with is one involving values of distances of ca. 5500-8000 kilometres on the open seas, i.e. of transoceanic differences in longitude of between 50° and 75°, not one which could be achieved in a densely populated area by means of surveying or by calculations deriving from thousands of ships’ voyages along the coast. The data cover the Indian Ocean between Lat. 4°24’ north and Lat. 5°21’ south and provide us with coordinates of a large part of this ocean determined on a purely nautical and mathematical basis. The figures can scarcely be regarded as coincidental, the more so since they constitute differences in longitude whose accuracy or proportions of divergence were only discovered after centuries of work.

Their more recent successors do not keep us in the dark about their methods. They know the traditional

<table>
<thead>
<tr>
<th>Point on the African coast</th>
<th>Point on the coast of Sumatra/Java</th>
<th>Al-Mahrī</th>
<th>Modern Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Muqbil Atoll (Mareek?)</td>
<td>Mākūfānī (Meulaboh)</td>
<td>4°24'</td>
<td>3°46'</td>
</tr>
<tr>
<td>2 Murūtū</td>
<td>Fansūr (Barus)</td>
<td>2°47'</td>
<td>46°21'</td>
</tr>
<tr>
<td>3 Barāwa</td>
<td>Priaman</td>
<td>1°10'</td>
<td>1°02'</td>
</tr>
<tr>
<td>4 Malawān (Imāma)</td>
<td>Indrapura</td>
<td>S 0°30'</td>
<td>278</td>
</tr>
<tr>
<td>5 Kitāwa (Pale Island)</td>
<td>Sundabari (Sillebar)</td>
<td>S 2°07'</td>
<td>292</td>
</tr>
<tr>
<td>6 Mombasa</td>
<td>Sundā (Ṣūnā)</td>
<td>S 3°44'</td>
<td>306</td>
</tr>
<tr>
<td>7 Ğaţrāt al-Ḥadhrāʾ (Pemba)</td>
<td>Bali</td>
<td>S 5°21'</td>
<td>317</td>
</tr>
</tbody>
</table>

Distant places with corresponding degrees of latitude on the east coast of Africa and in Java/Sumatra according to Sulaimān al-Mahrī and the modern map.

“In order to properly grasp the importance of the distances listed by al-Mahrī for the history of geography, cartography and navigation, we need to look at how they diverge from the corresponding modern values (cf. the adjacent figure).
astronomical method of determining differences of longitude by using lunar eclipses, and they know the method of dead reckoning used by seafarers, but they do not rely on these methods and their results. As navigators they were not only responsible for the courses of ships, but also at the same time, as superb experts in the astronomy, mathematics etc. cultivated in the Arab world, they developed their own method of triangulation, whereby two of the sides of a triangle were linked, on the one hand longitudinally with terrestrial points and on the other hand latitudinally with circumpolar stars. They knew how to determine their distance from the Equator from the altitude of the pole and their direction on the basis of specific fixed stars (which they were able to achieve in the course of time by means of a sophisticated compass). Thus the condition was met for moving on to triangulation.19

After these brief remarks on the nature of Arab navigation in the Indian Ocean, we may add a few words about its representatives. We learn about Arab navigation through the works of its two greatest exponents, Ibn Māgid and Sulaimān al-Mahrī, from the first half of the 9th/15th and the first quarter of the 10th/16th centuries. Recent research first received some idea of their importance through the excerpts from their works in the Kitāb al-Muhīṭ of the Ottoman admiral Sīdī ‘Ali (d. 970/1562), which have been made available and studied in parts since 1834. The discovery of the extant original texts, their publication, partial translation and study only occurred in the course of the 20th century. Not often, but every now and then, we also hear in these writings something about their predecessors. Ibn Māgid mentions the works of several navigators who were active in the 4th/10th century and whom he calls authors who had not yet presented their material systematically.20

