THE DEVELOPMENT OF MARITIME HYDROGRAPHY AND METHODS OF NAVIGATION

Lecture delivered by HENRI BENCKER, on April 5th 1943.

The " Société des Conférences de Monaco " has kindly done me the honour to call upon me to treat before you a subject which is possibly a little dry although dealing with things of the sea, viz. the development of maritime hydrography and methods of navigation.

I am all the more willing to fulfil this mission as we are indebted to the generosity of the Princely Government for the foundation and upkeep, since the year 1921, of a special Institute, situated in the Principality and entrusted with the co-ordination of all questions relating to the world's hydrography.

But, first of all, what is meant by " hydrography " ? It is customary to designate under this heading that branch of geographical science dealing with the regimen of current or stable waters which is peculiar to a given continental area. But from the stand point which concerns us, maritime hydrography is really the *art of compiling charts* and drawing up documents for the use of mariners with regard to the safety of their navigation and in view of ensuring the proper steering of their ships in all navigable parts, including oceans, seas and adjacent coastal zones.

It includes the carrying out of necessary maritime surveys for the security of navigation viz. : coastal triangulation and shore topography measurements, the taking of soundings and sea depths, the description of coastlines, the study of tides and sea-currents.

Its aim is to publish in an appropriate form for the use of navigators all data relating to the correct configuration of navigable regions and all nautical information which may be of service to them.

This as you may see, is a fairly wide programme, considering that the sea occupies about 3/4 of our terrestrial globe, that the coastal line length of oceans and seas may be roughly estimated at 360.000 kilometers (i.e. nine times the circumference of the earth) and that at the present day there exist for this particular study (according to the latest Year-Book published by the International Hydrographic Bureau) over 32 national Hydrographic Offices. These services employ a specialized staff of over 6.000 hydrographic surveyors or draftsmen. They control a fleet which, before the war, could be estimated at 117 surveying ships representing a tonnage of 87.000 tons with an aggregate crew of about 15.200 men.

The number of charts available for navigators in 1940 may be said to amount to about 17.000. Out of this number, about 7.000 are original coastal charts and 2.000 are general charts relative to oceans beyond coastal territorial waters.

This immense portfolio of charts (which if spread out would cover the whole area of the Monaco harbour) is supplemented by about 450 volumes of original sailing directions serving as coastal guides (a sort of Michelin's guides for navigators) and 40 volumes giving a description of light-houses, beacons, buoys and all other navigational aids for the whole world.

In order to maintain and keep up-to date this large nautical lbirary, Hydrographic Offices issue daily some notification sheets called " Notices to Mariners " for the correction of books and charts, involving, according to the year, from 10.000 to 12.000 articles. Such are the immediately and constantly kept up to date documents which are now available to Mariners for the accomplishment of their duties.

In the maritime sense which we attach to it, the word " Hydrography " is not solely confined to these documentary items; more generally speaking, it also implies the teaching of methods of navigation and the study of all the modern improvements incidental to these methods.

Originally " Hydrography " was almost synonymous to " Navigation ". These two subjects are really so closely interconnected that it would often be difficult to separate the theoretical teaching of navigation from the data collected precisely with a view to ensure the proper steering of ships at sea. In France, they designate under the name of " Ecole d'Hydrographie " a center where professors of hydrography teach navigation to future master-mariners while the " Ingénieurs hydrographes " of the " Service hydrographique " are more especially entrusted with the compilation of charts, of documents in connection with sailing directions and accessorily of some navigation tables.

So that, in the brief exposition which I propose to submit to you this evening and in this ancient and limited history of the development of the world's maritime hydrography and of the various events which have contributed to ensure in this respect a basis for our fundamental knowledge, I shall also have to refer to efforts made and successive stages accomplished for the improvement of navigation, since these two arts practically go pari passu complementary to each other with a sort of rocking motion. As regards the collecting of nautical information, it is the navigator himself who is responsible for its supply to the Hydrographic Service which in its turn centralizes data received, sorts them out, analyzes them, makes a scientific study and finally hands them back to the navigator in a systematic and more directly available form.

Historically speaking and confining ourselves to the end of the quaternary period which witnessed the appearance of man on our planet, world's hydrography began by the accident which by common consent is called THE FLOOD. The stranding of Noak's Ark, on the foreshore of Mount Ararat or rather on the highest summits of the Himalaya does not entail, for lack of charts at the time, any responsibility either on the part of any Hydrographic Service, nor on that of the illustrious patriarchal agriculturist who for 300 days, according to the Bible, played the part of an Admiral between sky and water to finally leave us to our fate of common castaways in this world.

According to western tradition, the world known to the Ancients was confined to the Mediterranean Basin. Navigation was still in its infancy at the time of the Phœnician navigators from Sidon or Tyre who never ventured very far away from the coasts, in their craft.

In the Xth Century B.C. Homer described the earth on Achilles's shield as being surrounded by the sea. At that time, Corsica was the limit of the civilised world; Scylla and Charybde were places which it was desirable to avoid at any cost.

According to Strabo, the historian (58 years B.C.-25 A.D.) the use of the first geographical maps, produced by the geometrician Anaximander of Miletus would date from the year 568 B.C., that is long before the time (500 B.C.) when the Carthagenian navigator Hanno, crossing " The Pillars of Hercules " made his famous voyage along the west coast of Africa as far as Guinea where he visited the Canary Islands (The Fortunatae Insulae) (where coins bearing the effigy of Carthage were recently found).

Navigation keeps to the coasts : Scylax, a Greek navigator, makes a periplus of the Black Sea and Mediterranean. Herodotus (484 B.C.) also refers to a periplus round Africa, by order of the King of Egypt, so that a precursor of Vasco de Gama by more than 2.000 years is supposed to have set off through the Red Sea on that expedition and returned 3 years later by the Strait of Gibraltar after having rounded Africa by the South.

