MAGNETIC CHARTS.

by

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MAGNETIC SURVEYS AT SEA.

The study of the terrestrial magnetic field is not only an important branch of physical science, it is also of special practical interest from its use in aerial and marine navigation.

Since the day when Christopher COLUMBUS noticed with anxiety that the angle of his compass needle with the meridian varied as his vessels advanced towards the unknown regions of the West, seamen have always been engaged in collecting all availible information relative to this phenomenon, and it seems to us that it would be of interest to review briefly the state of our knowledge on this subject, the magnetic charts used by seamen, and the manner in which they were drawn up.

It is rather curious to note that, at first, the variation of the magnetic needle was studied for the needs of mariners, and particularly at sea. Although the phenomenon of variation was known, the *portulans* were oriented on the magnetic meridian, so that the compass course was given directly. This system was quite logical, since the changes undergone by variation, in place and time, were unknown ; it was abandoned when knowledge of these changes was obtained.

The first attempt at a magnetic survey of the oceans is that of the astronomer Edmund HALLEY who, from 1698 to 1700, in the sailing ship *Paramour Pink* made numerous observations of Variations in the Atlantic. In 1701, he published a chart of the lines of equal magnetic Variation for the Atlantic Ocean, and a short time afterwards, a similar chart for the Indian Ocean and the West part of the Pacific. (*)

In 1829, ROSS discovered the North Magnetic Pole.

(*) In 1899, W. VAN BEMMELEN published at Batavia under the title: "*Die Abweichung der magnet nadel*" some lists of ancient values of the magnetic variation and some isogonic charts for 1500, 1600, 1650, and 1700. This representation, although necessarily very rough, gives a very interesting idea of how the magnetic variation has changed with time.

From 1840 to 1845, numerous magnetic observations were made, particularly in the Southern seas, under the direction of SABINE, in the vessels *Erebus, Terror,* and *Pagode,* one of which was commanded by Captain ROSS, nephew of the above.

The three elements of terrestrial magnetism were determined by using a new instrument — Fox's circle — which, for the first time, enabled fairly accurate measurements of dip and horizontal force to be made at sea.

Thereafter the principal scientific expeditions which were organised and which devoted themselves to a systematic study of this subject are:

The voyage round the world of the frigate *Novara,* 1857-60; the *Challenger* expedition 1872-76; the frigate *Gazelle* 1874-76; the voyage of the *Dubourdieu* in the Atlantic 1895; the voyage of the *Pola,* 1895-96, and 1897-98; the voyage of the *Aurora* (Colombo and Tokyo) in 1895-96; the campaign of the *Albatros* (Colombo and Hobart) 1896-97; of the *Freundsberg* (Tokyo-Tchemulpo) 1898-99; of the *Saida* (East Coast of Africa) 1898-99; of the *Donau* (Honolulu-Nagasaki) 1900-1901; the voyages in the Antarctic of the *Gauss* 1901-1903 and the *Discovery* 1904.

And, for a long period, every vessel undertaking scientific exploration gave an important place to the study of terrestrial magnetism and made observations either at sea or at their bases. Numerous magnetic observations were made in this manner by the *Endeavour* the *Resolution,* the *Adventure* and the *Discovery,* with COOK, 1768-79; by the *Boussole* and *Astrolabe,* with LA PEROUSE 1785-88; the *Espérance* with d'ENTRECASTEAUX, 1791-1793; the *Géographe* with BAUDIN; the *Naturaliste* with HAMELIN, the *Casuarina* with DE FREYCINET and the astronomer BERNIER, 1800-04; the *Uranie* with DE FREYCINET 1817-20; the *Coquille* with DUPERREY, 1822-25; the *Recherche* in Iceland and Scandinavia in 1835 with LOTTINS and BRAVAIS; the *Astrolabe* and the *Zélée* with DUMONT D'URVILLE 1837-40; the *Manche* in Iceland and at Jan Mayen in 1892 and by nearly every man-of-war which sailed in little known parts of the world.

By means of these researches, a general knowledge of the whole of the phenomena was obtained, and the two principal periodic changes, which affect the magnetic elements, became known; *i. e.* the diurnal change (change in the course of a day) and the annual change (mean change from one year to another).

The first, which is of secondary importance to navigation. seems intimately connected with the altitude of the sun above the horizon; the second is a slow change which may, in a given position and during a few years, be considered as proportional to the time.

But, in spite of the efforts of many scientists and their ingenious hypotheses, the origin of terrestrial magnetism still remains completely unknown, and all that is known is that the greatest part of it resides in the interior of the earth. There are no means whereby the data of the magnetic field may be determined, *à priori,* at any point of the globe; and when data have been observed, it is not possible to predict, with precision, what the value will be some years later. Even in places where the magnetic variation has been known for several centuries, as at London (1540) and at Paris (1541)

it is easy to make a mistake of ½ degree in predicting the value 20 years ahead. The curve of variation has a periodic aspect, but the period and the amplitude are very variable from one point to another. At London, the period has been about 230 years, whilst at Rio de Janeiro the compass-needle has not ceased its movement towards the West for 230 years and it seems that the period will be almost double that of London.

