Remanent Magnetization of “Pleistocene” Deposits. *

—— Palaeomagnetism in Japan ——

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ABSTRACT

The intensity and direction of magnetic polarization of a horizontal stratum of Pleistocene deposits are measured by means of an induction-type magnetometer. The thickness of the examined part of the sedimentary layer, Narita-bed, is about 7 meters, and its age is ranged from -4.2×10^4 to -7.6×10^4 years corresponding to the uppermost and deepest parts.

Roughly speaking, the direction of the magnetic polarization of each part of the layer is not much different from that of the present geomagnetic force, though there are fairly systematic deviations within a few tens degrees.

From the results of examination of statistical reliability of the apparent direction of polarization and of the constitution of remanent magnetism, it was proved that the direction of polarization ought to agree, within the error of a few degrees, with the geomagnetic force at the time of deposition of those materials.

1. Introduction.

The measurement of intensity and direction of natural remanent magnetization of sedimentary strata has been systematically continued in our laboratory since 1941 for the purpose of determining the geomagnetic field in the past geological times, and a few results have already been reported. [1], [2] Here in this paper, the recent knowledges of remanent magnetism of the Narita-bed — a Pleistocene deposit — will be summarized together with those of some experimental examinations of the physical characteristics of the remanent magnetism.

The Narita-bed is an almost horizontal stratum, 3° in its maximum dip, and it is widely distributed in the Kwantō District around Tokyo. Its upper part of about 7 meters in thickness was examined in the present study.

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2. Measuring Apparatus and Samples.

The apparatus for determining the intensity and direction of remanent magnetization of sedimentary rocks is, in its principle, just the same as that devised by E. A. Johnson and A. G. McNish [3], though a few parts have been improved for the sake of convenience for actual measurement and of good stability of measuring system. The specimen to be measured is always a 1.8 *cm* cube. Since the samples of Narita-bed are rather loose, they were enclosed in a cubic cell made of waxed cardboard, on which the direction of the sample *in situ* was marked.

In our apparatus, the sample was rotated with the speed of 25 cycles per second by a synchronous motor in order to eliminate the noise chiefly due to the commercial electric power of 50 cycles. The gain of the low-frequency amplifier was kept about 90 *db* at its maximum around the above-mentioned frequency. The sensitivity of the whole system was calibrated with a standard cube of the same size made of "dacite" before and after every series of measurements, *i. e.* determination of both of intensity and direction of 10~15 samples. The direction and intensity of this standard magnetic sample was calibrated successively with the stronger magnetic needles, the strongest one of them being carefully measured by means of an astatic magnetometer.

The error in determining the intensity is about 2% in mean value, not exceeding 5% in individual cases, while that in the direction will be less than 3°, where the error in determining the direction of samples *in situ* is also taken into account.

3. Results of Measurements.

The direction of natural remanent magnetization of 271 samples of the upper part 7 meters thick of Narita-bed is shown with declination (*D*) and dip (*I*) in Fig. 1, where the abscissa shows the depth of each sample measured from the upper boundary of this stratum.

For the purpose of examining the reliability of the direction, two vertical columns about 10 *m* apart horizontally were examined. The result showed that the directions of magnetization of these two samples on the same horizontal plane coincide with each other within the deviation of 4° in both declination and dip. The direction of magnetization given in Fig. 1, therefore, will represent that of the horizontal layer of the corresponding depth, at least, in its neighbourhood.

As will be seen in Fig. 1, the declination changes with depth within the range of 50° *E*~20° *W*, while the dip does within 40°~70°. Roughly speaking, both the declination and dip do not far differ from the present geomagnetic values, though it seems that both curves are composed of some regular changes with depth. On the other hand, the intensity of the remanent magnetization takes various values from 6×10^{-6} to 1.0×10^{-4} *e.m.u./cc.*

Fig. 1. Changes in Direction of Natural Remanent Magnetization of Narita-bed with Depth.

4. Characteristics of Remanent Magnetism of Narita-Bed Samples.

For the purpose of examining the characteristics of remanent magnetization of the measured samples, the volume content of ferromagnetic minerals in 15 typical samples was measured by means of the usual volume-metry method. The relation between the volume content (q) of ferro-magnetic minerals and the intensity of natural remanent magnetization (J_n) is shown in Fig. 2, where it can be concluded that the latter is nearly proportional to the former.

