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NATURAL REMANENT MAGNETIZATION OF THE WELLMAN METEORITE

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Abstract. Magnetic measurements revealed that the NRM of the Wellman meteorite (H5) varies with the position within the meteorite. In the outer part with a thickness of about a few cm, the intensity of the NRM is high ($\sim$100 Am^{-1}) and the remanence consists of almost a single component. On the other hand, the NRM intensity in the internal part is as low as 10 Am^{-1} and consists of three components. The directions of these three components are coherent among multiple samples. The two components with the lower coercivities are magnetically very soft, and must have been acquired on the earth's surface. The magnetic stabilities of the surface magnetization and that of the hard component of the internal remanences are high and similar to each other. The stable direction of the internal magnetization is almost antipodal to the surface magnetization. These observations suggest that all the remanences of the Wellman meteorite have been acquired during the fall through the earth's atmosphere and on the earth's surface.

Introduction

Natural remanent magnetization(NRM) of meteorites has been studied for the purpose of revealing the magnetic field in the early solar system (for example, Stacey et al., 1961; Butler, 1972; Banerjee and Hargraves, 1972; Brecher and Arrhenius, 1974; Brecher and Ranganayaki, 1975; Sugiura, 1977; see review by Nagata, 1979). The main difficulty of the study lies in finding a convincing evidence which confirms the extra-terrestrial origin of the remanences carried by meteorites. Most of the previous studies were concerned with a single specimen from a meteorite. However, the spatial distribution of the NRM within a whole meteorite can be helpful to investigate the origin of the NRM. This type of investigation has been made by Weaving(1962) for the Brewster meteorite(L6). In this paper we report the magnetic properties of the Wellman meteorite.

Sample Description and Experiments

The Wellman meteorite was found in 1940 in Terry County, Texas at latitude 33°02'N and longitude 102°20'W. The original weight was 50.1 kg and the size was about 20 to 30 cm. The meteorite is classified as H5.

The meteorite was sampled from edge to edge as shown in Fig. 1. Among the sixteen samples, eight (Sample Nos. 1, 3, 5, 7, 9, 10, 12, and 14) were available for magnetic measurements. Sample No.1 is from the left edge of the meteorite and includes the fusion crust. Sample No.14 is the rightmost one among the present samples and is about 3 cm inside from the right edge. These samples were oriented with a coordinate system shown in Fig. 1 to enable comparison of remanence directions from different parts.

The NRMs of the samples were measured by a Schonstedt SSM-1A spinner magnetometer, and were progressively demagnetized by alternating fields(AF) with a three axis tumbler system. The initial susceptibility of the samples was measured by a Bison susceptibility bridge and a spinner magnetometer.

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Results

In Fig. 2, the intensity of the NRMs, the initial susceptibility, and the alternating field which reduces the intensity of the remanence to 1/10 of the original value are plotted as a function of position in the Wellman meteorite. The intensity of the outer samples (Nos. 1 and 14) is large ($\sim$100 Am^{-1}), whereas the internal samples show the low intensity ($\sim$10 Am^{-1}). The intensity of Sample No.12 has a transitional value between the surface and the internal samples. Compared to the NRM intensity, the initial susceptibility is rather constant throughout the meteorite, suggesting that the metal content of this meteorite is approximately constant from the edge to the center. The coercivity of the remanence indicated by $H_{1/10}$ varies in a somewhat complicated manner. There seems to exist a trend that the coercivity decreases from left to right in addition to the increase of the coercivity at the surface.

