Magnetic field irradiated from Bendego octahedrite

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Introduction

For a search of meteorites by remote sensing being buried in Antarctic ice sheet, the most convenient technique may be the magnetic method, because iron and ordinary chondrites irradiate strong magnetic field from their constituent of iron nickel (FeNi). These meteorites should have a dipole magnetic field resulting from natural remanent magnetization (NRM) and induced magnetization under the geomagnetic field. On the other hand, magnetometer is developed sensitively, and is small and low power. For example, a 3-component fluxgate magnetometer with GPS and data logger is 0.1 nT, 300 g in weight including battery and 0.2 W respectively.

Bendego octahedrite 5360 kg (density of 7.56) was found in 1784 at Bahia state in Brazil. The main mass (about 5000 kg) has been displayed at the entrance hall in National Museum, Rio de Janeiro. We investigated the magnetic field irradiated from Bendego using a 3-component fluxgate magnetometer. The basic magnetic properties of a small piece of Bendego were studied in order to understand the magnetic field.

Magnetic anomaly

As the main mass cannot be moved from the entrance hall to the outside due to too heavy weight, removable furniture at the hall in the museum was removed to the other rooms. But lights hung from the ceiling were left. Pillars and walls of Building seemed to be stone, but iron rods may be buried in the concrete floor and the ceiling. An elevator located about 23 m off to the SSE direction from the Main mass. The main mass was mounted on a marble and wooden pedestal. The lowest height of the mass is 99.5 cm off from the floor and the highest surface is 180 cm one. The lights were placed at 3.8 m off above from the floor.

The magnetic anomaly was measured between 17:33 and 19:22, Dec. 18, 2009. There was no magnetic storm during the measurement, while the field intensity decreased to 5 nT at Vassouras geomagnetic observatory (lat: -22.40°, lon: -43.65°), Brazil. The IGRF of the National Museum (lat: -22.90°, lon: -43.23°) is F= 23293.1 nT, declination (D) = -22.0° and inclination (I) = -37.5°. A 3-axes fluxgate magnetometer (company, type) was employed for the measurements of magnetic field. The direction of x-axis of magnetometer was roughly maintained to the north direction, and the magnetic field was recorded for more than 10 seconds in the data logger of the magnetometer. Each grid of 51.5x51.5 cm was set in the hall of 12.9x4.6 m, where Bendigo was located at the center of the area. The height of magnetometer sensor was 228 cm from the floor. Namely the minimum distance from the magnetometer to the main mass is 48 cm. The representative magnetic field intensity at each grid was decided by average of the total magnetic field intensity (F) during 10 seconds.

The magnetic anomaly of the main mass is shown in Fig. 1. The magnetic field changed from 15000 to 28000 nT was observed around the sample. The field distribution seemed to have a dipole, and the anomaly pattern was consistent with the direction of the geomagnetic field, as the positive peak at NW and the negative one at SE sides. The background of magnetic field showed a high gradient toward SSE direction and a low one toward NNW from the sample. Probably the former is due to the magnetization of the elevator and the latter is due to that of the neighboring room.

Basic magnetic properties

A small sample (3.96 g) was cut into 4 samples and each was named Bendego 1-4. Bendego 1 and 2 were almost cubic (0.5 cm) but the other two had more irregular shape. Their weights were between 0.75 and 1.06 g. NRM of these samples varied in the range of 3.86×10^{-3} - 1.79×10^{-2} Am^2/kg (average: 8.43×10^{-3} Am^2/kg). The direction was scattered widely, whereas the precision parameter (K) is 1.3. The scattered NRM direction is inferred that Bendego was not contaminated magnetically by strong artificial magnets.

The sample of Bendego 3 was AF demagnetized up to 100 mT as shown in. The NRM seems to be decomposed into 3 components at 10 and 40 mT; the soft component between 0 and 10 mT was demagnetized straight to 10 mT and the hard one was done between 10 and 40 mT. The last component between 40 and 100 mT varied zigzag around the coordinate axes.