Very anxious to monopolize trade, Phœnician and Carthaginian navigators kept to themselves their own nautical information and rendered it even unnatural through diabolical or monstruous legends intended to frighten away prospective competitors.

Through Greek Authors such as Herodotus (484 B.C.), Eratosthenes (276 B.C.), Strabo (58 B.C.-25 A.D.) and Ptolemy (IInd Century A.D.) we can follow the progressive reconnaissance of the globe in antiquity. Its development was chiefly due to the conquests of Alexander the Great who lived from 356 to 323 B.C.

The use of the first plane charts dates from the time of the Alexandria Geometricians' School, founded by Alexander the Great and represented mainly by Hipparchus (135 B.C.) who invented the " Climates " scale or " Latitudes ".

Claudius Ptolemy's geography written in Greek about 160 A.D. with 27 annexed charts, is the first atlas summarizing the state of geographical and nautical knowledge at the end of antiquity. The world extends from Thule (possibly Iceland) visited by Pytheas of Marseilles (325 B.C.) to India beyond the Ganges (reconnoitered by Megasthenes, a Greek geographer); and from Ethiopia (viz: Africa) to the Erythrean Sea with Zanguebar (Zanzibar) and Indian Ocean closed, to the South of the Equator by the supposed existence of a vast Austral Continent linking Ethiopia to Eastern Asia.

Ptolemy, actuated by astronomical and mathematical considerations, strove to compile a really scientific chart. His predecessors, especially Marin-of-Tyre, had confined themselves to the indication in *stadia* of distances between towns and principal places. Navigators also used for navigational purposes the sort of documents called " stadiasms " the best known of which (handed down to us in the shape of a copy made by a monk in the 13th Century) is that of Castorius (known under the name Peutinger's Table—in 12 sheets). Ptolemy after having thought out the division in degrees of longitude and latitude made a drawing of countries and arranged notable places according to this method. Unfortunately, the measurements supplied to him by previous writings were based on vague and greatly exaggerated estimates, especially in the West-East direction. He assigned to the Mediterranean 20 degrees too many in longitude : starting originally from the meridian of the Fortunate Islands (Canary Islands), errors accumulating and expanding eastwards in the eastern part of his charts.

When, after the oblivion of the Middle-Ages, his geography found its way to Italy towards the end of the XIVth Century, when it was translated into Latin, it aroused quite a passion for discoveries. Owing to these errors, the presumed extent of the Ocean was reduced by almost 3.250 miles in width, which incited Columbus to attempt his voyage. Likewise, Ptolemy's hypothesis relative to the existence of an austral continent, counterbalancing the lands of the northern Hemisphere which was accepted as an article of faith, gave rise eventually to Captain Cook's voyages of exploration in the South Pacific Ocean.

After the Roman Empire and during the Middle-Ages, the field of geographical knowledge, which lay fallow for some time, was re-cultivated by the Arab School. A large portion of the trade was still carried on in the Mediterranean, although the Arabs' navigation was developing not only in the Mediterranean but also in the Indian Ocean as far as the south of the Zambesi River and the Sunda Isles. In the Atlantic, Magrurin, a Moor, is supposed to have discovered the Antilla Island (marked on Andrea Biancho's chart (1436). He constructed a silver world's map for King Robert of Sicily (today we make them with paper) and wrote a treatise on geography with a large appended chart showing Atlantic Islands, such as the Fortunate Islands (Canary Islands), the Casiterides (The Azores), the Hesperides (Madeira) and Thule (Iceland). A certain Ben-Farouk is supposed to have landed in the Canary Islands in 999.

The disciples of the Moorish School of Cordua continued the Ptolemaic tradition of plane charts whose use was introduced by them among European Navigators. Towards 1201, the Arab Shereef Edrisi, a Nubian geographer, gave in his " *Geographical Relaxations* ", a description of the western shores of the Mediterranean. We are also indebted to Arab Navigators for the improvement of the Astrolabe and the use of the compass that came from the East and was introduced by them in Europe towards 1242 : this instrument is actually minutely described in a letter by the Equerry Pierre de Maricourt, dated 1269, a long time before the invention attributed to Flavius Gioja, an Amalfitan pilot, in 1302.

So that with these new tools, navigators who up to then had rarely lost sight of land, dared to venture further off, mariners became bolder and launched out into Ocean navigation.

In the XIIth and XIIIth centuries, the Genoese and Venetians, masters of the Eastern trade, improved Alexandrian geographers' charts : In 1270, the ship that sailed towards Tunis with the French King Saint Louis on board was a Genoese craft. Six days after leaving Aigues-Mortes, as they became uneasy because they had not yet sighted the Sardinian coasts, the ship's pilots (" navis principes ") spread out a world's map before the King and said pointing out " This is where we are, Cagliari is close by ". It is the first chart we have heard being used on board, according to the chronicler Guillaume de Nangis's account.

But the first chart handed down to us is one of the XIIIth century, preserved at the " Bibliothèque Nationale ", in Paris, under the name of " Carte Pisane ", it is the normal type of the " Portulan ". These portulans were charts copied on parchment and originally on whole skins; they were illuminated in the brightest colours. Pilots marked the coastline with a nomenclature of ports, banners and various rhumbs fixed according to a system of transversal lines and compass-cards. Copies were made by specialized draftsmen who had to be supplied with skins or parchments. When drawing them, they very sensibly kept them up-to-date according to the latest discoveries.

We have also an atlas by Pietro Vesconto (1313) of the Genoese School, a planisphere by Cavignano (1320), a very fine chart by Angelino Dalorto (1325) which is part of Prince Corsini's collection in Florence and of which the Royal Society of London published a coloured reproduction in 1929. We should also mention the Venetian planisphere by the Pizzigani Brothers dated 1367.

These nautical documents were used in conjunction with the calculation table called "Toleta de Martelojo" for the purpose of dead reckoning.

