# MAGNETIC PROPERTIES OF AN IRON METEORITE (YAMATO-75031) AND A PALLASITE (YAMATO-74044)

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***Abstract:*** The thermomagnetic curve of the matrix phase of Yamato-75031 (iron meteorite) reveals that the major constituent is 15% Ni plessite and the minor one is 8% Ni kamacite, which correspond respectively to the α-phase of matrix plessite and the Widmanstätten kamacite plates.

The thermomagnetic curve of the metal part matrix of Yamato-74044 (pallasite) shows that the major constituent is 6.6% Ni kamacite. The matrix of both samples contains the taenite phase of about 30% Ni in weight.

## 1. Introduction

Among 991 pieces of Yamato meteorites found and collected from the "Meteorite Ice Field" in the neighborhood of the Yamato Mountains in East Antarctica, two are iron meteorites and one is a stony-iron. The two irons are Yamato-75031 of 60.2 gm in weight and Yamato-75105 of 19.6 gm, while one stony-iron is Yamato-74044 of 51.8 gm. The metallographic and magnetic properties of Yamato-75105 have already been reported (NAGATA *et al.*, 1976), while the metallographic properties of Yamato-74044 and Yamato-75031 are separately reported (FISHER *et al.*, 1978). According to the results of metallographic studies of these meteorite samples, Yamato-75105 is a Ni-poor ataxite, Yamato-75031 a nickel- and phosphorus-rich ataxite and Yamato-74044 is a pallasite. The major chemical elements in the iron base of the metal phase of the three samples, revealed qualitatively by the X-ray fluorescence analysis, are given in the following table.

| Samples \ Elements | Si | Ni | Co | P | S | Al | Cu | Ti | Nb |
|---|---|---|---|---|---|---|---|---|---|
| Yamato-75031 | 0.06 | 15.3 | 0.76 | 1.0 | 0.025 | 0.06 | 0.035 | <0.01 | <0.01 |
| | | | (Mo, Cr, V, Mn<0.01%) | | | | | | (wt %) |
| Yamato-75105 | 0.35 | 5.65 | 0.52 | 1.7 | 0.1 | 0.25 | — | 0.12 | — |
| Yamato-74044 | 3.3 | 10.6 | 0.75 | 0.1 | 0.1 | 0.5 | <0.01 | <0.01 | 0.02 |
| | | | (Mo, Cr, V, Mn<0.01%) | | | | | | |

As shown in the table, the Ni contents in the Fe base of the three meteorites cover three quite different ranges. It is expected therefore that the thermomagnetic characteristics of the three samples are considerably different from one another. Moreover, the P content is anomalously rich in Yamato-75031 and Yamato-75105, whence the shreibersite phase in these samples may play a significant role in their metallographic and magnetic characteristics. Actually, shreibersite grains (75%Fe, 10%Ni, 15%P) are enveloped by high phosphorus kamacite of $\alpha$-phase (91%Fe, 7%Ni, 2%P) in the matrix of kamacite (95%Fe, 5%Ni) in the metal phase of Yamato-75105. The thermomagnetic curve of this sample also corresponds to each of the three phases (NAGATA *et al.*, 1976). In an iron meteorite, Yamato-75031, also, coarse shereibersite grains surrounded by swathing kamacite phase (7.5%Ni) are detected (FISHER *et al.*, 1978). The major parts of this meteorite, however, are occupied by the plessite matrix of about 16%Ni, which contains a large number of fine Widmanstätten kamacite plates. In the present magnetic study, the major characteristics of the plessite phase only will be thermomagnetically examined, excluding the coarse shereibersite grains, because the metallographic and magnetic examinations of the shereibersite phase may need detailed studies on individual grains which have structures considerably different from one another.