According to Ibn Māgid, the elder of the two, navigation is “a theoretical and empirical science, not simply one caught up in a paper tradition, ‘ilm ‘aqlī taqribi lā naqli. He divides the seafarers into three groups: the first are the ordinary pilots whose navigation sometimes works and at other times does not, whose answers are sometimes right and sometimes wrong. These are the sailors who do not deserve to be called mu‘allim. Those belonging to the second category, the ordinary mu‘alima, are known for the size and the range of their knowledge; they are skilful, are familiar with the routes

of the places to which they sail, but when they die they are forgotten. The third class of seafarers is the best. Whoever belongs to this class is very well known, is familiar with all navigational operations and is a scholar who ‘writes texts’ which are useful in his lifetime and after. Ibn Māgid lays down the regulations which a captain needs to observe on his voyage and the moral principles to be expected of him.”21

“According to Sulaimān al-Mahrī the nature of nautical science (aṣl ‘ilm al-bahr) consists of theory (naẓar al-‘aql) and empiricism (taqriṣa). These are the two bases: what is tested and agrees with the theory is correct and reliable … According to Sulaimān al-Mahrī, the discipline is subject to the law of change (qānuʿ at-tadrīği l-far‘iyāti), particularly as regards the details, [42] whereas the basic outlines can be regarded as being approximately correct (maʿa sibhat qarinat al-aṣl). Ibn Māgid is convinced that he himself has developed a great deal in the subject, but that in his earlier works he has also written things which need to be corrected.”22

Both navigators were well acquainted with many sciences of the Arab-Islamic world and possessed a high degree of knowledge, particularly of Arab astronomy, which was indispensable in their special field.23 They knew and carried on their ships the main astronomical instruments for measuring altitudes, such as the astrolabe and the quadrant, and worked with them when the need arose.24 However, the instruments with which they were better acquainted and which were more functional for them were the instrument known in Europe as Jacob’s staff and—particularly among Portuguese seafarers—as balestilha, and the compass. Thanks to its easy usability for the determination of latitudes according to the pole altitude, the former was a suitable instrument for the navigators of the Indian Ocean while navigating on the high seas. The astrolabe, on the other hand, was more suitable for use on land, for the measurement of the latitudes of places, while on board a rocking boat errors of up to 5° or 6° had to be anticipated when measuring altitudes with the astrolabe. The instrument marked in Ḭṣaba’s (thumb’s widths) was known to earlier Arab navigators as ḥasabāt (boards) or ḥatabāt (wooden plates). The number of plates was prefer-

20 ibid, vol. 11, p. 179.
21 ibid, vol. 11, p. 177.
22 F. Sezgin, op. cit., vol. 11, p. 178.
ably twelve, according to Ibn Mājid, and they were available in larger, medium and smaller formats. The instrument was known as kamāl (the perfect one) in later centuries. In this connection I cite the famous report from the Asia of the Portuguese historian and geographer João de Barros (1490-1570) about the meeting between Vasco da Gama and the Muslim sailor Malemo (mu'allim, “master”) Caná, a native from Gujerat, on the south-east coast of Africa. The report also gives information about the character of the Arabic graduated maps of the Indian Ocean: “Among them came a Moor, a Guzarate by birth, by the name of Malemo Caná, who agreed to travel with them both because of the pleasure that our company afforded him and as a favour to the king, who was looking for a pilot for them. However, when Vasco da Gama had dealings with him he was very much content with the man’s knowledge, especially when he showed him a map of the whole coast of India, which was divided up, in the manner of the Moors, into very small meridians and parallels of latitude, without any compass rose. Since the rectangle of these meridians and latitudes was very small, the coast was very exactly represented by those two gradations from north to south and east to west, without containing the multiplication of the winds of the normal compass of our chart, which serves as a basis for the others. And when Vasco da Gama showed him the large wooden astrolabe and other metal astrolabes which he used to record the altitude of the sun, the Moor was not at all surprised, saying that some helmsmen (pilots) on the Red Sea employed triangular instruments of tin and quadrants whereby they recorded the altitude of the sun and the star which they particularly needed for navigation, whereas he and the sailors of Cambaya and all of India recorded their distance with a different instrument, not with those, because their navigation was dependent both on specific stars, from north to south and also on other large stars which pass across the firmament from east to west. He showed this instrument to him at once, and it consisted of three plates.”

