SECULAR VARIATIONS OF TERRESTRIAL MAGNETISM.

by

PROF. DR. A. NIPPOLDT - Potsdam.

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In the Year Book for 1926 we gave a short summary of the present state of research with reference to the origin of the magnetization of the earth, in other words of terrestrial magnetism. We find that besides the magnetization, which is still in our days covered by the hypothesis of a ferro-nickel core to the earth, there is another magnetization the seat of which is within the outer crust of the earth.

It is a well-known fact that the terrestrial magnetic field does not retain the value which it had at a given moment, but that it undergoes continual modifications which are called variations, hence it cannot be denied that the problem has become more enigmatic at the moment. But these variations, in themselves, have this much to the good, that they will give information as to the causes of the general field. This is the case when these variations are not engendered by some outside influence, but by oscillations of the terrestrial magnetic field itself. When we measure the oscillations of this field the hope is awakened that we may be able to draw from them some conclusions as to the causes of the whole terrestrial fields.

There are, however, two groups of terrestrial magnetic variations; the first group is caused, if we can apply this metaphorical expression of events which are inherent to the living world to those inherent to the dead world, by the reciprocal relation between the electric radiation of the sun and the magnetism of the earth. Those of the second group are really variations in the field itself.

The first group includes regular and irregular variations (perturbations) such as the diurnal ones, others with a 27 day period, the annual ones, those with a period of 11 years, and the luni-diurnal ones. The second group contains but one, namely *secular variation.*

Before directing our attention to this variation we must, while awaiting a possible later and more complete description, stop for a moment to examine those of the first group. For the sake of simplicity we will refer to them as the "rapid" variations.

The sun emits, without interruption, a corpuscular electric radiation and also ultra-violet light. The other radiations of the sun are of but minor importance from the point of view of terrestrial magnetism. The ultra-violet light is diffused in every direction in exactly the same way as the visible light of the sun. Only that part which is contained within a small cone, which corresponds to the sun's parallax, reaches the earth and, in fact only on the day-light side, propagates itself in the atmosphere and makes the upper layers

thereof electrically conductive. The same phenomenon is induced by the electronic radiation of the sun, but as soon as this radiation moves in the vicinity of the earth-magnet it undergoes a deviation in its course. So long as the course of the electrons lies parallel to the lines of force of terrestrial magnetism, the electrons have a tendency to travel further along these lines and thus they reach the polar caps of the earth by routes which, it is true, are somewhat round-about. These electronic courses prefer places on the earth where, at the instant of their arrival, the time is from 7 to 12 o'clock in the evening, and in exact opposition to the ultra-violet radiation the night-hours are the more active. Should the sun present, in addition to its regular radiation, areas of special activity, *viz.* sun-spots and faculae, the special electric radiation emanating from these areas is added; this radiation consequently did not exist before the formation of the areas and it ceases when they disappear. Should the solar area and the earth be in favourable conjunction the terrestrial magnetism will appropriate some of these radiations. At the moment when these reach some point in the highest layers of the atmosphere the electric conductivity is immediately modified and this is the cause of magnetic storms, in other words, rapid and irregular variations.

Part of the regular and irregular electronic radiation of the sun flows towards us in or near the plane of the magnetic equator; when this occurs the courses followed have a large component perpendicular to the lines of force of terrestrial magnetism and consequently have a tendency to move in circles around these lines. From the combined effect of all the equatorial radiations there arises thus a ring of electrons surrounding the earth which is called the *annular current.* We do not yet know its exact distance from the earth; it is about 1,000,000 kilometres. As, at this distance, there is no atmospheric air, the ring cannot become luminous and thus we cannot see it, whereas the radiation which reaches the polar caps produces "polar light", in certain conditions.

The principal action of the electric and ultra-violet irradiation of the earth is that, when it is absorbed by the atmosphere, the two become disassociated and thereby become conductors. We must picture to ourselves, therefore, that the earth is surrounded on all sides by an electro-conducting layer. This is but the layer which was found later, at about 100 kilometres altitude in round figures, by wireless telegraphy and which was named after HEAVISIDE. On account of the daily warming due to the sun and the movement of the tides this layer is raised and then lowered and displaced horizontally daily; there is, therefore, the movement of an electric conductor against a magnetic field, in this case the terrestrial magnetism. Consequently induced currents are produced therein and their magnetic action appears as rapid magnetic variations.