The Catalan School improved Mediterranean hydrography to a great extent. The Saracens of Majorca had set up in the island a nautical school where the celebrated Raymond Lulle published in 1286 the "*Phœnix of the Wonders of the World*" a work on pilotage and cosmography which is also a treatise on chart compilation.

This Majorcan School has left to us : a Planisphere by Angelino Dulcert (1339), a Mediterranean Atlas by Jacques Farrère (1346) preserved in Paris, the Catalan Atlas compiled for King Charles V the Wise (1337-1380) by a certain Abraham Cresques of Majorca in 1375; the latter while constructing charts was also keeping, with the assistance of his family, a bathing establishment which in those hard times, seemed to be a much better paying proposition than a navigating clientèle.

A copy of the Catalan planisphere of Vallsecha compiled in Majorca in 1439, was used by Amerigo Vespucci, the Godfather of America.

In 1438, the Infante of Portugal, Don Henry the Navigator, in his seclusion of the Sagres Promontory, where he was devoting himself passionately to the study of things of the sea, sent for Master Jayme of Majorca, for the purpose of instructing Portuguese Naval Officers in the art of Navigation. Nautical Science was therefore changing its home, it left the Balearic Isles for Portugal to seek new adventures along the Ocean coasts in that impulse of world's hydrography which meant to drive away the terrifying legends of the sea of darkness.

These voyages of discovery aroused great interest in public opinion. From the Islands of Cape Verde, *Antonio di Noli* brought some gold powder; *Lanzarotto* brought back to Portugal 200 natives, amongst which, some black girls who were readily adopted by the most noble Lisbon families.

The nautical results of these voyages were naturally recorded on charts of which some have reached us. We shall merely refer to the following, which are due to the Italian School and constitute valuable objects of collection, showing the stages of reconnaissance of the West Coast of Africa.

1426 : Chart of the Canary Islands of Madeira and the Azores, by Giacomo Giroldi (Venice).

1460 : Chart of the Arguin Bank waters (Milan).

1473 : Chart of the Islands of Cape Verde and Bissagos (Italian manuscript in the Bibliothèque Nationale).

1489 : Venetian Chart of the Gulf of Guinea and Congo.

1502 : Genoese Chart by Nicholas Carneiro, showing all stations (padraõ) on the South and East Coast of Africa, visited by the Portuguese. (Cape Agulhas had been rounded by Vasco da Gama in 1497; the sea route to India, by the South-East, was open.)

However, plane charts used for showing waters like those of the Mediterranean with small latitude area, by their projection to a constant scale on a system of compass bearings or rhumbs distributed by means of compass-cards, called loxodromic charts, could not be adapted for the representation of regions with great changes of latitude. As early as 1456, Portuguese Navigators used to carry on board ship large astrolabes for measuring latitude, on land, at each of their places of call.

Joao de Santarem crossed the line for the first time in 1471, but history does not relate if this event was the occasion of the traditional "ducking" ceremony.

From 1478, navigators could avail themselves of the "Almanach perpetuum" computed by Abraham Zacuto which provided them with sun astronomical tables for calculating latitude. The innovation introduced by Portuguese and Spanish hydrographic Surveyors was to no longer restrict themselves to the use of the compass and bearings, liable to variations, but to replace plane charts by "spherical" charts maintaining the parallelism of meridians while also preserving the relative dimensions of lands.

Wood-engraving in Europe dates from 1423. With Guttemberg, typographic printing dates from 1450. One of the first applications of this new art was made in Cartography in as much as a printed edition of Ptolemy's Atlas was issued at Vicenza in 1475 after a manuscript by the Mount Athos Monks dating from the XIIth Century. Copper-engraving began in 1496. In the XVIth Century manuscript charts were gradually replaced by engraved charts. Still the "portulans" or hand copied charts were not discarded when the first printed charts appeared at the end of the XVth Century. People were prejudiced against printing and navigators were of opinion that hand copied charts were more easily kept up-to-date, so that draftsmen continued to practise their art in the XVIth and XVIIth Centuries. Nordenskjöld in his book entitled "Periplus" published in Stockholm in 1897 gives a very complete list of the best known famous portulans. In the latter period, it was the Oliva family (Messina) and Olive at Marseilles who held the speciality started 3 centuries before and handed down from father to son by the Cresques of Majorca.

It was the Portuguese Bartholomew Diaz who actually initated Ocean Navigation in 1486 when he made a voyage during which after a zigzagging course across the Atlantic he rounded the Cape of Good Hope.

In 1492, before launching out across the seas and oceans on the Westward trade route to India, the Genoese Christopher Columbus, had been a printed book canvasser and had derived his knowledge from the "Ymago Mundi" by Cardinal Pierre d'Ailly, Rector of the University of Paris, which had just been printed in 1480, when Columbus attended the naval school of Sagres. The German Cosmographer and navigator who had settled down in Lisbon, Martin Behaim (Bohemia) of Nuremberg (1459-1506) technical adviser to the Junta of Badajoz, a pupil of Regiomontan (Koenigsberg) had just constructed his globe in 1491, on which the Azores where shown as lying half-way to Zipangu (Japan) the farthest eastern island of Asia. This globe was an inspiration to Columbus.

After his 3rd voyage (in 1502) he wrote to Queen Isabella of Spain, speaking of the earth "I have come to the conclusion that it is not quite round but is pear shaped : the part with the stalk is the highest and the nearest to Heaven".

We are indebted to Bartholomew Columbus, Christopher's brother, for the introduction of the first charts illustrating voyages of discovery; he contributed in particular to the compilation of Caneiro's world map in 1502.

