

## WHAT GEOMAGNETISM MEANS TO NAVIGATORS (1)

by Elliott B. ROBERTS

Captain, U.S. Coast and Geodetic Survey, Chief, Division of Geophysics

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### HISTORICAL IMPORTANCE

Let us look at one of man's early and farreaching technical accomplishments, the magnetic compass. This simple little gadget, which anyone could improvise, helped much to liberate man from his bonds and to initiate a change in his world beyond his most fantastic dreams.

The ancients had no compasses. Vessels upon the open sea were dependent, when the heavens were obscured, upon the master's precarious judgment of wind and sea. This highly uncertain feature of the seagoing life had a certain tendency to stifle exploration. In the 12th century, however, man's interest in the behaviour of the lodestone, an age-old curiosity dating from the 7th century, B.C., resulted in a vast discovery. Magnetized materials, when freely mounted, had the gift of finding directions ! It didn't take man long to find practical use of this magical property. At first he floated bits of lodestone on wooden chips. Later he learned to hang them on threads or to balance them on needle points.

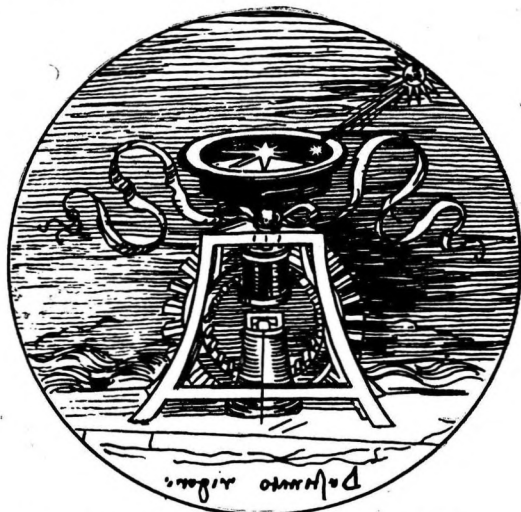


Fig. 1. — Idea for magnetic compass drawn by Leonardo de Vinci about 1500.

With growing technical competence and the help of his wonderful new tool, man no longer needed to grope blindly over the sea. He ventured farther into the unknown, confident of finding his way back. Thus he found an insistent new spirit of adventure, ushering in the age of exploration. Inevitably there was expansion of the known world, familiarity with many of its odd corners, charting of the waterways, development of new areas, and now our modern industrial world. The compass was an important influence in the beginning of all this growth.

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Man never succeeded in explaining the mysterious lodestone. It is easy to see, therefore, why we have a store of ancient superstition holding it to be a cure for dropsy, gout, fever — even domestic discord ! Early mariners feared the needle would lose its virtue by the odor of onions or garlic. Mariners were enjoined to forego these delicacies.

Science has explained the effects, if not the nature, of magnetism. In 1269 Peregrinus described pivotted compasses, writing in a spirit of experimental approach we now term the scientific method, showing the way for the later great works of Copernicus, Galileo, Francis Bacon, Gilbert, and Newton. Onions and garlic, alas, gradually returned to favor.

#### MODERN IMPORTANCE

The magnetic compass does not nowadays float upon a chip of wood. It has been improved in every possible way for so simple a gadget, to suit a variety of uses. Formely, because of speed and simplicity, it was important in surveying. George Washington used it. Today it still has military use, and parts of the Alcan Highway were so located. But here we will deal only with the compass in navigation, and related features of geomagnetism.

The oscillations of the marine compass needle have been damped by attaching it to a stabilizing card balanced in liquid in a bowl made spherical to prevent eddies of the liquid, and of copper for the added damping effects of foucault currents. The whole is suspended in gimbels, and fitted with elaborate binnacle devices to counteract stray magnetic influences from the ship.

Simple, inexpensive, small and light in weight, and above all, reliable, this basic instrument of navigation is used by all ships. Many vessels are too small to carry the large and expensive gyro-compass. Ships of whatever size require a standby — for who can guarantee that the fascinating gyro will not sometime fail.

Use of compass is inevitable in the navigation of aircraft. Radio beams, loran, omni-range beacons — all are subject to failure, particularly at long range over the ocean or in the arctic. Recourse, to find friendly shores, must be the magnetic compass. Aircraft compasses, whether liquid or the marvelous fluxgate, even though they have elaborate gyro-stabilizers, electronic remote readers, or what-not, must use the earth's magnetic field, which we call geomagnetism.