“And because in our Geographia [universalis] in the chapter on nautical instruments we deal with


the shape and the use of the same, it may suffice here to know that they serve them in the operation for which we use an instrument which seafarers call Jacob’s staff and about which we shall likewise speak in the chapter cited as well as of its inventors.\footnote{27}

Now I come to the second main instrument of navigation in the Indian Ocean, the compass, one of the basic components of navigation on the high seas mentioned above (p. 37 ff.). According to the impression created by the works of Ibn Mażid and Sulaiman al-Mahi, navigation on the high seas was based on the system of the compass, at the latest in the 9th/15th century, and probably even earlier. The compass did not replace the older system of orientation by fixed stars, but improved and enlarged it. The division of the plane of the horizon into 32 parts of the old system was retained and complemented by the division into 360 degrees. The navigators in the Indian Ocean called the arcs of the division of the circle of the horizon into 32 parts, which at the same time show the angle of the course, hann (plural aḥnān). In this word we find the origin of the term rumb, which occurs in European languages in different forms.\footnote{28} The compass was either referred to as huqqa (“box”) or baṭt al-ibra (“box of the nail, lit. house of the needle”), the needle itself being ibra or samaka (“fish”).\footnote{29} We may conclude, from statements which are not quite unambiguous, that at least the two great navigators knew the deviations of the magnetic needle.\footnote{30} This assumption is supported by the fact that the Ottoman admirals Sidi ‘Ali (d. 970/1562), who summarised the works of the two navigators (see above, p. 41) in a treat about a special sundial (dā‘ir-e-yi mu‘addil an-nahār, see above, II, 158 ff.), shows himself to be conversant with the magnetic deviation and determines it for Istanbul at 7° (ibid, p. 159).

The Arab navigators tell us less about the forms of the compass than about its uses.\footnote{31} However, the information gap regarding the forms is bridged, to a large extent, by the Portuguese sources. The oldest Portuguese report about the compass used in the Indian Ocean goes back to Vasco da Gama. He narrates with astonishment that “magnetic needles after the manner of the Genoese” are used there, besides quadrants and sea charts.\footnote{32} This statement is particularly important for us because we can infer from it that the advanced type of the compass from the Indian Ocean reached Europe before the first Portuguese expedition. The Genoese, Christopher Columbus, carried a similar one with him.\footnote{33} The most detailed description of the three types of the compass used in the Indian Ocean is given by the Portuguese historian Hieronimus Osorius (1506-1580). He even informs us about the different stages of their development.\footnote{34} His information enabled us to reconstruct all three types completely (see below, p. 61 ff.). The most developed of the three is the one that continued to be in circulation in Europe up to the 19th century. Its main characteristic is that the entire compass disk with the 32 markings, suspended according to the system subsequently known as “Cardanic”, rotates together with the magnetic needle fixed below. With the even more advanced type, which Ibn Mażid refers to as his own invention, the magnetic needle does not move the compass disk from below, but rotates freely suspended above it\footnote{35} (see below, p. 65).

Now we come to speak briefly about the remaining third component of navigation on the high seas, the graduated chart, without which the determination of positions would not be possible. Referring the reader to the Geschichte des arabischen Schrifttums\footnote{36} for the treatment of this question and without repeating the arguments here, I will summarise the result achieved there, namely that within the Indian Ocean a highly sophisticated type of graduated sea chart was developed, which can only be understood as the product of an interplay over centuries between a familiar mathematical geography and a highly developed astronomical navigation. Not only the data of Arabic-Turkish sources create this impression, but also the testimony of the Portuguese and other European seafarers and the...
studies of the extant map material. The Portuguese encountered not only a wealth of highly developed cartographic material, but also an advanced type of astronomical navigation. Moreover, according to their own accounts, the Portuguese were stimulated and encouraged to set out on their expeditions by the maps which reached them from those distant regions. When we notice on a Portuguese world map, probably dating from the years 1519-1520, which is provided with longitudes and latitudes (and is ascribed to Jorge Reinel),\textsuperscript{36} that the distance between the east coast of Africa and the west coast of Sumatra is 57° at the Equator and differs from the modern value (56°50') by a mere 10' and is, on the other hand, only 20' away from the value of the Arab navigator Sulaimân al-Mahri, we can presume that the Portuguese map maker must have had a model at his disposal, which, at least with regard to the Indian Ocean, can have only originated locally, and that only after centuries of continuous activity.

