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Translated from
Comptes-Rendus Acad. Sc. Paris, Series B, 263 (26 September, 1966) 779-783

by

E.R. Hope

Directorate of Scientific Information Services
DRB Canada
January 1968

T 4 F

68-027

The Defense Research Board is grateful to the author and to MM Gauthier-Villars S.A., Paris, for permission to publish this translation.

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CONCERNING REVERSALS AND ORIGIN OF THE GEOMAGNETIC FIELD

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Paleomagnetic field-reversals must be attributed to electromagnetic induction effects produced by eruptive solar corpuscular jets occurring at a rate of one per 100,000 years.

In a preceding Note [1] we have sought to evade the problem of paleomagnetic field-reversals, with which the igeneous rocks confront us, by attributing the reversals to the effects of volcanic electricity (the reversals deduced from sedimentary rocks appearing doubtful). But certain recent work, like that of Vlasov and Kovalenko [2] on Devonian sediments, carries conviction and persuades us that the geomagnetic field does reverse, simultaneously at all points of the globe, at intervals no longer than a megayear. This finding, which is counter to all theoretical expectations, makes geomagnetism one of the major problems of the geophysical domain. What is more, it is the purpose of the present Note to show that the phenomenon of geomagnetism must not be attributed to internal causes but to causes external to the earth and in fact of solar origin; it thus becomes a problem not only of geophysics but of space physics.

1. If we rule out gyromagnetic theories, we might hope for a solution from magneto-hydrodynamics (dynamo theory). The relevant laboratory experiment involves a Barlow wheel rendered superconducting at 3^{O}K, with a magnetizing winding in series. Once excited, this machine will, like a magnet, provide an intense magnetic field without expenditure of energy, but it would not be capable of exhibiting the observed reversals.

G. Lippmann [3], studying the "no-resistance circuits" that characterize celestial bodies, has pointed out that every displacement or deformation of the circuits sets up elastic forces tending to bring the system back to its initial state, which is in the nature of an equilibrium position. The concept of a solid inner terrestrial core in equilibrium at the center of a turbulent "liquid" core is incompatible with the effect of centrifugal force. The fluid state that is postulated and the high velocities that are required are, at hyper-pressures, inconceivable. Finally, one can show [4] that the available thermal energy is, from the evidence of meteorite radioactivity, smaller by three orders of magnitude than the magnetic energy. The core could not be in a state of thermal convection.

2. The cause of the reversals must therefore be sought in external processes in space, and these can only be attributed to the sun; we have to invoke the inductive effect exerted by a sun which has, for the moment, the character of an an eruptive star [6]. A half dozen Red Dwarfs of type M5 are known which exhibit activity-bursts of great intensity. P. Van de Kamp pointed out that the

B-member of the pair Krüger 60, after being apparently stable for thirty years, in March of 1951 exhibited a change of magnitude from 11.4 to 9.9 (i.e., its brightness was multiplied by six in just two minutes) after which it resumed its ordinary brightness. On the 25th of September, 1952, V. Oskanjan observed on U.V. Ceti a flare which increased the brightness by 250 times (the visual magnitude changing from 12 to 6.5). The brightness increased abruptly during two minutes, then diminished exponentially over three hours. More than seventy of these Dwarfs are known. Our sun has never experienced a Nova explosion (10^{44} ergs), but there is nothing to prevent our supposing that a G2 Dwarf of age 6,000 million years could have shown signs of instability during the last 10^9 years, with an increasing tempo which today might be as much as once per 10^5 years. The bursts would be characterized by the simultaneous and repeated emission, in the vicinity of the solar equatorial plane (sunspot region), of twenty or so detached jets of protons, one of which would have a good chance of traversing the neighborhood of the earth. The sun, in its descent along the main series of the Hertzsprung-Russell diagram, is likely moving, by way of gaseous emission, toward the stellar type U Geminorum (G5), a type which exhibits increases of 3 magnitudes in brightness every 50 days. Though the sun, in order to reverse the terrestrial magnetic field, must produce greater flares than those which it presently exhibits, there is no need for these outbursts to be so strong. The greatest magnetic storms, which cause a 5% diminution of the horizontal component, are associated with a brief flare just visible in white light. An area equal to 10^{-4} of the solar disc, if raised to 30,000°K, would increase the solar constant by only 1%. During the last two 11-year cycles, four flares of this kind were accompanied by detached jets of solar cosmic rays which encountered the earth. Using recorders with a low time-constant, we have shown [7] that the proton current was abruptly established, in the space of a few minutes, and then decreased exponentially over an hour's time. On the 23rd of February, 1956, the energy of these protons reached a value of 50.10^9 eV. Thus the proton jet which we envisage will not need to be so very powerful.