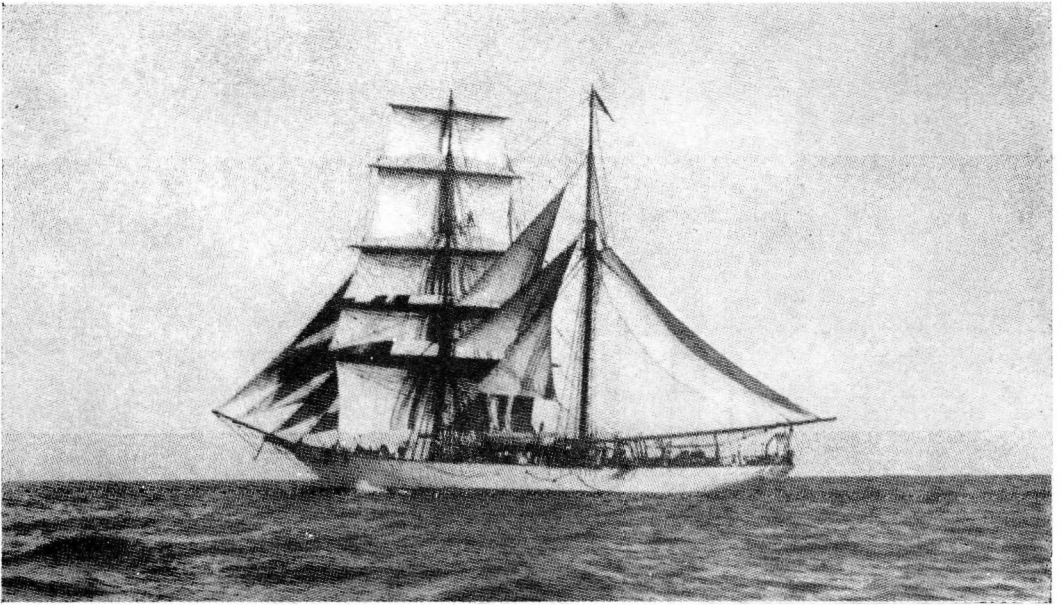
#### GEOMAGNETISM

This inscrutable force, completely enveloping the earth, is all-pervading, and cannot be escaped, or tampered with. The ancients thought it to stand immovable and unchangeable through light and darkness, fair weather and storms. We know better now, but we have never explained it !

One of the most persistent quests in the realm of science has been man's effort to measure, study, and understand this mysterious force. In 1600 Dr. William Gilbert, after exhaustive experiments, produced his important work *De Magnete*. This foundation stone in the science of electricity and magnetism summarized the then known properties of magnetic bodies, and suggested that the earth is a great magnet.

This was brilliant insight in view of what was then known of geomagnetism. Indeed, in a general way, this magnetic field is similar to that of an extremely small, inconceivably powerful bar magnet, or dipole, near the earth's center. Actually it would be 342 km. off center and tipped at an angle of 11 degrees. But this is only a first appearance. The idea of the earth being a magnet, a lump of lodestone, so to speak, just doesn't fit the facts. The interior is too hot to be capable of magnetization. Irregularities of distribution, and a condition of slow change, also deny Gilbert's idea.

A better and more plausible idea is the magnetic field surrounding a flowing stream of electric current, though we have no good explanation of what started or maintains it, or why it changes as it must to produce the phenomena we see. Various schemes have been described, showing circulation of the earth's interior materials, by convection or dynamic causes, resulting in dynamo effects. Involved computations based on these speculations support the physical plausibility of the idea.



*Fig. 2.* — Non-magnetic Vessel *Carnegie*, operated 1909-1929  
by Carnegie Institution of Washington for ocean magnetic surveys.  
Lost at Apia by fire in 1929.

## MAGNETIC POLES, EQUATOR, LATITUDE

There are no actual poles on the surface — they would have to be down inside, consistent with the dipole or the dynamo models. We would have, however, places where the lines of force, which indicate the direction of the attractive force, are observed to stand vertical. Actually such places exist. They are quite large, poorly defined, changeable and uncertain, and important in navigation mainly because of the fact that compasses won't work near them. One is in the vicinity of Prince of Wales Islands, Canada, at 73 N and 100 W. The other is in Antarctica, at 73 S and 156 E.

The field, as shown by the lines of force at any place, lies at some angle of dip from the horizontal, with a horizontal component. This is the case everywhere except on a line girdling the earth, in places north and elsewhere south of the geographic equator. This so-called magnetic equator has exquisite interest for magneticians, but not for navigators. The horizontal component of the force is related to the magnetic latitude, and varies from a maximum at the equator to a useless nothing at the poles. The amount of dip, and of field strength, have important bearing upon the magnitude of navigational compass deviations.