The progressive demagnetization is valuable to decompose a remanence into constituent components. The best information is given by plotting the variation of the magnetization vector to the two orthogonal planes (Zijderveld, 1967). The plots for the surface sample (No. 1) and one internal sample (No. 3) are shown in Fig. 3. The slight flexure observed at the AF field of 4 mT indicates that the NRM of sample No. 1 consists of two components. But the directions of the two components are close to each other. A similar trend was also observed in Sample No. 14 except an additional component at the low coercivity range (< 1 mT). The remanences of the internal samples (Sample Nos. 3, 5, 7, 9, 10, and 12) are quite different from the outer samples, although the variation of the remanence against AF demagnetization is mutually correlated. The coherence indicates that the magnetization of the internal part of the Wellman meteorite consists of three components (see Fig. 3). The lowest coercivity component dominates at the coercivity range of 0 to 1 mT, the intermediate component from 1.5 to 4 mT, and the highest coercivity component from 4.5 mT to the higher magnetic field.

The directions of remanences obtained by the least squares fit

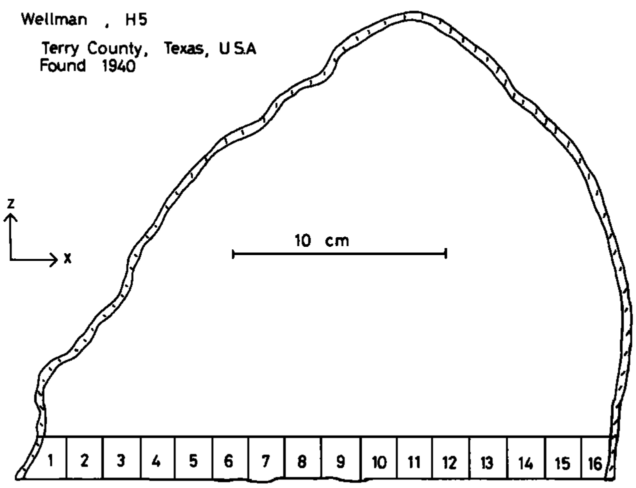

Fig.1 Cross section of the Wellman meteorite. Sample configuration is also shown.

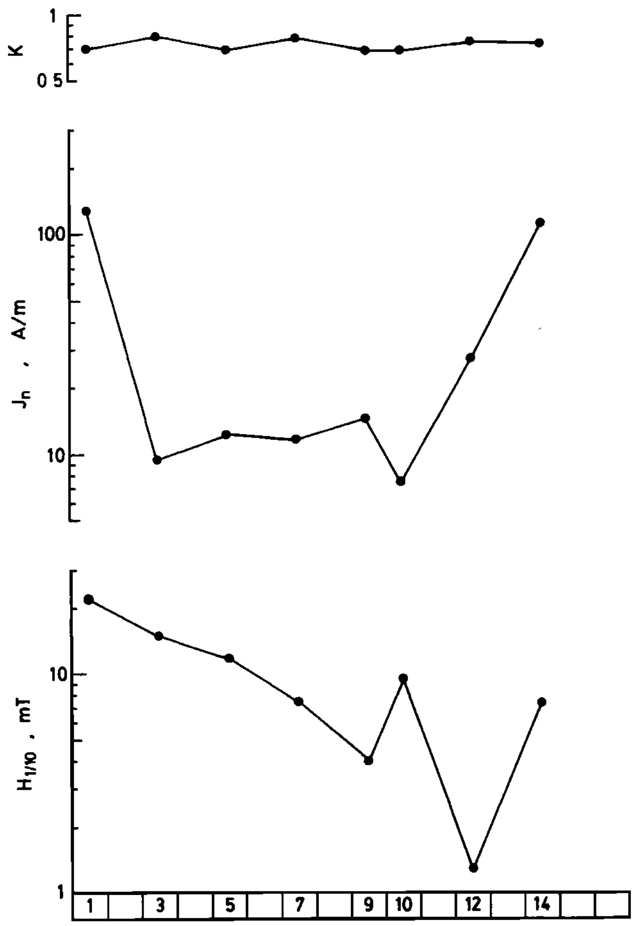

Fig.2 Variation of the magnetic properties across the Wellman meteorite. K;the initial susceptibility, J_n;the intensity of the natural remanence, $H_{1/10}$;the alternating field which reduces the NRM intensity to 1/10 of the initial value.