The metallic phase only of a pallasite, Yamato-74044, has been metallographically examined in fair detail (FISHER *et al.*, 1978). The metal phase of this sample can be represented by coarse plessite grains surrounded by the taenite band in the kamacite (~6%Ni) matrix. The plessite grains have very fine structures which may be due to a martensite-like transformation which might have occurred at low temperature. In the present magnetic study, however, the kamacite matrix phase only will be thermomagnetically examined because of the same reason as for Yamato-75031 sample. An additional thermomagnetic measurement of the silicate phase of Yamato-74044 has been made to be compared with the metallic phase characteristics. The main aim of this kind of magnetic studies of meteorites is to establish the magnetic identification scheme on the basis of the average magnetic properties of bulk samples of various kinds of meteorite. This report is a part of the general magnetic studies of meteorites along this line.

As a supplementary note, results of examinations of the natural remanent magnetization also are reported at the end of this article.

## 2. Thermomagnetic Characteristics

Fig. 1 illustrates the thermomagnetic curves of the metal matrix phase of Yamato-75031 iron meteorite, which were obtained on the experimental condition that the magnetic field intensify $=5.5$ kOe, and the atmospheric pressure $=10^{-5}$ torr. As shown in the figure, the major $\alpha\rightarrow\gamma$ transition temperature $(\Theta^*_{\alpha\rightarrow\gamma})$, in the heating process is 714°C but the transition temperature further extends up to 752°C, while the main $\gamma\rightarrow\alpha$ transition temperature $(\Theta^*_{\gamma\rightarrow\alpha})$ in the cooling process is 418°C but the transition temperature extends up to about 560°C. The heating and cooling thermomagnetic curves in the second-run measurements have given approximately same characteristics. These thermomagnetic characteristics represent that the major magnetic phase of this sample is 15%Ni plessite and the minor parts (about 3%) are kamacites of 8%Ni. Since the matrix phase of this sample comprises the main matrix of plessite of 15~20%Ni and fine Widmanstätten kamacite plates of about 7.5%Ni on the average, the main ferromagnetic phase represented by $\Theta^*_{\gamma\to\alpha}\simeq 418°C$ corresponds to the $\alpha$-phase parts of the plessite, while the minor parts represented by $\Theta^*_{\gamma\to\alpha}\simeq 562°C$ to the Widmanstätten kamacite plates.

The intensity of saturation magnetization ($I_s=125$ emu/gm) of this sample is considerably smaller than that of the stoichiometric (85%Fe 15%Ni) alloy ($I_s\simeq 200$ emu/gm) and that of Yamato-75105 meteorite ($I_s=190$ emu/gm) which contains 5%Ni. This result would be natural, because the plessite phase comprises not only the $\alpha$-phase but also the $\gamma$-phase. Although the volumetry of $\gamma$-phase with the aid of the integrated X-ray intensity method has suggested that a volume fraction of the $\gamma$-phase is about 15% (FISHER *et al.*, 1977), it seems likely that the present magnetic result suggests a considerably higher percentage of the $\gamma$-phase content (about 30%). However, as the mass of the sample magnetically examined in the present work is only 1.35 mgm, a possible heterogeneous distribution of the plessite composition may have to be taken into consideration.

Fig. 2 shows the thermomagnetic curves of the metal part of pallasite, Yamato-74044. The $\Theta^*_{\alpha\to\gamma}$ temperature in the heating curve and the $\Theta^*_{\gamma\to\alpha}$ one

