ECONOMISTS TODAY TELL US that the drivers of great economies are advanced technology, efficient finance and productive manufacture. It is true that throughout history these factors have always been the sine qua non of successful economies. However, in the age of the great discoveries, the ability to navigate the seas was as important as these other factors. Several elements played a part in this dominance of the forces of unknown seas, including shipbuilding, astronomy, navigational techniques and map-making.

In the thirteenth century, the seeds of the dramatic expansion in seaborne trade and travel were sown in Europe with the introduction of the magnetic compass. It would be some two hundred years before this invention and its related mapping and navigating skills were applied in a meaningful way to voyaging beyond Europe and the Mediterranean. Nonetheless, without the progressive developments in sea charts derived from the compass during the intervening decades this expansion would not have been possible.

The exact connections between the compass and the appearance of usable navigational charts are not well understood, but it is probable that the compass first contributed to the development of sailing guides in textual form, which were eventually transformed into graphic form as sea charts. Since this development preceded a printing industry in Europe, all of these works, whether texts or maps, were manuscripts. In fact, the tradition of manuscript sea charts continued into the late seventeenth century.

The sailing guides were called portolani by the Italians, roteiros by the Portugese and rutters by the Dutch and English. They were practical guides in textual form for making voyages from port to port in the Mediterranean, thus the derivation of their Italian name. A surviving manuscript copy of one of the earliest portolani, Lo Compasso de Navigare,

An outstanding portolan chart of Europe and the Mediterranean by Diego Homen (1538). It contains most of the stylistic features of the genre: compass roses, rhumb lines and wind heads.

amount of drawing surface which was frequently filled with an illustration or the author's inscription.

Many of the earlier examples appear to have been nailed to a dowel, rolled and tied with a ribbon which was sewn into the neck, although other methods of storage were also employed. Most of the charts produced by the so-called Thames School in London in the early seventeenth century were pasted in panels to an assembly of four hinged wooden boards about one centimetre thick.

Since they were all manuscript, no two charts or atlases were alike in size, decoration or cartographic content. The cartographer seldom had access to skins of identical dimensions, and even the atlases, made from skins cut to a uniform size for a given atlas, exhibit significant variations between consecutive atlases of the same cartographer.

Little is known of the economics of the production of these charts. It is likely that some were produced in workshops where a well-established cartographer supervised the work of

A portolan chart (1563) showing the discoveries of Fernão Gomez in the 1470s; detail of the coast of West Africa.
assistants and signed the finished product. Given the intricacies of the process from preparing and cutting the skin to drawing the coastlines to lettering and decorating, the charts must have been relatively expensive. Nonetheless contemporary reports seem to indicate that most if not all ships carried one or more charts on all voyages.

The profitability of the trade is likewise unclear. It is probable that the better-known cartographers, at least in the earlier periods, were well compensated. There are some indications that, as printed sea charts came into use after about 1600, journeymen practitioners found it difficult to make ends meet. William Dobbins, the seventeenth-century ‘Escheator of the Province of Ulster’, visited the premises of a London chartmaker, Thomas Comberford, in 1655 to purchase a portolan chart, and found the cartographer living in abject poverty.

There is no generally accepted comprehensive definition of a portolan chart. Given that the production extended over four hundred years in many different cities for different clients with different purposes, perhaps this is not surprising. The most useful definition seems to be stylistic, and most members of the class share a number of these common features.

It is a manuscript chart on vellum produced using the technique of an illuminated manuscript. Cartographic details are drawn against a background of network lines radiating from the centre and points on the circumference of a ‘hidden circle’ inscribed on the vellum. These radiating lines were called ‘rhumb lines’ and represent the 16 or 32 compass directions. As they originated from several points on the chart, they form a regular pattern of bearing lines and are useful to navigators at sea. Little or no cartographic detail in the interior of the continents is included, but the coastline is covered with the placenames of ports, all written in on the landward side of the coastline so as not to obstruct the view of the sea. Sometimes the chart is highly decorated with religious images, illustrations of local rulers, flags, coats-of-arms, compass roses and town vignettes. Finally, it is constructed on a simple, planar projection which maintained a constant spacing for lines of latitude and longitude, ignoring the sphericity of the Earth, rather than on a mathematically complex projection such as the Flemish cartographer Gerard Mercator (1512-94) first published in 1569, which allowed any compass heading to be represented as a straight line.