The amplitude has been 35° at London; at Manilla and Havana it appears to be only a few degrees.

In consequence, it has been found necessary to draw the lines of equal change of the magnetic elements; these lines are very irregularly spaced. Whilst in France, for more than 30 years the magnetic elements have varied at all points by almost the same quantities, in a region of similar extent, such as Madagascar, differences of nearly 10' in the annual change of variation are found in the same year between two points on the island.

A great work has been undertaken with the hope of accumulating material which would at last enable the origin and the laws of terrestrial magnetism to be solved, and also with the immediate object of providing seamen with more accurate values of the magnetic elements than those which they possess at present. Since 1905, this great work has been carried out by the Carnegie Institution of Washington.

Certainly, all civilised countries had, already, commenced to draw up magnetic charts of their own countries; but observations at sea were scarce; those which were made at isolated islands were often invalidated by local anomalies, and owing to ignorance of the values of the magnetic elements over more than three-fourths of the globe, any real basis for theoretical research or any precise value for magnetic charts published for the use of navigation, was impossible.

In 1917, during the first cruises of the *Carnegie*, L. A. BAUER and W. J. PETERS reported errors of variation in the magnetic charts then in use, which frequently reached 2°, and in certain parts of the Pacific 4°, in some parts of the Indian Ocean 6°, and on the S. W. Coast of Australia 12° to 16°. The error in the dip was generally less than 5°, but sometimes reached 9°; the errors in the horizontal force varied from 2 to 10 % they were of the order from 0.005 to 0.015 c. g. s. and reached 0,060 c. g. s. in the South seas.

The CARNEGIE INSTITUTION OF WASHINGTON (*) organised expeditions, which took land observations in all parts of the globe, and particularly in those where the number of observations already taken was very small; thus from 1905 to 1921 they took 3316 observations for variation, 2147 for dip and horizontal force; and from 1905 to 1926 observations were taken at 5685 stations, of which 561 were visited several times in order to determine the annual change.

(*) The *Department of Terrestrial Magnetism of the Carnegie Institution of Washington* has given the results of its work in numerous publications from 1904 to 1927, the list of which has been published in a special pamphlet and to which we have referred for the bibliography. See also: "*Hydrographic Review*" N° IV, of May 1925, page 33, an article on this Institution.

The Institution has built special vessels, which are almost free of iron, and sent them out to all parts of the globe; the *Galilee*, from 1905 to 1908, traversed 73,000 nautical miles; the *Carnegie*, from 1909 to 1921, 291,000 nautical miles, covering the Oceans with a close net and also observing on land at 234 stations.

The polar regions, which are of great importance from the point of view of magnetic phenomena, were not neglected: in 1915-16 the *Carnegie* made a voyage around the South seas.

During the 1913-1918 Canadian Arctic Expedition, under the direction of VILHJALMUR STEFANSSON, observations for variation were taken at 26 different points between the parallels of 74° and 80° North, and the meridians 98° and 124° West, and differences varying from + 21° to — 34° were found between the values thus obtained and the values deduced from British Admiralty Chart N° 2598 of 1928. These differences are all the more annoying as the compass has proved itself to be a very useful instrument for aerial flights in polar regions. The data on the magnetism of these regions has been greatly enriched by the publication of the results of AMUNDSEN'S expedition in the N. W. passage in 1903-06, the Swiss expedition to Greenland in 1912-13, the Amundsen expedition in the *Maud* in 1818-21, and again in 1922-25 between Siberia, the Bering Straits and the islands of New Siberia, and by MAC MILLEN'S three expeditions to Baffin Land and Greenland in 1921-1925.

By means of this accumulation of observations, magnetic charts of the world were drawn up which are much more accurate than those in existence before the work of the Carnegie Institution of Washington began. During the cruise of the *Carnegie* in 1919-21, she was able to verifly these charts; comparisons made with the magnetic charts published by the Hydrographic Office of the United States for 1920, showed in general, differences of variation of less than 1°, and only once in the Indian Ocean, reached as much as 2,5°; for the dip, they only once exceeded 3° and for the horizontal force rarely 4% of its value. Moreover, it should be noted that the greatest differences were found in the Indian Ocean and the South Atlantic, where the secular changes are greatest and most variable from one place to another.

ANNUAL CHANGE.

The value of the magnetic elements varies continuously and follows an unknown law. However, if it has been observed in some place at different dates, it is possible to determine a curve of the values of the magnetic elements as a function of the time and then, empirically to extend this curve slighty so that it is possible to make a prediction at a later date than that of the last observation. This extension is generally made by assuming that the annual change remains constant during several years, or by finding the equation of a curve which passes as nearly as possible through the points given by the observations. Ten to twenty years after the date of the last observations, these methods generally lead to inadmissible errors, therefore observations must be taken periodically at fairly close intervals.