The Portuguese Magellan, navigating in the service of Spain, and his lieutenant Sebastian del Cano are credited with the *first circumnavigation of the globe* from 1519 to 1521. Magellan's mission was to sail round America to seek a passage toward the South Sea, that New Ocean which Balboa caught sight of from summits of Darien's Isthmus in 1513, after Diaz of Solis had died while looking for that South-West Passage.

During these long crossings the problem which arose then for navigators was :—

Firstly : Fixing position at sea by Latitude and Longitude.

Secondly : The availability of accurate coastal and ocean charts to mark this position, without error.

At the end of the XVth Century, navigators were in possession of the instrument for measuring latitude; the *astrolabe* already described towards 1295 as a nautical instrument in the "*Arte de Navegar*" by the Majorcan Raymond Lulle, the use of which was popularized by the masters of the Junte of Badajoz, a kind of nautical Committee, who taught in 1484 the determination of latitude by the Pole star and that of meridian latitude by means of *sun declination tables.* They also used for measuring the altitude of heavenly bodies over the sea horizon an instrument called *Jacob's staff,* a cross-bow or geometrical cross, which, to our knowledge, remained in use from the year 1300 to 1725.

As far as longitude was concerned, although Columbus and Vespucci tried in 1494 the lunar method of eclipses and employed the "*Calendarium eclipsium*" published in 1473 together with the conjunctions of the planets computed by the astronomer *Regiomontan* of Kœnigsberg, the problem was only solved in practice 250 years later when mariners could avail themselves on the one hand of an instrument capable of measuring longitude : the *marine chronometer* or " longitude machine " invented by Harrison in 1736, constructed by Le Roy in 1767 and, on the other hand, of good nautical ephemerides such as Tobias Meyer's *Lunar Tables* dating from 1753.

It was only in 1668 after the publication of *Cassini's ephemerides* that they really started to make use of the eclipses of Jupiter's satellites for the determination of longitudes on land.

In France, towards the end of the XVth century, the pilots of Dieppe brought back from their distant voyages nautical information and observations which were collected by a priest of the Village of Arques : Pierre Desceliers. With the assistance of his pupil Jean Levasseur, he tried to utilise these data for practical instruction; so that through this private enterprise a school of Hydrography was founded at Dieppe and the first charts described as " réduites " were compiled and constituted a notable improvement on portulans.

In 1483, a pilot of Saint-Gilles-sur-Vie : Pierre Garcie alias Ferrande, seems to have been the first to have published sketches especially made for the reconnaissance of coasts by mariners. These sketches were got together in the form of directions entitled : « Grand routtier, pillotage et encrage de la mer " and printed in 1520.

Towards 1530 the progress of Portuguese and Spanish cartography seems to come to a stand still, responsible authorities wishing before all to keep secret the information likely to assist the development of their national trade.

It was then that the English School and, later, the Dutch School came to give hydrography a new revival, their data were more readily made public. That was the time when *Drake* made his voyages and visited the coasts of New Albion (now British Columbia) and made his trip around the world in 3 years, it was also in that period that Holland having once conquered the Dutch Indies, made a dash for Australia with Tasman's voyage in 1642.

The Dutch whose maritime progress was manifesting itself with such glamour learned from the Dieppe Hydrographers the secret of their charts of which they became the publishers. Later, towards the middle of the XVIIth century, Dutch charts thanks to their quality had replaced all documents of the same kind.

Mercator's projection (or cylindrical projection) assigning increasing lengths to the various degrees of latitude when going from the Equator to the Pole, is supposed to have existed long before the man whose name it bears: a solar time piece made by the Nuremberg Cartographer Erhard Etzlaub, contained, as a matter of fact a small scale map of Europe with augmenting latitude degrees.

Mercator's invention took place in 1555 although it is said that Alonzo of Santa-Cruz, Magellan's pilot, was supposed to have compiled similar projection charts 16 years before at the request of King Charles the Fifth.

Gerard Krœmer, alias Mercator, was born in Ruppelmonde, near Antwerp in 1512; apprentice and later assistant to Gema Frisius, he was a copperplate engraver in 1535 with Plantijn. Mercator was the author in 1541 of a remarkable terrestrial globe conspicuous for the loxodromic lines he traced on it.

It was in 1569 that Mercator completed the world's map which made him famous " ad usum navigantium " for the use of navigators (a combination of 18 sheets of 1 m. 50×2 m. 50 size) a copy of which is now preserved in the Breslau Library and was reproduced in 1931 through the good offices of the International Hydrographic Bureau.

Mercator's work was the first " réduite " chart to see the light : the loxodromic problem, which is that of the " route oblique " was thus claiming attention; a chart became not only a surveying representation of sea areas but also a nomogram or kind of calculating instrument for working out the various problems of navigation by simple graphic constructions.

Although Pedro Nunez referred to this loxodromic method in his " Arte et Ratione Navigandi " of 1566, the mathematical law of Mercator's net (which the latter had found empirically) was only made clear later by the Englishman Wright in his treatise " *Certain Errors in Navigation detected* ", published in 1599; having discovered the " law of meridional parts" he improved Mercator's plotting, the final accurate formula being given only in 1645 by Henry Bond, a follower of Briggs, the inventor of logarithms.

The Dutch cartographic period began at the end of the XVIth century. After Abraham Ortellius, cartographer to the King of Spain in Antwerp in 1570, it extended up to about 1660 and included famous cartographers and engravers amongst whom should be cited : Lucas Janzonius Waeghenaer who wrote a book (1584) entitled "Speighel der Zeevaerd or The Mariner's Mirrour". In 1592, the protestant clergyman and Cartographer Plancius had been able to secure Portuguese data and produced the chart used by de Houtman in 1597 for sailing round Africa *en route* for the great archipelago of Asia. In 1595, one year after his father's death, Mercator's son published in Germany a collection of charts which he named "Atlas" after the mythical King of Lybia to whom the first celestial globe is attributed. This atlas was far better than Ortellius and Gastaldi's collection (1550). Jodocus Hondius and Peter van der Keere were responsible for its first Dutch edition in 1606. There was a second edition in 1654 by Johannes Jansonius who published it then under his own name with the title "The Torch of Navigation".

