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ON THE DISTRIBUTION AND THE SECULAR VARIATION OF TERRESTRIAL MAGNETISM.

IN two papers* read before the Philosophical Society of Washington, May 25th, the following main results were obtained:

The minimum change in declination along a parallel of latitude at any particular time, and the minimum average secular change along a parallel of latitude during a given interval of time occur near the equator; both quantities generally increase on leaving the equator.

Exactly the reverse is the case with regard to the inclination, viz.:—

The maximum change in inclination along a parallel of latitude at any particular time, and the maximum average secular change along a parallel of latitude during a given interval of time occur near the equator; both quantities generally diminish on leaving the equator.

These laws were established with the aid of data scaled from magnetic charts from 1780 to 1885 at points 20° distant in longitude and in latitudes 60°N, 40°N, 20°N, equator, 20°S, 40°S and 60°S. They again point to the same conclusion reached previously by the writer in a somewhat different way, namely, *that the distribution and the secular variation of terrestrial magnetism appear to be closely related; they are subject to similar laws. It is hence probable that they are both to be referred primarily to the same cause. This common cause seems to be connected in some way with the earth's rotation.*

If we regard the earth as uniformly magnetized, having its magnetic poles coincident with the geographical poles, and take the X axis of a system of coördinates whose origin is in the center of the earth, parallel to the magnetic axis, we shall get the fol-

* 'On the Secular Variation of Terrestrial Magnetism' and 'A Preliminary Analysis of the Problem of Terrestrial Magnetism and its Variations.'

lowing expression for the potential function at any external point, viz.:

$$\psi = \frac{4}{3} \pi \mu a^3 . \frac{x}{r^3}$$

a is the mean radius of the earth, r the distance of the point from the origin, and μ the intensity of magnetization per unit of volume.

For points on the earth's surface, this reduces to:

$$\frac{\psi}{a} = \psi_a = \frac{4}{3} \pi \mu . \sin \phi = c . \sin \phi \qquad (1)$$

φ is the geographical latitude and $c = \frac{4}{3} \pi \mu$.

This formula is doubly interesting just now, as it has been recently deduced empirically by Professor W. von Bezold.* This eminent investigator, when considering the mean values of the geomagnetic potential along parallels of latitude, found them subject to the simple law $\psi_a = c. \sin \phi = 0.330 \sin \phi$. Since $c = \frac{4}{3} \pi \mu$, and the magnetic moment, M, of the earth is equal to $\frac{4}{3} \pi \mu . a^3$, we find that von Bezold's empirical coefficient implies a value of the magnetic moment equal to 8.52×10^{25} against 8.55×10^{25} as determined by Gauss. We thus see the theoretical significance of von Bezold's factor.

Since for the case supposed the horizontal component of the intensity, H, is directed meridionally, it follows from (1) that:

$$H = \frac{\delta \psi}{a \delta \phi} = c . \cos \phi \qquad (2)$$

Furthermore, with the aid of simple transformations:

$$V = 2 c . \sin \phi \qquad (3)$$
$$F = c . \sqrt{3 \sin^2 \phi + 1} \qquad (4)$$
$$\tan I = 2 \tan \phi \qquad (5)$$

V being the vertical force, F, the total and I, the inclination. Formulæ (2), (3), (4) and (5) are familiar to every nautical geomagnetician.

* See his admirable paper 'Über Isanomalen des erdmagnetischen Potentials,' Sitz. berichte d. Kgl. Preuss. Akad. d. Wiss. zu Berlin. Phys.-math. Classe, April 4, 1895.

Now the writer finds that these formulæ give the mean values of the magnetic elements along parallels of latitude with a high degree of precision. As this paper will be printed in full in the *American Journal of Science* beginning with the August number, I will select but one typical example.

1885.

Latitude	I obs'd *	I Comp'd	O.–C.
60° N	74°.9 N	73°.9 N	+ 1°.0
40°	59 .7 N	59 .2 N	+ 0 .5
20°	34 .3 N	36 .1 N	− 1 .8
Equator	3 .2 S	0 .0	− 3 .2
20°	36 .8 S	36 .1 S	− 0 .7
40°	57 .2 S	59 .2 S	+ 2 .0
60° S	70 .2 S	73 .9 S	+ 3 .7

Since, according to equation (2).

$$c = \frac{4}{3} \pi \mu = \frac{M}{a^3} = H . \sec \phi \qquad (6).$$

we can get a fair value of the magnetic moment of the earth without the aid of the laborious Gaussian computation by simply scaling the value of H for equidistant points along a parallel of latitude from isodynamic charts and substituting the mean of the values thus found in (6).

Thus I get for 1885 as the mean result of the scalings along 40° N, 20° N, Equator, 20° S and 40° S, the value of $0.325 a^3$ for M, against $0.322 a^3$ resulting from the 1885 Neumayer-Petersen re-computation of the Gaussian co-efficients.

But why should the values obtained on the assumption that the earth is uniformly magnetized, and its magnetic axis coincident with the geographical axis, so nearly agree with those based upon observed quantities? It seems to me that this opens the question whether the asymmetrical distribution of land and water is the primary cause of the asymmetrical distribution of telluric magnetism, as generally supposed. Why do the 'anomalies' in the distribution so nearly cancel each other in going along a parallel of lati-

* These quantities are the results of the scalings of Neumayer's charts for the points mentioned.

tude? Does this again imply that the rotation of the magnetic earth is an important factor?