In order to determine the annual change at sea, the *Carnegie* decided to cross her courses, during her successive cruises, at a certain number of fixed points and a value of the annual change was deduced from the various observations made at these points. This value is less accurate than that given by similar operations on shore, where the determination of the elements can be made with greater precision, and always at exactly the same place. Without doubt, a better result would be obtained by taking sufficient observations to retrace the isomagnetic curves and by deducing from their change of position the values of the annual change; but this method would necessitate that a complete new magnetic survey be made, each time, around the point where it is desired to determine the annual change.

On land, permanent magnetic observatories continuously furnish precise knowledge of the magnetic elements in their locality. Photographic recorders register the slightest variation in the values of these elements, and frequent absolute measures check these values. In regions where the observatories are close enough together, the necessary information is obtained thus. Unfortunately, their distribution leaves much to be desired, there are only sixty, of which about 40 % are in Europe. In order to remedy the scarcity of observatories in the Southern Hemisphere, the Carnegie Institution of Washington, since the 1st January 1919, maintains an observatory with photographic recorders at *Watheroo*, latitude 30° 19' 05. 3" South, longitude 115° 52' 38" East (West coast of Australia) and, since 1921, an observatory at *Huancayo* (Peru) where photographic recorders have been in operation since 1st March 1922. This observatory is situated near the Magnetic Equator at 11,000 ft (3,350 m.) above sea level. Moreover, the Institution contributes, with New Zealand, to the support of the *Apia* Observatory (Samoa), 13° 48' 4" South, 188° 14' East, which was established in 1902 under the auspices of the Gottingen Gesellschaft der Wissenschaften and of the German Governement, with the object of cooperating with the German Antarctic Expedition of 1902-04.

There is another magnetic observatory in Australia at *Toolangi*, which is supported by the Melbourne Observatory; New Zealand supports one at *Christchurch* 43° 32' South, 172° 37' East.

Apart from these Observatories, there are no others in the Southern Hemisphere except those at *Batavia-Buitenzorg*, *Mauritius*, *Tananarive* (Madagascar), *St-Paul de Loanda* in Africa, *Vassouras* (Brazil), *Quiaca* and *Pilar* (Argentine) and in the *South Orkneys*, 60° 43' South, 44° 47' West.

In regions where there are no magnetic observatories, it is at least possible to obtain information of considerable value on the annual change, by taking once a year or even five years, a good series of absolute observations at exactly the same point.

The Coast and Geodetic Survey of the United States, not content with the five magnetic observatories which are maintained throughout the year, operate thus, and revisit a certain number of their old observation spots every year.

PREPARATION OF MAGNETIC CHARTS.

Since magnetic charts prepared from land observations are based on more accurate observations than those made at sea, the magnetic field over the land is, generally, represented with greater detail and accuracy. Hydrographic operations on coasts, by making magnetic observations, provide useful additional information for preparing these charts, and increase the number of magnetic stations in areas which concern Navigation.

Terrestrial magnetic charts give information as to the value of the magnetic elements in the neighbourhood of coasts. This information can be used directly by the mariner and the greatest consideration should be given thereto when preparing magnetic charts of the seas and oceans.

Unfortunately, comparison between the magnetic charts of neighbouring countries becomes difficult on account of the various dates for which the charts are drawn up, and one cannot but endorse the wish expressed by the Section of Magnetism and Terrestrial Electricity, at the Prague Congress of 1927, that "It is desirable that the magnetic net of various countries should be reduced to the same dates, in such a manner as to obtain, *ipso-facto*, a magnetic chart of the whole area which is covered by magnetic nets."

Some particulars are given below of a certain number of terrestrial magnetic surveys which conern maritime countries :-

A. SCHMIDT published some magnetic charts of NORTH GERMANY for 1909 (*Die magnetische Vermessung* 1e *Ordnung des Konigreichs Preussen*, 1898 to 1903, published by the Kgl. Preuss. Met. Inst., Berlin.)

A. Petermann's Geographische Mitteilungen, 1913, contains a diagram of isogonic lines in GERMANY for the 1st of January 1912.

DENMARK publishes some magnetic charts for Jutland. The Danish Magnetic Observatory is at Rude Skov. : See *Annuaire Magnétique* 1922-25 of the Meteorological Institute of Copenhagen. Observations are made in *Iceland* and *Greenland* also.

A magnetic survey of HOLLAND was published for the 1st of January 1891 by Dr. VAN RYCKVORSEL in *Nieuwe Verhandelungen van het Battafseh genootschap der proefondervindelijke Wijsbegeerte te Rotterdam.*

A magnetic survey of BELGIUM for the 1st of January 1913 was published by A. HERMANT in the *Annales de l'Observatoire Royal de Belgique, nouvelle série, Physique du Globe, Tome VI.*

BRITISH ISLES. The first magnetic surveys in the British Isles were carried out in 1836-38 and then in 1857-62. The first complete survey was carried out by RUCKER and THORPE in 1884-88, with 205 stations; it was carried out again in 1889-92 with 677 stations, and yet again in 1914-15 by G. W. WALKER with 183 stations. The last published the results for the 1st of January 1915 in the *Philosophical Transactions of the Royal Society of London, Series A. vol.* 219, page 1. The Ordnance Survey then took over this survey; it published the results of observations made in 1925 in the Channel Islands (7 stations) and in 1926 in the South of England (30 stations). These are reduced to 1925,5 or 1926,5.

