

THE ROLE OF THE SEA AND THE SEAFARERS IN EARLY GEODESY (*)

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"Of all the waters under Heaven there is none so great as the ocean. A myriad rivers flow into it without ceasing, yet it is never full, and the Wei-Lü current carries it continually away, yet it is never empty. Springs and autumns cause no change in it; it takes no notice of floods and droughts. Its pre-eminence over the Yangtze and the Yellow River no measures nor numbers can express."

(From an ancient Taoist text, the Chuang Tzu book, - 4th/ - 3rd cent., after. J. NEEDHAM IV:3, 549).

INTRODUCTION

The mood of awe and wonder of the ancient Taoist Chuang Tzu contemplating the constancy of the vast ocean in its continuous change stands in stark contrast to our current pride of achievement in having tamed this mysterious infinity and cut it down to a finite size, a size where we can circumnavigate it, discover its secrets and exploit its riches. How did we get here from there? It is relatively easy to be impressed by the stupendous technical developments of the recent decades and dismiss the earlier times condescendingly as ignorant and fumbling. Yet it may behoove us to take out a few minutes from our present technical hustle and bustle and try to appreciate and empathize with our ancestors' quest to cope with and understand their mysterious universe. Their first uncharted steps on the long road, after all, were the basis of our achievements, guided as these were by a long training in scientific-technical adaptations and extensions of precedents. As Lucan (1st cent.) already noted, even dwarfs perched on the shoulders of giants can see further than the giants themselves.

(*) This is the third in a trilogy of articles on early geodesy.

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Tracing the cultural achievements inherent in the beginnings of geodesy in ancient times is a rewarding experience as it gives a glimpse into another world. The present paper is the third in a trilogy (FISCHER 1981, 1982) and concentrates on the sea. It is not intended here, however, to recount the developmental phases of ship building, navigation, marine geodesy, etc., through the centuries, but to gather some of the specific sea aspects hidden here and there in the general history of geodesy. Usually, until the recent fabulous growth of marine geodesy and the controversy of whether it should be considered as part of geodesy or as a new discipline by itself, the geodetic activities were taken to be inherently land-based. The obvious argument referred to its roots in the age-old need for cadasters and land surveyors, and the subsequent development of geodetic control nets on the continents. But this is only half the story. The other half derives from the just-as-old quest to know the size and shape of the Earth, and here water bodies are an integral part of the Earth's surface (about 71 %). Most significant, however, are the specifically geodetic questions which delineate geodesy from other earth-disciplines: "where? what direction? how far?", to which the sea made its characteristic contributions, hampered though they were until very recently by their special technical difficulties.

A MIXTURE OF OBSERVATION AND IMAGINATION

One of the oldest existing world maps representing ancient ideas about the ocean and its share of the Earth's surface is on an often-cited Babylonian clay tablet of the - 7th century (British Museum; E. UNGER, 1935). It is centered on Babylon, "the hub of the universe", and its circular shape is framed by a circumfluent "Earthly Ocean" or "Bitter River", beyond which there are "Seven Islands", regularly spaced and pointing toward the ultimate "Heavenly Ocean". According to the text, the Seven Islands are connected with the phenomenon of the sun's rise and fall, but also with the dwelling of a "hostile horned bull". Obviously, the map articulates the observations of the time: the endlessness of the ocean and the sky, and the heavenly phenomena. Maybe, the hostile horned bull, in this context, represents an explanation of where thunder and storms come from?

Tsou Yen, a member of the great Chinese Academy of the Gate of Chi in the - 4th/ - 3rd century, taught that China was only one part in 81 of the whole world. Nine provinces form a continent surrounded by a sea. There are nine such continents surrounded by seas, and the Great Ying Ocean surrounds them all. Tsou Yen, considered as the founder of ancient Chinese scientific thought, was not just making up a story; he was credited to have examined small objects as well as the great events throughout the ages and to have drawn from them inferences about the vastness of Heaven and Earth and the Tao of the universe (J. NEEDHAM, 1956).