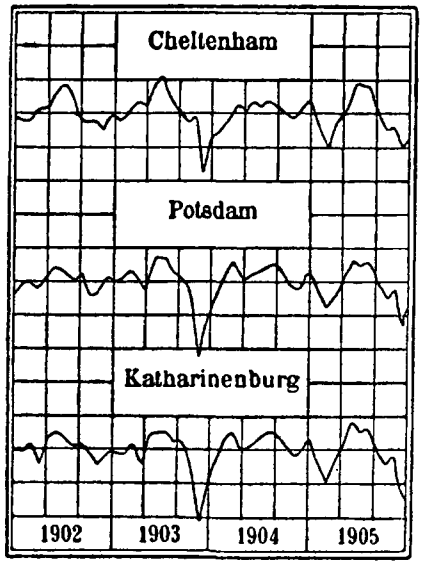
By its very nature the magnetic field of force of the rapid variations is exterior, *i. e.* it is outside the solid earth. However, the currents in the HEAVISIDE layer again induce currents in the earth, these are the telluric currents, or at any rate a definite part of these currents; but this inner part of the rapid variations is small compared with the direct outer part. We must, therefore, consider the distinctive sign of the rapid magnetic variations; they issue from an exterior field of force which superimposes itself on to the terres-

trial magnetism, properly so called, as an extraneous field; for this reason the rapid variations cannot enlighten us in any way on the subject of the essence of the earth's magnetism.

But it is quite another matter with the secular variation. We are fully aware that its cause must be located in the interior of the earth.

For many years a distinction was made in this between an interior and an exterior part; we can easily understand that this was due to the method of calculation by which it was attempted to conceive the reason for the secular variation.

Historically, the secular variation was the first which was discovered. At first it was but occasionally that observations for declination were renewed at the same place; even allowing for the inaccuracies of the first observations the rapid variations remained entirely unknown whereas, finally, secular variation became quite evident. When, a long time afterwards, magnetic observatories made a permanent study of terrestrial magnetism the expression "secular variation" was taken to denote the change in the mean variation from year to year. However, even in this change there is a considerable fraction due to rapid variations. One year has more magnetic perturbations than another; thus its mean value could only increase or decrease with reference to the true secular variation on account of the fact that solar activity was greater, *i. e.* the exterior field was greater. It is not astonishing, therefore, that the change in annual means contains a portion which is not due to interior causes. It is necessary, therefore, to eliminate the exterior forces from the annual change; this is done by means of experimental data, which show that magnetic perturbations are events which always affect the whole world. When an electronic cloud, coming from the solar surface, reaches the earth, conductivity will, in fact, be distributed at first in one place only; but electro-magnetic impulse is propagated at the speed of light, which means that, in view of the small dimensions of the earth, it is recorded practically simultaneously everywhere. This applies not only to the first impulse but also to the succeeding swarms of electrons. In a word, the portion which comes from the exterior can be isolated on account of the simultaneousness of the changes in variation.

