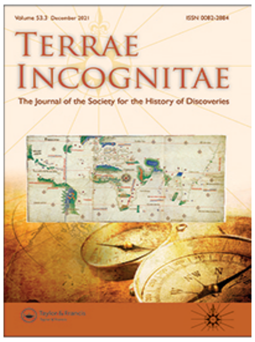

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The Mapping of Africa on the Nautical Charts of the Age of Discovery

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The shape of Africa on Iberian nautical charts of the late-fifteenth and early-sixteenth century is surprisingly mature. The portrayal of the outline of Africa on the Cantino planisphere of 1502 is so good that it was not surpassed in the next two, possibly three centuries. The African coastline on the Cantino planisphere is a mosaic of accurate regional charts on the plate-carrée projection, each with its own scale and orientation. The same holds for its Iberian predecessors. The shape of the parts of Africa depicted on these regional charts was essentially correct on the oldest chart (c. 1471) and was copied to later charts. The projective properties of the regional charts are incompatible with the navigation and charting techniques used in that period. Therefore, serious doubt is cast on the established view that Portuguese pilots and cartographers were the original creators of the source charts.

KEYWORDS Cantino; Africa; cartometric analysis; map projection; nautical chart; Age of Discovery

La forme de l'Afrique sur les cartes nautiques ibériques à la fin du quinzième siècle et au début du seizième siècle est d'une maturité surprenante. La représentation du contour continental de l'Afrique sur le planisphère de Cantino de 1502 est si exacte qu'elle n'a pas été dépassée dans les deux, possiblement trois siècles suivants. L'analyse cartométrique révèle que la côte africaine sur le planisphère de Cantino est une mosaïque d'exactes cartes régionales sur la projection plate-carrée, chacune avec sa propre échelle et orientation. De même pour les prédécesseurs ibériques du planisphère de Cantino. La forme des parties de l'Afrique représentées sur ces cartes régionales était essentiellement correcte sur la plus vieille carte (circa 1471) et a été copiée sur les cartes ultérieures. Les propriétés projectives des cartes régionales sont incompatibles avec les techniques

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de navigation et cartographie de cette époque. Donc, il faut vraiment douter de la thèse établie que les pilotes et cartographes portugais aient été les créateurs originels des cartes des sources.

MOTS CLÉS Cantino, l'Afrique, l'analyse cartométrique, la projection cartographique, la carte nautique, l'Age des découvertes

La forma de África en las cartas náuticas ibéricas de finales del siglo XV y principios del XVI es sorprendentemente madura. La descripción del contorno continental de África en el planisferio de Cantino de 1502 es tan buena que no fue superada en los dos o quizás tres siglos siguientes. El análisis cartométrico revela que la costa africana en el planisferio de Cantino es un mosaico de mapas regionales exactos en proyección plate-carrée, cada uno con su propia escala y orientación. Lo mismo vale para los predecesores ibéricos del planisferio de Cantino. La forma de las partes de África representadas en estas cartas regionales era esencialmente correcta en la carta más antigua (c. 1471) y fue copiada en cartas posteriores. Las propiedades proyectivas de las cartas regionales son incompatibles con las técnicas de navegación y de cartografía utilizadas en ese período. Por lo tanto, se arrojan serias dudas sobre la opinión establecida de que los pilotos y cartógrafos portugueses fueron los creadores originales de las cartas fuente.

PALABRAS CLAVE Cantino, África, análisis cartométrico, proyección cartográfica, carta náutica, Era de los Descubrimientos

Introduction

The Portuguese historian of cartography Armando Cortesão described the Cantino planisphere of 1502 (Figure 1) as "the greatest monument in the history of Portuguese cartography."[1] Despite its Italian name and ownership, the chart was drawn by an anonymous Portuguese cartographer. Its fame rests on its novel interpretation of the world's geography. A striking feature of this chart is the similitude of its portrayal of Africa with that on modern maps. The Cantino planisphere constitutes a clear break with medieval ideas about world geography and with Claudius Ptolemy's world geographic model. It shows the recently discovered parts of the Americas as well as an African continent that can be rounded to reach Asia.

The Cantino planisphere is a manuscript world map or chart of approximately 220 cm × 105 cm drawn on six sheets of vellum in the style of Mediterranean portolan charts. The representation of Southeast Asia appears to be inspired by Ptolemy's *Geography*; the Indian subcontinent may have its origin in Arab or Indian mapping; the Caribbean and the northern coast of South America derives mainly from Spanish sources, while the east coast of Brazil is based on Portuguese data. In the far north, Newfoundland and the southern tip of Greenland may be seen. Newfoundland was

[1] Armando Cortesão, "History of Portuguese Cartography," Volume II (Coimbra: Junta de Investigações do Ultramar – Lisboa, 1971), p. 81.

FIGURE 1 The Cantino planisphere. By courtesy of Biblioteca Estense, Modena, Italy.

discovered by John Cabot, but its rendering on the Cantino planisphere is based on data from Gaspar Corte-Real's exploration journey in 1501. The southern tip of Greenland was also charted by Corte-Real. The Mediterranean, the Black Sea, and the Atlantic coast of Europe appear to have been copied from a Mediterranean portolan chart.[2]

The shape of the Atlantic and Indian Ocean coastlines of Africa on the Cantino planisphere reflects a much higher degree of detail and maturity than the coastlines of the New World. We know the latter was charted at the end of the fifteenth and the beginning of the sixteenth century by Portuguese and Spanish explorers. When the development of cartography is traced through sixteenth, seventeenth, and eighteenth-century maps, a gradual, iterative improvement of, for instance, the portrayal of the Americas and Southeast Asia becomes evident, which was driven by the steady accumulation of new geographical knowledge. The charting of the African coastline on the Cantino planisphere appears to have skipped such a development path. As will be shown in this essay, no development other than a steady extension of the coverage of the African coast took place after 1471. It is true that no charts from the period between 1434 (the rounding of Cape Bojador by Gil Eanes) and 1471 are extant. Although it is tempting to assume a development path in that period of 37 years, it needs to be realized that in that case the coastlines of the New World ought to have reached the same level of maturity in about four decades after their discovery, but that is manifestly not the case. Similarity with the earlier portolan charts of the Mediterranean and the Black Sea springs to mind here. The only obvious flaw in the shape of Africa on the Cantino planisphere appears to be its exaggerated longitudinal extent, which is apparent even to the naked eye. Both the accuracy of the representation of the African coastlines and its longitudinal exaggeration demand an explanation. These aspects will be addressed in this essay through cartometric analysis of the Atlantic and Indian Ocean coasts of Africa depicted on the Cantino planisphere and several other late-fifteenth-century Iberian charts.

[2] https://commons.wikimedia.org/wiki/File:CantinoPlanisphere.png.

Mainly on account of the portrayal of Africa, the Cantino planisphere is widely regarded as the first *latitude chart*, a chart on which the latitudes of the charted points are correct, apart from random measurement errors. The longitudes of points on such a chart are subject to random errors as well as cumulative systematic errors. To the best of my knowledge, the only available English-language cartometric study of the Cantino planisphere is that of Joaquim Alves Gaspar.[3] Gaspar concluded that the Cantino planisphere is indeed a latitude chart and that its longitudinal exaggeration of the African continent is "fully explained by the use of the cartographic methods of the Renaissance, once the effect of [the neglected] magnetic declination has been taken into account."[4] His conclusions are refuted by the results of the analysis presented in the current essay.

The Longitudinal Exaggeration of Africa on the Cantino Planisphere

At first sight, Africa on the Cantino planisphere appears to be quite evenly stretched in east-west direction. This is illustrated in Figure 2, in which the solid line is a modern outline of Africa on the *plate-carrée* projection and the dotted outline protruding from the East African coast is the outline of Africa traced from the Cantino planisphere. The plate-carrée projection is also known as the *equidistant cylindrical projection*, centered on (true-to-scale at) the equator. A chart on this projection is also known as a *plane* or *square chart*; its meridians and parallels form a graticule of squares.

Compressing the Cantino outline of Africa in east-west direction by about 10% (the dashed line in Figure 2) to bring the longitudes of the westernmost and easternmost points of Africa, Cape Verde and Cape Guardafui, into agreement with their correct locations on a modern square chart results in a striking similarity between the compressed Cantino outline and the modern outline of Africa; agreement also occurs at Cape of Good Hope. Small shifts and rotations of large sections of coastline would improve the degree of congruence further. Figure 2 thus suggests that the African coastline on the Cantino planisphere may consist of several regional charts. Therefore, a more detailed cartometric analysis, using the method I developed for my earlier analysis of Mediterranean portolan charts, seems justified.[5] This method allows the boundaries between such regional charts to be determined iteratively by statistical testing; when no regional charts exist, none will be indicated.