In 1925, the Magnetic Observatories of Greenwich and Kew had to cease making observations. A new observatory was established at Abinger and began work in 1924.

Magnetic surveys have also been carried out in *India, Australia, New Zealand, South Africa* and *Egypt.*

FRANCE AND THE FRENCH COLONIES. The first magnetic chart of France was drawn up for the 1st January 1885 with 80 observation stations, by Th. MOUREAUX of the Central Meteorological Office, and again for the 1st of January 1896 with 617 stations. The survey was then taken up again under the direction of the Comité Français de l'Union Géodésique et Géophyqique Internationale (Section of terrestrial Magnetism and Electricity), the Institut de Physique du Globe of the University of Paris and by the Central Bureau of Terrestrial Magnetism. The data for the chart were reduced to the 1st of January 1921, the spacing of this new net seems to be closer than any other in the world.

From 1883 to 1900, the Central Magnetic Station was at Parc St. Maur. In 1900, owing to the disturbance produced by the establishment of an electric tramway, it was removed to Val Joyeux.

The magnetic survey of the French Colonies has not advanced so far, charts have been prepared, however, for the different colonies by the Central Bureau (See *Magnetic Atlas,* published under the direction of Ch. MAURAIN, Paris, 1925, which contains charts of the isogonic lines, for the 1st of January 1921, of France, the French Colonies and the States of Central and Western Europe. See also : *Annales de l'Institut de Physique du Globe and the Annuaire du Bureau des Longitudes.*)

In SPAIN, under the direction of the Geographic Institute of Madrid, MM. UBALDO DE AZPIAZU and RODRIGO GIL measured the magnetic elements at 117 stations and published the values for the 1st of January 1914. A new chart of isogonic lines for the 1st January 1924 was prepared in accordance with measurements made at 285 stations by MM. GIL, FORT and AZPIAZU.

ITALY AND ITALIAN COLONIES. The Magnetic Observatory at *Pola* has had to cease making observations since the war as they were vitiated by the proximity of electric cables. Once a year, however, absolute magnetic determinations are still made there.

The study of terrestrial magnetism is carried out under the direction of the *Real Ufficio Centrale de Meteorologia e Geodinamica* of which Professor PALAZZO is the director and which is established at Rome.

The principal work was carried out by the Rev. Father DENZA, by Professors Ciro CHISTONI and Luigi PALAZZO. The two latter have issued a general magnetic chart of Italy reduced to 1892. Professor PALAZZO has prepared also special magnetic charts for Sicily and Epoch 1892,5 for Sardinia ; he has studied the perturbational influence of the ground and of volcanic formations. A new edition of the magnetic chart of Italy is being prepared. Professor PALAZZO has also made magnetic observations in Tripoli, Eryhrea and in Italian Somaliland ; he has published a magnetic chart of Erythrea Epoch 1913,5 and Benadir, thus providing a valuable contribution towards the study

of magnetism on the East coast of Africa, which is not well explored in this connection.

Observations had previously been made in the Adriatic during the years 1850-54; 1867-70; 1889-90 and 1907. The results are published:- for 1850-1854 by Karl KREIL - *Magnetische und Geographische Ortbestimmungen an den Küsten des Adriatischen Golfes im Jahre* 1854 ; for 1867-70 by J. SCHELLANDER in the *Jahrbuch der K. K. Zentralanstalt für Meteorologie* and *Erdmagnetism*, Wien, Vol. 6, 1869 ; for 1889-90 by J. LASCHOBER and W. KESSLITZ in the Appendices to Nos II and III of the *Mitteilungen aus dem Gebiete des Seewesens*, 1892; for 1907 by W. KESSLITZ in the *Veroffentlichingen des Hydrog. Amt in Pola*, Group IV. Supplement IV. 1907 (with chart).

The results of the magnetic observations of the *Pola* in the Red Sea are published in the following books: - K. ROSSLER - *Denkschriften der K. Akademie der Wissensch, Wien, Math. und Natur W. Classe.* Vol. 65 and 69, and also in:- *Berichte der Kommission für Oceanographische Forschungen*, 6th series, 1898 and 7th series, 1901.

Numerous observations were made on the coasts of the Red Sea and particularly in Erythrea during the hydrographic expedition of the *Ammiraglio Magnaghi* in 1923-24. It is possible to make comparison of the results for the Red Sea with those obtained by the *Pola* in 1895-96 and in 1897-98 (See "*Annali Idrografici*", Vol. 11, 1923-1924).

The following publications of Professor PALAZZO should also be consulted:-

Misure magneto-telluri eseguite in Italia negli anni 1888 et 1889 ed *Osservazioni relative alle influenze perturbatrici del suolo. Rend. Acc. Lincei.* Vol. VII, 1° sem., Roma, 1891.