## THE EFFECT OF MAGNETIC FORCE ON COMPASS NEEDLES, etc.

A magnetized body in a magnetic field experiences no overall pull, or translational force, unless it is long enough that the two ends are in areas of materially different field strength. For practical purposes this does not occur in the geomagnetic field. One pole of a magnet receives as much attractive force as the other, but in opposite directions, so that the effect is a turning force to bring the two into exact line with the magnetic lines of force. The magnet does not point to any particular point. It merely points out the direction of the lines, and if they are distorted into any direction whatever by some local magnetic force, that is what your magnet will show at that place. If the magnet is counter-weighted and free to turn only in the horizontal plane, it responds to the horizontal component of the field. This is the invaluable reaction that has made the compass what it is in world history.

## REGIONAL MAGNETIC VARIATION EFFECTS

As lately as Columbus' time, it was believed that the needle does point true north. In western Europe the compass variation was slight, and small errors were laid to faults of construction or use. As he progressed west across that unknown ocean, Columbus found his compass failing, by increasing amounts, to point out the pole star. It gave him great concern, and caused near mutiny of the crew. One tale has it that the Great Mariner convinced them it was caused by Polaris' eccentricity ! Another suggests that he stole out at night and placed bits of metal about the compass to make it return to the pole star. This, if true, was doubtless the first compensation job of history. But « firsts » were not strange to Columbus !

Columbus' difficulty with the compass was but a slight intimation of the coming need for widespread observations and surveys, to find out just how the compass can be expected to point in any place. Later analyses have shown that the distribution of magnetism within the earth can be divided mathematically in two parts, one part regularly formed, the other capriciously distorted on a rather large scale. The combined field, though having regular form, is superficially irregular, and only actual observation will disclose the features. The variation in the United States varies from 22 W in Maine to 24 E in Puget Sound. Arctic adventurers find the compass pointing everywhere — even south. Why these irregularities ?

The answer is to be found in that hypothetical system of dynamos within the earth. A central dynamo can be thought of as generating the main, regular part of the field. Smaller ones only part way within the globe are cause of the regional irregularities. These are all known through magnetic surveys, and are known also to change materially within a few hundred years.

## LOCAL, MAGNETIC ANOMALIES

This is far from the whole story. As we intensify our survey we find more and more strictly local irregularities which must be associated closely with the actual ground beneath our feet.

The crust of the earth contains much permanently magnetized material — in fact, an interesting study in magnetic history — paleomagnetism — employs measurements of the residual magnetization of geological specimens of known age. Many crustal rocks have varying degrees of magnetic susceptibility — somewhat analogous to electric conductivity — and warp a magnetic field by attracting the flux to their vicinity. A significant lesson is that the outer crust distorts the magnetic field into countless irregularities. These may be associated with individual boulders, which affect a magnetic measurement as the steel of a ship affects the compass, or with ore deposits, or major geological structure. One of the more profitable methods of discovering types of geological structure that may contain petroleum involves magnetic exploration. The discovery of the Michigan iron fields resulted from the noting of compass irregularities.

Obviously, magnetic surveys are not everywhere sufficiently intensive to have discovered all the anomalies — particularly those of quite local character and extent. This may be particularly true in Alaska, where the magnetic material is extremely close to the surface, so that the needle may vary twenty or thirty degrees from normal in many places. However, there are probably few irregularities such as to interfere with navigation. One is at Port Snettisham, Alaska, but the charts are prominently marked. It is said that one severe local anomaly near Jussaro Island in the Baltic caused several ship losses. The largest known local anomaly is at Kursk, south of Moscow, where magnetic formations cause almost 180-degree compass deviations in a large area. These anomalies are fixed, and do not change with time, as do the regional irregularities.

## GEOMAGNETIC OPERATIONS IN THE UNITED STATES

Obviously, in view of this highly complex magnetic field, comprehensive magnetic surveys are required to permit intelligent use of compasses.

The Coast and Geodetic Survey has long performed this function as a necessary adjunct to its work of compiling nautical and aeronautical charts. Alexander Dallas Bache, a former Bureau Director, and one of the founders of the National Academy of Sciences, set up a magnetic observatory at Philadelphia in 1840. Observations at widely distributed field stations were inaugurated and large numbers eventually obtained in order to disclose the field over the United States. This laborious and technical work requires skilled field observers. All elements of the field are measured, for a variety of purposes in addition to the simple compass needs discussed in this article.