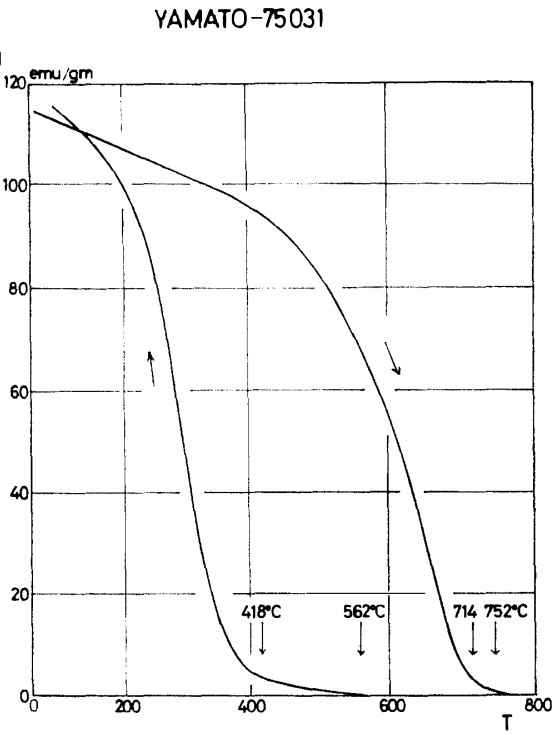


*Fig. 1. Thermomagnetic curves of the matrix of an iron meteorite, Yamato-75031.*

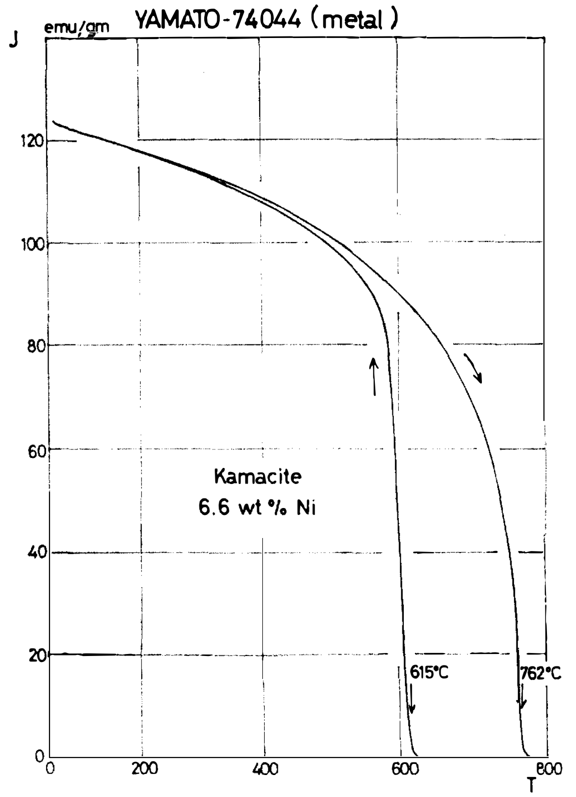


*Fig. 2. Thermomagnetic curves of the matrix of metallic phase of a pallasite, Yamato-74044.*

in the cooling curve indicate that the main ferromagnetic constituent in this sample is represented by the 6.6%Ni kamacite. This magnetic result is in approximate agreement with the nickel content in the matrix kamacite phase (about 7%Ni) obtained by the electron-probe analysis. Since the phase transitions $\alpha \rightleftarrows \gamma$ in the kamacite component are sharply represented by the thermomagnetic curves in Fig. 2, it may be no doubt that the main matrix component of this sample is $(6.5 \pm 1)$%Ni kamacite. However, the saturation magnetization ($I_s \simeq 135$ emu/gm) of the magnetically examined sample is considerably smaller than that of the stoichiometric (6.5%Ni 93.5%Fe) alloy (about 210 emu/gm). Since the kamacite matrix is neighbored by the Ni-rich taenite band which envelopes the dark plessite grain (FISHER *et al.*, 1978), the examined sample which appears metallic bright in color may contain both 7%Ni kamacite phase and 40–20%Ni taenite one. If it is assumed that about 25% of the examined sample (of 2.35 mgm in weight) is occupied by the Ni-rich taenite, all the observed magnetic data can agree with the results of metallographic studies. This assumption leads to the bulk nickel content of 10.5% for example. Then, in accordance with the result of comparison of the present magnetic data with the metallographic ones, it may have to be emphasized in the future that the magnetic measurement should be carried out directly on exactly the same sample which itself has been metallographically analyzed in detail, particularly in the case of iron or stony-iron meteorites.