Cartometric Analysis

Cartometric analysis is any form of numerical analysis of the geometric properties of a usually historical map or chart. The cartometric process begins with the selection of a large number of corresponding pairs of *identical points*. The X, Y coordinates of every

[3] Joaquim Alves Gaspar, *From the Portolan Chart of the Mediterranean to the Latitude Chart of the Atlantic*, PhD diss., Universidade Nova de Lisboa, Lisbon, 2010. Most of the scholarship on Portuguese nautical charts is written in Portuguese, which has therefore remained largely inaccessible to English-speaking scholars.

[4] Joaquim Alves Gaspar, "Blunders, Errors and Entanglements: Scrutinizing the Cantino Planisphere with a Cartometric Eye," *Imago Mundi* 64, no. 2 (2012), pp. 181, 191.

[5] Roel Nicolai, *A Critical Review of the Hypothesis of a Medieval Origin for Portolan Charts*, PhD diss. (Houten: Uitgeverij Educatieve Media, 2014), pp. 200–210.

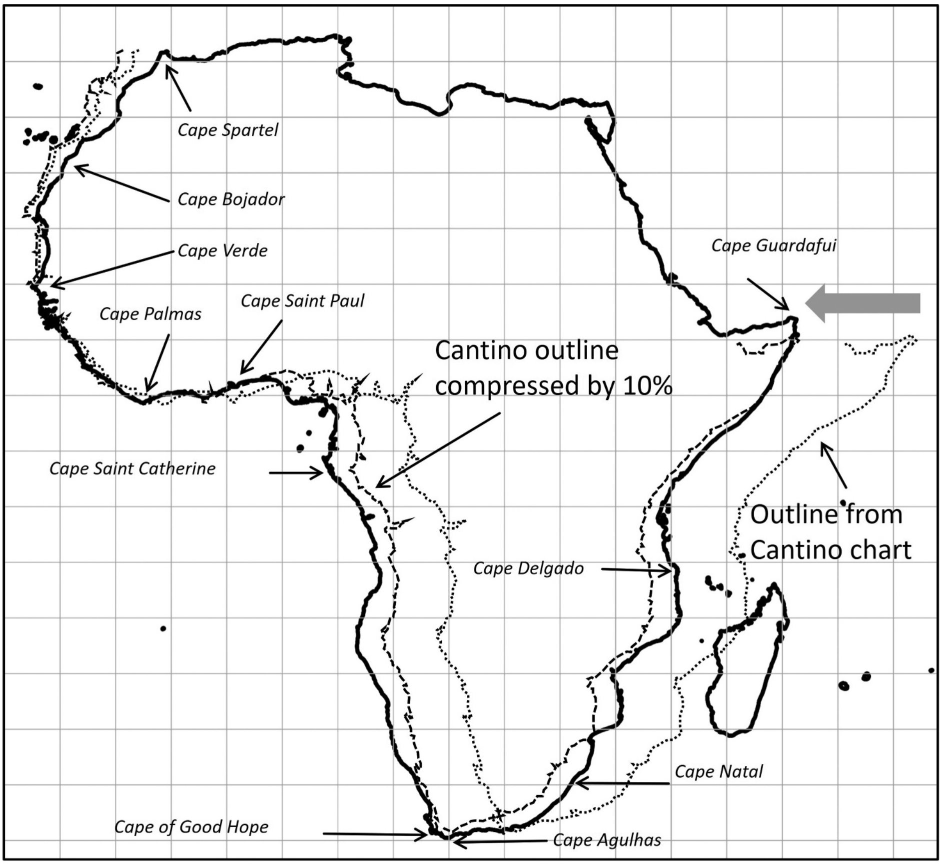

FIGURE 2 The longitudinal stretch of Africa on the Cantino planisphere. The locations of the headlands mentioned in this essay are shown. The reference map (bold black outline) is a square chart; the graticule has latitude and longitude intervals of 5°.

identical point on the historical map are measured, as well as the latitude and longitude of each corresponding point on the reference map. My method consists of best-fitting a historical map or chart to a reference map or, rather, a digital reference dataset. Usage of the latter allows the reference map to be expressed in any map projection by computation. The good fit of the African continent on the east-west-compressed Cantino planisphere with a modern square chart of Africa (Figure 2) suggests the plate-carrée projection. The parameters to be determined to achieve the best fit are the shift, rotation, and separate scale factors in the X and Y directions. The east-west stretch of Africa on the Cantino planisphere results in a different east-west and north-south scale, which must be resolved separately. I identified 286 identical points on the Cantino planisphere, using the software package MapAnalyst to measure their coordinates.[6] I used my own software to calculate from those coordinates the best estimates for the X and Y shifts, the rotation, and the scale

[6] Bernhard Jenny, "MapAnalyst - A digital tool for the analysis of the planimetric accuracy of historical maps," *e-Perimetron* 1 (2006), Nr 3: pp. 239–245.

factors. These define a transformation, which relates the geometry of the historical chart with that of a modern reference chart and allows the latitude and longitude of any point on the historical chart to be computed from its X, Y coordinates and vice versa. This process is also called *georeferencing* the (historical) map or chart.

Even after *best-fitting* the historical chart to the reference map, differences, called *residuals*, remain between the positions of each identical point on the transformed historical chart and the reference map. Best-fitting through least-squares estimation implies that the computed transformation minimizes the sum of the squared residuals. If the map projections of the historical map and the reference map are the same or sufficiently compatible and there is no significant distortion of the map carrier (vellum in this case), the residuals of the chart will reflect the chart's accuracy, which can be represented by the square root of the mean of the squared residuals, also known as the *Root Mean Squared Error* (RMSE). The RMSE values have been computed separately for latitude and longitude.

Africa on the Cantino Planisphere: A Mosaic of Regional Charts

Calculating the best fit for the African Atlantic coastline south of Cape Bojador optimizes the fit of that coastline section to the reference map but results in significant deviations of the other sections of the African coast from the reference map (Figure 3). This may be likened to attempts to lay rectangular carpeting in a room that is not quite rectangular. Optimizing the fit along one wall will result in a poor fit along the other walls, evidenced by a surplus or shortage of carpeting along those walls. In Figure 3, this is reflected by a regional clustering of residuals of identical points. The mean of the point residuals on the Atlantic coast is zero, but point residuals of other regions form clusters away from zero, demonstrating that the African identical points on the Cantino chart consist of several distinct, regional subsets. The existence of at least five of those can be deduced from Figure 3. I stress that Figures 2 and 3 do not represent the final results of my analysis, but the beginning; their function is to establish the best cartometric analysis approach.

The next step, calculating the best fit for each subset separately, produces the shift, orientation, scale, and east-west stretch of the transformation for that subset. The criterion for establishing the endpoint of one regional subset of points and the start of the adjacent subset is the size of the residual of the first identical point of the adjacent subset against a statistically defined threshold value.

This refined analysis allows more subsets to be identified. The African Atlantic coast splits into two; from Cape Bojador to Cape Saint Paul, 60 km east of the Portuguese fort of São Jorge da Mina at present-day Elmina, Ghana, and from Lagos, Nigeria up to Lüderitz, Namibia. These two subsets have nearly the same scale and orientation but are shifted slightly relative to one another. A small coastal section from Lagos to Cape Saint Catherine (Gabon) deviates in that it has a significantly larger north-south scale. Whether this should be counted as a separate regional subset or merely as a scale correction of the northern part of the Central African coastline cannot be established unequivocally. With the possible exception of this section, the internal consistency of the geometry of each region and the step changes in the shift, orientation, and scale between