The largest parts of ferro-magnetic minerals contained in Narita-bed are those of 0.04~0.08 mm in their mean diameter, and chiefly composed of magnetite, because it was proved that their Curie-point is about 590°C. These magnetite minerals are nearly the same in their form and size as the micro-crystals scattered in groundmass of igneous rocks. Since, further, these deposits of Narita-bed are believed to originate from the igneous rocks ejected in the North-East Japan, the constitution of ferro-magnetic minerals in Narita-bed and consequently the characteristics of their remanent magnetization would be not much different from those of igneous rocks, though the intensity of their remanent magnetization should be

Fig. 2. Relation between Intensity of Remanent Magnetization (J_n) and Content of "Magnetite" (q).

more or less reduced owing to the demagnetization effect during a long period. That is to say, it is presumed that the remanent magnetization of ferro-magnetic minerals in our case is the thermo-remnant magnetism [4] which was caused during cooling in geomagnetic field when they were the compositions of igneous rocks. At this point, Narita-bed will be fundamentally different from the varved clays of New England, the ferro-magnetic minerals in which were determined by J. W. Graham [5] to be very fine single crystals of magnetite, less than 1μ in diameter, the whole crystal being occupied by only a single magnetic domain. In the varved clays, therefore, the magnetization of ferro-magnetic minerals will be nothing but the spontaneous magnetization. On the contrary, the magnetite minerals in Narita-bed are too large to be composed of only a single domain.

Now, the ratio of natural remanent magnetization (J_n) of the 15 samples mentioned before to their corresponding thermo-remnant magnetization (J_t) obtained by cooling from 600°C in the present geomagnetic field is shown in Fig. 3. Here will be a relation that

$$J_n = \left| \sum_i \vec{\mu}_i \right| = \sum_i \mu_i \cos \theta_i,$$

where μ_i and θ_i denote respectively the magnetic moment of each ferro-magnetic particle and the direction in angle of each moment measured from the resultant average direction.

As will be seen in Fig. 3, J_n is nearly proportional to J_t , and the ratio J_n/J_t is almost kept constant, taking 0.12. If we take into account the demagnetization effect and the difference between the old and present geomagnetic fields, the ratio J_n/J_t may somewhat differ from the true value of $\sum_i \mu_i \cos \theta_i / \sum_i \mu_i$, since μ_i in the deposits *in situ* may not exactly equal to that newly re-produced in the laboratory.

Since, however, the above-mentioned difference may not exceed a few tens percent, it will be presumed that the resultant magnetic moment of the congregation of a large number of ferro-magnetic minerals in Narita-bed is about 10 % of their total sum, i. e.

$$a \equiv \frac{\sum_i \mu_i \cos \theta_i}{\sum_i \mu_i} \sim \frac{J_n}{J_t} \sim 0.1$$

5. Probable Mechanism of Magnetic Polarization.

The quantity a defined in the foregoing paragraph shows the rate of orientation of ferro-magnetic minerals into a special direction. It is practically impossible that the quantity a takes 0.1 or exceeds it as a result of random accumulation of these minerals. For example, the number (N) of ferro-magnetic minerals in a cubic specimen is always larger than 7×10^8 according to the result of actual counting.

Fig. 3. Relation between Natural Remanence (J_n) and Thermo-Remanence (J_t).

Then, the probability (P) that the resultant moment of random accumulation of N magnetized particles exceeds α times the moment of their total sum is given by

$$P = \sqrt{\frac{2}{\pi}} \frac{1}{\sigma^3} \int_{r_0}^{\infty} r^2 \exp\left(-\frac{r^2}{2\sigma^2}\right) dr,$$

where $\sigma^2 \equiv \frac{N\bar{\mu}_i^2}{3}$ and $r_0 = \sigma N\bar{\mu}_i$,

and practically $P \leq 3 \times 10^{-45}$ for $\alpha=0.10$ and $N \geq 7 \times 10^3$ in the present case.

Hence, it will be firmly concluded that the magnetic polarization of Narita-bed should be caused by some external magnetic force. That a mass of artificial deposits of the same materials in still water, 2 meters deep, has an apparent remanent magnetization coinciding with the direction of geomagnetic field was proved in the laboratory experiment. This agreement of the direction of remanent magnetization with that of geomagnetic force was especially good in declination. Recently, H. Manley [6] has reported a remarkable fact that the ferro-magnetic minerals such as natural magnetite mixed with Plaster of Paris are orientated into the direction of geomagnetic field, the dried mass of the mixture having the permanent magnetization coinciding with the direction of geomagnetic field. Being judged from his result, the magnetic moment affecting ferro-magnetic particles by geomagnetic field seems to be sufficiently large for overcoming various resistances.