The similarity between this world picture and that of the Babylonian map is evident, with the difference of nine instead of seven islands and the commonsense nature of these islands as continents like ours rather than as mystical regions. The general concept of such discoidal world maps seems to have reached China from Babylon via India.

While we are used to the number seven in the Bible and in folk tales, the choice of the number nine in this context sounds curious to us at first, until we realize its frequent use in Chinese symbolism for underlying order. An ancient mathematical classic (*the Chou Pei Suan Ching*) says: "...The rectangle originates from $9 \times 9 = 81$ The methods used by *Yü the Great* in governing the world were derived from these numbers...". This is interpreted as referring to the basic role of numbers represented by the multiplication table. (Compare the German name of the multiplication table as the "Einmaleins", the 1×1). The stress on the specific number nine may come from the early Chinese use of the decimal positioning system (already seen on the oracle bones of the - 13th century) with nine numbers available for each position (the zero symbol appears much later). Thus any number could be written with only nine numerals, which exemplified the symbolic pervasiveness of the number nine and its special grip on ancient Chinese legends.

The western heirs of the ancient Babylonian culture held similar world views. Homer (- 9th cent.) tells of the mighty "oceanos" washing the "oikumene" on all sides. The oikumene was the inhabited part of the world as he knew it: the Mediterranean area. Anaximander of Miletus (- 6th cent.) drew a map of it, as a flat disk centered at Delphi in Greece, where the "navel of the Earth" was marked by a fancy stone (still to be seen in the museum there). Anaximander's map was roughly contemporary with the Babylonian map, but did not show any mystical areas beyond the circumfluent ocean. Yet the Greeks also wondered whether there were other oikumenes besides their own. They thought that the world came to a precipitous end not far beyond the western end of the Mediterranean Sea, the Pillars of Hercules and the Sacred Cape of Iberia. They also knew that the climates and living conditions changed toward north and south, from the frigid to the torrid zone, the natural limits of human habitation. Thus the habitable world might just be part, maybe a quarter, of the Earth. What was beyond its limits? Who could see and tell? In a story by Lucian (+ 2nd cent.) a traveler to the moon is asked to be sure « to tell all about the shape of the Earth, the distribution of land and water, and everything else on it as you can see it from up there ».

While land surveying, one root of geodesy, responded to the immediate local needs of society, it was the oceans that sparked global geodesy. Most of it at first was speculation, of course, but legends and stories also contained a kernel of a considerable amount of hard facts, accumulated from observation and experience.

Even though the ends of the ocean seemed to coincide with the ends of the world, the nearby ocean was an object of practical observation: there were currents that could be used as natural waterways to venture into the sea, and there were winds as driving forces, whose favors made the difference between a ship's safety or destruction. A Chinese symbol of the all-involving challenge of sea ventures may be seen in the fact that one of the ancient oracle-bone characters (middle of - 2nd mill.) in the form of a sail developed a meaning of "all", "every", "generally speaking" (J. NEEDHAM, 1971).

Chinese sailors were aware of three currents carrying away the waters in three directions; one toward north, one toward south, and the third toward that boundless deep of the Great Eastern Ocean where the waters gradually slope downwards to an abyss or whirlpool; where the Wei-Lü drains into the world from which men do not return; where the waters pour down into the Nine

Underworlds. (*Wei-Lü* means : ultimate drain. The Wei-Lü current seems to be the ancient name of the current now known under its Japanese name, Kuroshio).