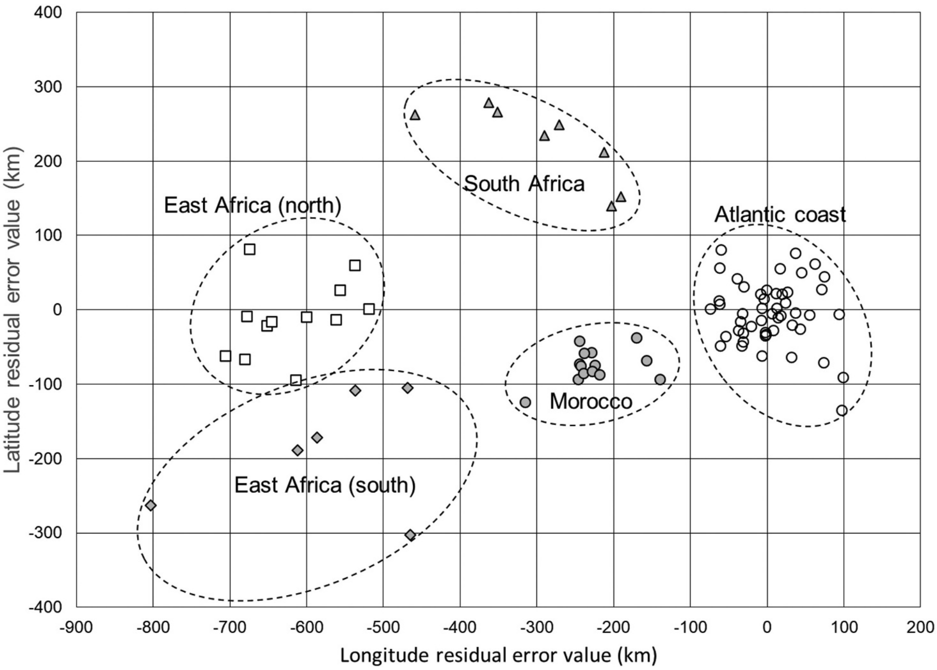

FIGURE 3 Clustering of residuals after best-fitting the Atlantic coastline of the Cantino planisphere between Cape Bojador and Lüderitz to the reference chart.

regions justify the conclusion that each subset of identical points corresponds to a separate regional chart.

East Africa has been computed as a single region in the best-fit calculation, although the residuals of the identical points indicate that this region splits into two with a boundary slightly north of Cape Delgado. However, computing these datasets as two separate units results in numerically unstable solutions for the orientation and scale factors, particularly for the section north of Cape Delgado, because of its small number of identifiable points, their poorer fit, and the poor geometry of those points (almost on a straight line). In Figure 5, which shows the division of Africa in regional charts, the split between these regions is indicated by a dashed line. A strong similarity thus exists with Mediterranean portolan charts, which are also mosaics of regional charts.[7]

The internal consistency of each regional chart is very good, as witnessed by the low values of RMSE for latitude and longitude per regional chart, shown in Figure 6. An exception is the Indian Ocean coast north of Cape Delgado; its accuracy is considerably worse than that of the rest of the African coast. In contrast, the RMSE values computed for the whole of Africa from Cape Bojador to Cape Guardafui, treated as a single chart, are 60 km (latitude) and 118 km (longitude). A strong reduction in RMSE values, as is visible for the regional charts, only occurs when the set of identical points consists of subsets with sufficiently different characteristics. The scale of Africa

[7] Nicolai, *A Critical Review*, pp. 211–270.

on the Cantino planisphere is about 1:13 million at the equator; 1 mm on the chart corresponds to 13 km in the real world. Surprisingly, the latitude accuracy is worse than the longitude accuracy for all regional charts of the Cantino planisphere except the Moroccan. The opposite would be expected because latitude could be measured reliably and accurately owing to Portuguese innovations in ocean navigation, but longitude had to be estimated indirectly and was subject to large cumulative errors until the longitude problem was solved in the eighteenth century.[8]

An east-west stretch of 13% was computed for the West African regional chart (Cape Bojador to Cape Saint Paul). The identical points on the Central African Atlantic coast are almost on a north-south line, which precludes reliable calculation of a separate east-west scale factor. A similar situation exists for the South African regional chart, but here the north-south extent hinges on a single point, Cape Natal, farthest to the northeast in the dataset. This too is insufficient for reliable calculation of the second scale factor. The scale of the South African and East African regional charts is 6–7% smaller than that of the West and Central African regional charts. The East African regional chart has an east-west stretch factor of 9%.

The longitudinal exaggeration of the African continent on the Cantino planisphere of about 10% is therefore due partly to the regional charts having been arranged in a mosaic with too large an east-west extent and partly to the east-west stretch of each individual regional chart for which an east-west scale factor could be computed.

The Moroccan Atlantic Coast and the Canary Islands

Figure 2 shows that the Moroccan Atlantic coastline on the Cantino planisphere diverges from the reference coastline; the 10% east-west compression of the "Cantino outline" exacerbates this divergence. While the net east-west stretch of the West African regional chart computes as 13%, the Moroccan regional chart has a net *compression* of 7% relative to the reference map. This appears to be caused by the Moroccan Atlantic coastline having been copied from a Mediterranean portolan chart, along with the Mediterranean, the Black Sea, and the European Atlantic coasts. It results in the east-west extent being compressed rather than stretched. The Moroccan Atlantic coastline from Cape Spartel to Cape Bojador features on many medieval portolan charts. Portolan charts are mosaics of regional charts, one of which covers the Atlantic Moroccan coast.

The coastline shape on the Moroccan regional chart of Mediterranean portolan charts agrees well with a modern map on the equidistant cylindrical projection with a true-to-scale parallel of 32°N, the mid-latitude of this coastal section.[9]This projection generates a graticule of rectangles. The length of a degree of longitude divided by the length of a degree of latitude at 32°N equals 0.85.[10] Consequently, a chart on this equidistant cylindrical projection will appear compressed by 15% in east-west direction when

[8] Derek Howse, *Greenwich Time and the Discovery of Longitude* (Oxford: Oxford University Press, 1980), pp. 68–73.

[9] While the Mercator projection may yield the best fit for the regional charts of Mediterranean portolan charts, at the accuracy level of those charts it is practically indistinguishable from the equidistant cylindrical projection with its true-to-scale parallel at the mid-latitude of an area with a small latitude extent.

[10] The factor of 0.85 is the cosine of 32°N.

compared with the square chart of Figure 2 with its graticule of squares, on which one degree of longitude has the same length as one degree of latitude everywhere on the chart (see also Figure 8). Had the Moroccan regional chart of the Cantino planisphere been copied from a Mediterranean portolan chart without modifications other than its scale, this east-west compression of 15% would have shown up in the cartometric analysis. However, if it were stretched in the east-west direction at the time it was copied, the net amount of compression would be less than 15%. The net compression computed by cartometric analysis is indeed less, viz. 7%, which corresponds with a stretch of 9.7% of the Moroccan coastline in the copying process from the portolan chart.[11] This agrees with the mean stretch for the whole African continent on the Cantino planisphere.

The mapping of the Canary Islands and Madeira is consistent with the Moroccan regional chart, to which they belong unequivocally. Their locations are compressed in east-west direction relative to the Moroccan coastline by the same 7%.

FIGURE 4 Mosaic of regional charts of Cantino Planisphere, rotated, shifted and subjected to east-west stretch, as calculated for each of the regional charts.

[11] This is computed as follows: 0.85*1.097 = 0.93 = 1–0.07. The last number is the 7% compression that was computed.

The Predecessors of the Cantino Planisphere

The Cantino planisphere's Iberian predecessors may shed more light on the longitudinal exaggeration and the division into such accurate regional charts. Only the following three complete Portuguese charts have survived.

1. The anonymous chart referred to as the "Modena" chart is widely considered to be the oldest-surviving Portuguese chart and is estimated to date from c. 1471.[12] It shows the African Atlantic coast from Cape Spartel to the lagoon of Lagos, Nigeria, and the European Atlantic coast up to Normandy, France. It measures 62 cm × 73 cm and is held at Biblioteca Estense, Modena, Italy.[13]

2. Pedro Reinel's chart has been dated to the period 1484–92 and shows the African Atlantic coast down to the Congo River, reached by Diogo Cão in 1483,[14] and the European Atlantic coast, as well as part of the western Mediterranean. It measures 71 cm × 94 cm and is held at Archives Départementales de la Gironde, Bordeaux, France.[15]

3. Jorge de Aguiar's chart is the earliest Portuguese chart that is both signed and dated (1492). The African coast is shown from Cape Spartel to Elmina, Ghana, and the chart includes the Mediterranean, the Black Sea, and the Atlantic European coast. It measures 77 cm × 103 cm and is held at Beinecke Rare Book and Manuscript Library, University of Yale, New Haven, USA.[16]

A chart that might not be Portuguese but is relevant for this analysis is the "Columbus map," which shows strong Portuguese influences in its coastal outlines. The French historian Charles de la Roncière claimed in 1924 that the chart was drawn by Christopher Columbus and his brother Bartholomew. While his claim has been contested by many historians, the name has stuck, be it in quotation marks. The chart probably dates from some time between 1488 and 1503.[17] It shows the African Atlantic coast between Cape Spartel and Luanda, Angola, as well as the European Atlantic coast, the Mediterranean and the Black Sea. It measures 70 cm × 112 cm and is held at Bibliothèque nationale de France, Paris, France.[18]