Supposing now that a large number (N) of magnetized particles, having $\bar{\mu}$ in their mean magnetic moment and initially random directions, drop through still water under the effect of magnetic force (H), we can get the resultant magnetic moment (J) of total deposits as

$$J = \sum_i \mu_i \cos \theta_i = N \bar{\mu} \overline{\cos \theta} = N \bar{\mu} \tanh\left(\frac{\bar{\mu} H}{2\lambda} t\right),$$

where t denotes the time need for dropping of a particle through water, while λ shows the total viscosity of water affecting the rotation of the magnetized particle. Thus, so far as the sedimentary layer assumes the deposit in still water without any disturbance, $\alpha = \frac{\sum_i \mu_i \cos \theta_i}{\sum_i \mu_i}$ ought to be equal to $\tanh\left(\frac{\bar{\mu} H}{2\lambda} t\right)$, this result showing that the longer the magnetized particles are kept freely in water, the larger becomes the amount of α . Provided Narita-bed assumes the deposit in still water, the comparison of its α -value with the result of laboratory experiment gives that the depth of sea, in which the Narita-bed particles were deposited, would be about 30 meters or more. Here, it must be mentioned that the orientation of magnetized particles in muddy substances at the sea bottom, as pointed out by H. Manley, is neglected.

However, it will be rather probable that the orientation of these magnetized particles were also subjected to various random disturbances. Then, the distribution of direction (θ_i) of magnetized particles in deposits will be symmetric around the direction of geomagnetic field (θ_0), and the dispersion of the distribution formula will be chiefly subjected to that of affecting disturbances, taking, at any rate approximately, the Gaussian form such as

$$f(\theta_i) = Ce^{-\frac{(\theta_i - \theta_0)^2}{k^2}}$$

Then, we get

$$\alpha = \frac{\sum_i \mu_i \cos \theta_i}{\sum_i \mu_i} = \frac{\int_{-\infty}^{\infty} \cos \theta f(\theta) d\theta}{\int_{-\infty}^{\infty} f(\theta) d\theta} = e^{-k\theta_0/4}$$

so far as the distribution of μ_i is independent from that of θ_i . By means of this relation, we can estimate the magnitude of k from the observed value of α . The mean error of the true value of θ_0 , which is ought to coincide with the direction of geomagnetic field affecting the deposition of the sedimentary layer, can be estimated in our case where the probable value of θ_0 was evaluated as the direction of remanent magnetization of a mass of deposit.

Putting $N \geq 7000$ and $\alpha \geq 0.10$, we get the amount of the standard error of θ_0 as

$$|\varepsilon| = \frac{k}{\sqrt{2N}} \leq 1.5^\circ$$

These results of statistical examination being summarized, it may be concluded that the direction of natural remanent magnetization of Narita-bed samples indicates, within the error of a few degrees, that of the geomagnetic field at the epoch when these materials were deposited.

6. The Age of Narita-Bed and the Geomagnetic Field in Pleistocene Age in Japan.

The age of three parts of Narita-bed layer were examined with the aid of the usual U - Ra method, the contents of UI and Ra and the estimated age being given in the following table.

Depth from the upper boundary	UI	Ra	Age
0.0 m	0.47×10^{-5} gr/cc	0.50×10^{-12} gr/cc	4.2×10^4 years
5.0	0.41×10^{-5}	0.58×10^{-12}	6.0×10^4
6.5	0.38×10^{-5}	0.70×10^{-12}	7.4×10^4

The depths corresponding to these ages being interpolated, the age of each part of Narita-bed is shown in the abscissa of Fig. 1. Again in this figure, we may say that the direction of geomagnetic field during about 36000 years, from 78000 years ago to 42000 years ago was not much different from the present one in Japan, the deviations in declination and dip being respectively $50^\circ E \sim 20^\circ W$ and $\pm 20^\circ$ at their maxima.

This conclusion well harmonizes with that given by E. A. Johnson, T. Murphy and O. W. Torreson [7] who examined the varved clays of New England as well as the deposits of Pacific Ocean bed. It will be worthwhile to note here that the declination in the figure shifts westerly with increase in depth from the uppermost part where D is about $40^\circ E$, reaching the most West deviation at about 5 meters in depth and then again shifts easterly. The facts that the fluctuations in both

declination and dip have mostly the period of 40~50 *cm* in thickness of layer or 1500~2000 years in time, and that the changes in declination are always larger than those in dip, will be also worthenough to be remarked.

However, the examination in details of the above-mentioned changes will be postponed until many data of the same kind measurements for various ages as well as for various regions are accumulated and the comparison among those data becomes possible.

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