Imagination also placed the habitation of immortals and of herbs of longevity and immortality on three holy mountain islands in this mysterious Eastern Ocean. That legend, in turn, provided an incentive to brave the dangers of the voyage and try to reach these islands. It is told that sea-captains were sent out repeatedly in the – 3rd century to bring those precious herbs home to the emperor. The sea-captains apparently had good common sense when reporting back without those herbs. One reported that the islands and what was on them, looked like clouds from the distance and, upon closer approach, sank below the waters and strong winds drove the ship away. Others told of difficulties with great sharks and the need for excellent archers to come along and kill them. Another told of having actually reached the island but been refused the herbs because he did not bring enough offerings from the emperor. Collecting more offerings, he set out to sea once more but was never heard of again. The inference was that he and so many others may have found some distant shores for a new life from where they could not or would not return to China. There is a good possibility that they may have reached Japan or even America.

The Western world also dreamed of various Utopian islands such as the Island of the Blessed or the Elysian Fields on the Fortunate Islands, or the land of the Hyperboreans in the remote north in back of the North Wind, etc., all in pleasant climate and environs, all unreachable to ordinary mortals. In the Sumerian – Babylonian epic *Gilgamesh* (– 3rd mill.), the waters separating the island of the immortals from us could only be crossed by Gilgamesh with the help of the gods.

The gods were repeatedly helpful to teach us how to cope with the formidable sea by watching the sun and the stars, cliffs and currents. Observations of important facts are transmitted in easily understandable, mythical or anthropomorphic language. Homer describes the horizon as where “the sun’s bright light drops into Okeanos” and from where “the stars rise after having bathed in Okeanos”, and he draws attention to the special circumpolar Bear, the Big Dipper, “who alone has no part in these baths”. The beautiful goddess Calypso advised Odysseus how to steer his ship by keeping the Big Dipper always to his left. And the beautiful goddess Circe warns him of dangerous currents, describing Scylla and Charybdis : “Divine Charybdis sucks down the black water. Thrice a day she belches it forth, and thrice she sucks it down, insatiably. May thou not be there when she sucks it down, for no one could save thee from ruin”.

Also Chinese sailors, transporting merchandize on the rivers, looked for divine assistance. They knew how to utilize the tides and the winds, and they watched the clouds for signs of storm; yet they also “worship Pho-Kuan, the Goddess of Wind and Wave, with sacrifices, and ask the monks to pray for them”. (From + 8th cent. Thang documents, NEEDHAM, 1971).

A widespread need of even experienced seafarers for all the protection they can get is understandable enough, particularly if one reads in the *Odyssey* of the gods’ unpredictable moods in changing the winds around to the despair and detriment of hapless Odysseus yearning to reach home. J. HORNELL (1946 *a*) points to the close relationship between a divine protector and a specific ship to the extent that the deity is invited and expected to take up abode in the ship’s prow during

voyage. He/she is made to feel welcome and honored by periodic worship and offerings. One of the still persisting rites of very ancient origin is the incision of an eye on each side of the bow, called the "opening of the eyes" or the "cult of the oculus", which originally symbolized the hope for the deity's watchful eye and then changed to an amulet against the effects of the evil eye. Engravings of ancient war-boats on bronze drums found in Indo-China (- 1st cent.) show clearly an oculus on the bow. And it was often painted on the "eyebrows" (prows) of Chinese vessels. It is assumed that this practice spread from ancient Egypt or Mesopotamia in all directions already in antiquity. The oculus is still to be seen on many Mediterranean vessels. HORNELL suggests that our current custom of blessing new ships and aeroplanes continues this long tradition of ancient practices.

Whether or not guided and sustained by divine or magic forces, the ancient seafarers must have been keen observers as well as hardy souls to accumulate a stock of practical experience in reading and interpreting natural phenomena, very different from and more reliable than that of the landlocked scholars. While armchair philosophers phantasized fearfully about the edges of the world without being harmed by incorrect hypotheses or conclusions, the seamen plowed the high seas well knowing that wrong decisions, incorrect interpretations, or overlooking certain facts may cost their lives. Yet there is evidence of prehistoric transoceanic voyages connecting various oikumenes before their geographic existence was mutually even known. It is Thor HEYERDAHL's (1960, 1971, 1978) merit to have demonstrated the possibility of such early voyages without the benefit of modern navigational instruments, through his expeditions with Kon-Tiki, RA I and RA II, and Tigris.