Another highly relevant map or chart is the planisphere or world map of Juan de la Cosa, held at the Museo Naval de Madrid, Madrid, Spain. It dates from 1500 and measures 96 cm × 183 cm.[19] La Cosa was a Basque pilot and the owner and master of the "Santa Maria." He accompanied Columbus on his first and second voyages to the New World. The date and authorship of his planisphere have been the subject of much debate. Arthur Davies has suggested that La Cosa did not draw the entire map himself,

[12] Alfredo Pinheiro Marques, "The dating of the oldest Portuguese charts," *Imago Mundi* 41 (1989), pp. 87–90.
[13] https://en.wikipedia.org/wiki/File:Anonymous_Portuguese_map_c.1471_(Estense).jpg
[14] Marques, "The dating," pp. 90–93.
[15] https://archives.gironde.fr/archives/fonds/FRAD033_IR_2Fi/view:144829
[16] https://brbl-zoom.library.yale.edu/viewer/1027151.
[17] Evelyn Edson, *The World Map 1300–1492. The persistence of Tradition and Transformation* (Baltimore: The Johns Hopkins University Press, 2007), pp. 211–214.
[18] https://gallica.bnf.fr/ark:/12148/btv1b59062629/f1.item
[19] https://commons.wikimedia.org/wiki/File:1500_map_by_Juan_de_la_Cosa.jpg.

but only the coasts of the New World, commissioning the drawing of the Old World to an unknown cartographer as he left Spain on an expedition to Colombia (Darién) with Rodrigo de Bastidas in October 1500.[20] Although La Cosa's chart shows the entire African continent, the coastline is realistically rendered only down to Cape of Good Hope. The Indian Ocean coast is based on imagination and was possibly inspired by Henricus Martellus's 1489 world map.[21] Although La Cosa's chart is Spanish, it is generally accepted that its Atlantic African coast can only be of Portuguese origin

I subjected the five charts described above to the same cartometric analysis as the Cantino planisphere, that is, solving for a shift, a rotation, and, if possible, two scale factors. All five charts show the same characteristics as the Cantino planisphere in that several coherent subsets of identical points can be distinguished, each with its own scale and orientation and thus likely corresponding to a regional chart. Although there is no

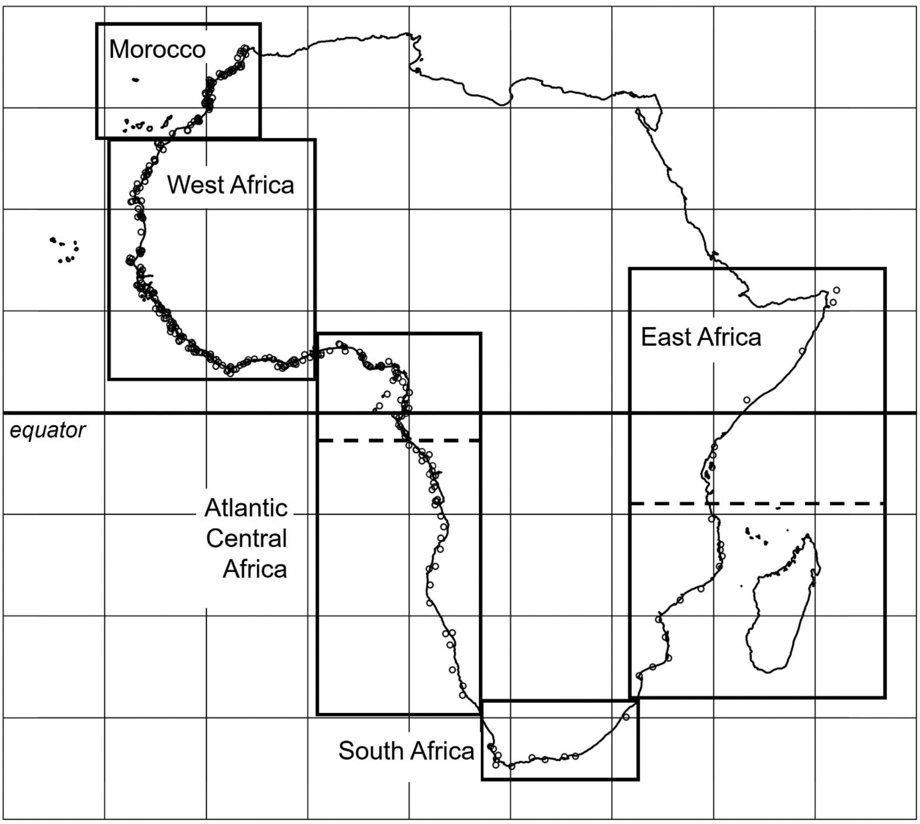

FIGURE 5 Identical points of all six nautical charts analyzed, transformed to the reference plane chart, and the division into regional charts. The graticule interval is 10°, which corresponds with about 1100 km at the equator.

[20] Arthur Davies, "The date of Juan de la Cosa's world map and its implications for American discovery," *The Geographic Journal* 142, no. 1 (1976), pp.111–116.

[21] Armando Cortesão, *History of Portuguese Cartography*, Vol. 1 (Coimbra: Junta de Investigações de Ultramar-Lisboa, 1969), p. 133.

perfect agreement between the regional charts regarding their precise coverage, there is considerable correlation. Figure 5 shows the identical points of all six charts, transformed to latitude and longitude according to the properties of their respective regional charts. Particularly the dense clustering of points on the West African coastline shows that the same charting of the coastline was used from the "Modena" chart onward. Following the African coastline anti-clockwise, the following regional charts may be distinguished.

(1) The Moroccan Atlantic coast, from Cape Spartel to Cape Bojador, the Canary Islands, and the Madeira group (all charts).
(2) The West African coast, from Cape Bojador to approximately Elmina ("Modena", Aguiar, La Cosa, and Cantino).
(3) The Central African coast, from Elmina to the Congo River (Reinel) or Saint Helena Bay (La Cosa and Cantino).
(4) The South African coast, from Saint Helena Bay to Cape Natal near present-day Durban, South Africa (Cantino).
(5) The southern part of the African east coast, from Cape Natal to just north of Cape Delgado (Cantino).
(6) The northern part of the African east coast, from Cape Delgado to Cape Guardafui (Cantino).

The "Columbus map" shows a slightly different division between the West and Central African regional charts. It is the only chart where a clear overlap zone exists between these two regional subsets of points, viz. between present-day Freetown and a location some distance west of the mouth of the Sassandra River. This appears to be a transition zone in which the cartographer corrected the overlapping section of the coastline in both point subsets to achieve a smooth join.

The Mediterranean, the Black Sea, and the European Atlantic coasts were analyzed for the Cantino, the Aguiar, and the "Columbus" charts, which confirmed their composition as a mosaic of separate regional charts, corresponding with the division I found earlier and thus suggesting that these regions were copied from a medieval portolan chart.[22]

The RMSE accuracy of all African regional charts is expressed graphically in Figure 6. While some variation can be seen, the accuracies are similar to what was found for the Cantino planisphere, except for La Cosa's planisphere, which is much coarser.

The Orientation of the Regional Charts

Figure 7 shows the rotation angles computed for all regional charts. The Moroccan chart, with the Canary Islands and Madeira, shows a rotation between +1.6° and −1.8°. Magnetic declination in the past can be estimated using a paleomagnetic model. I used the CALS3k.4 model for my analysis.[23] Magnetic declination along the Moroccan coast

[22] Nicolai, *A Critical Review*, pp. 228–262.
[23] Monika Korte, Catherine Constable, "Improving geomagnetic field reconstructions for 0–3 ka," *Physics of the Earth and Planetary Interiors* 188 nos. 3–4 (2011), pp. 247–259.

