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ACQUISITION OF NATURAL REMANENT MAGNETIZATION IN SNOW AND ICE CONTAINING ROCK DUST

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Abstract: Paleomagnetic study of the dirt-ice collected at the Allan Hills in Antarctica showed stable remanent magnetization in the dirt-ice (FUNAKI and NAGATA, Mem. Natl Inst. Polar Res., Spec. Issue, **39**, 209, 1985). However, the magnetization mechanism has not been investigated at all. We performed the experiments to make clear the magnetization mechanisms of the dirt-snow and dirt-ice. Two types of artificial samples were prepared for this purpose. One was the dirt-ice frozen from the wet-snow and the other was the dry-snow containing rock dust. The former samples acquired the stable remanent magnetization parallel to the geomagnetic field. This natural remanent magnetization (NRM) was acquired immediately during the freezing process from the wet-snow. The latter samples preserved under the low temperature conditions of both −10 and −20°C, acquired gradually the NRM in the direction of the geomagnetic field. The NRM's moment in the latter samples was not saturated during the 22-day preservation in the low temperature conditions. The acquisition of NRM advanced more effectively under the temperature of −10 than −20°C.

The experimental data obtained indicate that the NRM of the dirt-ice and dirt-snow may become a useful means for paleomanetic and glaciological studies.

1. Introduction

Yellow-colored dirt-ice layers involving volcanic ash were reported by NISHIO *et al.* (1984) and KATSUSHIMA *et al.* (1984) from blue-ice fields of the Yamato Mountains in Enderby Land of East Antarctica. FUNAKI and NAGATA (1985) studied natural remanent magnetization (NRM) of the dirt-ice layers collected from the Allan Hills. They reported fairly stable NRM against alternating field demagnetization. The NRM directions measured from 10 subsamples were almost identical in a dirt-ice sample.

The dirt-ice samples collected from mountain regions in Toyama Prefecture also showed stable remanent magnetization, although still in the stage of preliminary measurements. This dirt-ice may have been formed through the frozen stage different from the Antarctic ice. It was presumably frozen from the wet-snow, which may be characteristic of superimposed ice.

The stable NRM in these dirt-ice samples may be useful for paleomagnetic and glaciological studies, but the mechanism of NRM acquision process has not been investigated. The magnetization mechanism may be different between the dirt-ice in Antarctica (derived from dry-snow) and the dirt-ice such as superimposed ice in the alpine region (from wet-snow).

To estimate the acqusition process of NRM in dirt-ice, we made the following experiments using artificial samples.

2. Sample Preparations and Experimental Procedures

For experiments in this study, were utilized the both −10 and −20°C low temperature rooms at Toyama University. The NRM of samples was measured by the

