The Emergence of Nautical Astronomy in Portugal in the XVth century

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Of the great oceans of the world, the Atlantic, because of its violence, was the last to be mastered by man. The task in its entirety had to wait for the Portuguese sailors of the Renaissance. Isidore of Seville (c. 570–636), a Christian writer of the late Roman Empire, had written of the Atlantic that it was 'incommensurable and uncrossable'.[1] Although Pliny (A.D. 23–79) refers vaguely to the Canary Islands,[2] all knowledge of them disappears in the Middle Ages until a Portuguese expedition under the command of the Italian Lanzarotto Malocello 'rediscovered' them in 1336.[3] Italian charts of the XIVth century begin progressively to show the Canaries, Madeira, Porto Santo and the Azores, but all aligned along a N/S axis without any appreciation of the relative distances between them or how far they lay from the European shore. The first written evidence of the Portuguese 'discovery' of the islands of Madeira and Porto Santo appears in 1419–20 and of the Azores in 1427, about the same time as they began to be colonised under the aegis of Prince Henry of Portugal, called the 'Navigator'.[4] The difficulties of returning to them on regular voyages was to motivate the Portuguese to develop methods of measurement using the Pole Star as a navigational aid and this led, not only to a greater accuracy in placing the islands on the charts, but also to a greater precision in the charting of the west African coastline which they were progressively exploring during the second half of the XVth century.

Claims that Portuguese nautical astronomy originated in Aragon and was transmitted from there to Portugal[5] or was introduced into Portugal from Germany by Regiomontanus and Martin Behaim[6] have long ago been shown to be baseless.[7] Its origins are indubitably Portuguese. The emergence of nautical astronomy in XVth century Portugal is closely connected with the use, by navigators, of the Mediterranean portulan chart and of the magnetic compass associated with it. For direction, mariners relied on magnetic rhumb lines on the chart which they converted to a course set by the compass. For distance they relied on a scale (*tronco das léguas*) on the chart to which they compared their estimation of distance run over a 24 hour period called a *singradura*.[8] The first use of astronomical observations was to check and improve the estimation of distance run.

The first recorded cases of observations by navigators in the Atlantic of angular distances between the horizon and a celestial body appear in the second half of the XVth century, the angular distances being given in terms of coded linear measurements. Thus in 1455, the Italian navigator Alvise da Cadamosto, at the mouth of the Gambia (Latitude 13° 30′ N) declared seeing the Pole Star 'low on the horizon at the height of a lance'.[9] This odd use of the term 'lance' to express an angular distance is also found in a treatise by Jacobus Angelus of Ulm, writing about 1490 in connection with a comet seen in 1402 with its tail to be 'one and half lances in length'.[10] Before him, Marco Polo, in a conversation between 1293 and 1310 with Peter of Abano, had spoken according to the latter, of the *polum antarcticum*, probably the 'Magellan clouds', being seen in the Indian Ocean '*elevatum quantitate lanceae militis*'.[11]

Other examples of coded linear measurements (for example, 'the height of a man') are given by the Portuguese mariner Pedro de Sintra (1462) in relation to the island of Shenge on the west African coast (Latitude 7° 55′ N)[12] and by the Venetian map-maker Fra Mauro, who in a legend on his world map of 1459 referring to the Indian Ocean, wrote of the 'Antarctic Pole' as being there observed at the height of a *brazo* – 'a (man's) arm'.[13] Coded linear measurements for angular distances appear to be of Arab origin, for in the work of Abd-al-Rahman al-Sufi, (10th century), we find *dzira* – 'an arm's length from elbow to forefinger' equal to 2° 20′; *kamat al-insan* – 'height of a man' and *rumh* – 'a lance', the latter being equivalent to 14°,[14] not very different from the 13° 30′ of the locality where Cadamosto observed the Pole Star at the height of a lance. No evidence is known to us showing how or where these coded Arab measurements reached the West.

The first reference to the use in the Atlantic in relation to the portulan chart, of an astronomical instrument (the quadrant), comes in a much debated text concerning the Portuguese navigator Diogo Gomes, who voyaged as far as the Cape Verde Islands in 1460–2. His oral recollections were taken down by Martin Behaim and copied by the German printer Valentim Fernandes, resident in Lisbon. Gomes recalls of his voyage:

> And I had a quadrant when I went to these places (that is, the neighbourhood of the Cape Verde Islands) and I wrote on the 'table' (limb) of the quadrant the height of the arctic pole and I found it (the quadrant) better than the chart. It is certain that one sees one's course on the chart, but once one has committed an error, one can never get back on the course one had set. (*Et ego habedam quadrantem quando ivi ad partes istas, et scripsi in tabula quadrantis altitudinem poli arctici, et ipsum meliorem inveni quam cartam. Certum est, quod in carta videtur via marinandi, sed semel errata nunquam redeunt ad primum propositum*).[15]