For approximately a hundred and fifty years, from the Pisan chart, the area of coverage of portolan charts was largely limited to Europe and the Middle East. The production centres were mostly Mediterranean and the users were probably merchant sailors from ports such as Venice and Genoa who depended on these charts to guide them to destinations in the Mediterranean and Black Seas. A few examples of portolan charts produced by Greek and Arab cartographers survive, but most date from the sixteenth century and are generally derivative of the European style. As trade increased with ports on the Atlantic coast of Europe, the British Isles and the Baltic Sea, the coverage was expanded to these coasts and seas. Nonetheless, in this period the portolan chart remained very much centred on the Mediterranean and destinations easily reached from there.

But by the middle of the fifteenth century the world of navigation was indeed changing. Land routes for the importation of exotic and highly sought-after Asian goods, long dominated by Venice and extended to European customers by their merchant fleets, were about to lose out to sea routes. The Atlantic route beckoned, the main obstacle being Africa and its unknown but hoped-for southern cape. The Christian kingdoms of Iberia, especially Portugal, were ideally situated to lead the European advance directly to the markets of the East. The Spanish and Portuguese had felt their way down the north-west coast of Africa as far as Cape Bojador and the Canary Islands in the fourteenth century, but now it was the Portuguese that took up the challenge.

As the coast was uncovered step by step, the discoveries found their way onto subsequent portolan charts. These newly revised charts in turn offered greater case and confidence for later voyages. In this way, the fortunes of voyagers and the cartmakers became mutually intertwined:
the voyagers depended on the latest charts to plan and guide their voyages, and the chart-makers depended on the latest news of recent voyages to update their charts.

A particularly significant portolan chart of this period of Portuguese exploration of the West African coast is found in an anonymous atlas now preserved in the British Museum (Egerton Collection, ms 73). This atlas, produced in Venice about 1490 and known as the Cornaro Atlas after the family that owned and presumably commissioned it, contains contemporary copies of thirty-seven charts of the period, including a chart of West Africa reflecting the latest Portuguese discoveries. Besides naming place after place on the coast south of Cape Bojador, there are other pieces of information useful for future pilots on the coast. For example, an interesting notice to mariners indicates the point at which the pole star dips below the horizon and thus is no longer visible. This marked an important point for the fifteenth-century navigator, because his repertoire of available navigating aids was quite limited.

The theory of determining latitude from the elevation of the sun or pole star was already well understood, but practical matters limited the application at sea. One problem was that navigators lacked instruments to take the angular measurement with sufficient precision from the rolling deck of a small ship. To get truly reliable latitude determinations, it was necessary for navigators to set up a measuring station on land. This was done at intervals, and the results of these readings quickly found their way onto the portolan charts.

Another problem in using the pole star, Polaris, is that it is not exactly over the North Pole, and throughout the twenty-four-hour day the star inscribes a small circle around true North. Over the centuries, the diameter of that circle has changed, and today it is about half of one degree, but in the fifteenth century it was about four degrees. A reading uncorrected for this error would result in a latitude error of up to two degrees, or over 220 kilometres, obviously unacceptable for navigational purposes.

A practical method for correcting this pole star error had been developed and was available to navigators in the atlases of a number of cartographers including Jean Rotz, a Frenchman who worked for a time in London, and Fernão Vaz Dourado, a Portuguese colonial in Goa. The logic of the correction was to visualise a human form straddling the celestial North Pole and orientated with his feet toward the ground. The navigator first identified the so-called guide stars and their placement relative to the imaginary human form. The table in the atlas or on the diagram then gave the necessary plus or minus correction to the measured elevation, depending on where within the imaginary human form the guide stars were found.

After crossing the invisible line of the Equator and entering the southern hemisphere, the great beacon of Polaris was no longer visible and the

Details of the interior of landmasses were normally either notional or illustrative. This African king was shown on a Spanish portolan chart of 1413.
The world map from the atlas by Jean Rotz (1542), which was presented to Henry VIII and carries a Tudor rose.

navigator's options become even more limited. The Portuguese sailors had magnetic compasses, but without correction for certain systematic errors, these instruments could deviate from true bearings by as much as ten degrees. There is no corresponding southern pole star, so dead reckoning became the primary navigating process, adjusted by the occasional latitude by solar elevation. (Dead reckoning is a method of estimating a ship's position by starting at a known point and calculating the present position by applying estimated speed, time and direction. Inevitable errors in these three factors caused by currents, compass errors and imperfect time-keeping, meant that after a few days, the dead reckoning position was at best an educated guess.)