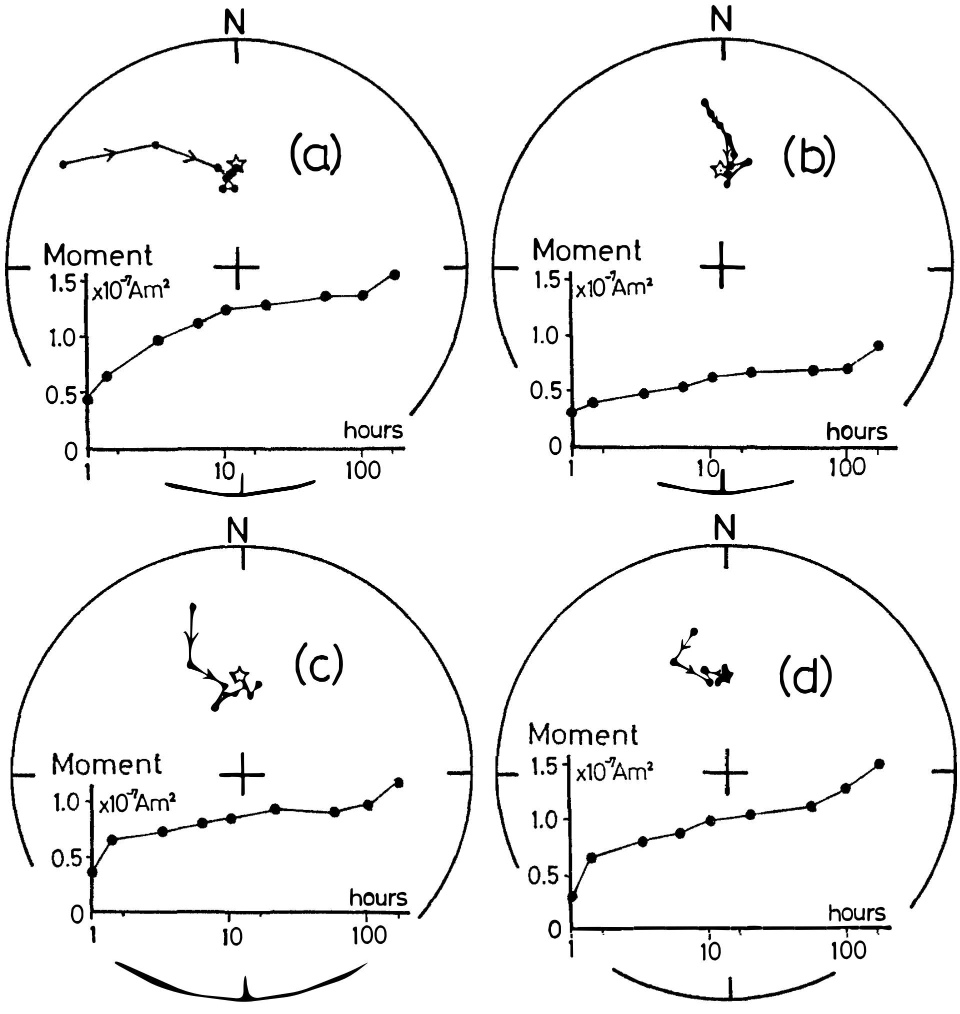

Fig. 1. NRM change with time for the dry-snow samples containing rock dust during the preservation at −10°C. The change of both direction (equal area projection) and moment in NRM with time is shown in each figure. The star shows the geomagnetic direction of the place where samples were preserved.

(a) Mixture of rock dust of 149–105 μm and snow particles larger than 840 μm (assemblage 1).

(b) Mixture of rock dust of 149–105 μm and snow particles of 710–500 μm (assemblage 2).

(c) Mixture of rock dust less than 74 μm and snow particles larger than 840 μm (assemblage 3).

(d) Mixture of rock dust less than 74 μm and snow particles of 710–500 μm (assemblage 4).

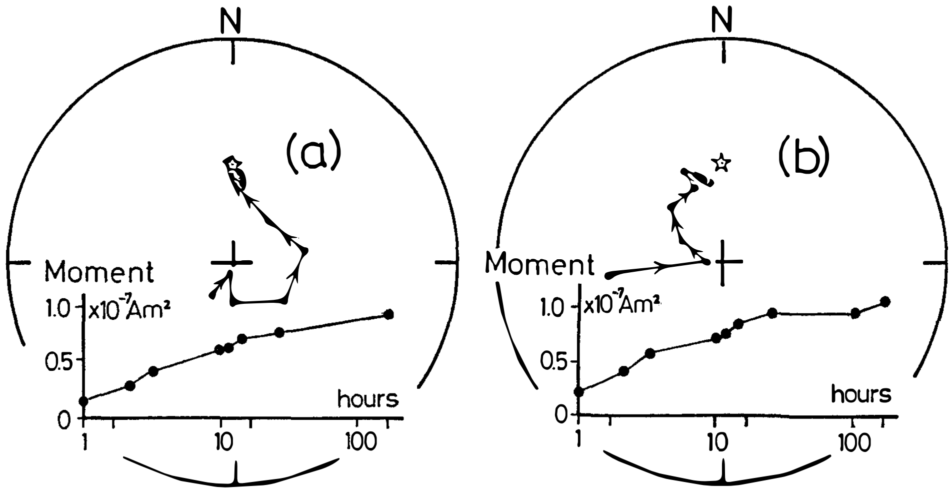

Fig. 2. NRM change with time for the dry-snow samples containing rock dust during the preservation at −20°C. The change of both direction (equal area projection) and moment in NRM with time is shown in each figure. The star shows the geomagnetic direction of the place where samples were preserved.
(a) Mixture of rock dust less than 74 μm and snow particles larger than 840 μm (assemblage 3).
(b) Mixture of rock dust less than 74 μm and snow particles of 710–500 μm (assemblage 4).

SQUID magnetometer (CCL GM-401) of Toyama University.

2.1. *The experiment with the dry-snow samples*

We prepared the rock dust from the blocks of Ouginosen andesitic lava in Tottori Prefecture. Magnetic cleaning experiments showed that these lava blocks have the stable TRM and little viscous remanence (VRM). Thermomagnetic analyses revealed that the principal magnetic mineral in these blocks is titanomagnetite.

To examine the grain size of both rock dust and snow particles, two kinds of rock dust and snow particles were used with the sizes less than 74 μm (rock dust 1), 149–105 μm (rock dust 2), 710–500 μm (snow 1) and larger than 840 μm (snow 2). Thus, four different mixtures, namely, snow 1 and rock dust 1 (1), snow 1 and rock dust 2 (2), snow 2 and rock dust 1 (3) and snow 2 and rock dust 2 (4), were prepared. Each mixture was put into a cubical case with 1 inch sides and was used in the experiment. Three samples of each mixture were experimented at −10°C, and two samples of mixtures (3) and (4) at −20°C. The weight percent of the rock dust mixed into the snow was the same, 11% in all experiments.

The NRM of the samples was measured at several time intervals (Figs. 1 and 2). The preservation of the samples and the NRM measurements continued for 22 days.

2.2. *The experiment with the dirt-ice from wet-snow*

We prepared the dirt-ice samples from the wet-snow as follows. The rock dust of the Ouginosen lava, less than 74 μm was mixed first with the snow particles. Then the mixture was put into the cubical plastic case, and four such cases containing dirt-snow were prepared. Three grams of water was added to two samples and five grams to the other two samples. The rock dust mixed in each sample was about 0.3 g. The samples were fixed in relation to the geomagnetic field and were frozen by the liquid nitrogen. Thus, the four dirt-ice samples were completed from the wet-snow.