Although the last sentence is admittedly obscure, it is generally agreed that the quadrant was not used by Gomes to obtain directly the latitudes of the places he had visited. From the evidence of an archaic text annexed to the *Reportorio dos Tempos* published by Valentim Fernandes in the 1551 and 1565 editions of the work (1st ed. 1518),[16] it has been shown that the quadrant was first used merely to establish *relative* north–south distances between Lisbon and places on the west African coast, as well as distances separating such places from each other; the main purpose being to compare and correct estimated distances as marked

https://doi.org/10.1017/S0373463397007674 Published online by Cambridge University Press

according to the traditional method on the portulan chart.[17] From the evidence of the text of the *Reportorio*, the names of the places on the African coast were simply written directly onto the limb of the quadrant.[18] Only later, probably towards the turn of the XVth century and at least before c. 1504, the date of the first known chart with a meridian graduated in degrees of latitude,[19] was the quadrant used to obtain absolute latitudes instead of relative distances.

The delicate problem in this development was the choice of a module relating celestial angular distance to terrestrial linear distance. Portuguese navigators in the XVth century, including Bartolomeu Dias, used a module of $16\frac{2}{3}$ leagues (or 70 miles) to a degree (a 15 percent error). Later, in the XVIth century, this was replaced by a module of $17\frac{1}{2}$ leagues to a degree (a 7 percent error).[20] The first module comes from Medieval Arab sources which can be shown to be claiming the authority of Claudius Ptolemy. Medieval Latin translators carelessly replaced Arab miles with Roman ones, the latter being considerably shorter.[21] The origin of the second module is unknown and first appears in the two booklets in Portuguese on astronomical navigation, published in c. 1509 and c. 1516, with which we shall deal in a moment.[22] The Portuguese soldier-sailor Duarte Pacheco Pereira forms the unique exception among navigators, followed by no one, in that he adopts the figure of 18 leagues to a degree (only a 4 percent error).[23]

The earliest attempt in Europe to measure experimentally the value of the degree of the meridian seems to have been that of the Spaniard Antonio de Nebrija (1441–1522), who, some time after 1510, is said to have measured the distance between Burgo de Osma and Alcalá de Henares, both lying on the same meridian or nearly and separated from each other by one degree less eight minutes. He found it equal to 20 Castilian leagues.[24] If the Castilian league in question was the same as the marine league, this was not far from the correct value, but nothing is known of the circumstances and methods of Nebrija's measurement and the result does not seem to have been taken account of by sailors at the time.

In 1500, the Pole Star lay about 3° 25′ distant from the geographic pole. Portuguese navigators in the XVth century, using a value of 3° 30′ (a good approximation), employed, in order to obtain the latter's true altitude, two methods for correcting the apparent altitude of the Pole Star at different times during the night as it revolved round the geographic pole. The figure of a man, with his navel centred on the geographic pole and with his arms outstretched and feet together, was imagined in the sky. From observation of the successive positions of the Guards (two stars of the *Ursae minoris* constellation), in relation to the figure's head, arms and feet, the necessary amount of correction was added to, or subtracted from, the apparent altitude of the Pole Star. This simple method dealt only with four different positions of the Pole Star. When the principal Guard (Kochab) was 'in the head', the Pole Star was 3° below the pole. When the principal Guard was 'in the feet', the Pole Star was 3° above the pole. When the principal Guard was horizontally in line with the Pole Star, 'in the east arm' or 'in the west arm', no correction was introduced, though the actual error in the last two cases, requiring in fact a correction of ±1·5 degrees, was not held to be significant in practice.[25]

Later, the figure in the sky was replaced by a 'wheel' or *Roda do Norte*, 'the wheel of the North Star', with eight positions on its circumference created by drawing diagonals through the centre in imitation of a compass rose. On each of the eight points were marked the apparent latitude of Lisbon, when the Guards were in any one of these positions at given hours in the night. The latitude of Lisbon was taken to be 39° (actually 38° 44′ N). The navigator, before leaving Lisbon, observed the height of the Pole Star, noting the position of the Guards; then later during his voyage, observed the height of the Pole Star again when the Guards were in the same position. From the difference in the apparent height of the Pole Star, he could calculate the distance he had sailed in a north–south direction since leaving Lisbon. On the other hand if he were to observe the Pole Star at a different time from that at which he had done so in Lisbon, he could calculate the necessary correction.[26] The corrections for the eight positions were thus as follows:

For the north-west/south-east diagonal	±30′
For the north/south diagonal	±3°
For the north-east/south-west diagonal	±3° 30′
For the east/west diagonal	±1° 30′.