Although the Portuguese advance southwards was excruciatingly slow, once the cape had been rounded by Bartolomeu Dias in 1488 progress in the Indian Ocean was nothing short of spectacular. In 1498 Vasco da Gama had established a base at Goa on the west coast of India and by the early sixteenth century the Portuguese were in the Spice Islands and Malacca on the Malay Peninsula. By the middle of the century, they reached Macao in China and finally Kyushu in Japan.

With the Portuguese dominating this route, other European competitors were forced to look for different routes to the East. By making some creative adjustments to the assumed circumference of the Earth (reduction) and East-West dimension of Eurasia (expansion), the Genoese navigator Christopher Columbus persuaded the Catholic monarchs of Spain to finance a mission to the East via a westerly route. The existence of two unknown continents was both a curse and a blessing to him. They presented a formidable obstacle to reaching Asia via this route, but the Admiral and his crew would surely have perished had they not found safe haven in the West Indies.

In the decades to follow, the English set up in Virginia and New England, the French in the St Lawrence river valley, the Dutch in Java and other ports in the East Indies. These and other coasts were explored and the results of these new findings found their way onto successive generations of portolan charts. This form of chart was to be a worthy vehicle for the exploding rate of geographical expansion. In the sixteenth and early seventeenth centuries, the coasts of virtually every habitable piece of real estate on the globe were added to the portolan charts.

As the progress in new discoveries extended the geographical range of coverage of the portolan charts, chart-makers faced new technical challenges. The first was based on the fact that the Earth is a sphere, and its surface cannot be projected or transferred to the flat surface of a map without some element of distortion. In the relatively limited area of the Mediterranean Sea, any errors introduced by ignoring the sphericity of the globe are relatively minor, especially when the typical voyage might have been not across the open sea but to a nearby port. On an oceanic voyage, however, especially at higher latitudes, the converging meridians on the physical globe conflicted with the parallel meridians shown on the traditional portolan chart.

Another problem experienced in long-distance ocean sailing was compass variation, caused by the fact that magnetic North is not identical to true North. This phenomenon presented a theoretical problem even within the Mediterranean, but on long distance crossings it often proved disastrous. A practical method for determining longitude at sea would not be available until the 1760s, so the East-West component
Correcting the altitude of Polaris, from the Jean Rotz atlas (1542). The figure is centred on Polaris; and the direction of the guide stars allows estimation of the daily movement of Polaris relative to true north.

of a voyage, and the charts derived from it, largely depended on dead reckoning.

Such problems were troublesome indeed to chart-makers who possessed an imperfect knowledge of the Earth’s properties and dimensions and often lacked an understanding of the spherical geometry needed to represent the sphere on a plane sheet of paper or vellum. Nonetheless, they did their best to produce and use practical tools, often creatively, though sometimes erroneously.

Navigation into and across the oceans hastened the development of improved instruments for measuring the altitude of celestial bodies, and by the early sixteenth century, latitude scales had become a more or less standard feature on portolan charts. This was followed a few decades later by longitude scales, although these were far from standardised. Some charts divided the 360 degrees of longitude into four repeating quadrants of 90 degrees each. Others maintained a single scale of 360 degrees, and there was no agreement as to the direction of counting: East to West or vice versa. A further difficulty was the question of the position of the prime meridian. On the earliest charts displaying a longitude scale, the prime meridian passed through the Canaries. It would be three hundred years before the International Meridian Conference (1884) established that the prime meridian would pass through Greenwich, after having graced such positions as Paris, Rome and even Philadelphia.

While the appearance of quantitative precision offered by the latitude and longitude scales might have provided some comfort to sixteenth-century sailors, they did present problems of geometric consistency in the light of the portolan chart’s planar projection and compass roses, especially on charts of large geographical coverage. Constant compass bearings cannot be straight lines on such charts and readings of longitude measured on a scale at the Equator cannot be applied with accuracy at higher latitudes. Some navigators and chart-makers of the period recognised that these problems and

A page of the Boke of Phisicography, by Jean Rotz (1542), showing the North Atlantic, with south at the top of the page.
those of magnetic variation existed but they did not know what to do about them.