We measured the NRM of the dirt-ice samples, immediately. Then, the preservation of the samples at low temperature (−10°C) and the NRM measurements were conducted during a period of 34 days. The samples preserved in the low temperature room were set so as to have the NRM's direction perpendicular to the geomagnetic field.

3. Results and Discussion

3.1. NRM of the dirt-ice samples from wet-snow

Two sets of the NRM change with time are shown in Table 1, which lists the NRMs measured immediately after the sample preparations, as well as those measured after 1 day and after 34 days.

All of the dirt-ice samples from the wet-snow acquired the NRM almost identical in direction to the geomagnetic field. During the preservation in the low temperature room, the NRM has little changed the direction, although the samples were set so as to have the NRM's direction perpendicular to the geomagnetic field. This indicates that the magnetization in the dirt-ice was not a viscous one.

There was a little difference of the NRM moment among the four samples, but no clear correlation existed between the water content in the samples and the NRM moment. It is concluded that the NRM acquired during the process of freezing depends on the amount of the rock dust (magnetic minerals) and is not affected by the water content of the wet-snow.

We can recognize that the NRM moment in Table 1 decreased by about 10% after 34 days preservation in the low temperature room. The decrease is not gradational but abrupt in the first day. It may be attributed to the magnetic particles which were not fixed during the freezing. These particles were then fixed during the preservation in the low temperature condition, to the different direction from that of the formerly fixed particles. Accordingly, the NRM moment decreased.

Table 1. NRM change with time for the ice samples frozen from the wet-snow including rock dust. Inclination of the geomagnetic field in the laboratory is 45°. Data of A is the averaged value of the two dirt-ice samples frozen from the wet-snow added with 3 g of water and that of B is the average of those added with 5 g of water.

Sample	Time (days)	Dec (°)	Inc (°)	Mom ($\times 10^{-8}$ Am^2)
A	0	−2.3	45.7	10.75
	1	−1.9	43.2	9.84
	34	4.3	48.4	9.27
B	0	4.8	45.8	11.05
	1	3.1	46.4	10.09
	34	1.4	49.7	9.78

Dec: Angle between the magnetic north and the horizontal component of NRM.
Inc: Dip angle of the NRM.
Mom: NRM moment of the sample.

These experimental results may be interpreted by the following magnetization mechanism. Magnetic particles in the wet-snow can move freely so that they are arranged in the direction of geomagnetic field by the magnetic correlative force. Most of these magnetic particles are firmly fixed during the freezing process and some are fixed in the low temperature condition afterwards.

3.2. *NRM of the dry-snow samples*

In the case of dry-snow samples including the rock dust (mixtures 1–4 in Section 2.1), the NRM gradually took the direction of the magnetic field and the moment increased, during the 26-day preservation in the low temperature room (Figs. 1 and 2).

The samples preserved at $-10°C$ (Fig. 1) acquired the NRM more efficiently than those at $-20°C$ (Fig. 2). It shows that the magnetization process depends on the temperature; higher temperatures favor the NRM moment increase.

As shown in Fig. 1, the samples of assemblage 1 and assemblage 4 acquired the NRM more effectively than the other two samples. There was no remarkable tendency of larger particles of snow or rock dust acquire more intensive NRM. The moderate size combination of snow particles and rock dust may acquire NRM effectively.

The rock block used in the preparation of the rock dust contains little viscous remanence (VRM), so it is difficult to consider that the increase of NRM moment in the dirt dry-snow is due to the increasing VRM. To explain these newly obtained results for the dirt dry-snow, the following is considered as one of the possible magnetization mechanisms.

The magnetic particles adhered to the snow particles became free at the time when the snow particles vaporized, and came to be arranged in the direction of the magnetic field and to be adhered again to the snow particles underlying the vaporized one. More efficient arrangement of the magnetic particles at $-10°C$ than that at $-20°C$ may be explained by that the magnetic particles drop effectively at high temperature where the vaporization of the snow particles is more efficient.

4. Summary

(1) Wet-snow including rock dust acquired the stable remanent magnetization in the direction of the geomagnetic field during the freezing process to the dirt-ice. Directional change of NRM was little under the low temperature condition. These results indicate that the NRM of the dirt-ice, such as superimposed ice, maintains the memory of the geomagnetic field of the time when the dirt-ice was formed.

(2) Dirt-snow acquired the NRM gradually with time in the direction of the geomagnetic filed. The magnetization process depends on the temperature; the temperature $-10°C$ is more favorable to the NRM moment increase than $-20°C$. The NRM may be acquired by the drop and arrangement of the magnetic particles during the vaporization of the snow particles.

The remanent magnetization in the dirt-ice and dirt-snow well-documented in these experiments would be very useful for the paleomagnetic study itself and may offer an important tool for the glaciological study such as monitoring the flow movement of the glacial ice.

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