There is no clear evidence to show when the method of the 'figure in the sky' or the later one of 'the wheel', both known as the *Regimento do Norte* or 'Rule for the North Star', were first used by Portuguese navigators, but it is conjectured by Luís de Albuquerque that they appeared between 1455 and 1475.[27] The corrections for the Rule of the North Star, though not of great accuracy, were sufficient for sailors and had the advantage of being simple. They appear in both the two booklets of rules for applying nautical astronomy with which we shall deal presently.

As the Portuguese, in their explorations down the west coast of Africa, approached the equator (they crossed it between 1472 and 1474),[28] the Pole Star sank lower and lower to the horizon and eventually ceased to serve them as a guide. It was then that a crucial breakthrough took place, in which observation of the meridian altitude of the Sun was substituted for observation of the height of the Pole Star, thus enabling navigation in either of the two hemispheres. The quadrant proving less suited for observing the Sun, there emerged, at least by the 1480s, the nautical astrolabe of the Portuguese, first described in 1517 by the Italian Alexander Zorzi. This was a simple instrument consisting of a graduated ring and an alidade fitted with two pinnules set relatively close together so that, as Zorzi notes, the observation of the Sun's rays through the pinnules could be more easily stabilised against the rolling of the ship.[29]

The calculation of latitudes by observing meridian altitudes of the Sun, a technique indispensable for astrological prognostications, was known in Europe from at least the XIIth century,[30] but it was never used either for map-making,[31] or for navigation before the XVth. The first texts specifically written for sailors, which expound the rules of procedure for calculating latitudes from the

https://doi.org/10.1017/S0373463397007674 Published online by Cambridge University Press

observation of the meridian altitudes of the Sun, appear in Portugal, printed in Lisbon at the beginning of the XVIth century. These texts were:

(i) *Regimento do astrolabio e do quadrante*, (c. 1509), known as the *Regimento de Munique* since the only known extant copy is in the Bavarian State Library in Munich.
(ii) *Regimento da declinaçam do sol*, (c. 1516), known as the *Regimento de Evora*, as the only extant copy is in the Evora Public Library, Portugal.[32]

The first of these booklets expounds, with numerous examples, a simplified method, using fairly rough approximations; the second attains a much higher degree of precision. While these two booklets were only printed in the first two decades of the XVIth century, there is evidence from the previous century that Portuguese sailors were already using the data and the rules given in them, no doubt in manuscript form. Drawn up specifically for use by sailors, the booklets contain tables of figures from which the declination of the sun can be known at any given date. These tables, indispensable for the calculation of latitudes, were taken from the work of the Spanish Jewish astronomer-astrologer Abraham Zacuto.[33] Born in Salamanca about 1452, Zacuto was the author of a substantial book in Hebrew of some 336 pages, the *Hajibbur hagadol*, of which only nine pages contain the tables necessary for the calculation of latitudes. There is nothing in it relating to the rules of procedure for calculating latitudes,[34] such as are found in the booklets. Such rules however were commonly known to astronomers in the Middle Ages. The Jewish physician José Vizinho, born probably in Vizeu (Portugal), at a date unknown, describing himself as a disciple of Zacuto, made a partial translation from the Hebrew of the *Hajibbur hagadol* and had it printed at Leiria (Portugal) in 1496 with the title of *Almanach Perpetuum*.[35] It was from the tables contained in the *Almanach Perpetuum* that all the nautical tables used by the Portuguese navigators up until the middle of the XVIth century were calculated.

The calculation of latitudes from observation of the meridian altitude of the Sun, as practised by astronomers/astrologers, required a series of relatively complicated operations difficult for sailors to master.[36] The observer must accomplish the following six operations:

(i) Observe the meridian altitude of the Sun.
(ii) Find in the astronomical tables for the day, month and year of the observation, the longitude of the Sun. The term usually employed was the 'place of the sun' in one of the twelve signs of the Zodiac, each sign being divided into 30°.
(iii) Find, in the table provided for this, the declination of the Sun for its longitude on the day, month and year of the observation.
(iv) Carry out a number of arithmetical operations in a formula which depends on the observer's position north or south of the equator and on the direction, north or south of his shadow.

These four operations were to be completed by two further ones in the case of the direct use of Zacuto's *Almanach*:

(v) Since the *Almanach* had been prepared for the period 1473–1476, for each subsequent 4-year period ending in a leap year, one had to add in from the *Almanach*'s *tabula equationis solis* a corrective constant of 1′ 46″ designed to take account of an advance of the sun of 42′ 56″ over the said 4-year period. This advance was caused by the difference between the length of the tropical year in the then used Julian Calendar and the real length of the tropical year in the period concerned.[37]

(vi) As Zacuto's tables of declination only gave the values of the Sun's longitude in whole degrees, one had to make interpolations, which were laborious.