Fig. 3 shows the thermomagnetic curves of the silicate part of Yamato-74044. As shown in the figure, the main ferromagnetic constituent of this sample is

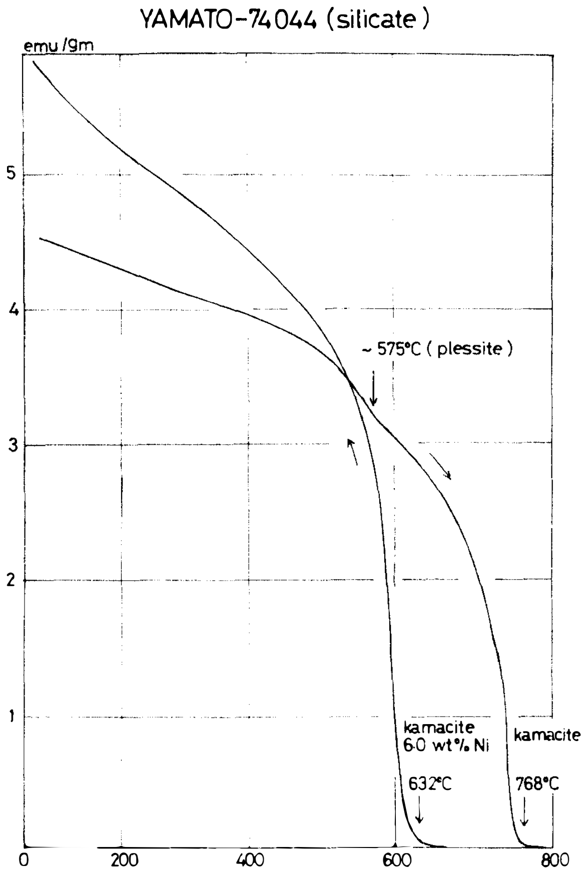


*Fig. 3. Thermomagnetic curves of the silicate phase of a pallasite, Yamato-74044.*

*Table 1. Magnetic and chemical compositions of Yamato iron and stony-iron meteorites.*

| Sample | Density (gm/cm³) | Major elements on the basis of Fe (wt %) Ni | P | Co | Magnetic transitions (°C) $\Theta$ | $\Theta_{\gamma\to\alpha}$ | $\Theta^*_{\alpha\to\gamma}$ | Corresponding phase | Saturation magnetization $I_s$ (emu/gm) |
|---|---|---|---|---|---|---|---|---|---|
| Yamato-74044 | 5.08 | 10.6 | 0.1 | 0.75 | — | 615 | 762 | 6.6% Ni $\alpha$ | 135 |
| -75031 | 7.47 | 15.3 | 1.0 | 0.76 | | | | | 125 |
| | | | | | (a) — | 418 | 714 | 15% Ni $\alpha$ | 118 |
| | | | | | (b) — | 560 | 752 | 8% Ni $\alpha$ | 7 |
| -75105 | 6.87 | 5.7 | 1.7 | 0.52 | | | | | 190 |
| | | | | | (a) — | 661 | 785 | 5.1% Ni $\alpha$ | 169 |
| | | | | | (b) 770 | | | (91Fe, 7Ni, 2P) | 14 |
| | | | | | (c) 220 | | | (75Fe, 10Ni, 15P) | 7 |

6%Ni kamacite, $\Theta^*_{\alpha\to\gamma}$ and $\Theta^*_{\gamma\to\alpha}$ values of which are given by 768°C and 632°C respectively. The other minor magnetic phase of about 575°C in transition temperature observed on the initial heating curve has disappeared on the cooling curve. the second-run thermomagnetic curves showing only the 6%Ni kamacite phase. This unstable magnetic phase could be identified to fine plessites which have been observed in the metal part of Yamato-74044 (FISHER *et al.,* 1977), and which might have been more definitely decomposed into the 6%Ni kamacite and the 40%Ni taenite by the reheating in laboratory.

The original saturation magnetization is about $I_s=4.5$ emu/gm, but it increased to about $I_s=6$ emu/gm after the reheating procedure. This result indicates the presence of about 3% of kamacite component in the silicate part.