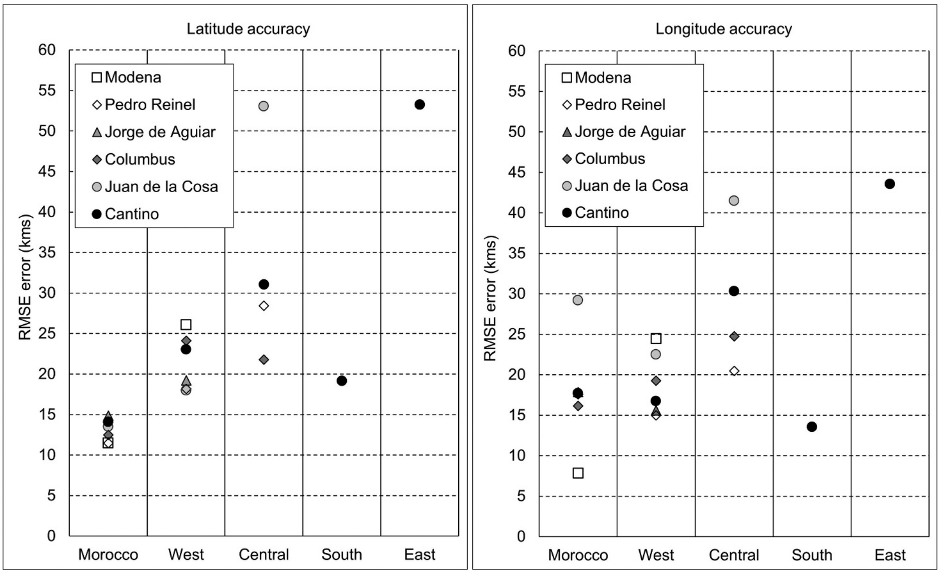

FIGURE 6 RMSE accuracy values representing latitude (left) and longitude (right) for all regional charts analyzed.

in the middle of the fifteenth century was between −8.0° and −8.5° (that is, easterly), which demonstrates that this coastal section was not charted using dead-reckoning navigation data from the fifteenth century. In that case, a much larger anticlockwise rotation angle would have been present because the rotational effect of magnetic declination would have been exacerbated by the effects of plane charting. While these errors are not constant along any long section of coastline and will cause deformation of its shape on the chart, the Moroccan Atlantic coastline is short enough for plane charting errors to look superficially like a rotation of about −4.5°, which would add to the magnetic declination to a total rotation of about −13° (I calculated these values). Neither could it have been surveyed in the early fourteenth century, when this area was portrayed on portolan charts for the first time, because magnetic declination was around −7° at that time. This effect is explained in more detail in the next section.

The rotation of the West African regional dataset is quite constant, about −7° (= anticlockwise) on four of the six charts, but the Cantino planisphere and Reinel's chart deviate with values of −3.3° and −4.7°, respectively.

In 1485, the Portuguese King João II commissioned his astronomer/astrologer José Vizinho to take latitude measurements in "Guinea," that is, West Africa. This survey might have offered a plausible explanation for the orientation correction of Africa on the Cantino planisphere compared to the earlier charts, but the (residual) rotation of -3.3° invalidates that explanation. Our only knowledge of this survey comes from a handwritten note in the margin in one of Columbus's books.[24] It is not

[24] William G.L. Randles, "From the Mediterranean portulan chart to the marine world chart of the Great Discoveries: the crisis in cartography in the sixteenth century," *Imago Mundi* 40 (1988), p. 116.

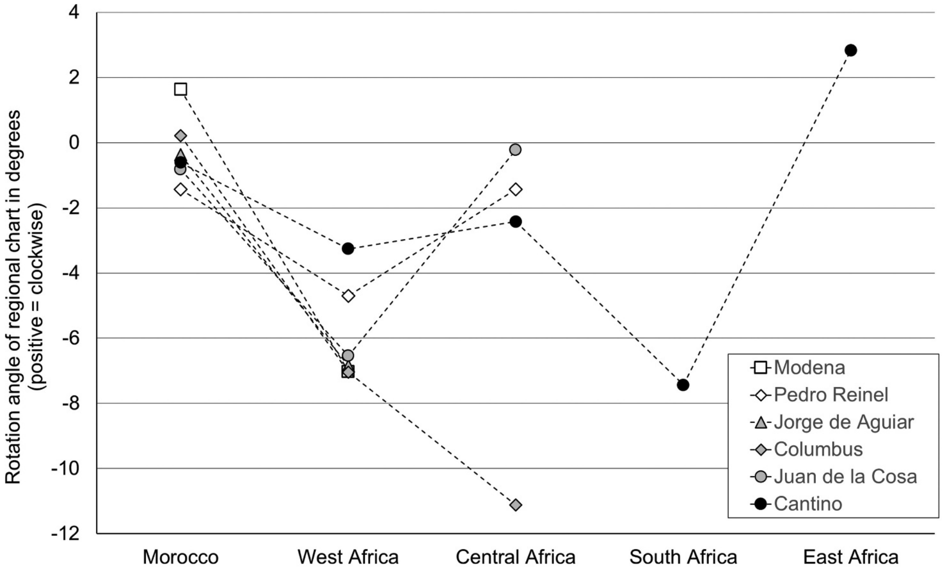

Figure 7 Rotations of regional charts in degrees. Positive rotation angles are clockwise.

known how many points the survey comprised and what area was covered, but, assuming he managed to survey a significant number of points, and considering he was an experienced astronomer, latitude errors in Vizinho's survey do not seem a likely explanation either for the residual rotation of −3.3°. The fact that the whole of West Africa south of Cape Bojador is rotated by this angle makes it even less likely. The deviating rotation angle of Reinel's chart (−4.7°) cannot be explained from presumed navigation or astronomic measurements either.

The commonly adopted explanation for the anticlockwise rotation of West Africa on the predecessors of the Cantino planisphere is that the mapping of West Africa on these charts is the result of surveys based on *dead-reckoning* navigation.[25] With this navigation technique, the pilot works out the change in the ship's position by magnetic course angle and estimated distance sailed. In the period under consideration that was done by plane charting. Proponents of this hypothesis point out that the rotation angle of −7° agrees well with the average magnetic declination. However, such reasoning overlooks the additional errors caused by plane charting of such a large area, as mentioned above, and by *variations* in magnetic declination along the coastline. This would have resulted in a considerably greater rotation angle, as well as distortion of the "Guinea" coastline. Starting an imaginary journey at Cape Spartel, the longitude error due to plane charting alone, that is, without magnetic declination, would accumulate from zero at Cape Spartel to 153 km at Cape Verde and, from there, would gradually reduce to 130–140 km along the Central-African coast. The presence of magnetic declination would introduce further errors, and its spatial variations would distort the coastline shape.

[25] Gaspar, "Blunders," pp. 190, 191; Randles, "From the Mediterranean," p. 116. Randles states that the Portuguese historian Teixeira da Mota expresses this view.

None of these errors is visible on the charts analyzed. The combination of dead-reckoning data and plane charting can therefore explain neither the shape nor the orientation of the West African coastline on the Iberian nautical charts.

The orientations of the Central African regional charts show more variation, with the "Columbus map" as a spectacular outlier. Experimentation to create a better mosaic by the cartographers, a simple lack of supplementary data, or the use of erroneous information from pilots are possible explanations.

Interlude; Plane Charting and Plane Charts

A commonly encountered misconception among historians of cartography is the idea that *plane charting* will result in a *plane* or *square chart*, that is, a chart on the plate-carrée projection. Gaspar argued quite strongly against this idea, as did I.[26] The name similarity between these two different concepts might have contributed to this incorrect belief. This misunderstanding plays a key role in the views that have been expressed about Portuguese nautical charts, as described in the previous section.

This can be explained as follows. Let an imaginary fifteenth-century Portuguese ship lay a south-southwesterly course from a location west of Cape Spartel (point A), as shown in Figure 8, its pilot measuring the latitude at points A and B. Using the Portuguese method of navigation, the pilot will intersect the parallel of point B with the course line to establish the location of point B. The left-hand picture attempts to convey the "correct" image as it would look like on the spherical earth. At the mid-latitude between points A and B, one degree of latitude is about 111 km, but, due to meridian convergence, one degree of longitude is about 94 km. The geometry of the small area of the sphere that this example describes is well represented by a chart on the equidistant cylindrical projection centered on the mid-latitude of A and B. I need to stress that this chart *does* take the effects of the curvature of the earth's surface into account by expressing the closer spacing of the meridians compared to the spacing of the parallels. This chart has a rectangular graticule of which the distance between the meridians is about 0.85 times the distance between the parallels (94/111). This is shown in the middle of the three images of Figure 8. If the fifteenth-century pilot would have had access to such a chart, he would have plotted the position of point B with only a small error, due to this chart's good approximation of the curved geometry of the earth's surface. Pedro Nunes proposed that the Portuguese pilots would use such charts instead of the square chart with an assumed implicit square grid.[27] That would have required the earth to be divided into latitude bands and the ship to use the chart that belonged to the latitude band in which it was sailing. Unfortunately, Nunes's idea never caught on and the Portuguese pilots continued to use the square chart with its implicit square grid. The error made as a consequence of this is shown on the right-hand image of Figure 8 as the distance between points B and B'. The only difference between the chart shown in the middle of Figure 8 and the square chart on the right is that the square chart is stretched in east-west direction such that the graticule becomes square. Had the

[26] Gaspar, *From the Portolan Chart*, pp. 33, 34; Joaquim Alves Gaspar, "The Myth of the Square Chart", *e-Perimetron*, Vol. 2, no. 2, (2007), pp. 66–79; Nicolai, *A Critical Review*, pp.70–81.