These interpolations, together with the adding in of the constant from the *tabula equationis solis*, rendered the direct use by navigators of Zacuto's *Almanach* exceedingly difficult. In order to simplify these operations for use by sailors, operations (ii) and (iii), in the booklets referred to, were made into one by enabling the determination of declination for each day of the year from a single table. The need to make interpolations (vi) was also eliminated.

In the *Regimento de Munique* (c. 1509), by sacrificing precision, simplification was carried to the point of neglecting the variation in declination over the 4-year period between leap years. The declinations were given on a 'single solar table', calculated for a given year, which scholars have been unable to identify with certainty, but which, according to Luís de Albuquerque, could be some year between 1483 and 1493.[38] Errors due to this simplification remained insignificant in relation to those arising from the readings of the instruments then used.[39] The *Regimento de Evora* (c. 1516), of greater precision, did, on the other hand, take account of the variation in declination during the four-year period for which it was prepared (i.e. 1517–1520). Navigators were thus relieved of the tedious work of having to do themselves the work of bringing Zacuto's tables up-to-date by the adding in of multiples of the constant from the *tabula equationis solis*. The *Regimento de Evora* turns out to be, as we shall see, an example of the model on which were based all the nautical tables used by Portuguese navigators from 1497 up to the middle of the XVIth century.

In trying to follow in detail how the Portuguese monarch's scientific advisers proceeded, we hope to show how the transfer of a technique from the domain of astrologers to that of mariners was achieved. Among these advisers, two were of singular importance: first José Vizinho, then Abraham Zacuto who came to Portugal in 1492; both played key roles. In the marginal notes in certain of his books, Columbus wrote that in 1485, (long before Zacuto's arrival in Portugal), the Portuguese King D. João II. had sent Vizinho 'to observe the height of the sun in the whole of Guinea (i.e. west Africa)',[40] and according to these same notes, that the Portuguese navigator Bartolomeu Dias had, in 1488, observed the latitude of the Cape of Good Hope (by taking the height of the Sun) with an astrolabe.[41] Unfortunately the evidence of Columbus' marginal notes in his books is extremely fragile, since the figures he quotes are always wide of the mark. Either they prove the incompetence of Vizinho and Dias in making their observations, or gross errors by Columbus in copying the figures. Italian scholars prefer the first solution; Portuguese ones the second. No solution to this vexed question appears anywhere in sight.

In the first note Columbus remarks that Vizinho had placed the island of Los Idolos in Guinea in Latitude 5° N and several minutes.[42] It is in fact situated between 9° 25′ N and 9° 32′ N; Vizinho had therefore apparently committed an error of 4° 25′.[43] In his second note, Columbus states that Dias had placed the Cape of Good Hope in Latitude 45° S,[44] whereas in reality it is 34° 22′ S. Whatever may have been the origin of Columbus' errors, confirmation that a systematic survey of the latitudes of places on the west African coast had indeed been undertaken by the Portuguese (but it is not known exactly when), comes from Duarte Pacheco Pereira in his work *Esmeraldo de Situ Orbis*, only written however about 1508. In it he writes that he had 'over a long period of years' in west Africa, 'observed the altitude of the sun and its declination to know in how many degrees each place lay in latitude from the equator toward the poles and that he had found that the circle of the equator passed over the promontory of Lopo Gonçalves' (actually 0° 36′ S).[45] Duarte Pacheco Pereira's survey was probably done, Luís de Albuquerque surmises, between 1485 and 1495.[46]

It can be conjectured that Vizinho's and Pacheco Pereira's task consisted in attempting to correlate the cartography of the traditional Mediterranean type nautical charts with that based on celestially determined coordinates in Ptolemy's *Geography*, copies of which were only to reach Portugal in the second half of the XVth century.[47] The *Geography* was, in the latter part of the XVth century, to provide the Portuguese with a theoretical framework for their projected voyages to India round the Cape of Good Hope.[48] Thus it was important for Pacheco Pereira to situate the equator (a theoretical marker) in relation to a feature of the African coast such as Cape Lopo Gonçalves inscribed (from direct experience) on the traditional nautical charts. Little is known of José Vizinho beyond the fact that he was the translator of Zacuto's book and that he had voyaged to Guinea. In 1483–4, according to the Portuguese historian João de Barros, he was one of a group of cosmographers called upon by the Portuguese King D. João II to examine the feasibility of Columbus' project of reaching Asia by sailing westward.[49] Barros also states that he, as one of the King's physicians, was together with other experts the inventor of 'the manner of navigating with the altitude of the sun, for which they had prepared tables of its declination, such as navigators use at present, now more accurate than at the start'.[50] In the expression 'now more accurate than at the start' (*já mais apuramente do que começou*), can perhaps be discerned a possible distinction between the rough method of approximation of the *Regimento de Munique* (c. 1509), and the more sophisticated one found in the *Regimento de Evora* (c. 1516). Zacuto, it is claimed, was the author of the model followed in the latter, while Vizinho (aided probably by Rodrigo) was the author of the former.[51] The tables in the *Regimento de Munique* were, if we can trust the evidence of Columbus, used for Bartolomeu Dias' voyage (1488), but there is no evidence to show that they had been used during the voyages of Diogo Cão (1484–86),[52] who had reached as far as 22° 10′ S on the coast of present day Namibia.[53]