The sea and the seafarers naturally contributed also to the concept of the spherical Earth. Historically, there were several sources for this concept. In ancient China, these were purely astronomic, augmenting the observation of circumpolar stars whose partially visible orbits needed a continuation underneath the Earth. The spherical or at least oval Earth (together with the Heavens like a hen's egg and its yolk) completed a logically consistent, equatorial astronomical system, but had no further impact on geodesy. In the West, by contrast, Pythagoras and his school derived a perfectly spherical shape of the Earth and the planets from his idea of a perfect, harmonious *cosmos*. This soon sparked questions about a proof as well as about the size of that sphere; and that had an incisive impact on geodesy. The oceans undoubtedly were part and parcel of that spherical surface, which may have been enhanced by the mental picture of a smooth, calm ocean surface. Aristotle tried to prove the spherical shape in various ways: by speculations about the effect of gravity which made all bodies fall toward the center of the world and form a compact ball there; by watching the horizon and stars when moving north; and by the round shadow of the Earth in lunar eclipses. These same astronomic observations, however, had been made earlier in Mesopotamia and Ionia, yet without forcing the same interpretation. Then Archimedes, the father of hydrostatics, envisioned an ocean-covered Earth to prove that "the surface of a fluid at rest is that of a sphere with its center at the center of the Earth". And Eratosthenes noted: "The Earth together with the sea is sphere-shaped" and he pointed out that the topographical irregularities, small when compared to the size of the Earth, must be overlooked to arrive at the spherical model. (That sounds like the marine geoid as the reference for elevations!).

The ancient mariners made their characteristic matter-of-fact contribution of purely observational day-to-day experience. Strabo describes it: "The spherical shape of the Earth... is proved from observations of the sea and sky, for here the evidence of the senses and common observation is alone requisite. The convexity of the sea is further proof to those who sailed; for they cannot perceive lights at a distance when placed at the same level as their eyes, but if raised on high, they at once become perceptible to vision, though at the same time further removed. So when the eye is raised, it sees what before was utterly imperceptible. ... Sailors approaching their destination, behold the shore continually raising itself to their view, and objects which had at first seemed low, begin to elevate themselves". And in a much older document, the report on the famous voyage to Sierra Leone by Hanno of Carthage (~5th cent.), it says (TAYLOR, *ibid.*): "Ships disappear hull down, a lantern must be placed at the masthead to be visible at a distance, while from the masthead the lookout saw land that was invisible from the deck. As one sailed north, more of the stars became circumpolar ones, while as one sailed south new stars arose, culminated and set, and at length the tail tip of the Lesser Bear touched the horizon".

While these observations perceive the surface of the sea to be curved in all directions, not just north-south, but not necessarily to be part of a perfect sphere, the sea as the major part of that sphere was always understood to represent the essential shape of the Earth. Both Aristotle and Eratosthenes built on this concept when discussing the possibility that "one could sail westward from Iberia to India along the same latitude circle, were it not for the immensity of the ocean". The question of how long that particular ocean arc was played an important role several centuries later for Christopher Columbus.