Bendego 3 and 4 acquired saturation remanent magnetization (SIRM) under the external magnetic field (h) // +z = 1.0 T, and then SIRM was demagnetized to 100 mT. The average SIRM intensity of these samples was 7.59×10^{-2} Am^2/kg. The spectrum of coercivity of Bendego 3 obtained by the differential SIRM intensity of each steps. The coercivity less than 35 mT is dominant, but the higher one more than 35 mT is minor component.

Thermomagnetic (Is-T) curve was obtained under the external magnetic field h=1.0 T from room temperature to 800 °C in the vacuum condition 10^{-3} Pa. The 1st run Is-T curve indicated α-γ phase transition at 775 °C in the heating curve and γ-α transition at 640 °C in the cooling curve. The phase transition temperature suggests that the magnetic mineral in the sample was kamacite with 7%Ni. The Curie point of taenite could not be identified in the Js-T curve.

Hysteresis loops at room temperature were obtained between -1.0 and +1.0 T in magnetic field for the original sample and the sample after heated. From the loops of the original sample, saturation magnetization (Is)=184 Am^2/kg, saturation remanent magnetization (I_R)=1.620 Am^2/kg, coercive force (Hc)=4.4 mT and remanent coercive force (H_{RC})=32.7 mT were obtained. It is remarkable that Bendego was not saturated to 1.0 T while the coercive force is small.

A portable susceptibility meter was attached on the flat surface of the main mass, avoiding sulfide inclusions. The average susceptibility of 10 points was χ=0.127 (cgs). As the density of octahedrite is assumed to be about 8.5 g, NRM 8.43 $x10^{-3}$ Am^2/kg is converted to 6.322 $x10^2$ emu/cc. The Königsberger ratio ($Qn=NRM/\chi F$) = 2.14 is given from these values, where the field intensity is F=23293.1 nT from IGRF.

A polished surface of Sample 4 was observed by reflected light using ferrofluid (Bitter Pattern). The surface consisted of kamacite and small amount of taenite. Magnetic domain was observed in kamacite. The dense accumulation of ferrofluid appeared on some taenite lamellae, suggesting the strong magnetic field is irradiated from taenite lamellae. Probably tetrataenite was formed at the dense accumulation area.

Conclusion

1. Bendego carries stable NRM between 10 and 35 mT
2. Direction of NRM scatters and the intensity is 8.43 $x10^{-3}$ Am^2/kg
3. Dominant magnetic mineral is kamacite with 7% Ni, but the strong magnetization appears at taenite lamellae (probably tetrataenite)
4. Bendego is not saturated by 1.0 T of the magnetic field. It is harder than that of chondrites
5. Susceptibility of Bendego is χ=0.127 (cgs) and Qn ratio is 2.14, suggesting the magnetic anomaly is resulted from NRM rather than the induced magnetization (we do not know NRM intensity of bulk sample)
6. Strong magnetic anomaly of 13000 nT as the dipole structure was observed on the main mass of Bendego. The direction of the dipole resembles that of the geomagnetic field
7. For search of Antarctic meteorites, magnetic method is useful to find iron or ordinary chondrite buried in the snow or ice

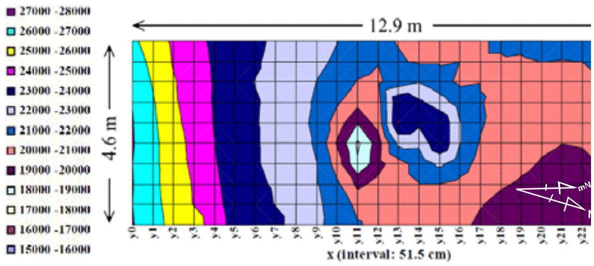

Fig. 1 Magnetic anomaly of the main mass of Bendego. N: true North, mN: magnetic north