From 1493, the second of the two important figures, Abraham Zacuto plays the major role. He is the author of the first four-year tables drawn up for use by navigators.[54] Expelled from Spain in 1492 with other Jews, Zacuto was brought to Lisbon by King D. João II, where he resided for four years during the reigns of King D. João II and of his successor King Manuel. In relation to the latter he was termed 'King's Mathematician',[55] and 'King's Astronomer'.[56] Forced to leave Portugal in 1497, he fled to Tunis and later to Damascus where he died in 1522.[57] The little information available on Zacuto's role in the development of nautical science in Portugal appears in Gaspar Correa's chronicle *Lendas da India*, a work whose historical reliability is the subject of contradictory evaluations by Portuguese scholars.[58] Correa was a man of mediocre education and understood little of nautical astronomy. He does, however, explain quite correctly how Zacuto had prepared a set of rules (*Regimento*) consisting of four-year tables of the Sun's declination, but he mistakenly makes Zacuto the inventor of the 'astrolabe' (*sic*) and of the rules for the Pole Star.[59] Zacuto's *Regimento*, referred to by Correa, contained the first 4-year tables drawn up for a period *later* than those for the period 1473–6 given in his major work printed in 1496. They were drawn up for the period 1497–1500 and were prepared by him for Vasco da Gama's voyage (1497) and were also later used for the voyage of Pedro Alvares Cabral (1500).[60] The Spaniard Martín Fernándes de Enciso obtained these tables secretly and published them in his work *Suma de Geographia*, Seville, 1519,[61] and it is from his publication that we know of them. The tables were later translated into English from Enciso's book by Roger Barlow in his manuscript work of 1540–1, *A Brief Summe of Geography*.[62]

If the oldest 4-year tables for navigators stand to be those prepared by Zacuto for Vasco da Gama's voyage, the oldest *printed* 4-year tables are those contained in the *Regimento de Evora* (c. 1516), calculated for the later period of 1517–20. It was thus on Zacuto's model that Portuguese as well as European navigators were to base all their tables until they were eventually replaced by new ones brought out in 1537 by the Portuguese mathematician Pedro Nunes for the period 1537–40.[63]

The precision of Portuguese nautical astronomy in practice was noted in 1505 by the Italian traveller, Lunardo da Chá Masser, who voyaged to the Orient in a Portuguese ship; he wrote:

> The Portuguese navigate by the altitude of the sun or by that of the Pole Star with the aid of an astrolabe. And they are utterly confident while out of sight of land for three months and they know exactly where they are and at the end of a given number of days, I found myself at the intended place of arrival, which is indeed a remarkable thing.[64]

In the southern hemisphere the Portuguese navigator Pero Anes had, by 1508, worked out a rule for navigating by observing the altitude of certain stars of the Southern Cross, as had been done in the northern hemisphere for the Pole Star.[65]

Portuguese nautical science was to spread to the rest of Europe mainly through works written by Spaniards. After Enciso, copied by Barlow, Pedro de Medina's *Arte de Navegar* (1545) went into seven editions in French and Martín Cortés' *Breve Compendio de la Sphera y de la Arte de Navegar* (1551) also went into seven editions in English. Cortés expounds a graphic method of calculating the declination of the Sun, a method first proposed in nautical circles by the Portuguese navigator Francisco Rodrigues (c. 1513).[66]

After a major breakthrough in the XVth century in the application to navigation by Vizinho and Zacuto of astronomical techniques used by astrologers, Iberian progress in nautical astronomy remained limited to improvements in precision in the XVIth and XVIIth centuries. No new major innovations occurred that were usable by navigators. Luís de Albuquerque has written that nautical astronomy only appeared in Portugal when the need for it was felt.[67] The conditions for its emergence were there from at least the XIVth century and existed throughout the XVth century; as Guy Beaujouan has noted, a common fund of Judeo-Luso-Castilian astronomical knowledge ran along what might be described as an axis linking Salamanca to Lisbon.[68] Mariners certainly did not take the initiative in drawing on this fund of knowledge and astronomers/astrologers are hardly likely to have sought to persuade sailors of its advantage to them. Who then was instrumental in getting the two parties to work together? On this crucial point evidence is at present lacking. Our conjecture is that the role of King D. João II is likely to have been central. Only royal command could have made an astrologer/physician like José Vizinho submit to the discomfort of a voyage to Guinea in a caravel in 1485 in order to observe the Sun with a astrolabe.