Sulle carte magnetiche d'Italia, eseguito da Ciro CHISTONI *e* Luigi PALAZZO, *per cura del R. Ufficio Centrale Meteorologico di Roma. Relazione di* Pietro TACCHINI. *Atti del I. Congresso geografico italiano a Genova*, 18-25 Sett. 1892. Vol. 2°, parte 1°; Sezione scientifica. Genova 1894.

Carte magnétique de Sicile Terrestrial magnetism and Atmospheric Electricity, Vol. IV, N° 2. Baltimore 1899.

Levé magnétique de l'Ile de Sardaigne. Procès-Verbaux et Mémoires du Congrès International de Météorologie à Paris, 10-16 Septembre 1900, Paris 1901.

Carta magnetica delle isodinamiche d'Italia. Atti del V Congresso Geografico Italiano in Napoli, 6-11 Aprile 1904, Vol. 2°, Sezione I, Scientifica, Napoli 1905.

Magnetic Charts of the Island of Sardinia, Terr. Magn. and Atmosph. Elect. Vol. XIV, N° 3. Baltimore 1909.

Misure magnetiche in Eritrea. Ann. Uff. Centr. Meteor. e Geod. Vol. XXXV, parte Ia, 1913, Roma, 1914.

Variazioni magnetiche secolaria Massaua col contributo di recenti misure. Atti Pontif. Accad. Nuovi Lincei. Roma, 1927.

Risultati di una explorazione magnetica nei Territori di Giuba e dell'Uebi Scebelli - Rend. R. Acc. Lincei. Roma, 1927. (*)

(*) These particulars have been kindly provided by the Professors Palazzo and Tenani.

CANADA (*). The Topographic Service has carried out more than 22,000 magnetic observations within Canadian territory; in addition, it collects all observations which concern that region, and which are undertaken by other Canadian or by foreign Institutions. It uses them for preparing curves of equal magnetic variation.

The method of drawing these lines is such that the mean difference between the results given by the chart and by observation shall be as small as possible. The degree of accuracy obtained in districts where there is no local anomaly is estimated at 5'.

The following charts, published by the Canadian Hydrographic Office, give curves of variation.

N° 412 *Telegraph Chart of the Maritime Provinces, Gulf and Lower St-Lawrence* (on this chart the variations are for 1922, and the secular change is shown).

N° 68 *Lake Ontario.*

N° 76 *Lake Erie* (Variations reduced to 1920).

N° 79 *Lake Huron* (Variations reduced to 1920).

N° 115 *Lake Superior* - (Variations reduced to 1925, small red circles indicate the positions at sea where local anomalies have been reported).

UNITED STATES OF AMERICA. The U. S. Coast and Geodetic Survey publishes every year the results of the observations made during the preceding year and, every five years, issues charts which give the lines of equal magnetic declination, inclination, horizontal, vertical and total intensity, and lines of equal annual change, for the territory of the United States and Alaska.

The first magnetic variation chart issued was reduced to 1st of January 1890. The last to 1st of January 1925 (See Coast and Geodetic Survey *Special Publication N° 126*).

The curves are extended over the waters off the coasts by using the results of observations made by vessels of the Coast and Geodetic Survey and of the Carnegie Institution of Washington.

It has also published magnetic charts for *Porto Rico*, the *West-Indies*, *Philippines*, *Hawaian Islands*, *Guam Island* and the *Panama Canal Zone.*

The important magnetic observatory at MANILLA is supported by the Weather Bureau; until 1904 it was situated at Manilla but has to be removed owing to the installation of electric tramways and is at ANTIPOLO since 1911.

BRAZIL. A magnetic survey of the N.E. part was carried out in 1922. An isogonic chart for September 1922 was published in the *Annuario* of the National Observatory of Rio de Janeiro.

JAPAN. A complete magnetic survey of Japan proper was carried out under the direction of the Earthquake Research Commission, by Prof. A. TANAKADATE. It was reduced to 1st of January 1895.

In 1912-13, the Hydrographic Office, with the assistance of the same Professor, made another survey which was reduced to 1st of January 1923.

(*) These particulars have been obligingly provided by the Canadian Hydrographic Office.

The method used for drawing the curves is as follows : Using as the origin

$$\varphi = 35^{\circ} \text{ North} \qquad L = 135^{\circ} \text{ East}$$

the constants of a function of the 2nd or 3rd degree of $\Delta\varphi$ and ΔL, which represent the magnetic element under consideration as closely as possible, are calculated by the method of least squares.

Thus, for each value of this element, the equation of the corresponding curve is obtained. The difference between the results from the curves and the results by observation are, when they exceed the probable observational error, what are called local anomalies ; these curves give the so-called "normal" values of the elements. The method is very suitable for drawing curves over the sea, either by interpolation (Inland Sea and Sea of Japan) or by extrapolation (East Coast of Japan). (See the *Bulletin of the Hydrographic Office, Imperial Japanese Navy*, Vol. II, Tokyo, 1918).

The method is in use in many countries for obtaining the so-called normal values ; frequently 2nd or even 1st degree formulae are taken to suffice.

The probable errors of the magnetic Variation and Dip obtained from these curves are about 6'. The divergences are shown against each observation spot.