to the orthogonal plots are shown in Fig. 4. For the outer sample (Samples No.1 and No.14), the intermediate and the hard components are plotted. The directions of the two components of Sample No.1 are similar and the direction of the hard component is given by the inclination I=11° and the declination D=−159°. The intermediate and hard components of Sample No.14 also do not differ much in their directions and the stable component is given by I=−37° and D=145°. For the internal samples, the directions of the three components (soft, intermediate and hard components) are shown separately. As evident from Fig.4, each component is reasonably clustered, which suggests that all the three components of the magnetization were acquired before the samples were cut from the meteorite.

In order to determine the origin of the remanences, the intensity changes of the NRMs during the AF demagnetization are compared with the changes of IRM (Isothermal Remanent Magnetization) and ARM (Anhysteretic Remanent Magnetization) in Fig.5. The IRM is acquired when a magnetic field is applied on the sample. If the magnetic field is maintained for a long time, VRM (Viscous Remanent Magnetization) is induced in the sample. These two remanences are the possible origin of the soft remanences acquired on the earth's surface. The ARM is an artificial remanence, but the magnetic stability of ARM is comparable to hard natural remanences such as TRM (Thermal Remanent Magnetization) which is the most valuable remanence for paleomagnetism. Hence, the ARM has been frequently used to investigate the origin of remanences. The ARM was acquired with a DC field of 0.05 mT and a peak alternating field of 30 mT, and the IRM was induced by applying a DC field of 5 mT. The NRM intensity of Samples No.1 and No.14 is comparable with the IRM intensity, but the stability of the NRMs against the AF demagnetization is much higher than that of the IRM. The stability of Sample No.1 and the stable part of Sample No.14 are comparable with the stability of the ARM. This result indicates that the remanences have a stable origin such as TRM. The low coercivity part of the remanences of the six internal samples resembles that of the IRM. Hence, IRM or VRM origin is suggested for these components. On the other hand, the high coercivity component (> 4 mT) shows a stable characteristic similar to the ARM and the surface remanence. Therefore, the component may have the same origin as the outer part of the meteorite.

Discussion

The present observation revealed the difference in the remanences between the outer part of a meteorite and the internal part. The surface of the meteorite was strongly magnetized compared to the internal part. The result is consistent with the study by Weaving(1962), although he did not mention the thickness of the surface layer. Nagata et al.(1976) observed the variation of the NRM intensity with the progressive removal of the fusion crust of Yamato 7307 achondrite, and concluded that the outer shell with a thickness of about 0.5 mm has a high intensity much different from the interior. Both of the above authors attributed the strong surface magnetization to heating of the meteorites resulting from the