\textsuperscript{36} ibid, vol. 11, pp. 398-400.
A measuring Instrument
for determining altitudes at sea

Our model: Hardwood.
Three square plates.
Thread with knots at regular intervals.
(Inventory No. C 2.08)

From a report by the Portuguese historian João de Barros, we gather, inter alia, that the seafarers of the Indian Ocean found those instruments which served astronomers on the mainland for the measurement of altitudes inconvenient on board pitching and rolling ships. He states that on his first expedition Vasco da Gama had shown his Muslim pilot “the large wooden astrolabe and other metal astrolabes which he used to record the altitude of the sun.” The “Moor” was not at all surprised, “but said, some pilots on the Red Sea employed triangular instruments of tin and quadrants whereby they recorded the altitude of the sun and the star which they particularly needed for navigation, whereas he and the sailors of Cambaya and all of India recorded their distance [according to angles] with a different instrument, not with those, because their navigation was dependent both on specific stars from north to south and also on other large stars which pass across the firmament from east to west. He showed this instrument to him at once, and it consisted of three plates.”¹ This instrument, which became known among the Portuguese by the name of balestilha, was called ḫaṣabāt or also ḫaṭabāt by the navigators in the Indian Ocean² (see above, p. 42).

² ibid, p. 230.

Illustration of the use of the instrument
According to our present knowledge of the history of astronomy and nautical instruments in the Arabic-Islamic world, the common notion that the Jacob’s staff was an invention of Levi ben Gerson or Johannes Regiomontanus proves to be untenable.¹ Not without being influenced by the Greeks, by the 3rd/9th century the Arabs were using, inter alia an instrument for establishing the heights of celestial bodies which was called dát aš-šu’batain (“That one with the two arms”). The assumption may be correct that this instrument, in the course of time, was superseded in the Islamic world by the further development of the astrolabe and the invention of new instruments for the observation of the altitude of heavenly bodies from the mainland, and that it gained greater importance on board pitching and rolling ships for determining pole altitudes in seafaring. In this connection it is of special interest to see that Regiomontanus measured the diameter of the great comet appearing in 1472 with the help of a Jacob’s staff whose cross-piece was divided into 210 units. Regiomontanus appears to have heard of this division, which we know from the navigators in the Indian Ocean, before the Portuguese expeditions.² Knowledge of this instrument, which was preferred by the navigators in the Indian Ocean, apparently reached Europe through travellers to Asia as early as the 7th/13th century. This instrument had earlier been called hašabāt (“boards”) in the Arabic-speaking world, and was later known as balestilha in Europe.³

“The arms move around an axis, and along these arms the navigator sights the two objects whose angular distance he wants to define. Then, with the help of a thread, the distance between the free ends of the arms is measured, which is double the sine of half the angle.”⁴

¹ For the discussion of the question and the literature, v. F. Sezgin, Qaḍiyat iktiṣāf al-ʿala ar-rasādiya “ʿasā Yaʿqūb”, in: Zeitschrift für Geschichte der arabisch-islamischen Wissenschaften (Frankfurt) 2/1985/Arabic part 7-30
Jacob’s Staff

Our model: Wood, length: 50 cm. Four cross−pieces for sighting that can be moved along the staff. Division into degrees on the staff. (Inventory No. A 4.22)

Another Jacob’s Staff

This form is characterised by several cross−pieces of plum wood. Our model is based on specimens (ballestilla) at the Museo Naval in Madrid\(^1\) and the Museu Marítim in Barcelona.\(^2\)

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Our Model:
Hardwood, length: 72 cm.
Adjustable dioptr sights on both arcs.
Fixed slit sight at the centre of the two arcs.
(Inventory No. C 2.07)

Davis Quadrant

In the further development of observation using the Jacob’s staff, after the simplest form of the cross-piece (backstaff), the one by John Davis (ca. 1607) with cross-pieces on both sides, which was called Davis Quadrant after him, or also English Quadrant, proved to be particularly practical. Here, standing with the sun at one’s back, the navigator sights the horizon across the larger arc of the circle in such a way that the light entering through the smaller arc is exactly in line with the horizon. By the addition of the angular measurements to be read off on the two arcs the user elicits the angle of altitude of the heavenly body concerned.1

Our model is based on specimens in the Museo Naval, Madrid,2 and in the Museu Marítim, Barcelona.3

1 v. Fr. Schmidt, Geschichte der geodätschen Instrumente, pp. 347-348, table XXII.
3 v. La navegació en els velers de la carrera d’Amèrica, op. cit., no. 53.
Marine Astrolabe
of Vasco da Gama

According to the Portuguese historian João de Barros¹ (1552), Vasco da Gama had a wooden astrolabe on board his ship during his first expedition. It was suspended “in the manner of a crane” from three poles and had a diameter of 3 palmos (= ca. 66 cm).

