work of Ptolemy was even printed for the first time, in 1475. Pope Pius II definitively rejected the Ptolemaic description of Africa and adopted that of Strabo—which was that of all the classical Greek geographers.

This illustrious Pope says, in his *Asiae Europaegue Elegantissima Descriptio:*

> Asia is joined to Africa by the nape of Arabia which separates our sea [the Mediterranean] from the Arabian Gulf. No one denies this; but he [Ptolemy] adds that at a certain point, they are connected by an unknown land mass which encloses the Indian Ocean. In this opinion he is almost alone. Because all the ones we know who wrote about the features of the Earth, place the Indian Ocean south and east, without ascribing to it any limit, hence they are of the opinion that it is a part of the *ocean-sea,* as recorded by those who navigated from the Arabian Gulf to the Atlantic Ocean and the Pillars of Hercules.[1]

For this reason, when Bartolomeo Diaz circumnavigated the Cape of Good Hope, Christopher Columbus judged the event, and rightly so, as the practical refutation of the Ptolemaic description of the limits of the inhabited world, and a powerful argument in favor of the project in which he played such an outstanding part.

NOTES

1. A clear reference to the expedition of Pharaoh Necho II.

SYMPOSIUM

The Science Behind Columbus

by Rick Sanders

For the modern reader, the attempt to discover the scientific and technological significance of Columbus' 1492 voyage is probably almost as difficult as it was for him to do what he did in the first place. Even leaving aside the politically motivated detractors of Columbus and his exploit, his admirers are not always helpful. Admiral Samuel Eliot Morison, for example, tries to have it both ways. First, he says that Columbus was barely capable of using the astrolabe and the quadrant, and that he underestimated the size of the Earth by twenty-five percent; later, he goes on to say that Columbus was among the world's best navigators, and that "no man alive, limited to the instruments and means at Columbus's disposal, could obtain anything near the accuracy of his results."[1]

To understand the outlines of how the science of Renaissance navigation positioned Columbus to undertake his great voyages, we have to answer the following questions:

- **What general cosmological and navigational knowledge, other than the astronomical sciences, was required to carry out the 1492 exploit?**

And, as to the astronomical sciences, we must know:

- **With what kind of accuracy could Columbus determine latitude? Did he use the stars, the sun, or both?**
- **How close was Columbus in his estimate of the Earth's circumference?**
- **If Columbus knew the Earth's circumference, did he know the size of the "hole" between Spain and "Cipango" (Japan); that is, did he know to what longitude Asia stretched, so that he might calculate the actual distance between East Asia and Spain?**
- **Did Columbus have any reliable way of finding longitude?**

Cosmology and General Seamanship

Cosmology

The "politically correct" cosmological view at the beginning of 1492—despite the counter-tradition of Nicolaus of Cusa and the Council of Florence—was that of Aristotle and Ptolemy, that the known world was an island in the midst of a chaotic, untraversable ocean. Columbus had the courage to accept instead the conclusions of Pierre d'Ailly, Cardinal of Cambrai, who in his 1410 *Imago Mundi* said:

> The length of the land toward the Orient is much greater than Ptolemy admits. . . .For, according to the philosophers and Pliny, the ocean which stretches between the extremity of further Spain [Morocco] and the eastern edge of India, is of no great width. *For it is evident that this sea is navigable in a very few days if the wind be fair.* [This part is heavily underscored by Columbus in his copy of the book.][2]

The Winds

Columbus assimilated the knowledge passed on to him by the Portuguese—including the portolan sailing charts and maps that he inherited from his father-in-law, Bartolomeo de Perestrello—and combined it with his own sailing experience and observations made while living in the Azores—for example, that between 25°N and 30°N, the wind blew steadily from the east, whereas at the Azores, the wind blew steadily from the west. Hence, without hesitation—clearly, he had mapped it all out in advance—Columbus sailed straight down to the Canaries, virtually due west at the right latitude; while on the way back, he sailed north as fast as he could to the latitude of the Azores, and then due east.[3]

The Magnetic Compass

Sailors, even well-versed in navigational astronomy, and with modern navigational aids, must still use *dead reckoning* to get an appproximate position. In first approximation, you assume the small surface you are covering to be flat, estimate your average speed, compensate for any currents, plot how far you have travelled north or south, and east or west, and complete the triangle. But on a cloudy day—or cloudy weeks, as is often the case in the North Atlantic—you must have a magnetic compass to determine the direction in which you are sailing.