ACKNOWLEDGEMENT

The reader will observe that this synthesis draws heavily on the very deep and thorough work of the late Professor Luís de Albuquerque whom I was privileged to know and work with over a number of years. What I have written would not have been possible had I not benefited constantly from his immense kindness and generosity in forwarding to me not only copies of his very considerable writings, but also numerous photocopies of rare out-of-print works difficult to find outside Portugal.

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[19] The chart of Pedro Reinel (c. 1504), reproduced in A. Cortesão & A. Teixeira da Mota, (1960). *Portugaliae Monumenta Cartographica*, Lisbon, Vol. I, Pl. III.

[20] A. Fontoura da Costa, (1939). *A Marinharia dos Descobrimentos*, Lisbon, pp. 210–216. A. Teixeira da Mota, (1960); Bartolomeu Dias e o valor do grau terrestre, *Congresso Internacional de História dos Descobrimentos*, Lisbon, *Actas*, Lisbon, (1961), Vol. II, pp. 199–209. Fontoura da Costa took the degree to be equivalent to 111 kms and the Portuguese league as equal to 5920 metres. (Cf. A. Fontoura da Costa, *op. cit.* p. 216.)

[21] C. A. Nallino (1944). Il valor metrico del grado di meridiano secondo i geografi arabi, *Raccolta di scritti editi ed inediti*, Vol. 4, Rome, pp. 412–416.

[22] A. Fontoura da Costa (1938). La lieue marine des portugais aux XVe et XVIe siècle, *Comptes rendus du Congrès International de Géographie*, Amsterdam, Vol. II, p. 7.

[23] Duarte Pacheco Pereira, *Esmeraldo de Situ Orbis* (c. 1508), ed. A. Epifánio da Silva Dias (1905); Lisbon, reprint Lisbon (1975), Liv. I, Cap. 2, p. 23. A. Fontoura da Costa (1939). *A Marinharia dos Descobrimentos*, Lisbon, p. 216.

[24] Armando Cotarelo Valledor (1947). *Nebrija Cientifico*, Madrid, pp. 33–34. Mario Méndez Bejarano (1923). *Diccionario de Escritores, Maestros y Oradores, naturales de Sevilla*, Seville, Tome II, p. 35.

[25] Manuel dos Reis (1961). O Regimento do Norte na astronomia náutica portuguesa da época dos Descobrimentos, *Boletim da Academia das Ciências de Lisboa*, Nova Série, Vol. XXXIII, pp. 108–127.

[26] Luis de Albuquerque (1965). *Os Guias náuticos de Munique e de Evora*, Lisbon, pp. 22–26.

[27] Idem. p. 27.

[28] A. Fontoura da Costa (1938). Descobrimentos marítimos Africanos dos Portugueses com D. Henrique, D. Afonso V e D. João II, *I Congresso da História da Expansão Portuguesa no Mundo*, 1ª Secção, Lisbon, p. 26.

[29] Alesandro Zorzi. Informatiõ hauuto Io Alexandro da Portogalesi .1517. in Veneza, Ms Magl. XIII, 80, fls. 131–140 (v.). Biblioteca Nacional, Florence. Printed in Francisco Leite de Faria & A. Teixeira da Mota, *Novidades Náuticas e Ultramarinas numa Informação dada em Veneza em 1517*, Centro de Estudos da Cartografia Antiga, Vol. XCIX, Lisbon, (1977), p. 20; also in *Memórias da Academia das Ciências de Lisboa*, Tome XX (1977), p. 20.

[30] Cf. Emmanuel Poulle (1971). Les conditions de la navigation astronomique au XVe siècle, *Revista da Universidade de Coimbra*, Vol. 24, p. 35.

[31] Cf. J. K. Wright (1932). Notes on the knowledge of latitudes and longitudes in the Middle Ages, *Isis*, Vol. V, pp. 97–98.

[32] Both works have been reprinted in facsimilé editions by J. Bensaude in the series *Histoire de la Science Nautique Portugaise*, Vols I & II, Munich, (1914); by Luís de Albuquerque, *Os Guias náuticos de Munique e de Evora*, Lisbon, (1965), (transcription of the Munich text with variants and the new chapters in the Evora text); in a facsimilé reprint of the Munich and Evora texts with introduction by Luís de Albuquerque taken from his 1965 work, but lacking Anexos B, C and D and his bibliography = *Guia náutico de Munique e Guia náutico de Evora*, Comissão Nacional para as Comemorações dos Descobrimentos Portugueses & Instituto Nacional de Pilotagem dos Portos, Lisbon, (1991).