The probable error for the horizontal force is from $\pm 65\,\gamma$ (γ = 0.000.01 c.g.s.)

Curves of equal annual change are obtained by the same method.

ANOMALIES.

SWEDEN publishes magnetic charts of her country ; they are noteworthy because of the numerous local anomalies which are met with there and which are usually due to ferrous ores (magnetite). Anomalies, the causes of which are various, are found in nearly all countries, but in Sweden they are very numerous and considerable. They even make themselves felt at sea, off the coasts, where the readings of the compass are often seriously affected. Since the action of a magnetic rock diminishes in inverse proportion to the square of its distance, it may be assumed that the action, as manifested at sea, is initiated in the sea bottom in the vicinity of the vessel. In Iceland also, where the effect of the volcanic mountains does not appear to make itself felt off the coasts, it has been noted that depths of less than 150 m. (87 ½ fathoms) may affect the readings of the compass nearly 11°. Similarly it has been noted that the action of Etna is almost imperceptible off the coasts of Sicily. (*)

These considerations lead to the assumption that there ought not to be anomalies over the great depths of the oceans.

In the Baltic, on the contrary, which is not a deep sea, there are anomalies along the coasts of Sweden and Finland, in the neighbourhood of the islands of Borholm, Öland, and Gotland, to the West of the Äland Archipelago, and off certain parts of the German coasts. They exceed + 2° for Variation, and cannot always be explained from what is known of the geological structure of the sea bottom. Special investigations were made from 1913 to 1924 all along the coasts of Sweden, Finland, and the Islands of Öland and Gotland by Mr. HELGE ODELSIO and Dr. Gustaf S. LJUNGDAHL, head

(*) See *Determinazioni di Magnetismo Terrestre*, by Lieut.-Commander Mario CUGIA - Genova 1925.

of the Department of Terrestrial Magnetism (See *Publications*, Stockholm 1922-1924-25); also in 1918 by Dr. HUITIKKA and again in 1925 by M. HELGE ODELSIÖ; they made known many of these anomalies. In 1924, the International Congress of Madrid insisted that systematic observations should be made in the Baltic. These were carried out from 1925 to 1926 with the assistance of the three States: Estonia, Finland and Sweden, using the Swedish surveying vessel *Falken* and the Estonian yacht *Cecilie*, which had no iron in their structure. Magnetic observations were made from the latter vessel by officers of the Swedish Hydrographic Office. The spacing of their net seems to be closer than any other executed up to the present time at sea. The important results of this survey showed that it would be advantageous to extend it over the whole Baltic and, also that work of this kind should be carried out off all coasts where local anomalies might be a danger to navigation. The Nautical Section of the German Reichswehrministerium also has carried out investigations of the magnetic field off its Baltic coasts where local anomalies have often been reported. During 1926, the surveying vessel *Panther* took magnetic observations in the Eastern part of the Baltic Sea, particularly for determining the magnetic variation at sea. This necessitated the use of wooden rafts, constructed without any iron. These observations were to have been continued in 1928.

In such areas, it would be of great advantage if an isogonic chart, showing the positions of localities where great anomalies exist were included in the Sailing Directions, as is done by Sweden.

The Danish and Netherlands Sailing Directions also include charts showing the isogons off their coasts. The *Portulano del Mediterraneo* Vol. V, which was published by the Italian Hydrographic Office in 1928, also contains a chart which gives the isogons for the Adriatic, a sea in which there are considerable anomalies. Thus the navigator can easily find most useful magnetic information from a large scale diagram of this description.

The value of the magnetic variation and its annual change is shown generally on marine charts at but few points; the isogonic curves being drawn on certain general charts of small scale only. It can hardly be done otherwise, in spite of the convenience of these curves to the navigator, because all additional matter which is not indispensable and which might impair the clearness of the chart should be avoided and, secondly, because the correction of these curves which, in order that they shall be of use, should be made frequently, is a rather delicate task on plates, particularly when they are engraved.

In positions where the local anomalies are great, the advantage of the resolution adopted by the Charts Committee of the 1926 International Hydrographic Conference and submitted for a ratification to the 1929 Conference, will be recognised:

"It is recommended that variation, obtained by accurate magnetic observations made at places near the coast, and which may be useful to seamen, should be mentioned on the charts near such places or in the title".

MAGNETIC CHARTS OF THE OCEANS.

The values of the magnetic variation given on marine charts are, as stated above, necessarily few and far between; interpolation between them is more difficult and less accurate than on a chart with isogonic curves. Moreover, these values of the variation are generally altered only when a new edition of the chart is made; hence they have to be corrected for the annual change for a considerable number of years, thus causing an extrapolation, which will not be very accurate if the value of the annual change inserted on the chart differs to any great extent from that which occurs in reality. As was stated above the actual annual change frequently differs by several minutes from that which was expected.

For these various reasons, the navigator who wishes to know the variation at sea should, for preference, use the Magnetic Charts of the Oceans which are published by certain nations at fairly short intervals. By using the latest editions the chances of error will be reduced to a minimum.