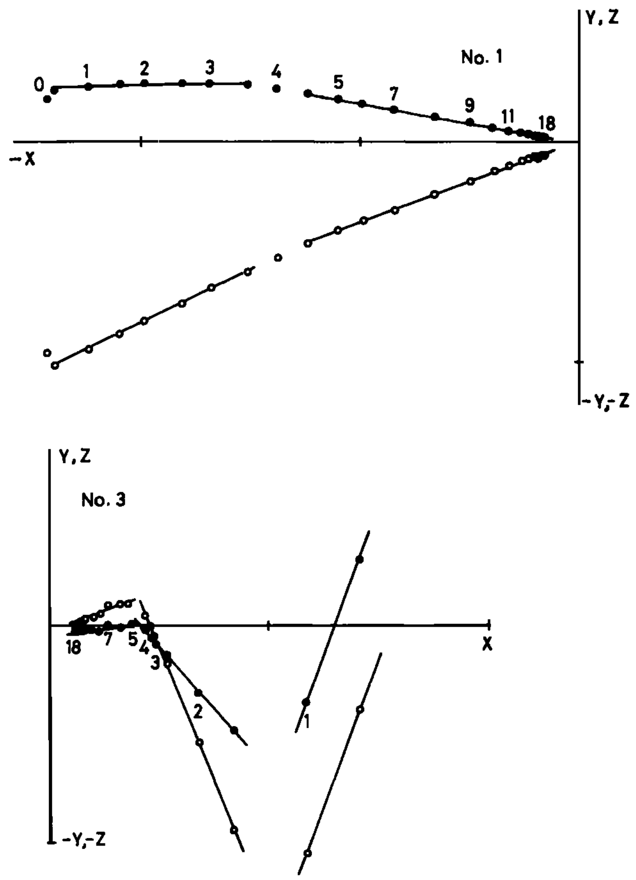

Fig.3 Orthogonal plots of the AF demagnetization curves for the surface' sample (No.1) and one internal sample (No.3). Numbers in the figure denote the alternating field in unit of mT.

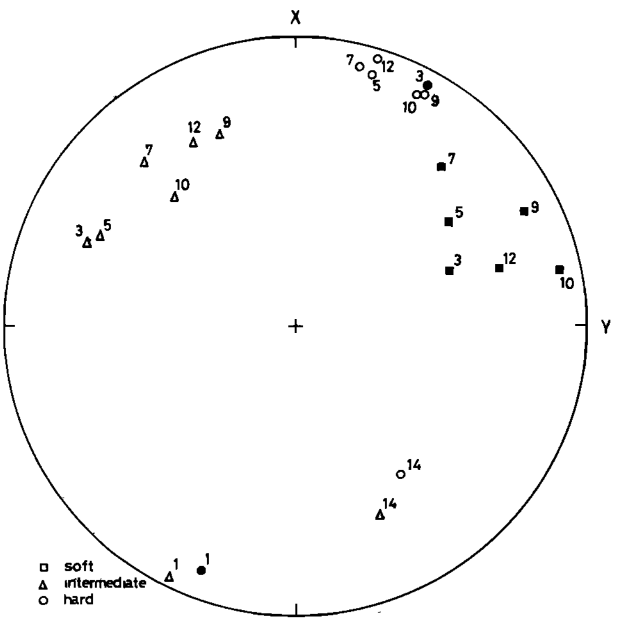

Fig.4 Equal area projection of the directions of the components of the magnetization.

fall through the atmosphere. They also concluded that the remanences of the interior are of the extra-terrestrial origin probably acquired at the early stage of the solar system. This conclusion is mainly based on the stability of the internal remanences.

The main difference between the present observation and the previous study by Nagata et al.(1976) is the thickness of the surface layer. In spite of the existence of the fusion crust in Sample No.1, the homogeneity of the magnetization, which can be estimated from the spinner measurement, is comparable with the internal samples. On the other hand, Sample No.14 revealed the highest inhomogeneity among the present samples, suggesting that the boundary of the surface layer lies within this sample. Since this sample locates about 3 cm inside from the right surface, the thickness of the surface layer of the right hand side is estimated to be about 3 to 4.5 cm. At the left edge, the homogeneity of the edge sample (Sample No.1) and the low intensity of the magnetization observed in Sample No.3 indicates the thickness to be between 1.5 and 3 cm. Although the surface layer seems to be not symmetric and the estimated thickness is much larger than the estimate by Nagata et al.(1976), we conclude the terrestrial origin of the strong surface magnetization from the present observation. Otherwise, it is difficult to explain the dependence of the magnetization on the present shape of the meteorite. However, the acquisition mechanism of the magnetization is not clear. Because of the low thermal diffusivity of the meteorite (Yomogida, 1982), the meteorite can not be appreciably heated to this depth during the fall through the earth's atmosphere. Moreover, the large NRM/ARM ratio observed in Fig.5 indicates a high ambient magnetic field (~1 mT), which is much higher than the earth's magnetic field on the surface (~0.05 mT), if the remanence is of thermal origin. Surface electric current induced during the fall through the earth's atmosphere might be responsible for the high magnetic field and the high temperature.