[33] J. Bensaude, (1912/17). *L'astronomie nautique au Portugal à l'époque des Grandes Découvertes*, Berne, facsimilé reprint N. Israel, Amsterdam, (1967), p. 26; Luís de Albuquerque, *op. cit.* pp. 76–82. For Emmanuel Poulle, the fact that the longitudes of the sun in the *Regimento de Munique* are given in whole degrees makes it impossible to identify the source. Poulle however sees the source of the *Regimento de Evora* as being the Alphonsine tables, 'without it being necessary to bring in the work of Zacuto' (Emmanuel Poulle, *art. cit.* pp. 43–44). To this point Luís de Albuquerque makes the rejoinder that Valentim Fernandes, who published the same tables as those in the *Regimento de Evora* in his *Reportório dos Tempos* (1518), declares that they had been prepared by Gaspar Nicolas from Zacuto's *Almanach Perpetuum*; Luís de Albuquerque (1977), Abraham Zacuto et l'*Almanach Perpetuum*, Idem. Estudos de História, Coimbra, Vol. V, pp. 61, 66.) Cf. also Valentim Fernandes, *Reportório dos Tempos*, facsimilé ed. by J. Bensaude (1919). *Histoire de la Science Nautique*, Vol. VII, Geneva, p. 52.

[34] J. Bensaude, *L'astronomie nautique au Portugal*..., p. 26.

[35] Francisco Cantera Burgos (1935). *Abraham Zacuto*, Madrid, p. 57.

[36] Cf. on this point A. Fontoura da Costa (1939). *A Marinharia dos Descobrimentos*, Lisbon, p. 91.

[37] Cf. António Barbosa (1928). O *Almanach Perpetuum* de Abraham Zacuto e as Tábuas Náuticas Portuguesas, *O Instituto* vol. 75, pp. 541–562.

[38] Luís de Albuquerque (1977). Abraham Zacuto et l'*Almanach Perpetuum*, Idem. *Estudos de História*, Vol. V, Coimbra, p. 80.

[39] Idem, *op. cit.* p. 76 and J. Bensaude, *L'astronomie nautique au Portugal*, p. 118.

[40] '...*rex Portugaliae misit in Guinea anno Domini 1485 magister Ihosepius, fixicus eius astrologus,* [*ad com*]*piendum altitudinem solis in totta Guinea*...' Note by Columbus in his copy of Pope Pius II's *Historia rerum ubique gestarum*, Venice (1477), reproduced by George E. Nunn, (1924). *The Geographical Conceptions of Columbus*, New York, reprint New York, (1977), pp. 6–7.

[41] '...*hoc anno de .88*...*Bartolomeus Didacus*...*navigaverit*...*usque*...*cabo de Boa Esperança*... *quique in eo loco invenit se distare per astrolabium ultra linea equinoctiali gradus 45*...' Note in Columbus' copy of Pius II, *op. cit.* reproduced by George E. Nunn, in *op. cit.* pp. 7–8.

[42] '...*alliis in die xi marcii invenit se distare ad equinoctiali gradus V minute in insula vocatur de los Idolos*...' Cf. Nunn, *op. cit.* pp. 6–7.

[43] A. Magnaghi (1928). I presunti errori de C. Colombo e la determinazione delle latitudini, *Bollettino de la Reale Società Geografica Italiana*, Vol. IV, pp. 462–463. Magnaghi tries rather unsuccessfully to defend Columbus.

[44] See note 40.

[45] Duarte Pacheco Pereira, *Esmeraldo de Situ Orbis* (c. 1508), ed. A. Epifánio da Silva Dias, Lisbon, (1905), reprint Lisbon, (1975), Liv. II, Cap. 11, p. 127.

[46] Luís de Albuquerque (1965). *Os guias náuticos de Munique e de Evora*, Lisbon, pp. 63–64.

[47] W. G. L. Randles (1986). O redescobrimento da *Geografia* de Ptolemeu na Itália do

Renascimento e o seu impacte em Espanha e Portugal durante os Descobrimentos, *A Abertura do Mundo*, *Estudos de História dos Descobrimentos Europeus*, eds. Francisco Contente Domingues & Luís Filipe Barreto, Vol. I Lisbon, pp. 145–49.

[48] Idem. (1989). La configuration cartographique du continent africain avant et après le voyage de Bartolomeu Dias: hypothèses et enseignements, *Congresso Internacional Bartolomeu Dias e a sua época*, Oporto, Vol. II, pp. 111–119.

[49] João de Barros (1932). *Asia*, Déc. I, Liv. III, Cap. 11, ed. Coimbra, p. 113.