3. The magnetic energy of the terrestrial globe, $M^2/3R^3$ (where M is the magnetic moment and R the radius), is in the neighborhood of 10^{25} ergs. A reversal would require twice this expenditure of energy, thus an energy much higher than that which is at present expended in magnetic storms (10^{24} ergs/year, according to S. Chapman). The 0.6-gauss polar geomagnetic field requires a magnetizing circuit with 10^9 ampere-turns. Since the actual circuit, at the periphery of the earth's conducting ferronickel core, can have only one magnetizing turn, the current must be as large as 10^9 amperes. Although the resistivity may be high, the resistance, because of the dimensions, will be very small, and the self-induction will be very great. But it would be impossible to attribute the reversals to an oscillation of the circuit. The relevant laboratory experiment uses an induction coil with a single turn of a superconductor, at 3°K, as its secondary winding. Breaking the inductor circuit creates in the secondary a current that persists for a long time after the brief inductive emf. The feeble Joule-effect dissipation of power gives the current a long persistence, as Lamb [8] showed as early as 1883. The current diminishes exponentially and its intensity is reduced to 1/e (37%) after a time equal to $4\sigma\mu R^2/\pi$, where σ is the conductivity, μ the permeability and R the radius of the circuit. If, for ferronickel at 1500°C, we take conductivity = $1/9\cdot10^4$ emu, $\mu = 1$ and $R = 5\cdot10^8$ cm (Roche's model, which best agrees with the geochemical and astronomical conditions), then this relaxation time is 10^5 years.

If the terrestrial core, although at a high temperature and non-crystalline, becomes somewhat ferromagnetic again at 10^6 bars pressure, the relaxation time would go up to several megayears. The core being devoid of turbulent thermal movements, the field will be stable.

Artificial satellites have revealed, at a distance of a few terrestrial radii and under quiet sun conditions, solar proton fluxes of $2.5 \cdot 10^6 cm^{-2} \cdot sec^{-1}$ (1.2 MeV) and of $5 \cdot 10^8 cm^{-2} \cdot sec^{-1}$ (150 keV). Let us suppose an eruptive jet 100 times more intense, with $\Phi = 5 \cdot 10^{10} cm^{-2} \cdot sec^{-1}$, or about one proton/$cm^3$, and having, at the earth's orbit, a diameter of 40 terrestrial radii. Its intensity will be $3 \cdot 10^{11}$ amperes. It will have no tendency to disperse, because it is propagated in an ionized conducting medium and it will be pinched by its own magnetic field. At the earth's orbit this jet will have, at a distance of 100 earth radii, a magnetic field of intensity 12 gauss, amply sufficient to reverse the terrestrial field. If the energy of the protons is 10^9 eV, so as to ensure a sufficient magnetic rigidity, then the energy expended by a hundred or so of such jets will be $3 \cdot 10^{29}$ ergs/sec, which is still 10^4 times less than the radiation of the sun ($4 \cdot 10^{33}$ ergs/sec). The field produced will be near to that of a central axial dipole, but with a possible inclination thereto (as we indeed observe at present). As a result there will be an indeterminacy in the paleomagnetic positioning of the geographic pole.*

Because of the rotation of the globe, the volume of the conductive magnetosphere ($\sigma = 10^{-10}$ to 10^{-12} emu) is swept by the magnetic field, and Foucault braking currents are induced in it. In other words, the field will tend to be frozen into the conductive medium and this will cause the geomagnetic axis to

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* This paragraph has been modified slightly, upon agreement with the author.