William Barentz (alias Guillaume Bernard) a pilot, was responsible for an Atlas of the Mediterranean and a chart of the Arctic Ocean where he died in the sea which still bears his name. His publisher was Nicholas Cornelius of Amsterdam.

The sea Atlases of Colom, Peter Goos, H. Donker and van Loon were published almost simultaneously about 1660 at Amsterdam. Editions with text in German, English, Spanish, French, Italian or Latin, allowed them to be used everywhere, so that at that time, Amsterdam was the publishing center of charts for the whole world.

For a long time the Dutch East Indies Company employed the Blaeu family as its cartographer. This company, long after the diffusion of engraved charts, went on using parchment track-charts which the ship masters were bound to hand over to the Company's official Cartographer after each voyage, for the purpose of correction and revision. The Blaeus were thus cartographers to the E.I.C. from 1633 and were *ex officio* the first to receive the nautical information collected. They compiled in particular the "Secret Atlas" of the Company from 1639 to 1648.

The Firm van Keulen replaced them for nearly a century and published the first volume of a "Great new Atlas of the Sea", the 6th and last volume of which was issued in 1753.

The engraving portion of the work was not always achieved by the cartographers themselves but frequently by talented artists of which one the most famous was undoubtedly Romejn de Hooghe who embellished the "Neptune Français" with very fine illustrations.

The middle of the XVIIth century showed a decisive turning-point in the development of nautical cartography resulting from new improvement of nautical instruments and a stricter application of scientific methods.

For the English quadrant called Davis Quadrant (1620), for the backstave observation of the sun they began to substitute a sextant invented by R. Hooke in 1664 which at that time was fitted with only one mirror but was improved upon and made available for sea work with the addition of a second reflection by Hadley and Godefrey in 1731.

Barentz was the first to use a clock in his voyage to Spitzbergen.

In 1665 Huyghenz took out a patent for the utilization of his cycloïdal pendulum at sea; he added to it a special spring for regulating the balance-wheel movement. Successive improvements made later in chronometers rendered them capable of being used for rectifying errors in dead reckoning, land falls and consequently in longitude.

They also began to use the log for measuring the ship's speed better than by mere guess work. A description of it is given in the "Traité d'Hydrographie" by Father Fournier, published in 1643, who complains that pilots "do not all cast the log in the same manner". Its use was made concurrently with that of the watch-glass or sand-glass or powder-glass for measuring the running through a narrow aperture of a certain quantity of egg shell powder checked with a silk thread pendulum. Some sand-glasses ran for as long as 30 hours. But many mistaken ideas prevailed in this respect in 1635, Norwood measured the value of the *nautical mile,* or minute of latitude by chaining between London and York. But it was only in 1672 that the true value was determined by the abbé Picard measuring the arc of meridian, which constituted the real foundation of Geodesy.

As early as 1671, Richer found out at Cayenne that the pendulum was 2 minutes 28 seconds slow, which proved that gravity was less there than in Paris. Newton and Huyghens inferred from this fact a flatness of the earth at the pole. Cassini's and Picard's investigations led to an opposite conclusion, so that in 1735, the "Académie des Sciences" made arrangements for two expeditions by Bouguer and La Condamine for the purpose of measuring an arc of meridian at the equator and that of Maupertuis and Clairaut for measuring an arc in high latitudes where they recorded for the degree 1.000 toises more than Cassini.

Dutch investigations made up to then solely by dead reckoning corrected by observations of latitudes or bearings often necessitated considerable corrections especially in longitude.

In France, Colbert urged King Louis XIV (1643-1715) to develop hydrography in a purely scientific direction. In 1661, as Minister for the Navy, he took over the Dieppe School of Hydrography on behalf of the State. It was in 1666 that the "Académie des Sciences" was founded. The Chevalier de Clerville and the de Vau Brothers were entrusted with the accurate surveying of the Channel and Ocean Coasts of France and latter of the Coasts of Provence. This work was completed in 1671 and 1678, respectively.

In his compilation of the map of France in 1679, Sanson's plotting was based implicitly on Ptolemy's longitudes. Cassini rightly stated that cartography was no longer up to scientific standard. In connection with the meridian triangulation work initiated towards 1680, it was found that Perpignan and Collioures were much farther east than was believed up to then, which led to a contraction of France within much narrower limits than those assigned to her.

When Louis XIV heard of the changes amounting to several degrees in longitude resulting from the astronomers Cassini and Lahire's investigations, for the coasts of France, he congratulated these academicians in these terms : "Gentlemen, I am sorry to note that your voyage has cost me an appreciable portion of my Kingdom".

Guillaume de l'Isle (1675-1726) compiled new charts on the basis of recent data which he combined with old ones and made corrections affecting the whole of the terrestrial globe. He and his pupil d'Anville may be credited with the construction of charts by really scientific methods. An Atlas of these charts was published from 1700 to 1712.

From 1693 to 1700, de Chazelles, a Professor of Hydrography at Marseilles, published the first "Neptune français", a collection of charts of the ocean coasts. After a mission to the Levant, he submitted to the "Académie des Sciences" a scheme for the "Neptune de la Méditerranée" which was edited by Engineer Charles Pesne : It was thus found out that the Mediterranean had been charted up to then as 500 nautical miles too long between Marseilles and Alexandria.

The general chart of the Mediterranean, preceded by a new edition of 16 Ocean Charts, was published in 1720 by the Pilot Royal Michelot and by Brémond, hydrographer to the King.

It was at that time (1720) that the "Dépôt des Cartes et Plans de la Marine" was created in France. It gathered the collections of the Engineers Pesne and Beauvilliers, the direction was entrusted to the Chevalier de Luynes, Post Captain, with Bellin (1703-1772) as hydrographic engineer and assistant. He occupied this post from 1721 to 1772. During this long career, he published an "Atlas Maritime" in 1751.