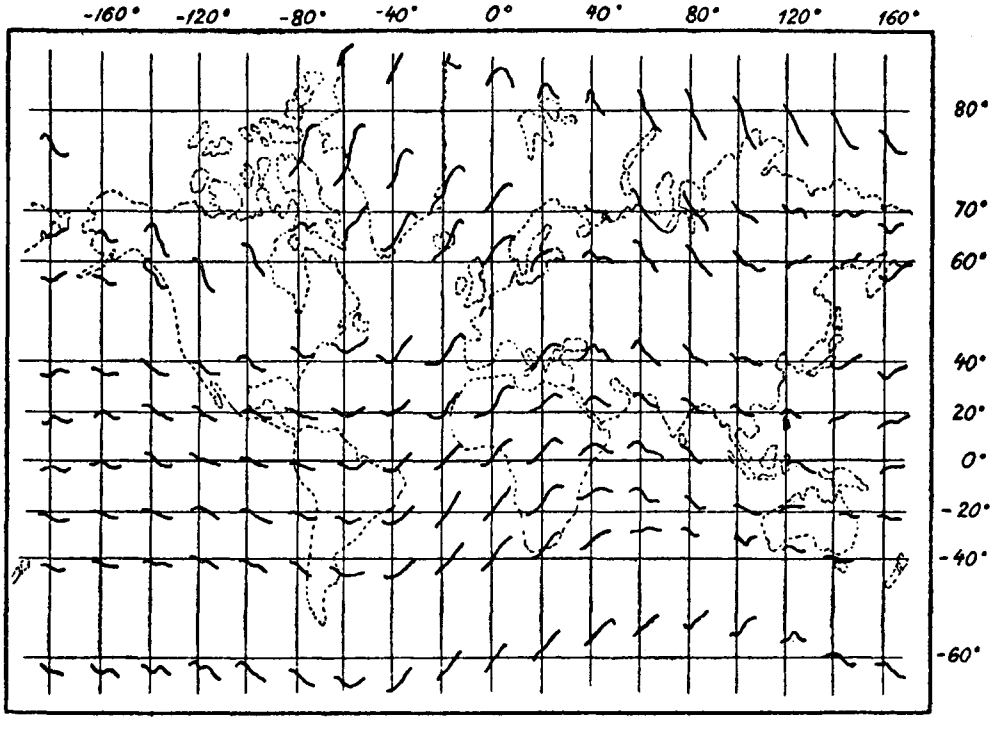


In other words this means that, from the variations from year to year, that portion which is a universal phenomenon must be extracted. This portion may be recognised from the fact that, in its own proper chronographic oscillations, it appears simultaneously in all magnetic observatories; for the moment no importance need be attributed to the size of its oscillations, *i. e.* their amplitude.

A large number of observatories carry out such work and in their year books give at least the figures and often the curves resulting there-

from. The figure above shows this external portion of the secular variation at three observatories :- Cheltenham, near Washington, Potsdam and Katherinenburg for the years 1902 to 1905. It can be seen at first glance that we are dealing here with a universal phenomenon. The curves shown are only those giving the frequency of the perturbations for the different years and parts of years. If they be considered separately, small divergences will be found in the changes of amplitude (not, however, in the chronographic characteristics). It should be noted that these divergencies become very much greater when polar observations, such as the fine series taken by the Finnish Observatory at Sodankylä, for example, are included in the comparisons. The reason for this is the fact that, in such cases, the immigrant electronic rays engender a special state of conditions.

Ad. SCHMIDT, who first learnt to isolate this universal phenomenon, pointed out also that the change of amplitude, so far as the horizontal elements are concerned, is very closely proportional to the *sine* of the latitude, and that consequently this external portion corresponds to an equatorial parallel current with a homogeneous field of force. Our curves, and thus the whole phenomenon, represent nothing else than oscillations in the intensity of the ring of



Secular Variation in Declination from 1500 *to* 1800 *according to* VAN BEMMELEN.

The curves give the secular variation of the declination at the points of the earth where they cut the meridians. This point of intersection corresponds to the year 1700. *On the right and left, along the parallels, the tenth part of the space between the meridians inserted corresponds to an interval of* 50 *years. On the ordinate, the same space represents* 5° *of declination. Upwards indicates westerly declination.*

CHART N° 1.

currents which we mentioned above. It has, therefore, on an average a field force of 150 to 200 γ.

If we extract this portion from the changes we will obtain the true secular variation.

A periodic movement of the secular variation is frequently spoken of. This comes from the fact that the element which was first measured, the declination, showed two extremes in Europe, an easterly maximum in about 1580 and a westerly maximum in about 1810. This difference of 230 years should entail a complete period of 460 years. Mathematical research carried out at various places has given a period of 477 years. W. VAN BEMMELEN, lately Director of the Observatory at Batavia, has taken the trouble to draw up isogonic charts for numerous periods 50 years apart and has increased considerably old observational material by careful search in old ship-logs. By this means he was able to find the change in the secular variation throughout the world at points of intersection of meridians and parallels. The accompanying chart (N° 1) gives the results which he obtained; from it we learn that the periodical movement was really special to Europe and that in other parts of the world it had at least a different rate of change. At any rate the transition is gradual.