ON BEING AMPHIBIOUS

"We are in a certain sense amphibious, not exclusively connected with the land, but with the sea as well" noted Strabo. He did not allude to any speculation that an aquatic hominid may have been our ancestor, as proposed by Sir Alister Hardy (1960), who points to rudimentary evidence such as our naked skin and the layer of fat beneath it, or the capability of newborn babies to swim. But while most of us prefer to live on land, there are many who thrive in a watery life style, either in a chosen career connected with the oceans or enjoying intensive water hobbies. There are, and always were, people preferring to live in houseboats or houses on stilts on the water (though not within the water). J. HORNELL refers to the possibility of prehistoric amphibious tribes living in raised houses on the waters of the Mediterranean coast to avoid the perils of land dwellings. Well known also are the lake dwellings of stilt villages in Alpine lakes (~2nd mill.) and in the waters of Indonesia still today. One thing is obvious: living under such conditions makes it of vital importance to get around in the water other than by swimming alone, yet learning to use water ways like roads belongs to the distant unrecorded past. Means to do that must have come from natural, relatively simple sources. J. HORNELL describes three basic groups of primitive water crafts: floats, skin-boats, and bark canoes. The observation of certain floating things such as fruits, logs, baskets, reeds,

bamboos, inflated hides, etc. would have invited ingenuity for further and further adaptations to enlarge standing and even sitting room, and for utilizing currents and winds as driving power while steering with a pole. A glimpse of what it may have been like is offered by contemplating the simple vessels being used today in some areas. A. VILLIERS (1963) shows some of these in photographs: a bamboo basket boat used in Vietnam; inflated hides tied together to support a raft in Himalaya streams; a raft formed from mangrove logs in Western Australia; and a boat of bulrushes with a sail of reeds used on Lake Titicaca in South America. Assyrian reliefs of the -9th century depict swimmers using gourds and inflated skins for support, and floating baskets covered with skins as they are still widely used today. Pytheas of Massilia (-4th cent.) and before him also Himilco of Carthage (-5th cent.) reported their surprise at seeing little primitive skin-boats of Brittany perfectly capable of negotiating a 300-mile crossing to Ireland. And one point of Thor HEYERDAHL's experiments was to duplicate for us the supposedly primitive ancient vessels made with skill and insight from native plants: the balsa-log raft from Peru, the papyrus-reed boat from Egypt, and the reed ship from Mesopotamia. In China, J. NEEDHAM tells us, the bamboo was the given native material and its special properties explain the different developments in Chinese ship designs.

While there can be no doubt about an age-old capability of water travel, one may ponder how the difference in land and sea milieu affected the response to the basic geodetic questions of distances (including elevations) and directions in antiquity.

Collecting information on long *distances* in antiquity was based on analogous units for land and sea: "a day's journey" of royal "mensors" or "bematists" walking evenly and counting their steps, and/or heavily laden caravan camels known to move evenly (IDELER, 1827) versus "a day's sail" or "etmal" (MŽIK, 1938). Ptolemy discussed, in much detail, why and how all such raw measurements were subject to some screening: travel reports from land travelers as well as sailors might have been exaggerated to dramatize the hardships endured, and thus need some reductions and comparisons with other sources of information (other reports; credibility of reporters; astronomical observations; climates; inhabitants; flora and fauna, etc.). Furthermore, the path of the marchers (with an army, for instance) or of a ship was not necessarily along a straight line, due to terrain variations; this too required a reduction to arrive at a straight map distance. In the case of a ship there is the additional question of a favorable wind which would influence the sailing speed, and there are the configurations of the shore line to be considered. And he gave detailed instruction of how to handle, e.g., the rounding out of a bay: assume it has a semicircular shape, then the direct line between entrance and exit would be the diameter, i.e. shorter than the arc by about one third. Another third must be subtracted because of the reduced speed in the bay. A further reduction would be needed for mapping along the meridian and the parallel circle.

The concern for straight map distances, however, only worried scholarly landlubbers intent on the construction of a consistent world map, not practical sailors intent on sailing safely from one point to another, when the diversities of the terrain, on the contrary, were of primary guiding importance. A record of sailing instructions (pilot books, peripli) contained, besides sailing distances, much more of vital navigational interest than a chart normally would, whether or not charts accompanied ancient peripli. E.G.R. TAYLOR (1957, 1971) quotes a number of

examples: Old Norse sailing directions for a crossing from Norway to Greenland told the pilot to keep so far north of the Shetlands that they were only just in sight, then keep so far south of the Faroes that their heights are half-hidden by the sea. A 3rd century Mediterranean pilot book advises how to get into port: "... sailing to Zygris, there is an islet, put into the place with it on your left; there is water in the sand", or "... close by lies a rather large island, put in with this on your right; there is a harbor accessible with any wind; water is to be found".