The duration of the inducing field (or of its greatest intensity) may be shorter than a day: cf. section 2 above; cf. A. Dauvillier, Rév. Gén. de l'Électricité, March, 1967, page 407 (top of first column). If so, the resultant induced current system might be left in an inclined position with respect to the Earth's axis of rotation. It is an interesting idea that such an induced current system, "frozen" in the conducting mass of the Earth, could persist for a long time in the inclined position. If this possibility can be demonstrated, it would explain the present enigmatic immobility of the geomagnetic pole in Greenland. From time to time, solar jets could cause abrupt shifts in the position of the geomagnetic pole; many such changes might occur within the period of averaging-out whereby the paleomagnetic pole becomes coincident with the geographic pole.

The most interesting notion is that a strong solar jet could reverse the geomagnetic field. One would suppose that this is a triggering effect. The translator has the strong impression that when the geomagnetic polarity changes, the new reversed field is of about the same intensity as the old field; that is, the rock magnetization on either side of a reversal zone does not obviously differ. If this is the case, it can only mean that the main geomagnetic field resides in the terrestrial core; the supposed external field can reverse the main field, but cannot change its intensity greatly. If on the contrary it can be shown that the intensity of the new field may differ greatly from that of the old, then it would be difficult to rule out a direct magnetization (Dauvillier). We note that the current system induced in the Earth will be such as to reflect the external inducing field; initially at least its site will be in the conducting layers of the atmosphere and outer mantle. [Translator.]

undergo a movement of precession (the westward drift), with a period which observation sets at some 2000 years. The result is a slowing-down of the earth's rotation --- which will therefore NOT be due to an impossible internal differential rotation. As is well known, we observe in H a 14-month variation with an amplitude (of a few gammas) closely proportional to the amplitude of the Chandler cycle of polar wandering. Magnetic reversals must therefore be accompanied by an abrupt change in the earth's rotation. (It is not very likely that the phenomenon of February 23rd, 1956, is an example of this, for the associated magnetic storm was nothing exceptional.*)

4. This mechanism reproduces all aspects of paleomagnetism and planetary magnetism. Since the eruptions are a chance occurrence, three cases may rise:-

(i) A proton beam issuing ahead of the earth, in the vicinity of the ecliptic, will induce a normal magnetism, while a beam passing behind the earth will produce a reverse magnetization. The latter will be the case with the earth and with the giant planets; it is thus that Jupiter's magnetism is in the reverse direction.

(ii) A series of successive jets happening to pass on the same side of the earth will maintain a field in one and the same direction for 30 megayears, as was the case, for instance, in the Permian. **

(iii) A contrary jet of intensity just sufficient to cancel the field will leave the planet magnetically neutral. This seems to be the case with Venus.

A celestial body of small mass, not possessing any homogeneous metallic and conducting core, will be magnetized only a little and for only a little time. This is the case with the moon and with Mars. The low density of the latter planet (4.1 $g \cdot cm^{-3}$) seems to imply that it is of the nature of Ovifak basalt or of sideroliths, that is, a peridotite rock containing 45% of granularly dispersed ferronickel. **

The mechanism is in accord with the polar migrations, which have already --- and quite independently --- shown us [9] that the earth's magnetism must be entirely reconstituted at least every megayear. The geomagnetic secular variation remains due to internal thermal causes associated with lithospheric convection currents. Periodic and random variations such as magnetic storms, according to the Lodge and Birkeland-Störmer theories, and the terrestrial magnetism itself, according to our new concept, would thus be due to similar solar effects, differing only as regards intensity (by a factor of 10^3) and occurrence-frequency. Moreover it seems probable that if the geomagnetic variations have a solar cause, then the same must be true for the origin of the terrestrial magnetism, its maintenance and its reversals --- just as for most geophysical phenomena.

5. For purposes of absolute stratigraphic dating, Doell and Dalrymple [10] have identified nine reversals during the last three megayears, the last of them going back to 700,000 years. If this pseudo-periodicity is the solar

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* The argument indeed must depend on a much greater emission of matter from the erupting sun and thus an enhanced Danjon effect. [Translator.]

** The original text has <u>50</u> megayears, <u>55%</u> ferronickel; misprints here corrected by the author. [Translator.]

relaxation period, the next reversal will take place in 200,000 years. It is uncertain whether or not the phenomenon may be accompanied by a few hours' increase of cosmic rays and solar constant so great that terrestrial life might be wiped out on the sunlit hemisphere. If it were possible by precise dating to associate the occurrence-times of great biological extinguishments with those of the magnetic reversals, this would provide a confirmation independent of the proposed mechanism.

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