Bauer, a Bureau magnetician, attempted to survey the magnetic field over the coastal waters of the country, using the *Blake*, a wooden ship; but inevitable magnetic impurities, inescapable even in such a ship, made the work of poor quality. Later, as Director of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, which he brought to a position of eminence in magnetic research, Bauer carried out magnetic surveys of the oceans of the world, using the non-magnetic and specially instrumented survey ship « *Carnegie* ». The work was well under way when, in 1929, the « *Carnegie* » was lost by fire. To this day compass variation allowances made by ships at sea are based upon extra-polations from that time — a woefully incorrect practice and a growing danger which we may soon make unnecessary by use of the newly developed techniques of aeromagnetic surveys.

## MAGNETIC TIME CHANGES

We have not yet reviewed all the reasons why magnetic chart compilation is so complex a job. I have described something of the tortuous shape of the magnetic field, but not of its unstable character. This is no frozen image we are dealing with rather an undulating form like the face of the sea. Hopeless confusion would result if we didn't have means for keeping track of it. There are, therefore, on earth more than 50 magnetic stations — seven belonging to the

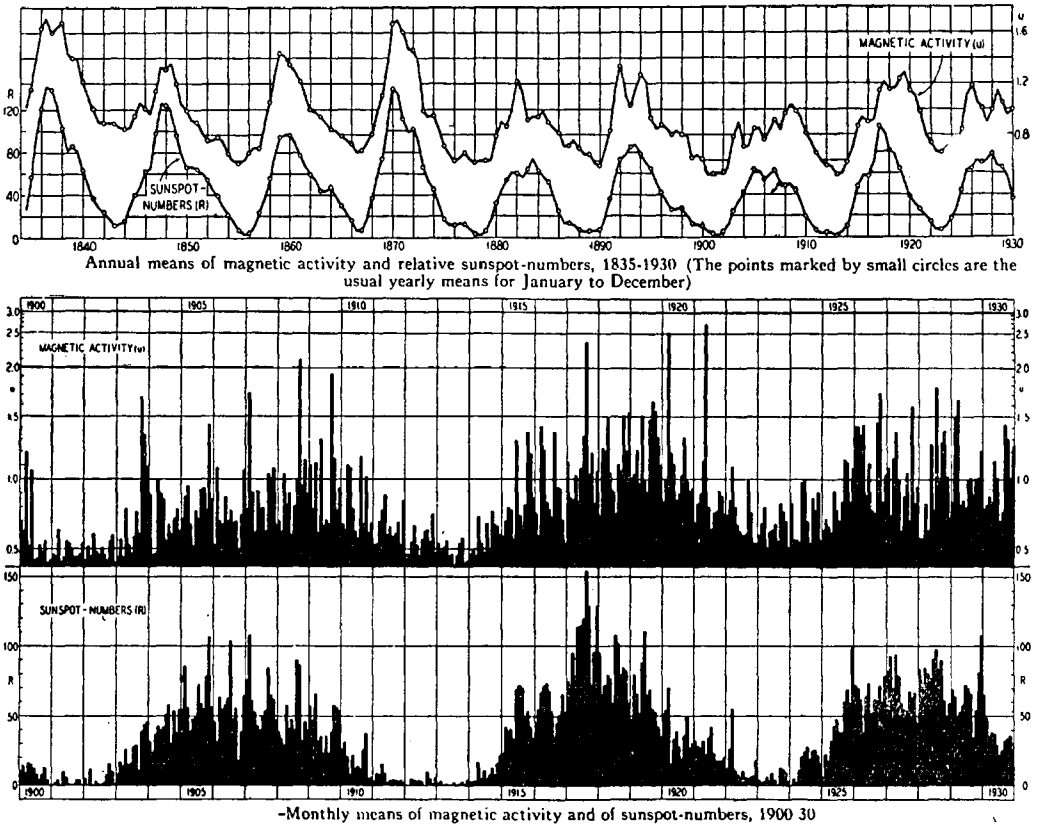


Fig. 3. — Relation between geomagnetic and sunspot activity from J. Bartels

United States — where variometers, in dead darkness and well shielded from temperature effects and possible stray magnetic disturbances, silently work year in and year out, recording the play of the earth's magnetic forces.