[27] Gaspar, *From the portolan chart*, pp. 27, 28.

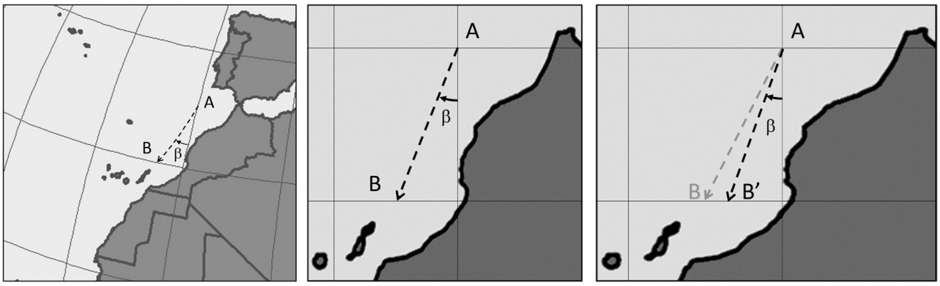

FIGURE 8 Straight course of an imaginary ship from A to B on the sphere (left), on a chart on the equidistant cylindrical projection centered on the mid-latitude of track AB (middle) and on a plane chart (right).

topography been rendered correctly on such a chart (which was not the case on charts from the Age of Discovery), the topography would have been stretched along with the chart and so would the (correct) track of the Portuguese ship. Due to the stretch, the angle of the ship's track with the meridians would be greater than on the chart in the middle. This is the crux of the problem: the Portuguese pilots did not understand that the east-west stretch of the square chart affected course angles, which they plotted on the chart as these were measured on the ship's compass. In Figure 8 this would have resulted in an erroneous position B', which would be east of the correct location of point B, indicated in gray. Since this error would never be undone, it would keep accumulating as our imaginary ship sails further along the African coast. After rounding the southern tip of Africa, the direction of the longitude error reverses; along the Indian Ocean coast it becomes a westerly error. A chart constructed according to this erroneous principle should never be considered to be a true square chart. It will have inherent distortions compared to a true square chart.

These distortions due to plane charting – and this holds for both the Portuguese method of navigation and dead-reckoning – may increase or decrease as a result of ignored magnetic declination. The longitude errors introduced by magnetic declination are shown in Figure 11 below. Because magnetic declination was easterly in the Atlantic Ocean in the fifteenth century it exacerbated the errors due to plane charting along the Atlantic coast, except along the south coast of West Africa. That is why Figure 12 shows a West African coastline that flexes east considerably, compared to the coastline on the Cantino planisphere.

Scale Variations of Regional Charts

The scale of a regional chart may be expressed as its latitude scale relative to the latitude scale of the most consistent regional chart on that nautical chart, which is the West African. In Figure 9 the (reference) scale of West Africa is therefore shown as 100% for all charts. The east-west scale is unusable because of its variations between most regional charts. The scale variations relative to West Africa on a single chart are shown by column; similar regions are indicated by the same symbol.

The scale consistency of the Atlantic coast of Africa on the Cantino planisphere is very good, but South and East Africa are 6–7% too small. On La Cosa's chart, the Central African coast, which runs down to Cape of Good Hope, is 24% too small. However, on the "Columbus map" the Central African regional chart is 29% too large (and its rotation is excessive, as shown in Figure 7). On four of the six charts Morocco is too small, but on the "Modena chart" it is 16% too large. The Mediterranean and the Black Sea, which were treated as a single region to simplify comparison, are 6-10% too large compared to West Africa on the three charts for which that region was analyzed.

The conclusion that can be drawn from these large variations in scale (and orientation) is that cartographers were unsure of the exact dimensions (and orientation) of each region. This is reinforced by variations in the length of the scale bars on the charts. The scale bars on the Iberian charts not only follow the style of the Mediterranean portolan charts, but their base unit *is* the "portolan mile" of the Mediterranean charts. The Portuguese used the Castilian league as their unit of length and reckoned, in general, four miles to the league. The scale differences that have been discussed so far were derived from the coastline topography on the charts. Considering all scale bars to express distances relative to the topography of West Africa, the mean league length on the scale bars of all six charts is 5,590 m, with variations from −4% to +3% of this mean.[28] That may be small compared to the scale variations of the regional charts, but it emphasizes the postulated uncertainty of the cartographers regarding the scale of the charts. I stress that the value of 5,590 m for the league was derived using modern knowledge of the topography of West Africa and the size of the Earth, which was unavailable to fifteenth-century Iberian pilots. The question of how long *they* believed the league to be cannot, therefore, be answered.

Some writers pay considerable attention to the question of the number of leagues per degree of latitude (lg/deg) valid for a given nautical chart, but that idea presupposes that the cartographer constructed the chart from a scale bar and that is invalidated by the variations in the length of the scale bars. Three so-called *modules* were published in sixteenth-century navigation manuals. The oldest is 16⅔ lg/deg. A module of 17½ lg/deg was the most often published value in the sixteenth century and a module of 18 lg/deg is mentioned sporadically.[29] While the first module appears to be a corrupted interpretation of the results of the degree measurement in the Syrian Desert near Raqqa under the Abbasid caliphate in the early ninth-century CE, the provenance of the other two modules is not known.[30]

Gaspar and, before him, Salvador García Franco (1957) found considerable variations in the number of leagues per degree on Iberian charts, ranging from 16.2 to 20 lg/deg. Both Franco and Gaspar calculated these values by dividing the length of one degree on the latitude scale of those charts by the length of a league on a scale bar of the same chart. Gaspar attributed these variations to one or more of the following factors: errors by the cartographer, imprecision in the drawing of the scale bars,

[28] With the Mediterranean being about 8% larger than West Africa (Figure 7), the mean mile length is 1,397.5 m, leading to a mean length of the Castilian league of 5,590 m. Correcting for the 8% larger scale of the Mediterranean reduces the mean mile to 1,294 m, which points to the portolan mile (c. 1,250 m) as the basis of the *tronca das leguas*, the scale bar on Portuguese charts, rather than the Italian mile of 1,480 m, claimed by Joaquim Alves Gaspar in "How large was the world in the sixteenth century? The Length of the Degree of Latitude in the Iberian Cartography of the Renaissance," *The Cartographic Journal* 52, no. 4 (2015), p. 319.

[29] Joaquim Alves Gaspar, "How large," p. 320. Gaspar lists the lg/deg module for a large number of Iberian charts and includes a similar list created by Franco.

[30] Paul Lunde, "Al-Farghani and the 'short degree'," *Saudi-Aramco World*, May-June 1992.

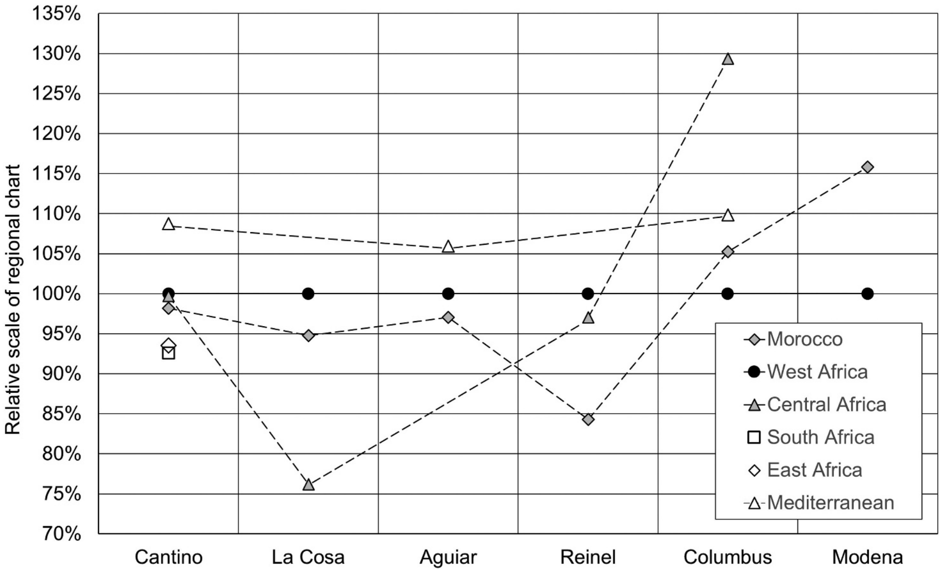

FIGURE 9 Scale of regional charts relative to West Africa on each nautical chart. Note that the axes definitions are different from Figures 6 and 7. Dashed lines in this figure connect similar regions on the various charts.

distortions in the vellum, and/or significant uncertainty in many measurements. However, Figure 9 suggests a perhaps more fundamental reason. Regional scale variations, which presumably did not vanish from charts produced after the Cantino planisphere, will frustrate attempts to establish a single degree-to-league ratio per chart. The variations found in the length of the scale bars on the charts alone (-4% to +3%) make the 16⅔, 17½, and 18 lg/deg modules practically indistinguishable.