The Royal Government of France can therefore be credited with the honour of having established the first official institution of the kind, which was the fundamental basis of all our Hydrographic Offices.

The Government of England in 1795, of Holland, of Spain, followed the example of France, after the *Dépôt français* had issued its first official charts ("Carte réduite de la Méditerranée" in 3 sheets) compiled by Bellin, which appeared in 1737 and were very favorably received by French and foreign navigators.

In 1745, d'Après de Mannevilette, a Captain of the *Compagnie des Indes* and hydrographer, published his "*Neptune Oriental*", in which he rectified the charts of the African coasts, of India and of China. He annexed to it a nautical direction which was all the more valuable at the time as it was the first work of the kind. To the end of his life he kept on improving this collection which served as a guide up to the end of the XVIIIth century, after having been recast in 1784 by Rosily. Similar English works by Alexander Dalrymple and James Horsburgh appeared later, namely the "Atlantic Neptune" which was published from 1774 to 1781.

In 1789, the hydrographic engineer Buache was appointed keeper of the nautical Archives and occupied this post until 1825. He set up a reliable issue of documents and instruments necessary to navigators. He was a member of the *Institut des Sciences* and had under him a young engineer, Beautemps-Beaupré whom he detailed to take part in the expedition under the leadership of d'*Entrecasteaux* that set off in search of the unfortunate Lapérouse party. In the course of this mission, Beautemps-Beaupré conceived new methods and laid down principles which turned hydrography into a real science and were soon adopted by all navies.

From that time, hydrographic engineers became also operators and were called upon to make systematic surveys for charts which they merely used to lay down and draw, before then.

Among the hydrographic works of the second half of the XVIIIth Century and beginning of the XIXth, I will only mention the following, as being the most remarkable.

1° The charts of the French Coasts, published by the Dépôt since the year 1737, with Rigobert Bonne's Maritime Atlas, published in 1762.

2° A Treatise on hydrography published in 1788 by Murdoch Mackensie, completed in 1819 by James Horsburgh, hydrographer to the East India Company.

3° Reports on 3 voyages in the Pacific Ocean and Austral Seas made by Captain James Cook (1768-1779).

4° The expedition to the North Pole made by Captain Phipps (Lord Mulgrave) in 1773, that employed many oceanographic scientific instruments and during which the first deep sounding was made at a depth reaching 780 fathoms (1.400 meters) with a sounding lead weighing 156 pounds.

5° The Atlas of the South Coasts of the Iberian Peninsula, published in 1778 by the Spanish hydrographer don Vincente Tofino, completed from 1784 to 1788 with 28 charts and plans of the Azores and Mediterranean.

6° The Pilot of Santo Domingo and the Antilles, published from 1784 to 1785 by Chastenet-Puységur.

7° La Pérouse's voyage (1786-1788) in the "Astrolabe" and the "Boussole" to the N.-W. Coast of America (the remnants of this unfortunate expedition were only found in 1827 at Vanikoro).

8° D'Entrecasteaux's expedition in search of La Pérouse, the relation of which includes an Atlas of 39 charts (1791-1794) compiled by Beautemps-Beaupré, who was geographer Buache's pupil.

9° Matthew Flinders's voyage to the Austral Lands (1795-1814). He was imprisoned in 1803 at Mauritius for 6 1/2 years by the French Authorities. He made a special study of the deviations of magnetic compasses.

10° The works of James Horsburgh F.R.S. (1796-1812), hydrographer to the East India Company who sailed about the Seas of China and compiled charts with nautical directions. From 1809 to 1811, he published his "Oriental Directory" which for a long time was kept up-to-date at the London Hydrographic Department by Commander Dunsterville.

11° An essay on the "Most practical methods for making Maritime Surveys" by Alexander Dalrymple, hydrographic curator to the East India Company, who became later from 1795 to 1818 the first Hydrographer to the British Navy.

12° Baudin's voyage made from 1800 to 1804 by Napoleon's order, to the Austral Lands, which resulted in the publication of 11 charts.

13° In 1802, Alcano Galiano explored the Archipelago, the Bosphorus and determined longitudes in the Mediterranean by means of 4 chronometers, for the completion of Tofino's Altas.

He was killed at Trafalgar where he commanded a Spanish Ship.

14° The Russian Admiral de Krusenstern, made hydrographic surveys of the Asiatic Coasts of the Pacific from 1803 to 1806 — 104 Charts were annexed to his report published in 1812.

15° Among British works, I may quote :—

The *Arcano del Mare* by Sir Robert Dudley, Duke of Northumberland, in Mercator's projection (1647-48).

John Seller's Sea Atlas *Hydrographia Universalis* or *English Pilot* (1675-1690).

The *English Pilot* in 5 volumes (from 1706 to 1748) and Sea Charts of 1775.

The *North Pacific Atlas* by Vancouver, 1798.

The *Complete East India Pilot* by White and Laurie (1800).

Arrowsmith's works (1814) and those of J.-W. Norie (1816).

Finally, the Walcker's works at the Admiralty and the India Office begun in 1796 and pursued by them until 1865.

The problem of longitude was successfully solved as a result of the scientific progress made during the XVIIIth century, on the one hand by a suitable setting up of the mecanism of chronometers and on the other hand through the computation of reliable ephemerides by Astronomers.