One creative but short-lived attempt at correcting these complexities was the dual latitude scale. This system applied a latitude scale on the western half of the chart that was displaced a few degrees from the latitude scale on the eastern half. This meant that the chart had two equators, two Tropics of Cancer and two Tropics of Capricorn. The idea of this system was to correct for the fact that when sailing on a due westerly compass heading, the course error introduced by compass variation would bring the ship to a different latitude after sailing some distance. A notable practitioner of this system was Diego Gutiérrez of the Casa de la Contratación in Seville. The dual latitude scale is visible in his sole surviving portolan chart, which was produced in 1550. The fallacy of this approach was apparent to other cartographers of the period and the dual latitude scale was soon discredited.

A more reliable method, espoused by Spaniard Pedro de Medina and Frenchman Jean Rotz among others, was to use the observed bearing of the noon-day sun to determine compass variation on the spot, and then use that known value to adjust compass headings. The procedure depended on the fact that, at local noon, the bearing to the sun was true South in the northern hemisphere (and true North in the southern hemisphere). By comparing the compass reading to this N/S line, the compass error could be deduced.

In 1542, while working in London, Rotz provided the detailed mechanical design of a portable instrument operating on this principle. It was essentially a magnetic compass equipped with the appropriate apparatus to sight the sun. Other sixteenth-century devices used an arm above the compass dial to cast a shadow representing the true N/S direction on the dial, but the principle was the same. Within a few decades, chart directions were given in true bearings and navigators were expected to make a correction using a value for compass variation obtained by the navigator from local measurement or from published tables.

While these charts were mainly practical aids to navigation, some were intended for other purposes, ranging from reference works to presentation objects to royal personages. The latter category tended to be mainly atlases of portolan charts, some of which are beautiful works of art, which rivalled the finest illuminated manuscripts and even today retain their vibrant colours, heavily gilt decoration and fine cartographic draughtsmanship. Among the finest examples are three such atlases preserved today in the British Library.

The first is the atlas of 1542 by Jean Rotz, who was working at the time in London and who presented to Henry VIII a folio atlas of eleven charts each measuring 76 x 59 cm. Rotz was of the so-called Dieppe School and had come to London seeking patronage at the English court. His atlas covered most of the coasts of the known world and undoubtedly helped set the stage for
British overseas expansion, which was to begin in earnest within a few decades.

Another magnificent presentation atlas, known as the Queen Mary Atlas, was produced by the Portuguese cartographer Diego Homen, who was then working in London. Commissioned in 1558 by Mary, it was not completed until just after her death the same year. Composed of nine large charts about the same size as the Rotz atlas, it bears an interesting political message. Since Mary was the wife of Philip II of Spain, the chart of the British Isles is decorated with a coat of arms consisting of English elements on one side and Spanish on the other. Mary's successor Elizabeth came into possession of the atlas and it is said that some years later she angrily took a knife to the offending Spanish half of the coat of arms and cruelly scraped it off the vellum. Whether this version is correct or if this act was at the initiative of her librarian,

Detail of the map of the eastern Atlantic seaboard of the Diego Homen atlas of 1558, its coat of arms purportedly defaced by Queen Elizabeth.

The arrival of a Portuguese ship in Nagasaki from a late 16th-century namban folding screen.

the results of the changing political alliances can be plainly seen on the defaced vellum.

Another outstanding presentation atlas, also drawn by a Portuguese cartographer, is the atlas of 1575 by Fernão Vaz Dourado. This work, one of six known atlases by this cartographer, was dedicated and presented to King Sebastian of Portugal, and fell into British hands in the eighteenth century. Vaz Dourado had earlier worked in Goa, the capital of Portuguese Asia, and his charts of the East are especially accurate and rich in decoration.

In its purest form, the portolan chart was a highly functional tool for navigation whether in the contained arena of the Mediterranean or later in the open oceans of the world. As a political or religious statement it presents a host of information on the thinking of the day. As a thing of beauty, it ranks with other highly acclaimed art forms of the late medieval and Renaissance periods.

Even though portolan charts continued to be produced until at least the end of the seventeenth century, from the middle of that century the portolan chart came to be replaced by printed charts. The earliest of these, produced in the seventeenth century, preserved many of the stylistic elements of their manuscript precursors. Gradually the mathematical inconsistencies of the portolan charts were corrected and the 'unnecessary' and 'non-functional' decorative embellishments were eliminated. Despite this evolution, today the lineage connecting modern Admiralty charts with the ancient portolan charts is quite apparent. The new charts may have been purged of the conceptual errors that so perplexed the producers and users of the portolan charts, but they are also missing the charming touches that make the early charts so fascinating today.

FOR FURTHER READING

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