Highly visible landmarks (mountains, temples, lighthouses) were vital guides to landfall. So was a decrease in water depth, and soundings were a must since ever. Pole soundings are depicted on Egyptian tomb carvings of the ~2nd millennium. Herodotus writes: "Approaching from the sea, when you are still a day's sail from the land, if you let down a sounding-line you will bring up mud, and find yourself in 11 fathoms of water, which shows that the soil washed down by the stream extends to that distance". (The Greek measure «orguia» was defined the same way as our fathom). E.G.R. TAYLOR notes that this observation is well supported by modern charts, if one allows for a very likely corruption of the text and reads 100 fathoms rather than 11. Our point here is, however, that depth measurements were routinely made by seamen, while land elevations did not appear on land maps until the 18th century, preceded by soundings off coasts and in estuaries as a common feature on 16th century charts (G.R. CRONE, 1978). Of course, civil and military engineers will always have been interested in heights. There is a Chinese "Sea Island Mathematical Manual" of the 3rd century (J. NEEDHAM, 1959), full of exercises to determine, by similar triangles, the height of an island seen from the sea, the size of a distant walled city, or the width of a river seen from a hill, etc. The last reminds of the legend about Thales who determined the width of a river from a lookout tower, and its duplicate story of how one of Napoleon's soldiers used the right setting of his cap for that same purpose.

Incidentally, the oldest land surveying tool, the rope knotted at fixed intervals, had its good use also at sea in the form of the lead line for soundings and, in the 16th/17th century, as an attachment to the log (Am. Practical Navigator, 1977) determining the ship's speed; and there is the persistent use of the term "knot" for the speed of one nautical mile per hour.

The first idea of *directions* must have come from the sun's rising and setting (east-west, orient-occident), divided by the shadow line at noon. Here are the four cardinal points, the Bible's four corners of the Earth, and the square Earth in ancient Chinese writings. This fundamental system of daytime "orientation" (derived from "orient"), and the corresponding night observations of the rising, setting, culminating, and circumpolar stars, was augmented by the seafarers by yet another system of directions, a system of winds on whose mercy the ship's fate so clearly depended. Realizing from experience that winds from the north, for instance, blew cold, those from the south were warm, others brought rain or were dry, winds were identified by individual names which then made up the direction names in the early wind rose. The Tower of Winds in Athens shows an eight-fold wind system, but Timotheus of Rhodos (~3rd cent.) distinguished twelve wind directions and later there were more subdivisions. Besides these more or less even subdivisions of the horizon, the mariners recognized wind belts and seasonal winds which helped or hindered sailing in a desired direction. They had learned to watch and utilize them, as well as the ocean currents, and that had made early ocean

voyages possible. They had observed the reversion pattern of the monsoon, for example, to schedule navigation between India, East Africa, and Southeast Asia. Similarly, the reversing home-blowing winds between Norway and Greenland had made sea traffic possible there. Since sailing speed depended on the right wind, sailing distances were often given with this in mind, naming the wind that should follow the ship to get you there. So we read, e.g., in Strabo: "From Chios to Lesbos is 200 stadia with Notus" (the south wind), or in Pliny: "From Carpathus to Rhodes is 50 miles with Africus". Clearly, knowledge of winds was all-important and every new observation was noted and added to the stock of experience to be transmitted. Strabo writes: "The (Mediterranean) sea routes all pass through a zone of fair weather, particularly if the sailor keeps to the high seas, ... the winds on the high seas are regular ... all piracy has been broken up and hence the sailors feel wholly at ease. Posidonius says that he observed a peculiar circumstance on his return voyage (from Gades) ... the eastwinds as far as the Gulf of Sardinia blew at a fixed time each year; that is why it took him three months to reach Italy; he was driven out of his course in both directions".