[50] Idem. Déc. I, Liv. IV, Cap. 2, *ed. cit.* p. 127. '...*esta maneira de navegar per altura do sol, de que fizeram suas tavoadas para declinaçam delle: como se ora usa entre os navegantes, já mais apuradamente do que começou*...' Among the other experts were a certain Master Rodrigo of whom nothing is known, and Martin Behaim, of whom Ravenstein, at the beginning of this century, showed that his contribution to Portuguese nautical science was negligible. Cf. E. G. Ravenstein (1908). *Martin Behaim and his Globe*, London.

[51] Luís de Albuquerque (1987). Introduction, facsimile reprint of Abraham Zacuto, *Almanach Perpetuum*, (Leiria, 1496), Imprensa Nacional – Casa da Moeda, Lisbon, p. 47.

[52] A. Fontoura da Costa claims, citing no evidence, that they were so used. Cf. A. Fontoura da Costa, (1939). *A. Marinharia dos Descobrimentos*, Lisbon, p. 95.

[53] W. G. L. Randles (1988). *Bartolomeu Dias and the Discovery of the South-east Passage Linking the Atlantic to the Indian Ocean (1488)*, Centro de Estudos de História e Cartografia Antiga, Vol. 188, Lisbon, p. 22.

[54] Luís de Albuquerque (1977). Abraham Zacuto et l'*Almanach Perpetuum*, Idem. *Estudos de História*, Vol. V, Coimbra, p. 80.

[55] Sousa Viterbo (1898). *Trabalhos náuticos dos Portugueses. Séculos XVI e XVII*, Lisbon, facsimile reprint Imprensa Nacional – Casa da Moeda, Lisbon, (1988), Pt I, p. 326.

[56] Abraham Zacuto (1496). *Almanach Perpetuum*, Leiria, facsimile reprint Lisobn, (1987), *explicit*.

[57] Francisco Cantera Burgos, *op. cit.* pp. 37–39.

[58] A. Fontoura da Costa calls him a writer of 'rare probity' (A. Fontoura da Costa, *A Marinharia dos Descobrimentos*, *ed. cit.* p. 96); Duarte Leite (*História dos Descobrimentos*, Lisbon (1959), Vol. I, p. 143) and Luís de Albuquerque (Abraham Zacuto et l'*Almanach Perpetuum*, Idem. *Estudos de História*, Vol. V, Coimbra, (1977), p. 62) are both perhaps too severe in their criticism.

[59] Gaspar Correa (1898). *Lendas da India*, Tome I, Lisbon, pp. 163–169. The work was written in Goa between 1529 and 1561, but was not printed until the 19th century.

[60] Luciano Pereira da Silva (1945). A Arte de Navegar dos Portugueses desde o Infante a D. João de Castro, Idem. *Obras Completas*, Lisbon, Vol. II, pp. 315–317.

[61] Martin Fernándes de Enciso (1519). *Suma de Geographia*, Seville, sign. a.viii (v.)–b.vii (r.).

[62] Roger Barlow (1932). *A Brief Summe of Geography* ed. with notes by E. G. R. Taylor, Hakluyt Society, 2nd series, Vol. LXIX, London.

[63] Pedro Nunes (1537). *Tratado da Sphera*, Lisbon, Idem. *Obras*, Vol. I, Lisbon, (1940), pp. 233–37.

[64] Lunardo da Chá Masser (c. 1505). Relazione, *Memórias da Academia Real das Sciencias de Lisboa*, Nova Série, Tome VII, Parte I, Lisbon, (1895), pp. 78–79. Observation of the Pole Star with an astrolabe is extremely difficult and much easier with a quadrant or a *balestilha* (Jacob's staff). The first Portuguese reference to the latter occurs in 1514. Cf. Luís de Albuquerque, *Os guias náuticos de Munique e de Evora*, pp. 106–107.

[65] João de Lisboa (c. 1514). *Livro de Marinharia*, ed. Brito Rebelo, Lisbon (1903), p. 22, 37–41; Luís de Albuquerque (1975). A Navegacão astronómica, Idem. *Estudos de História*, Vol. III, Coimbra, pp. 234–255.

[66] Martín Cortes (1551). *Breve Compendio de la Sphera y de la Arte de Navegar*, Seville, Segunda Parte, Cap. VII; Cf. Luís de Albuquerque, *Ibid.* pp. 218–226.

[67] Luís de Albuquerque (1991). *Dúvidas e Certezas na História dos Descobrimentos*, 2ª parte, Lisbon, p. 52.

[68] Guy Beaujouan (1969). *L'astronomie dans la péninsule ibérique à la fin du Moyen Age*, Agrupamento de Estudos de Cartografia Antiga, Vol. XXIV, Coimbra, p. 17.