(A) The BRITISH ADMIRALITY, at the present time, publishes Variation Charts of all the seas of the world every 5 years and charts giving the Dip and Horizontal Component every 10 years. These charts give the annual change of these elements also.

These charts are prepared under the direction of the Royal Observatory at Greenwich by the Magnetic Observatory at Abinger. The first step is the revision of the annual change chart. For this purpose, the following data are used:-

1. Observations made at permanent observatories.
2. Observations made at the land repeat stations of the Carnegie Institution of Washington and at the intersections of the tracks of the "Carnegie".

Then all fresh material obtained since the issue of the previous charts in the shape of new surveys, new observations at sea by the Carnegie Institution, and observations made by H. M. ships, is collated and used to revise and correct the previous edition of charts where required. The charts thus corrected are then reduced to the new epoch by means of the revised secular variation charts. For this purpose the values of the magnetic element at the intersection of every 5° of latitude and longitude are read off from the charts and are reduced to the new epoch. These values are plotted on the new charts and the isomagnetic lines are then drawn by interpolation. These curves should obviously connect up with those shown on the charts, published by various countries, which have been compiled from land magnetic surveys.

Variation charts have been published for the following years: 1858, 1871, 1880, 1895, 1907, 1912, 1917, 1922; the most recent ones are reduced to June 1927. They consist of the Mercators Chart of the World N° 2598, mean scale: 1:45,000,000, and three sheets N^{os} 3775, 3776, 3777, mean scale 1:16,000,000, showing respectively the Atlantic Ocean, the Indian Ocean with the Western parts of the Pacific, and the Eastern part of the Pacific.

It is estimated that at the best places, the values of the variation are

accurate to within about 0.2°; but, in areas where the data are old and annual change is uncertain, the error, in extreme cases, may be 1°. (*)

Chart N° 3598 shows the curves of equal magnetic Dip for 1922.

Chart N° 3603 gives curves of equal Horizontal force for 1922 in c. g. s. units.

These two charts are on a mean scale of 1 :45,000,000.

All these charts bear insets giving the curves of equal annual change of the element; on charts N^{os} 2598, 3598, 3603, the polar regions are represented separately.

(B) THE HYDROGRAPHIC OFFICE OF THE UNITED STATES OF AMERICA publishes three Charts of the World on Mercators projection showing the terrestrial magnetic elements, each at intervals of 5 years; the latest ones are reduced to 1st January 1925, They are on a mean scale of approximately 1:36,300,000

In preparing these charts the results of all observations taken in the United States and other countries are collated and reduced to the new epoch by using the best values of the annual change obtainable. They are then plotted on sheets on a scale approximately three times as large as that of the final publication, and smooth curves are drawn through the points where the magnetic elements are of equal value.

In order to ascertain the degree of accuracy represented by these lines, it should be remembered that these observations are of unequal precision and spacing in the various parts of the world, and also that it is necessary to draw mean curves only, because sinuous curves, which would represent accurately the observations in regions where the best surveys have been made cannot be drawn as a rule, owing to the great distance apart of the observations.

Where there are sufficient data, the charts should give values of the Variation and Dip to within 0.1°; but in those parts where very few observations have been made the errors may reach 0.8°.

In like manner, the errors for the curves of equal horizontal intensity may attain from 1 to 8 units in the third place of decimals. (**)

Chart N° 1406 gives the curves of equal declination or variation of the Compass.

Chart N° 1700 the curves of equal magnetic Inclination or Dip.

Chart N° 1701 the curves of equal Horizontal Intensity of the Earth's Magnetic Force in c. g. s. units.

The polar regions are not shown on them Northward of the 78th degree and Southward of the 69th. Figures in parentheses, on the first two charts, indicate the annual change of the element.

The *Pilot Charts* published by the Hydrographic Office of the United States of America give among much other information the curves of equal variation; these curves are reduced to the same epoch as the magnetic charts published by that Office. Pilot Charts N^{os} 1400, 3500, 1401 and 2603 which

(*) These particulars have been kindly provided by the Hydrographic Department, British Admiralty.

(**) These particulars have been kindly provided by the Hydrographic Department, Washington, D. C.

concern the North Atlantic Ocean, the seas of Central America and the North Pacific and Indian Oceans are published monthly, and Pilot Charts Nos. 2600 and 2601 which concern the South Atlantic and South Pacific Oceans, quarterly, On each of these six Pilot Charts there is an inset, giving the annual change.

(c) GERMANY. The MARINELEITUNG has published charts Nos 2, 2*a* and 2*b*, which were prepared by the DEUTSCHE SEEWARTE.

They give the curves of equal magnetic Variation, equal Dip and equal Horizontal Force for 1920. These charts of the world extend from the parallel of 80° N. to that of 60° S.; they are on a mean scale of 1 : 80,000,000. Figures, in parentheses, indicate the annual changes of the elements. The horizontal intensities are reckoned in "Gaussian units". (1 "Gaussian unit" equals 0.1 c. g. s. units). (*)

The latest editions of chart N° 2. (Variation) are reduced to the epochs: 1905, 1910, 1917 and 1920; the last was published in December 1925 from material collected up to September 1924.