These changing magnetic effects are of many kinds, and they have important implications in navigational use. I would like to divide them in two main classes. First are transient effects, including magnetic storms and a somewhat regular daily effect, and second are the secular, or long-period changes. The transient effects do not often achieve magnitude of concern in compass use; however, magnetic storms are intimately related to the cause of radio communication failures and loss of radio navigational aids. The secular change on the other hand is slow, and in a year or two has little practical effect, but it goes on and on unremittingly, with all the time in the world, and its cumulative effect is great. We must, therefore, have periodic revision of the magnetic charts, and of the compass roses, and isogonic lines.

### MAGNETIC STORMS AND RADIO FADEOUTS

Magnetic storms are not completely understood, but we know them to be closely related to sunspots, their frequency according directly with the sunspot cycle of about 11.2 years. We even anticipate such storms when we see great sunspots coming around the sun. Magnetic storms rarely disturb the compass more than a degree or two. Probably four degrees is a maximum in the United States, but it may be considerably more in Arctic areas. These are essentially disturbance effects, never providing any prolonged variation errors.

Just how it works is not so obvious. Ultraviolet solar radiation of our upper atmosphere, coupled with the effects of particle streams ejected from the disturbed solar areas, disrupts the steady-state ionization of our upper atmosphere. Irregular streams of electric current have associated magnetic fields which play in wild confusion over the steady normal field. This play is faithfully recorded at a magnetic observatory, giving vivid evidence of confused ionospheric layers which cannot reflect radio signals beyond the turn of the horizon. In this way the magnetic variometer renders assistance in the study of radio wave propagation and affords one of the best and earliest indications of impending fadeouts. Those concerned with air operations in remote parts of the world have an important interest in this feature of geomagnetic investigations.

### DAILY CHANGE

The somewhat systematic but not entirely predictable diurnal change is caused by regular electric currents in the inosphere. This daily occurrence is caused by ultraviolet radiation. It is of no significance in navigation, but it is important to the geomagnetic surveyor collecting basic data for making magnetic charts. Here again the observatories are needed. Field observations made for a magnetic survey can be largely cleared of the troublesome effects of the transient fluctuations by the use of corrections drawn from the record of the nearest magnetic observatory. Daily change is almost entirely associated with the solar day, but there are slight traces of lunar effects, detectable only through elaborate statistical analysis of observatory records. This is probably caused by the presence of lunar tides in the terrestrial atmosphere.

### SECULAR CHANGE

The secular, or long-period change of the geomagnetic field is irregular and unpredictable. It may continue hundreds of years in one direction before the inevitable reversal. Magnetic information for navigation must reflect careful analysis of this.

We take secular change effects to be the result of growth or decay of the smaller, regional dynamo systems perhaps halfway toward the earth's center. These seem to change materially within a few hundred years, causing the slow changes that so complicate our work of compiling magnetic charts.

The greatest known secular change rate affecting variation, except in the unstable polar areas, is about 15' per year, in Madagascar. A center of intensive change is called a focus, and all well known foci appear to be drifting slowly westward. This may have some implications concerning our ideas on circulation of material within the earth — the dynamo theory.

### MAGNETIC CARTOGRAPHY

All these ramifications of the science of geomagnetism are directly or indirectly of great concern to the navigator who must rely on magnetic data. Magnetic cartography is a vastly complex matter. The more closely we examine the details of the mixed-up magnetic field, the more numerous are the twisted convolutions seen to be. Among the more difficult problems are the decision when and where to stop developing the tortuous contours, and how much to smooth out the results to make a legible and useful chart. This results in the arbitrary suppression of a great deal of detail, but gives the navigator good average variation values over long distances.

Since it is slow and painstaking work to make magnetic surveys, obviously old records must be employed for much of the information. These old values are scattered in time as well as in position, and each must be reduced to epoch by application of endlessly varying corrections. Irregular rates of change, each peculiar to its location, require elaborate and complex formulation, and innumerable separate computations.

Isogonic charts, or the magnetic details on nautical and aeronautical charts, are snapshot pictures of this restless magnetic field, designed for a particular date. They may be used within a few years of the construction date, by using a correction based on the associated annual change information, but not too many years, thanks to the unpredictable nature of magnetic phenomena. Geomagnetism in the broader sense is a branch of the science of geophysics, and contributes significantly to our understanding of our planet. From this brief account, stressing the navigational aspects of the subject, you can see why magnetic surveying is a never-ending job. In the United States we recompile the isogonic charts of our country and of the world at five-year intervals, in order to give navigators the benefit of the latest collected data, and to save them the possibility of dangerous error in using their compasses. This is one of the most important objectives we have in our work in geomagnetism.

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