Expertise in navigation by sun and stars, by winds, ocean currents and tides, and by landmarks, soundings, and sea-bottom samples, left room yet for using any other possible aids for safe sailing and home-coming. The "Periplus of the Erythraean Sea" (ca. +60) which covers the region between the Red Sea, Arabian Gulf, and western India for the benefit of merchant ship owners, is quite diversified (TAYLOR, *ibid.*): Approaching the Indus, it said e.g., the pilots noted the change in the color of the water far out to sea, and near the Indian coast they saw a large number of sea-snakes rising up from the bottom and floating on the surface. Chinese sailors, according to the Thang documents mentioned earlier, go up the Yangtze River with reliable winds in certain months; but lacking these, "in the third month they rely on migrating birds, and in the fifth they look for the wind on wheat". Old Norse sailing directions, also mentioned earlier, advise to keep the ship south of Iceland "so that the sea-birds and whales can be seen". The Irish monks may have been alerted to the existence of an island and thus be guided to Iceland by watching the direction of the annual migration of geese, the noisy and conspicuous birds wintering in the Shannon Estuary by the tens of thousands. Besides watching the flight and whereabouts of birds, there was a wide-spread practice of taking shore-sighting birds on board as direction finders (J. HORNELL, 1946 *b*; TAYLOR, NEEDHAM). Apart from the archetype of Noah sending out a raven and a dove from his ark, there is mention of such birds in the Dialogues of Buddha (-5th cent.), in Pliny about the sailors of Ceylon, in stories about Floki, the Great Viking, in Chinese documents and elsewhere. A competent navigator certainly had to be a many-sided expert. A 4th century Indian text (NEEDHAM IV: 3) pays tribute to such a one, considered an incarnation of Buddha: "He knew the courses of the stars and could always readily orient himself; he also had a deep knowledge of the value of signs, whether regular, accidental or abnormal, of good and bad weather. He distinguished the regions of the ocean by the fish, by the color of the water, by the nature of the bottom, by the birds, the mountain landmarks, and other indications".

It thus should come as no real surprise that the seafarers, depending for survival on their factual, no-nonsense tradition, were unaffected in the dark ages by the western otherworldly disinterest in geographic facts and the collapse of geodesy

and mapping. They kept collecting and recording information in their pilot books, and it was they who, in the 13th century, rekindled informative mapping with their sea charts, based characteristically on directions rather than a latitude-longitude grid of Greek-Roman design. Why sea charts, all of a sudden, when pilot books had been sufficient till then? This was a response to the revolutionary introduction of the magnetic compass into navigation. Authors disagree on where to give credit for this instrument : to the maritime center at Amalfi, to the Norse, to the western or eastern civilization, but J. NEEDHAM (IV : 1) assembled several old Chinese texts as evidence for a Chinese origin. It is accepted, at least, that Chinese sailors used the magnetic compass by 1090, a century before European sailors, whose use is first mentioned in 1190.

These Mediterranean sea charts (Portolans) showed wind directions emanating from one or two specific centers, so that the bearing of a ship's course between two points, taken as a straight line, could be found as a parallel to one of those directions. Together with a scale for distance, they provided a map coordinate system specifically suited for the sailors' needs. It made it possible to plot the course of a whole voyage in advance. While the distances had to be estimates from the experience of the pilot books, it turned out the dead-reckoning method was surprisingly correct within 2% (CRONE, *ibid.*). For the relatively small latitudinal spread of the Mediterranean Sea, the underlying assumption of a flat Earth was good enough for these maps. Latitude became more important when sailing along the Europe-African coast. The difficult longitude problem of converging meridians was circumvented in practice by finding the latitude first and then going east-west by dead-reckoning (Am. Practical Navigator). It was later addressed by the Mercator projection (16th cent.), an ingenious device to help chart a ship's course between any two points. It depicts meridians as parallel straight lines and thereby also a rhumb line (intersecting meridians under a constant angle) as a straight line. Thus a ship's track can be plotted in segments of straight lines of constant bearing.