Henry Sully, a clock maker in France, and John Harrison, in England constructed the first time-keepers. In 1736, one of Harrison's chronometers was tested for the first time at sea, but it was only in 1767 that the French clockmaker Pierre Le Roy could produce a sufficiently reliable instrument which in a thrilling voyage by land and sea from the Havre to Amsterdam and back, was able to keep accurate time for 46 days, within 38 seconds. In 1771, Verdun de la Crenne, the Chevalier Borda and Pingré, during a voyage on the fregate "La Flore", made tests with the watches presented for competition by the makers Le Roy and Berthoud. Captain James Cook during his second Austral voyage in 1772, tried a time-keeper constructed by Larcum Kendall and Arnold. In 1791 the latter had already more than 28 chronometers in use on board of vessels.

The "Board of Longitude" created in 1714, was done away with in 1828. It had lasted 114 years. During the first third part of the XIXth century, the lunar methods for the determination of the time of the first meridian were preferred to the chronometrical method on account of the defectiveness of watches which required constant checking by direct astronomical observations.

The XIXth century recorded the definite victory of the chronometer. From 1859 to 1887 progress made in connection with these instruments was the subject of a publication by the French Hydrographic Office of many "Cahiers de Recherches Chronométriques" with which is coupled the name of the hydrographic engineer Caspari (1876).

As regards astronomical ephemerides, it is fitting to recall that from 1668 to 1671, the abbé Picard and La Hire organized the Observatory of Paris. In 1675, the Greenwich Observatory was founded by Flamstead who initiated meridian observations in series.

The first volume of the "Connaissance des Temps" (Nautical Almanac) appeared in 1679. Newton expounded his law of universal gravitation in 1685 and made public in 1713 his theory relating to the moon whose positions he determined at the time within 5 minutes.

That question was of particular interest to the British Government who instituted the Board of Longitudes. The French "Bureau des Longitudes" was only founded in 1795 by the National Convention, but, as early as 1745 the French "Connaissance des Temps" gave already a list of 140 geographical positions determined astronomically (228 in 1778).

In 1763, the Astronomer Royal Nevil Maskelyne (1732-1811) worked out the method of lunar distances for the determination of longitude. In 1766, he published the first volume of the "British Nautical Almanac" with the Tables of the Moon computed by the German Astronomer Tobias Mayer of Göttingen in 1763 which were accurate within from 1' to 1' 1/2. This degree of accuracy was reduced to 30" by using Bradley's observations and further improved by Burckhart whose equations served for the compilation of the "Connaissance des Temps" from 1817 until 1861 when they were replaced by Hansen's Tables.

The method of lunar distances, in its turn, completely disappeared in 1905 when lunar tables were left out of the "Connaissance des Temps"; they are as dead as Julius Caesar, as the English saying goes !

The XIXth century inaugurated the era of methodical coastal surveys. In 1808 Beautemps-Beaupré published his "Méthode de levé hydrographique", in which he expounded a method of position determination by *subtended angles* inspired to him by Dalrymple in 1771 (Borda's repeating circle in 1775). Beautemps-Beaupré undertook a complete new survey of the North and West Coasts of France, which was carried out from 1816 to 1838. That of the South Coast was made by his successors from 1839 to 1844 and led to the publication of the "Pilote Français" with 613 charts.

Following the example of France who created her Hydrographic Office in 1720, England founded hers in 1795, with Alexander Dalrymple as first Hydrographer who had held a similar position with the East India Company. Spain founded her Hydrographic Office in 1800 the United States of America in 1816, Russia in 1827, Portugal in 1849, Germany in 1861. Japan, Italy, Sweden, Norway, the Netherlands founded theirs from 1871 to 1874.

All these offices share the immense duty of making and keeping up-to-date the surveys of their national and colonial coasts : hydrographic parties became more and more numerous in the course of the XIXth century; scientific voyages of exploration of seas and oceans were organized. The era of steam navigation contributed new means but introduced many fresh requirements. The laying of telegraphic cables through the oceans necessitated a new technique in deep sea soundings and a more complete knowledge of sea bottoms and submarine topography.

In 1837 the American Captain Sumner invented a new method for fixing position at sea by "position line", which was soon taken up by mariners and became known as the Marcq Saint-Hilaire Method in 1873.

Sir William Thompson improved the magnetic compass, navigation was then equipped with precision instruments and became more scientific and safer.

Old errors in longitude about the position of lands due to imperfect land falls by sailing vessels, which errors had sometimes led to the belief in the duplication of islands (as for example New St. Helena) gradually disappeared, positions became less doubtful, the list of well determined geographical position fixes became henceforth longer and permitted to lay down a reliable triangulation net to serve as a basis for all surveying operations.

The hydrographic surveyor must as a matter of fact plot every point on his chart in the position which it occupies in relation to other conspicuous features, in particular the position of each of the soundings made by him for the purpose of showing the sub-marine relief must be determined in relation to the fixed and visible points of the field by means of actual triangulation effected on board the craft or surveying ship by means of sightings taken with a sextant or better still, with the hydrographic circle conceived by Borda as early as 1775.

It would be superfluous, in this short paper, to give details and even a general idea of the development of coastal hydrography from the beginning of the XIXth century up to the present day.

The few statistics which I quoted at the beginning of my lecture, the large number of charts published up to the present time, bear witness to the accumulated efforts and works which have contributed for the last 150 years to make more precise our knowledge of coastal waters.

I will confine myself to refer to the general bathymetry of oceans and its present degree of advancement.

At the time of the "Challenger's Expedition" (1872-76) deep sea soundings were made by means of a 440 lbs. weight hanging from a 25 mm. thick rope : on account of friction, it took 1 hour 1/2 for the weight to reach a depth of 5.000 fathoms.

The results of this campaign were published in 1886 by John Murray together with a chart of all deep sea soundings obtained up-to-date. Since then, the sounding machine was improved upon, by using, instead of a hempen rope, a 2 to 3 mm. thick metallic wire rope loaded with a 130 lbs. weight (detachable) running down at the rate of 2 meters per second, a catch ensuring the release of the weight once it touched the bottom, as the wire rope is not strong enough to pull up the weight against water friction.