The magnetic compass had arrived in Europe probably from China some time between 1000 and 1111 A.D.. Now, the magnetic field lines of the Earth are relatively constant (changing only over decades or centuries) for a specific latitude and longitude; and even though it is true that the magnetic compass did not point exactly to true astronomical North in Europe at the time of Columbus, this variation was constant and was routinely corrected for, using astronomical readings, by compass makers.

But, when you change longitude and latitude, your compass may begin to vary wildly. As Alexander von Humboldt recounts Columbus' experience:

> The important discovery of the magnetic variation, or rather, that of the change of variation, in the Atlantic Ocean, belongs, without any doubt, to Christopher Columbus. He found on his first voyage, on the 13th of September 1492, that the compasses, whose declination had been up till then to the northeast, declined towards the northwest, and that this declination to the west increased the following morning. On the 17th of September. . .the magnetic declination was already a quarter of a wind, "which very much frightened the pilots.". . .
>
> The observation of the 14th of September 1492 [marks] a memorable epoch in the annals of *navigational astronomy* of the Europeans. [All emphasis and quotation marks in the original.][4]

Humboldt makes clear that Columbus' discovery was not that of the *variation* of the magnetic compass, but that

> west of the Azores, the *variation* itself *varied,* that from N.E. it became N.W., and that on one occasion when none of the eight or ten pilots travelling with him had any idea where they were, Columbus used the declination of the compass to assure everyone that he knew where they were, one hundred leagues west of the Azores.[5]

Latitude

Any amateur astronomer can determine his latitude *on land* within a half a degree or so, with a simple homemade quadrant. It is enough to measure how far Polaris (the Pole Star) is above the horizon: that angle is your latitude. At the time of Columbus, Polaris was about 3½° off true North, so simple corrections based on the relative position of the two brightest stars of the Little Dipper, or the position of Cassiopeia, were required. A simple way to do this was written into the main handbooks, such as the oldest surviving navigation manual, the *Regimento do Astrolabio e do Quadrante.*[6]

The other primary way of determining latitude is to measure how far the sun is above the horizon at noon, take into account the declination of the sun above or below the celestial equator for that day. The information required to do this—primarily the tables of declination for the sun—were to be found in the same *Regimento,* in the section on the "Rule of the Sun," which gave the sun's position in the Zodiac, and its declination day by day. According to historian of navigation E.G.R. Taylor, "in the list of latitudes which the manual provides, the positions are with few exceptions, correct within half a degree—often to within ten minutes."[7]

But, could navigators determine their latitude from shipboard? Yes, but less accurately. There are places to stand on a ship where the pitch and roll are very small; then you could take various readings, compensate for motion, etc. Navigators must have been able to do this quite accurately, or else common "latitude sailing"—sailing along a latitude line—would have been impossible.

Columbus Knew the Earth's Circumference

A common piece of disinformation circulated to discredit the project that culminated in the discovery of the Americas, is that "Columbus underestimated the size of the Earth by twenty-five percent." This allegation is backed up by a dispute over the length of the "mile" and "league" in Columbus' day.

However, there is a direct and obvious way to prove the contrary—that Columbus knew the circumference of the Earth virtually exactly.

Columbus got his education in advanced navigation in Portugal. The oldest surviving navigation manual, the *Regimento do Astrolabio e do Quadrante* cited above, contains a statement that allows us to prove without serious doubt that the length of the league used at the time of Columbus was correct, and corresponded to the correct circumference of the Earth:

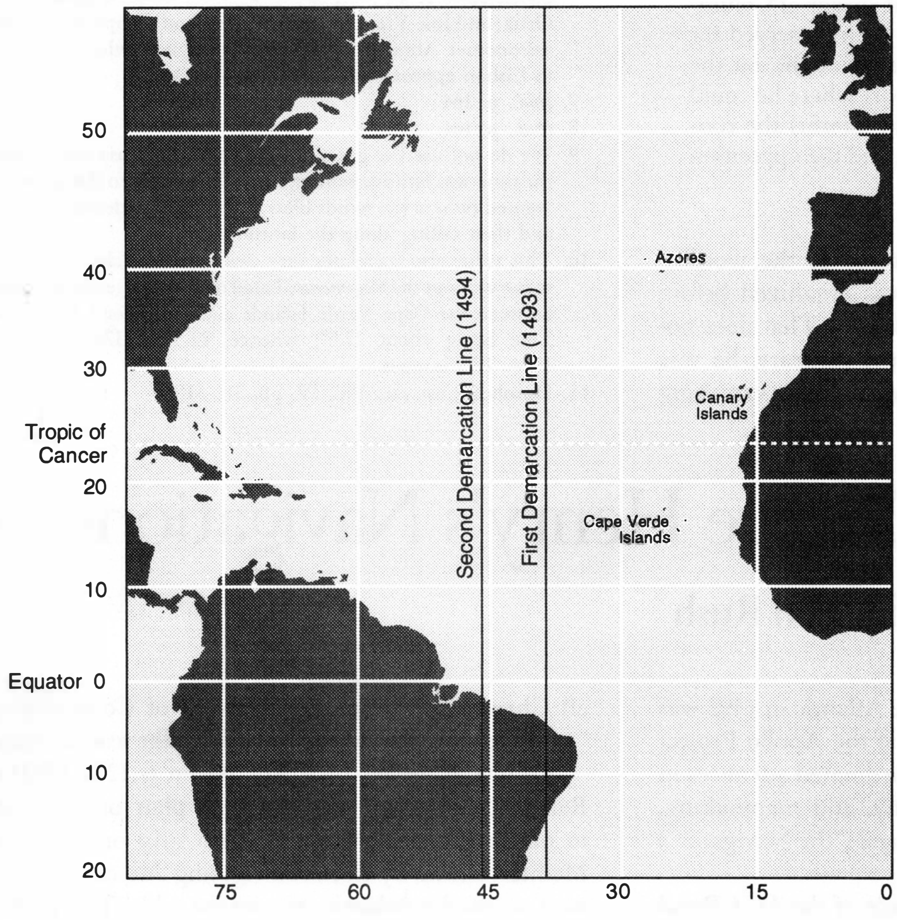
> Know that the degree of North-South is 17½ leagues, and that sixty minutes make a degree.[8]

Proof

We can prove the length of the league, using the Second Demarcation Line, which today's scholars show cutting Brazil at 46.5° West—just as it appeared on the Portuguese *Cantino World Map* of 1502 (SEE Map V). According to the 1494 Treaty of Tordesillas, this line was to be located "370 leagues west of the Cape Verde Islands."

- Since the average longitude of the Cape Verde Islands is 24° West, the difference between the Islands and the Demarcation Line is 46.5° − 24° = 22.5°;
- Therefore, the linear distance[9] between the Islands and the Demarcation Line is 22.5° × 111.116 km × cosine 16° (the average latitude of the Cape Verde Islands) = 2,403.26 km;
- Therefore, since 370 leagues was set at 2,403.26 km, 1 league = 2,403.26 ÷ 370 = 6.4953 km.;
- And, since according to the *Regimento* there were 17.5 leagues to the degree,[10] the circumference of the Earth would come be to 17.5 × 360 × 6.4953 = 40,920.4 km.

The actual average value for the Earth's circumference is calculated today at 111.116 km × 360° = 40,001.8 km!



MAP V. *The Second Demarcation Line, 1494.*

Distance between Spain And 'Cipango' (Japan)

This is a more difficult question, since maps before Columbus do not show a continent between "Cipango" and Europe. It appears that Marco Polo did not know how to determine longitude (which became possible only in the late fifteenth century, when almanacs began to be published predicting eclipses and occultations of planets and stars by the moon). Marco Polo seems to have estimated the distance he travelled by the land equivalent of dead reckoning, something which is not easy, given mountain ranges, deserts, and so forth. Thus, even if the size of the Earth were known, it would be difficult to determine with any degree of exactitude, the size of the "hole" between the Canaries and "Cipango" (SEE Map I).

Out best guess is that the Florentines, basing themselves on Plato's account of Atlantis, or on Pliny, or on Pierre d'Ailly, might have concluded that there was land about thirty days sailing west. Perhaps they thought this was India; perhaps, something else.