As shown in Fig.3, the remanence in the internal part of the meteorite consists of three components. The soft and the intermediate components have a stability similar to the laboratory IRM. Hence, the origin of these remanences can be attributed to VRM or IRM acquired on the earth's surface. On the other hand, the stability of the hard component is high and comparable to the surface magnetization and ARM, suggesting the stable origin of the magnetization. The component may be attributed to the extra-terrestrial origin following the previous work. Then, the observed (NRM/ARM) ratio (0.2~0.5) may suggest an intensity of the magneic field at the early stage of the solar system. However, the mean direction of the hard component (I=−8° and D=22°) is almost antipodal to the surface magnetization observed in Sample No.1. Therefore, it is more reasonable to assume some relation between the hard component of the interior and the surface magnetization. We propose that the magnetization of the surface layer affected the internal part during the acquisition of the remanence of the internal part. The strong surface magnetization can cause an internal magnetic field, the magnitude of which is comparable to the earth's magnetic field. The direction of the internal field depends on the shape of the surface layer, and it is possible to find a shape of the layer which causes the internal field anti-parallel to the surface magnetization. Observation of the magnetization throughout the whole meteorite is crucial for any further discussion. The above conclusion implies the terrestrial origin of all the components of the remanences of the internal part. Although not explicitly stated in Weaving(1962), the direction of the magnetization of the surface layer of the Brewster meteorite is similar to that of the internal part (see Fig.2a of his paper). Therefore, the situation in the Brewster meteorite is similar to the present Wellman meteorite, though the directions are anti-parallel in the present case. The difference of the relative magnitude between the earth's magnetic field and the internal field due to the surface magnetization can cause these two cases.

From the present observation, we conclude that the remanences of the Wellman meteorite were all acquired during the fall through the atmosphere or on the earth's surface. Although we do not know the situation in other meteorites, it is to be noted that, if the present samples (surface and internal samples) are separately used for the paleo-intensity measurement, the surface sample gives a large intensity, whereas the internal samples show a low intensity comparable with the previous estimates for ordinary chondrites (Stacey et al., 1961; Weaving, 1962; Nagata and Sugiura, 1976). Clearly,

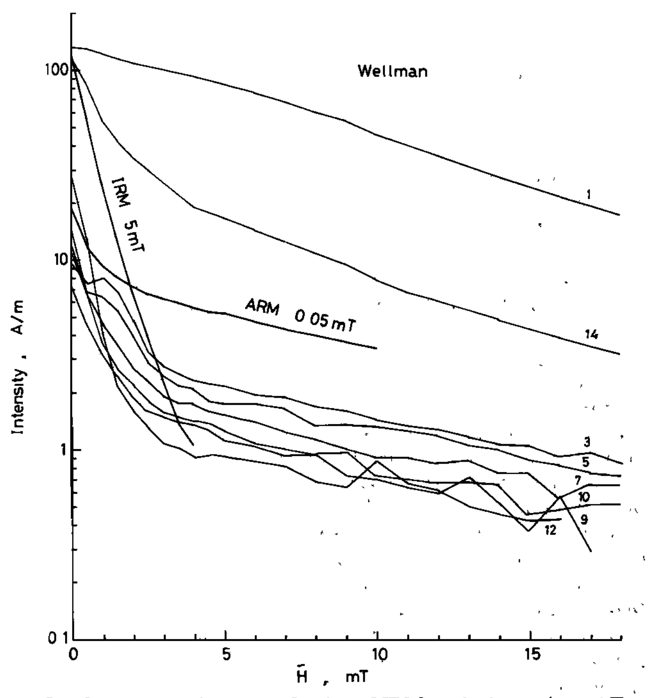

Fig.5 Intensity change of the NRMs during the AF demagnetization. The AF demagnetization characteristics for IRM and ARM are also shown for comparison.

more investigation of the magnetism of meteorites similar to the present study is necessary for identifying the origin of the remanences of the meteorites.

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