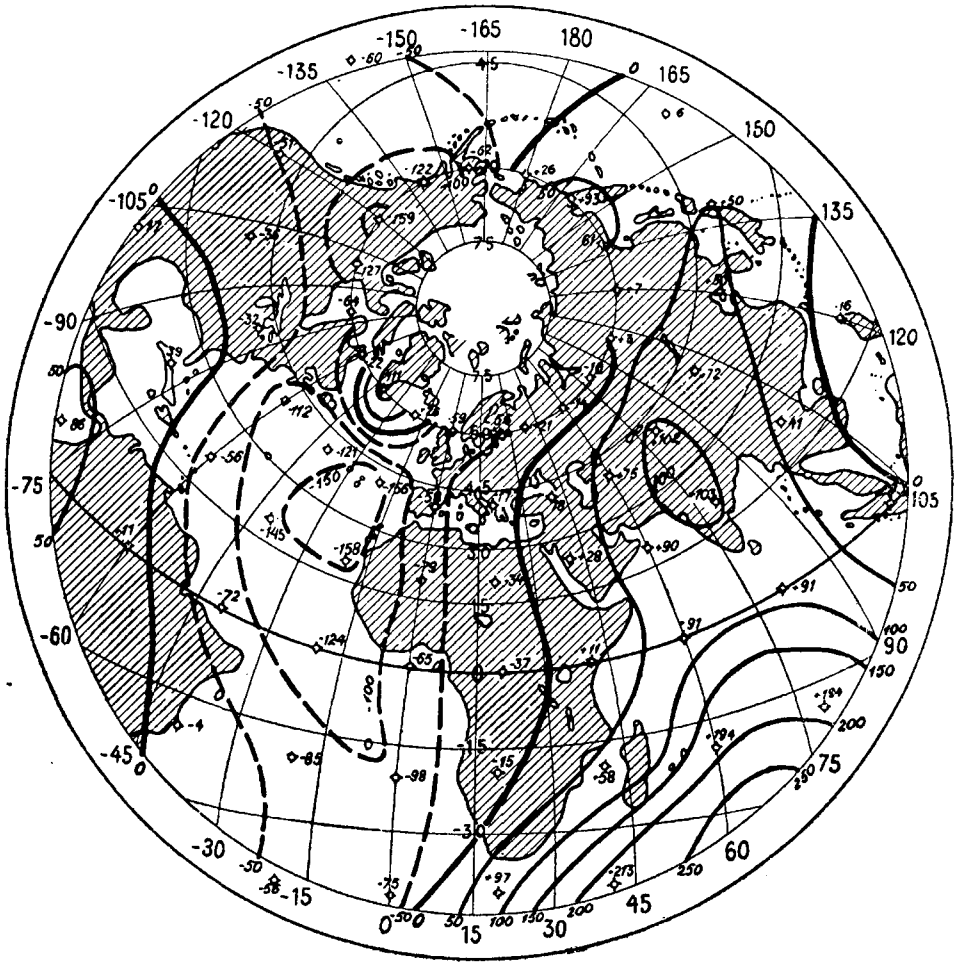
Since this investigation doubts have arisen as to the existence of a period in any place and that which occurred in Europe between the dates mentioned is considered to be a matter of chance.

Besides, it was supposed that the action should affect the whole world uniformly, or ar least that, in its distribution on the terrestrial surface, there should be some simple relation to longitude and latitude. For this reason, at the instigation of Ad. SCHMIDT, J. BARTELS tried to represent the distribution of the secular variation over the earth by a spherical functional expression for different intervals of time. While doing this it appeared clearly that secular variation is not a phenomenon of planetary nature but of local terrestrial nature; besides, the author of this article had already deduced this shortly before, from early preliminary investigation by BIDLINGMAIER.

The second chart shows this perfectly clearly. Its lines represent curves of equal secular variation according to the vertical intensity. We recognise that there are on the earth one or two closed areas where the vertical intensity increases secularly and others where it diminishes.

These areas are as large as continents or oceans, but they do not in any way correspond to any continent or ocean. We deduce therefrom that the origin of secular variation exists in the fact that some contiguous parts of the solid globe increase their magnetism at times, whereas others decrease theirs. It is quite comprehensible that the source thereof is not to be found in the ferro-nickel core but in the crust, particularly within the layer which we know to be heterogeneous. Only those layers can be concerned in which differences between minerals of one sort and another occur, *i. e.* that, at the most, depths should be taken into consideration wherein crustal differences are still to be found. The secular variation, therefore, gives us a means for separating the portion which belongs to the nuclear field from that which belongs to the

crustal field. It is herein that the great importance of the continuation of its investigation lies.