Marine Astrolabe of Diogo Ribeiro

The cartographer Diogo Ribeiro, who was in the service of Spain, depicted a marine astrolabe (astrolabio náutico) consisting of a single disc in his maps from the years 1525, 1527, and 1529.\(^1\) Thus he was probably following the tradition of the astrolabe made by Ibn aṣ-Ṣaffār in Toledo in 420/1029 (see above, II, 95).

\[\text{Fig. from D. Ribeiro, Mapamundi (1529).}\]

Our model: Brass, engraved. Diameter: 18 cm. Rotating alidade with diopter sights. Two scales of 90° serve for the measurement of altitudes; below these is engraved a scale for the hour-angle. Made by Eduard Farré-Olivé (Barcelona). (Inventory No. C 2.04)

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Marine Astrolabe

Based on a Portuguese specimen from the 16th century and made by Martin Brunold, Abtwil, Switzerland

Our model:
Brass, engraved.
Diameter: 20 cm.
Rotating alidade with diopter sights.
On the front are engraved two scales of 90° and the year 1555.
(Inventory No. C 2.01)
Nautical Quadrant

This quadrant for determining the position at sea was also depicted by the cartographer Diogo Ribeiro on his three world maps from 1525, 1527 and 1529.

Our model:
Brass, engraved.
Radius: 15 cm.
Diopter sights on the side.
Scale for measuring altitudes, below it a scale for the hours before and after noon.
Projection of the 12 signs of the zodiac above the 90° angle mark.
Made by Eduard Farré-Olivé (Barcelona).
(Inventory No. C 2.05)
Simple Hourglass

Our Model:
Mouth-blown glass in a wooden frame.
Height: 26 cm.
(Inventory No. C 2.09)

Replica of a sandglass as used for navigation. There were log-glasses with short duration for determining the vessel’s speed, and also hour-glasses which emptied in the course of one watch (1 glass, ca. 2 hours).

Fourfold Sandglass

Our Model:
Mouth-blown glass. Wooden frame.
Height: 26 cm.
(Inventory No. C 2.10)

Since time measurement for navigational purposes must be very precise, chronometers were taken as sets on board until quite recently. In this way errors could be detected.
The caravel was one of the most important types of ships of the 9th/15th c. It probably developed from Maghribi vessels used by coastal fishermen. The rig fixed with ‘lateen’ sails (attested since the 2nd/9th c.) permits manoeuvring more forcefully against the wind than spar-rigging—it is one of the important steps forward in the history of seafaring—and probably reached western Europe via the Arabs.

Our model:
Wood, fittings and nails: brass; rigging: thread. Without sails. Length across the axis: 143 cm (Inventory No. C 3.02)

For this kind of vessel, which dominated the sea-trade in the Indian Ocean for centuries, the ‘lateen’ rig is, inter alia, characteristic, as well as the elastic joining of the planks of the hull with linen.

Gift of the Minister for Religious Affairs and Endowments of the Sultanate of Oman, Mr. ‘Abdallāh b. Muḥammad as-Sālimī.

dāw
(Dhow)
Crane for Lifting a Boat

The picture reproduces a representation from the atlas of the Turkish admiral Piri Re’is (ca. 1525). An island in the Sea of Marmara with a monastery is shown, to which a boat is being lifted by means of a crane.¹

Our model:
Artificial stone, cast.
Height: 50 cm.
Wooden crane.
(Inventory No. C 3.11)

¹ v. Piri Reis and Turkish Mapmaking after Columbus.
The Khalili Portolan Atlas by Svat Soucek, London
1996 (= Studies in the Khalili Collection, vol. 2), plate