The variations in scale and orientation reported in this essay only make sense if the nautical charts were constructed from a set of regional charts of which scale and orientation were poorly known. One might be inclined to think that the variation in the scale of Central Africa of 24% (too small) on the La Cosa planisphere and 29% (too large) on the "Columbus map" might have been found easily from only a few good latitude observations in Central Africa. However, the La Cosa planisphere is not Portuguese and the cartographer may not have had access to Portuguese latitude data. We do not know where to place the "Columbus map" in this respect. Were reliable latitude observations still uncommon at the time? Did cartographers not have access to all data or did they selectively disregard pilots' results? Or were they overwhelmed by the contradictions in the data?

The Longitudinal Exaggeration of Africa on Thirteen Maps and Charts

To understand why Africa on the Cantino planisphere has a longitudinal exaggeration of about 10%, a comparison with more maps and charts from that period may be enlightening. The open bars in Figure 10 represent the longitudinal stretch factor of the West African regional charts of the five pre-Cantino charts I analyzed. For the

Cantino planisphere, the mean value for the whole of Africa is shown. By far the largest stretch value of this group is present on the Kunstmann III chart from 1506.[31] This chart shows the Mediterranean and Africa down to the Great Fish River, the farthest point reached by Bartolomeu Dias in 1488. I subjected this chart to a cursory inspection only, as it postdates the Cantino planisphere.[32] The longitudinal exaggeration of five world maps from the first half of the sixteenth century is shown by the black bars in Figure 10. The longitudinal extent of Africa from Cape Verde to Cape Guardafui on these planispheres was expressed relative to its latitudinal extent from Cape Spartel to Cape Agulhas. I did the same for a modern plane chart and the ratio of those two numbers is shown in Figure 10. The longitudinal exaggeration according to Claudius Ptolemy is shown by the crosshatched bar.[33]

Remarkably, the *smallest* longitudinal stretch value (0.8%) is found on the *oldest* chart, the "Modena chart" (c. 1471). The Aguiar chart (1492) also has a small amount of stretch (1.7%). Marques suggested Jorge de Aguiar used an older *pattern* (template) for this chart than Pedro Reinel used.[34]

The variation in the longitudinal exaggeration of Africa on the planispheres and the nautical charts makes an arbitrary impression. Unlike the first six white bars in Figure 10, which represent a constant east-west scale enlargement, the black bars also reflect arbitrary small changes in the African coastline on the relevant planispheres. This leads to the question: why was the longitudinal extent of Africa exaggerated by all cartographers and by so much? A likely explanation appears to be the debate on the size of the inhabited world at the end of the fifteenth century. The size of the inhabited world was one of the key topics in Columbus's attempts to obtain support for his project to reach East Asia ("India") by sailing to the west.[35] Medieval scholastic thinkers and philosophers from antiquity had left a heritage of often contradictory ideas about the geography of the world, despite general agreement that the longitudinal width of Asia and Europe was very large. Some had maintained that it ought to be possible to reach East Asia by sailing west across the Atlantic; others denied that. The ideas expressed in Ptolemy's *Geography* were a key argument in the debate in Portugal, but not in Spain, where the focus was on medieval scholastic considerations.[36] Ptolemy's *Geography* contained the only available numeric estimate for the width of Europe and Asia at the time.[37] Ptolemy claimed that the extent of

[31] I. Kupčík, *Münchner Portolankarten. Munich Portolan Charts* (Berlin: Deutscher Kunstverlag, 2000), pp. 35–39. Accesible online at https://gallica.bnf.fr/ark:/12148/btv1b59055658/f1.item.r=Ge

[32] According to Gaspar this chart predates the Cantino planisphere: Joaquim Alves Gaspar, "The Planisphere of Juan de la Cosa (1500): The First 'Padrón Real' or the Last of Its Kind?," *Terrae Incognitae*, 49, no. 1 (2017), p.88, footnote 30.

[33] In his *Geography* Ptolemy lists the longitude of the Aromata promontory (modern Cape Guardafui) as 83°. He measured longitude from the meridian of Hierro, the westernmost island of the Canary Islands. The correct longitude difference between these points is 69.3°, so Ptolemy's figure is just under 20% too large. The *Geography* does not describe Cape of Good Hope, because Ptolemy considered the Indian Ocean to be land-locked. Hence no Cape of Good Hope could exist in Ptolemy's worldview.

[34] Marques, "The dating," p. 95.

[35] William G.L. Randles, "The evaluation of Columbus' India project by Portuguese and Spanish cosmographers in the light of the geographical science of the period," *Imago Mundi* 42 (1990), pp. 1–23.

[36] Randles, "The evaluation," pp. 7–8.

[37] In his *Tratado em defensam da carta de marear* (Treatise in defense of the nautical chart) of 1537, Pedro Nunes expresses pride in the achievement of Portuguese navigators, who, going around Africa, placed Cape

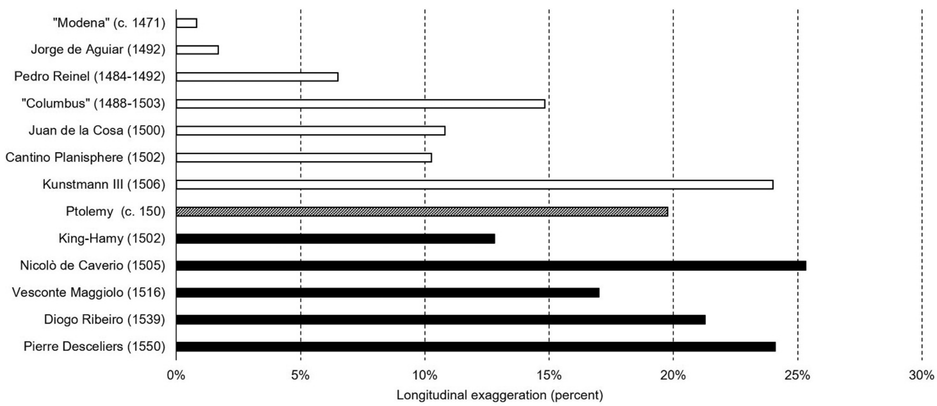

FIGURE 10 Longitudinal exaggeration on nautical charts and a number of sixteenth century "planispheres."

Asia and Europe was 180° of longitude, which is about 18% too large. According to Ptolemy, Marinus of Tyre, his predecessor, even believed it to be 225°. That might explain why the "Modena chart," which presumably predates the Columbus debate, and the Aguiar chart, putatively based on an older template or pattern, show hardly any longitudinal exaggeration. Incidentally, the large longitudinal stretch on the "Columbus map" accords with Columbus's attempts to "sell" a longitudinal extent of Asia and Europe that was as large as possible, but that does not prove that Columbus drew the chart.

The Reigning View on the Longitudinal Exaggeration of Africa

The reigning opinion on the reason for the longitudinal exaggeration of the Cantino planisphere is that the navigational capabilities of the period are to blame. This idea was elaborated in detail by Joaquim Alves Gaspar, who claimed that ignored magnetic declination, in combination with the Portuguese method of ocean navigation, is the cause of the increased east-west extent of Africa on the Cantino planisphere. The Portuguese method of ocean navigation consisted of measuring the ship's latitude and intersecting the parallel of latitude thus found with the magnetic course steered since the previous ship's (midday) position, using plane geometry. This is also referred to as *set-point navigation*.[38] Gaspar's inspiration appears to come from D. João de Castro, who, in his *Roteiro de Lisboa a Goa* of 1538, describes how magnetic declination introduces longitude errors.[39] While Castro explains this in words, it is most easily understood through a diagram. Figure 11 explains the principle in terms of plane geometry, which is how Castro would have understood it.