A dividing line between early and not-so-early geodesy is not clearly given, and it seems we may have passed that line already. Yet, to round out the topic, one ought to mention just one or another later development.

In mapping : As the revival originated in sea charts, typically reflecting the seamen's need and experience, it is no wonder that these as well as later maps (CRONE, *ibid.*) showed fairly accurate and detailed shore information but blanks inland which only gradually were filled up. Soundings appeared on maps before any spot elevations were shown. Contouring started with high and low water lines and underwater isolines in estuaries, before any land contouring.

In geodesy : The modern concepts of the marine geoid, the reference surface for depths and elevations, the level surface representing the figure of the Earth with its extension to a system of potential surfaces, the study of tides and currents, bathymetry as a source of geodetic information, etc., are all building on a basis of early ideas and experiences.

SYNOPSIS OF EARLY GEODETIC HISTORY FROM A WATERY VIEWPOINT

- * Global geodesy began with the contemplation of the vast ocean and speculation about its extent.
- * Evidence of high sea voyages dates back for several millenia. These precursors of the great discovery voyages of the 15th/16th centuries were made without navigational instruments, but attest to a comprehensive knowledge of celestial navigation, and patterns of winds and currents.
- * Transoceanic sea lanes were established while landlocked people were afraid of the precipitous edge of the world just outside of the Pillars of Hercules, or of the ultimate drain in the Great Eastern Ocean.
- * The curvature of the sea surface was recognized as a daily experience while learned astronomers thought up fancy hypotheses to support their belief in a flat Earth surface.
- * The calm ocean surface always represented the essential figure of the sphere-like Earth. Topographical elevations above that surface were to be neglected to arrive at the Earth model (Eratosthenes). Archimedes used the fluid earth concept for a theoretical hydrostatic proof of sphericity.
- * Distance measures at sea were different but analogous to land measures. A day's sail (versus a day's journey) was accumulated by dead-reckoning (versus counting steps). Reports of both were reduced for credibility, terrain variations, and compatibility with other indications.
- * Elevations (landmarks) and particularly water depths were of great importance, but played no role in land geodesy.
- * The knotted rope was an ancient measuring device on land and it was used at sea for the sounding line, later for measuring speed.
- * A specific direction system was established by mariners from observation and utilization of wind patterns, not used for orientation on land.
- * Other direction and haven-finders were utilized by mariners where possible: observation of migrating birds, shore-sighting birds taken on board, color of water, sea-bottom samples, etc.
- * Observational data were systematically collected along shores and accumulated in written sailing directions. These were kept up of necessity also during the dark ages of the western collapse of geodesy and mapping.
- * The use of the magnetic compass on shipboard started a new era of mapping, with unique sea charts.
- * These Portolan charts of the Mediterranean were the first maps to scale since antiquity. They had a coordinate system of directions and distances, characteristic for and responsive to the mariners' needs. It was now possible to chart and plot an entire voyage in advance.

- * The contents of these charts reflected the contents of the pilot books : detailed shore information but very little inland. Only gradually did mapping advance inland.
- * Topographical information on maps began with soundings long before spot heights were shown. The same applies to contouring.
- * Latitudes were not of great significance within the Mediterranean, but became important when sailing along the Europe-African coast. The difficulty of the converging meridians was practically evaded by dead-reckoning along the desired latitude parallel, and led to the Mercator projection later on.
- * The modern geodetic concepts such as the marine geoid as a special potential (level) surface and a reference for elevations may be seen as a mathematically refined, sophisticated version of ancient ideas.

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