The latest editions of chart N° 2*a* (Dip) are reduced to the epochs 1905 and 1920. The last was published in July 1923 from material collected up to September 1922.

The latest editions of chart N° 2*b* are reduced to the epochs 1905 and 1920. The last was published in July 1925 from material collected up to August 1924.

Chart N° 2 is, in principle, brought up to date every five years, and charts N° 2*a* and 2*b* every 10 years. It was owing to the war that an exception was made to this rule.

In preparing these charts, use is made of all published material, whether land or sea observations; they are corrected for annual change by means of such data as are available. The very numerous results published by the Carnegie Institution of Washington form one of the most important sources of information. The curves, naturally, are adjusted curves which do not take local anomalies into account; they are the result of information the completeness of which varies considerably in different areas. (**)

It should be noted that the Sailing Directions published by the MARINELEITUNG contain Variation charts for the regions dealt with in each. These charts are somewhat more accurate than the general charts and give data as to local anomalies where necessary. They are not published at regular intervals. The last edition of the *Dampferhandbuch fur den Atlantischen Ozean* gives a variation chart for the Atlantic, reduced to 1920.

On the 21st of each month, the DEUTSCHE SEEWARTE publishes a *Monatskarte* for the *North Atlantic Ocean*, very similar to the American *Pilot Charts*, which like the latter, gives lines of equal Variation; they may be used for navigation without correcting for the annual change.

(*) This must not be confused with the *Gauss*, C. G. S. unit of magnetic field.

(*) These particulars have been obligingly provided by the Deutsche Seewarte of Hamburg.

The SEEWARTE has published two atlases also which give information of the same type relative to the South Atlantic and Indian Oceans respectively for each month. The isogonic lines for the South Atlantic are reduced to 1926 and those for the Indian Ocean to 1915. Lastly, a meteorological atlas of the Pacific Ocean, which was published in 1896 shows the lines of equal variation, dip and horizontal intensity for 1895.

(D) The HYDROGRAPHIC DEPARTMENT OF JAPAN publishes charts Nos 6024, 6043, and 6044 which give the magnetic variation, dip and horizontal intensity for the 1st of January 1923 in the neighbouring seas of Japan, (from New Guinea to the Sea of Okhotsk and from the Marshall Islands to Borneo). Chart No 6024 gives, in addition, the lines of equal annual change of variation. The isomagnetic lines are drawn by calculating, as stated above, the empirical equations of the curves from the data of the latest surveys of the Imperial Japanese Navy, the latest magnetic charts of the British Admiralty and from Russian charts. The mean scale is approximately 1 : 10,000,000.

The probable errors calculated from the curves are:

For the magnetic variation	± 5.06′	in the northern regions of Japan
	± 6.87′	in Southern regions of Japan and China.
	± 19.83′	to the south of Japan and in the Marshall, Caroline, and Marianne Islands.
For the magnetic Dip.	± 11.33′	to the W^{d} of longitude 150° E.
	± 25.54′	to the E^{d} of longitude 140° E.
For the Horizontal Intensity	± 85.86 γ	for Japan and China.
	± 154.26 γ	to the South of Japan and in the Marshall, Caroline, and Marianne Islands.
For the annual change of the magnetic variation.	± 0.290′	in the Northern regions of Japan.
	± 0.351′	in Southern regions of Japan and China.
	± 0.344′	to the South of Japan and in the Caroline, Marshall and Marianne Islands.

New editions of these charts are issued at intervals of 10 years. (*)

In addition, the HYDROGRAPHIC DEPARTMENT OF JAPAN, reproduces the British Admiralty magnetic charts Nos 2598, 3598, 3603, 3776 and 3777 under Nos 6005, 6004, 6003, 6022 and 6023.

(*) These particulars have been kindly provided by the HYDROGRAPHIC OFFICE OF TOKYO.

CONCLUSION.

The purpose of this article is, firstly, to recall to mind which are the original sources available for reference in order to obtain the elements of terrestrial magnetism in the vicinity of the coast and secondly, which charts give their elements for the Oceans.

By using these, the navigator can always have at hand a chart of magnetic variation reduced to an epoch which is not past by more than $2\frac{1}{2}$ years and, in consequence, it is only in special circumstances that he need make corrections for the annual change.

Charts of the World giving the magnetic variation over large areas of land and sea are also used frequently by aircraft, and for this reason acquire a new interest. Hence it would be of great value if the isogonic lines on these charts were always drawn over the continents as well as over the oceans. Moreover the problem of ascertaining the values of magnetic variation at high altitudes awaits solution; local anomalies should disappear, the form of the isogonic lines should be more regular but may perhaps be very different since all that part of the phenomenon, and it is by far the greatest part, which is initiated within the interior of the globe should become attenuated, whilst that part which is due to the exterior will acquire greater importance. Here is a wide range of study which has scarcely been touched and which was the object of a special wish expressed by the Section of Terrestrial Magnetism and Electricity which was adopted at the Madrid Congress on the 7th October 1924.