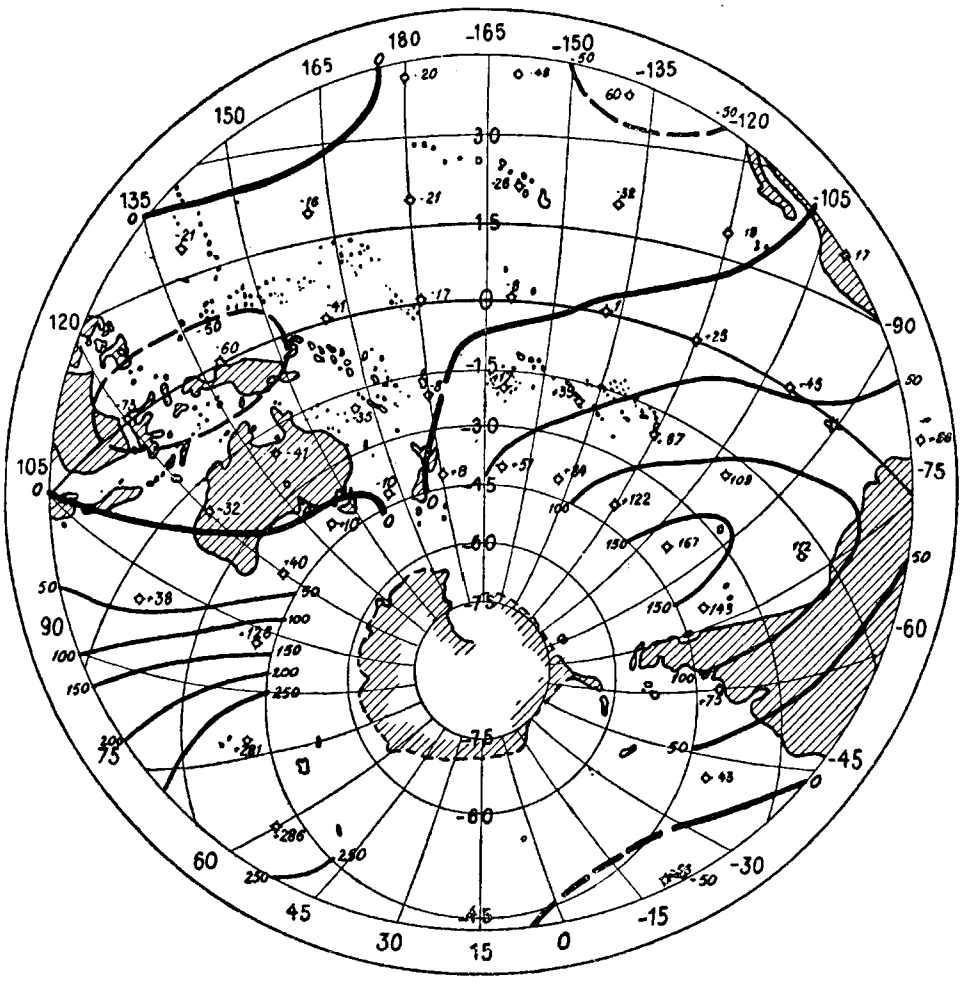


Lines of equal value of the Secular Variation in Vertical Intensity.
Secular Variation according to BARTELS.
CHART N° 2 *a*.

The moment has not yet arrived to differentiate between the processes to which it gives rise in the crust. Several hypotheses can be put forward. The magnetism may increase because the terrestrial heat recedes or because the magmatic masses move horizontally within the magnetized masses, as is assumed for other reasons in geology.

It is also possible that the continental drift, as suggested by A. WEGENER manifests itself in this way. In view of all these possibilities it is not permissible for the present to make any definite assumptions in undertaking this research. However, it is now the case that we consider the essence of secular variation from an entirely different angle than we did a few years ago; in entire opposition to other terrestrial magnetic phenomena it is a local geographical phenomenon and is not a general terrestrial nor cosmic phenomenon.

It has a very close analogy to the secular uprisings and depressions of portions of the crust which are movements mainly dealt with by geology, but it differs from these by a very important factor, namely the much greater rapidity with which it occurs.



Lines of equal value of Secular Variation in Vertical Intensity.
Secular Variation according to BARTELS.

CHART N° 2 *b.*

It is a problem, full of promise for the future, to explain the essence of the secular variation and to penetrate the mystery, which is still so deep, of the processes the activity of which becomes apparent in the terrestrial crust. Terrestrial magnetism alone reveals them to us, yet they must make their presence known by some means or another in the form of other imposing geophysical phenomena.