If we connect by lines all the places on the earth's surface having the same departure (with due regard to sign) from the values as computed from above formulæ we get a series of curves that converge around two foci of maximum and minimum departures. I have carried out this idea with the aid of my collected data in the case of the inclination for three epochs, 1780, 1880 and 1885. I call the curves thus obtained lines of equal departing inclination, or, briefly, 'isapoclinics.' It is especially remarkable that these lines close around two points not on *opposite* sides of the equator, but on the *same* side.* Their preliminary positions are:

	Latitude.	Longitude.
For 1885.		
North end attracting focus,	20°S.	40°W of Gr.
South end attracting focus,	5°S.	40°E of Gr.
For 1780.		
N. F.	0°	50°W.
S. F.	0°	60°E.

These positions are subject to a slight revision. The main part, however, is brought out very clearly in both cases, viz.: *that the chief cause of distortion of the primary symmetrical field can be represented as due to a secondary polarization approximately equatorial in direction.*

I then showed that the isapoclinics obey in a remarkable degree the laws governing a magnetic system. They do not run at random. Thus, for example, the foci or poles of this secondary system fall nearly on the agonic lines of the actually observed field, and the secondary magnetic equator running roughly north and south marks out approximately the places where occurs the maximum declination. *In a word, the magnetic field which we actually observe can be nearly obtained by super-imposing a secondary equatorial field upon a primary polar one.*

By comparing the maximum horizontal intensities of the the two systems, as found in the respective magnetic equators, I find that the *polar field is about five to six times stronger than the secondary, and that the axis of the resultant system would make an angle of about 10° with the rotation axis.*

Furthermore, the secular variation phenomena can be qualitatively explained by the shifting of just two such poles as belong to the secondary system. It cannot be explained by the disturbance of poles on *opposite* sides of the equator.

We should thus have to refer both the distribution and the secular variation to apparently the same kind of a polarization.

This harmonizes with the empirical conclusions at the beginning of this paper.

Since the intersection of the agonic lines with the equator fall so nearly together with the positions of the isapoclinic foci, a fair idea, perhaps, can be obtained of the shifting of these foci from the motion of the agonic lines along the equator. I find that both agonic lines have been moving westwardly along the equator for the last 300 years at the average rate of about 0.°2 per annum. If the motion continues around the equator at this rate the resulting period would be about 2000 years, but I do not wish to be understood as asserting that this is the secular variation period.

A possible third field, which has been made probable by Dr. A. Schmidt's beautiful researches, was also pointed out. Schmidt found, namely, that not the entire observed magnetic effect on the earth can be referred to a potential; currents that *pierce* the earth's surface seem to make themselves felt. Perhaps his currents can be explained thus: If an arbitrarily magnetized sphere rotates in a conducting fluid,

* Similar results have been obtained by von Bezold in the paper cited, and by A. von Tillo as seen in his preliminary paper in Comptes Rendus, Oct. 8, '94, pp. 597–599. It is very much to be hoped that von Tillo's charts will soon be published.

the surface of contact of sphere and fluid being conducting, currents will be incited in the fluid that will pass into the sphere and out again.

In the case of the earth there is no fluid with reference to which the solid earth performs a *total* differential rotation; still there are *partial* differential rotations due to moving streams, ocean currents, tidal waves and air currents. Such a field, if it exist, can be differentiated with the aid of the potential theory.

Purely local disturbances would constitute a fourth—the 'anomalous field.'

We as yet have no satisfactory answer as to the *origin* of the earth's primary magnetic field, neither has the astronomer an answer to the query 'Whence the moon.' He, however, accepts the moon's existence and computes its disturbing effects upon the earth's motions. Just so it is with the earth's magnetism. We do not know whence it has come, but we know it is there. We know that to-day the magnetic earth is rotating about an eccentric axis, and so let us ask ourselves *What is the effect of the self-inductive action of the rotating magnetic earth? How is the principle of the conservation of energy when applied to the motions of the magnetic earth to be fulfilled?*

L. A. Bauer.

ON A DEVONIAN LIMESTONE-BRECCIA IN SOUTHWESTERN MISSOURI.

The brecciated limestone which it is proposed to describe in this paper outcrops near the base of Eagle Ridge, on the west side of the valley of Dry Creek, five miles west of the town of Galena, county seat of Stone County, Missouri. The several members of the Devonian strata in this portion of the State are, in their normal condition, very regular and evenly bedded, and are perfectly conformable, from their base, to and with the overlying Kinderhook Group. They rest, with slight local unconformity, on the magnesian limestones of the Ozark Series, and then out toward the east, at the expense of the lower members, each stratum overlapping that which is under it. In the vicinity of the limestone breccia they present the following sections: 1. Green Shale, 7 feet. 2. Shaley Limestone, 10 feet. 3. Speckled Crinoidal Limestone, 3 feet. 4. Basal Conglomeratic Sandstone, 4 inches.

Proceeding south along the west side of the valley we find the first indication of a disturbance in the form of a gentle undulation of the upper portion of the shaley limestone, No. 2 of the section. A few hundred yards further we encounter the first of a series of huge masses of breccia, consisting of the light gray, amorphous limestone and thin shale of No. 2, broken into angular fragments of various sizes, and recemented, partly by a similar substance, and partly by the subsequent infiltration of calcareous matter occurring now in the form of calcite. The original bedding planes have been mostly obliterated, and the breccia weathers out along the hillside in boulder-like masses, 10 to 20 feet thick, and 50 to 100 feet in width. A stratum of shaley limestone at the base of these masses partially retains its original appearance, and from its relation to the more massive breccia overlying it the whole is seen to have been subjected to violent contortion and fracture, such that boulders of hard limestone have been forced into the midst of calcareous shale. There are about half a dozen of these masses exposed along the valley side, in a distance of about 1000 feet; then the undulations decrease, and at one-half mile from where the first disturbance in the strata was noticed they entirely cease, and from thence down the valley the strata are in their normal condition.

There is no indication of the action of water in the formation of the breccia. All the fragments are sharply angular, and frequently a fossil has been broken through