An easterly error in navigation (and charting) results from the ship sailing a course south of west or east in the presence of an *easterly* magnetic declination (Figure 11 left). A course

Guardafui at the same longitude as Ptolemy. Cited by Gaspar, *From the Portolan Chart*, pp. 170–171. Nunes clearly appears to consider Ptolemy's value for the longitude of Cape Guardafui to carry weight.

38 Cortesão, *History*, Vol. II, p. 439. The relevant section was written by Luis de Albuquerque.

39 Cortesão, *History*, Vol. II, pp. 441, 442. See also Gaspar, *From the Portolan Chart*, pp. 18–20.

north of west or east in the presence of a *westerly* magnetic declination also results in an easterly error (Figure 11 right). Although navigators became aware of magnetic declination toward the end of the fifteenth century, they were unable to understand it. The more enlightened among them might have realized that magnetic declination varies by location, but, lacking data, they would have had no idea about the pattern of the variations.

As appealing as this straightforward explanation might be, it does not take into account the significant errors caused by plane charting. Systematic application of the set-point method to charting would result in a so-called *latitude chart*, a chart on which the latitudes will be (approximately) correct, but the longitudes will contain cumulative errors due to magnetic declination and plane charting, as explained above in the section *Interlude; plane charting and plane charts*. The resulting coastal outline would have to agree sufficiently with the longitudinal characteristics of Africa on the Cantino planisphere to prove or at least suggest causal relationship.

This can be tested by computing a virtual route along the African coast, from Cape Spartel to Cape Guardafui through a series of points on the coastline of the Cantino planisphere, that is, as Africa would have been charted by Portuguese sailors. However, I stress that this does not imply the condition or assumption that Africa would have to be charted in a single journey. The absence of random errors in the data allows the effects of only the systematic errors to be assessed. These would have been repeated by pilots on successive journeys, provided magnetic declination did not change significantly between journeys. Using the available identical points on the Cantino planisphere, I computed the theoretical magnetic compass bearings from one point to the next from the known latitudes and longitudes of these points. With these compass bearings and their known latitudes, the theoretical position of each point can be computed by applying the set-point method. I use the designation "theoretical" here to indicate the absence of random measurement errors, which is not achievable in practice. Joining the dots yields a theoretical coastline shape that can be compared directly with the coastline shape on the Cantino planisphere.

The magnetic declination values I used in my simulated charting were extracted from the CALS3k.4 model. In order to simulate the hypothesized progressive charting of Africa, I used the magnetic declination for the year 1446 for the section of coast from Cape Spartel to Conakry, 1470 for West Africa up to Pointe Noire (Congo), 1483 for the coast from Pointe Noire to the Great Fish River, and 1495 for the East African coast. Gaspar, who also computed such a theoretical outline of Africa, used the date of 1500 for the entire perimeter of Africa and designed his own paleomagnetic model for the South Atlantic and Indian Oceans by extrapolating, both spatially and temporally, magnetic declination values measured by Castro in 1538 and 1541[40]. This yielded larger westerly declination values than those estimated by using current paleomagnetic models.

Figure 12 shows the results; white dots are the selected coastal points on the Cantino planisphere. Black dots connected by a solid black line are the outcome of

[40] Gaspar, *From the Portolan Chart*, pp. 175-182.

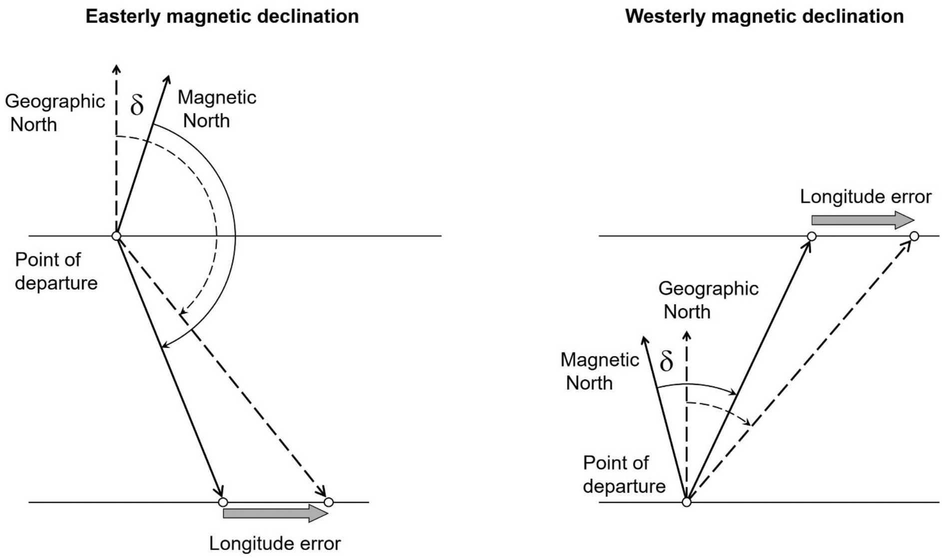

FIGURE 11 Longitude errors caused by an easterly magnetic declination on a south-easterly course (left) and by a westerly magnetic declination on a north-easterly course.

applying the set-point method, using the CALS3k.4 model for the Atlantic and Gaspar's model for the Indian Ocean. Gray dots connected by dashed lines represent the same calculation, but with CALS3k.4 values for the entire African coast. The agreement of the outline thus created with that of the Cantino planisphere is distinctly worse than the piecewise fit by the regional charts shown in Figures 4 and 5: while the RMSE values of regional charts' best fit on the Cantino planisphere are 31 km for latitude and 27 km for longitude, the corresponding values for the set-point-charting solution are 71 km and 230 km, respectively. Both the eastward flexing of the coastline from Cape Spartel to Cape Verde and the westward flexing of the east coast are caused chiefly by plane charting. With the north-easterly courses in the Indian Ocean, this works against and exceeds the effect described by Castro. While there is undeniably a correlation between the outlines of Africa on the Cantino planisphere and generated by set-point navigation, a causal relationship cannot be concluded.

The explanation presented in this essay, proposing that Africa on the Cantino planisphere and its predecessors is a mosaic of accurate regional charts on the plate-carrée projection, which are stretched east-west according to the cartographer's ideas, explains the shape of Africa on these charts considerably better (see Figure 4). Plane charting and ignored magnetic declination, the standard ingredients of fifteenth and sixteenth-century charting techniques, precluded the generation of the plate-carrée map projection. That suggests the Portuguese cartographers had access to existing source charts on the plate-carrée projection. As Figure 5 shows, this is reinforced by the fact that there are no fundamental differences in the coastal shapes of Morocco, West, and Central Africa between the charts analyzed, although the Central African region features on fewer

FIGURE 12 The charting of Africa using the "set-point" method.

charts, so there is less to compare. Any shape differences of the regional charts are caused by different east-west stretch factors, which appear to be artifacts introduced by the cartographers. These regional charts do have different orientations and scales, but that does not affect the coastline shape. This leads to the conclusion that the Cantino planisphere and its five predecessors show essentially the same mapping of Africa. Therefore, the path of progress that many researchers believe to see in those charts and expressed in titles such as "From the portolan chart … to … " is an illusion.[41] While progress in navigation is undeniable, this progress is not reflected in the mapping of Africa on nautical charts of the Age of Discovery.

It is concluded that the regional charts were copied from one chart to the next, be it rotated, rescaled and stretched east-west, presumably to suit the cartographer's ideas. No trace is visible of the large random longitude errors that hampered navigation until the end of the eighteenth century; on the contrary: longitude is even more accurate than latitude on the majority of regional charts. Nor is any effect visible of systematic cumulative longitude errors due to plane charting and magnetic declination. This holds for both set-point and dead-reckoning navigation.

[41] See Notes 3 and 24 above.

Conclusion

The shape of Africa on the Cantino planisphere and fifteenth-century Iberian nautical charts is incompatible with assumptions of either set-point or dead-reckoning navigation and charting; either method would have led to systematic errors that ought to have been identifiable on those charts, but are not. Africa on the Cantino planisphere and its predecessors is a mosaic of source charts on the plate-carrée projection, rotated, rescaled, and subjected to east-west stretch, apparently to suit the ideas of the cartographer. This conclusion casts severe doubt on the generally-held assumption that fifteenth-century cartographers charted Africa based on navigation measurements taken by Portuguese sailors.

Notes on contributor

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Disclosure Statement

No potential conflict of interest was reported by the author(s).