To-day, this system is advantageously replaced by echo sounding apparatuses invented in 1913 by the German professor Behm and improved by Professor Langevin, of France.

These apparatuses send out a sound impulse which goes down to the bottom of the sea at an average speed of *1.500 meters* per second, is reflected and comes back to the transmitter by which its return is recorded. Thus, 11 seconds are sufficient to effect 8.000 meters (5.000 fathoms), deep sea soundings, without the least submarine hindrance. Moreover, this method makes it possible to record operations automatically, which is a great convenience in sounding.

Since practically 1922, the method of echo sounding is generally employed by all exploring ships that have largely contributed within these last 20 years to make more accurate and extend our knowledge of ocean submarine topography. In this respect, it is fitting to recall the German Atlantic Expedition of the "Meteor" (1925-1927), that of the "Carnegie" (1928-1929), of the "Willebrord-Snellius" to the Indian Sea, of the "Discovery" (1929-1930) to the Antarctic, of the "Ramapo" (1929-1940) in the North Pacific.

A record sounding to a depth of 10.830 meters was made by the German cruiser "Emden" in 1927 in the Mindanao trough to the east of the Philippines Islands. If the highest point of the Mount Everest, which is estimated at 8.800 meters, be taken into account, this sounding would give a difference in level of 19 kilometers 630 for the earth's crust, which represents about 1/300th of the globe radius.

The 7th International Geographic Congress, held in Berlin in 1899, decided to publish a General Bathymetric Chart of the Oceans in 24 sheets, of which the first edition was produced in 1903 by Prince Albert I of Monaco.

The International Hydrographic Bureau undertook in 1935 a new edition of that chart which now (end of 1942) contains the recording of 254.700 deep sea soundings (2 m. 40 $\times$ 4 m. 05).

It will be noted that the submarine relief shown by isobathic lines affords the most varied types of topographic submarine formations : submarine valleys, submarine canyons, submarine mountains and peaks as well as a vast continental plateau whose area with favorable fishing grounds is estimated at 250.000 kilometers in length by an average width of 90 kilometers beyond shore, which represents an area of 22 millions of square kilometers, that is 1/17th of the immersed surface of the globe (361×10^6 km^2).

Our XXth century has also introduced fresh developments in Navigational methods. This century of speed, electricity, cinema, could not abide by the practices of the previous one. In 1904, wireless telegraphy was applied for the first time at sea to the automatic transmission of time by means of time-signals.

This made the testing of chronometers easier, mariners having no longer to make time observations and calculations on the artificial horizon. In 1912, by international convention, the same fundamental meridian was adopted for the unification of world's time by a system of standard time-zones.

Hertzian waves made a very great contribution to the determination of longitude; a new apparatus : the prismatic astrolabe, inventend in 1910 by Claude and the hydrographic engineer Driencourt permitted the rapid solution of position problems by the method of equal altitude of stars.

Aviation, after the war of 1914-1918, also made a contribution to hydrography by applying aerial photography to coastal topographic surveys. Various technical processes of photographic restitution have given rise to ingenious but complicated instruments.

Radio-acoustic ranging at sea with transmitting or repeating stations installed on *radio-acoustic buoys* makes it possible since 1920 to apply the principles of submarine phonotelemetry or ranging to hydrographic surveys.

Searches for rocks and isolated dangers, the survey of fairways are now made by hydrographic dredging with *divergent or towed dredges* from 200 to 6.000 meters in extent. Similarly, the survey of banks at sea is made with floating signals and buoys successfully anchored at great depth.

Chart soundings are plotted not at mean sea level, but for safety's sake at lowest tide level. Tide observation is therefore a fundamental part of all hydrographic surveys and is made by means of tide-gauges or *automatic registering maregraphs.* For banks in the open sea a *plunging maregraph* invented by Favé in 1887 is employed.

An analysis of the data collected allows the anticipated computation of tide predictions and the publication of tide tables. Hydrographic Services have been publishing yearly Tide tables regularly since 1833. The tide predicting machine called " Tide predictor " contrived by Thomson in 1876 permits to obtain predictions mechanically by means of certain constants determined once for all. Flamstead was the first to supply a table of High Water time at London Bridge for the year 1683. Tables for the port of Liverpool were regularly computed by the Reverend George Holden since 1770. In 1836, predictions dealt with 9 English ports and Brest. In 1942, hydrographic offices extended their predictions to about 160 ports distributed all over the world.

Moreover, a service of international cooperation is now functionning for the exchange of tide predictions as well as for the compilation of astronomical ephemerides and information intended for the construction of magnetic charts.

In the field of hydrography, the need for liaison between the various Hydrographic Offices has been acknowledged for a long time. International cooperation as regards things of the sea is made necessary on account of the frequent intercourse of mariners of all nations and the identity of their interests and requirements. For this reason, *International Maritime Conferences* and *International Navigational Congresses* have become more frequent. The XIth Congress, that met in May 1908 at Saint Petersburg, admitted the necessity for a more special Assembly dealing with questions relating to charts and sailing directions. This Assembly was convened in March 1912 at *Saint Petersburg.* After the world's War (1914-1918) an International Hydrographic Conference was convened in London in 1919. It brought together the qualified representatives of 24 maritime nations who decided to create the International Hydrographic Bureau whose headquarters has been established in 1921 at Monaco. The business of this Bureau is to propose the unification of nautical documents, to undertake general studies, to propose new methods concerning hydrography; periodically it convenes Conferences of Hydrographic Office Directors and their Assistants for the discussion of technical questions of general interest and the co-ordination of the hydrographic work of National Hydrographic Offices.

Although some stages have still to be got through before reaching a very desirable unification of methods, a more general use of the metric system, for instance, it may be stated that the last twenty years have witnessed a great step towards the common goal which has become the motto of all hydrographic services : "*to make Navigation easier and safer in all parts and in all the seas of the World*".