Longitude

Columbus, along with Amerigo Vespucci, was at the absolute frontier of technology in his attempts to get an accurate measure of longitude. As reported by Alexander von Humboldt:

> [The] desire [of Vespucci and Columbus] to substitute the observation of the conjunction of the planets and the moon for lunar eclipses, and of thus increasing the ways of determining the longitude of a ship, was due to the influence exercised in Spain and Italy of Arab astronomy. From the century of Albategni to the work of Ibn Jounis, a long sequence of occultations of stars and oppositions of planets had been observed over a vast extent of countries, from Cairo to Baghdad and Racca. The change of direction which navigation was undergoing towards the end of the fifteenth century, made the necessity felt of obtaining and increasing the number of astronomical methods. But although it was possible to conceive of using [these new methods], the imperfection of nautical instruments hindered their success even more than the imperfection of tables. We have already seen, according to the journal of the first voyage of Columbus, the major part of which has been preserved for us by Las Casas, that the Admiral "sought, on the 13th of January 1493, in Haiti a port where he could tranquilly observe (*para ver en que paraba*) the conjunction of the sun and the moon, and the opposition of the moon and Jupiter."[11]

The science—in the broadest sense of the word—behind Columbus' achievement, was organized before he was born, at the Council of Florence. That does not diminish his glory, however. On the contrary, he was a fitting prototype of that once proud, now vanishing American, who has the ingenuity and imagination required to assimilate and put into practice the breakthroughs made by scientists—thus changing world history for the good, more than thousands of his detractors have changed it for the worse.

NOTES

1. Samuel Eliot Morison, *Admiral of the Ocean Sea: A Life of Christopher Columbus* (Boston: Little, Brown and Company, 1942), p. 195.
2. Alexander von Humboldt, *Examen critique de l'histoire de la geographie du Nouveau continent et des progres de l'astronomie nautique aux quinzieme et seizieme siecles* (*Critical Examination of the History of the Geography of the New Continent and of Navigational Astronomy during the Fifteenth and Sixteenth Centuries*), Vol. III, pp. 29-31 (translated from the French by the author).
3. In *Cosmos,* Vol. II, p. 262, Alexander von Humboldt speaks of a map of Toscanelli's, different from the well-known one, which Columbus had in his possession. For on Sept. 25, 1492, Columbus showed Martin Alonso Pinzon a map "on which many prominent islands were delineated."
4. Humboldt, *op. cit.,* Vol. III, pp. 29-31.
5. *Ibid.,* pp. 39-40.
6. E.G.R. Taylor, in *The Havenfinding Art* (New York: American Elsevier, 1971), pp. 162-63, says that the *Regimento* was probably written in 1481 by three people: master Rodrigo, the Royal physician to King John of Portugal; the Royal chaplain, Bishop Ortiz; and José Vizinho, a learned Jew and disciple of the famous astronomer Abraham Zacuto of Salamanca (who himself came to Lisbon approximately ten years later).
7. *Ibid.,* p. 164.
8. *Ibid.,* p. 164.
9. We do not use the great circle distance, because the practice at the time was latitude sailing, i.e., sailing down to the latitude you wanted (where the winds blew steadily in the desired direction), and then sailing along the latitude line.
10. This value also correlates very closely to the calculation we can make without the *Regimento,* based on the difference in longitude between the Cape Verde Islands and the Second Demarcation Line being about 22.5°; whence, 22.5° = 370 leagues, and 1° = 17.3 leagues.
11. Humboldt, *op. cit.,* Vol. IV, pp. 311-315.

SYMPOSIUM

Prince Henry's Navigations

by Tim Rush

Columbus' voyage across the Atlantic in 1492 was the westward application of the Apollo Project of the Renaissance: the coordinated advances in navigation, shipbuilding, astronomy, and mapmaking, pioneered by Prince Henry of Portugal ("the Navigator") (1394-1460).

Henry's project was, in the words of the 1454 Papal edict which raised his efforts to a strategic priority for all Christendom after the 1453 fall of Constantinople, "to prove devotion to God by making the seas navigable."

From the period of Roger Bacon (c.1214-1292) and Ramon Lull (1232-1315), a strategic plan for Christianity to outflank the Venetian-Moslem grip on the eastern Mediterranean, by circumnavigating Africa, or heading west across the Atlantic, was on the table. This plan was further developed by the scientific participants of the