In Table 1, the observed values of $\Theta^*_{\alpha\to\gamma}$, $\Theta^*_{\gamma\to\alpha}$ and $I_s$ of Yamato-75031 and -74044 meteorites are summarized together with those of Yamato-75105 iron meteorite, where $\Theta$ represents Currie point of a ferromagnetic component which has a thermally reversible magnetization. As already reported (NAGATA *et al.,* 1976), the thermomagnetic analysis of Yamato-75105 has given ratios of (5.1%Ni kamacite):(91%Fe, 7%Ni, 2%P):(75%Fe, 10%Ni, 15%P)$\simeq$ 88:7:5 in weight, which satisfy the observed values of $I_s$, $\Theta$, $\Theta^*_{\alpha\to\gamma}$ and $\Theta_{\gamma\to\alpha}$ as well as the chemical data of contents of Ni and P. In a similar way, the compositions of the matrix phases of Yamato-75031 and the metal part of Yamato-74044 can be approximately represented, on the basis of the observed data of saturation magnetization and magnetic transition temperatures and the chemical data given in Table 1, by (6.6%Ni kamacite):(20%Ni taenite)$\simeq$ 68:32 for Yamato-74044 and by (14%Ni kamacite):(8%Ni kamacite):(20%Ni taenite) $\simeq$ 60:4:36 for Yamato-75031.

### 3. Natural Remanent Magnetization

The physical meaning of the natural remanent magnetization (NRM) of iron and stony-iron meteorites is not always clear, because there is a large possibility that those meteorites which are thermally much more conductive than the stony meteorites might have acquired the thermoremanent magnetization on entry into the earth's atmosphere in the presence of the geomagnetic field. Figs. 4 and 5 illustrate the AF-demagnetization curves of NRM of Yamato-75031 and Yamato-74044 respectively. NRM of Yamato-75031 is fairly stable against the AF-demagnetization field up to the 250 Oe peak, whereas that of Yamato-74044 is substantially so unstable that no significance may be placed on it. The isothermal remanent magnetization (IRM) acquisition characteristics are represented by (IRM)$=3\times10^{-6}$ $H^2_{ex}$ emu/gm/Oe$^2$ and (IRM)$=1.8\times10^{-5}$ $H^2_{ex}$ emu/gm/Oe$^2$ for Yamato-75031 and Yamato-74044 respectively, where $H_{ex}$ denotes the applied external field intensity. These results could suggest that NRM of Yamato-75031 can be acquired as IRM in a magnetic field of about 20 Oerestes, but the stability of IRM thus acquired is extremely weaker than NRM against the AF-demagnetization, as shown in Fig. 4. Since metallographic

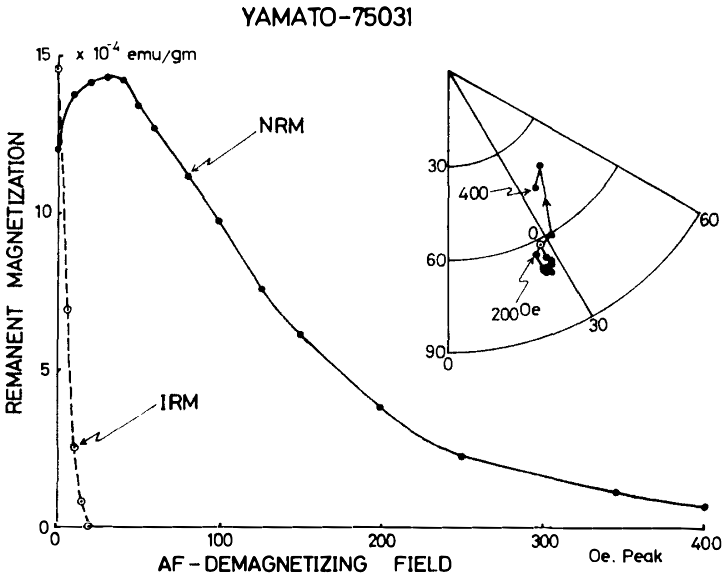


*Fig. 4. AF-demagnetization curve of NRM of Yamato-75031 iron meteorite in comparison with that of its IRM.*

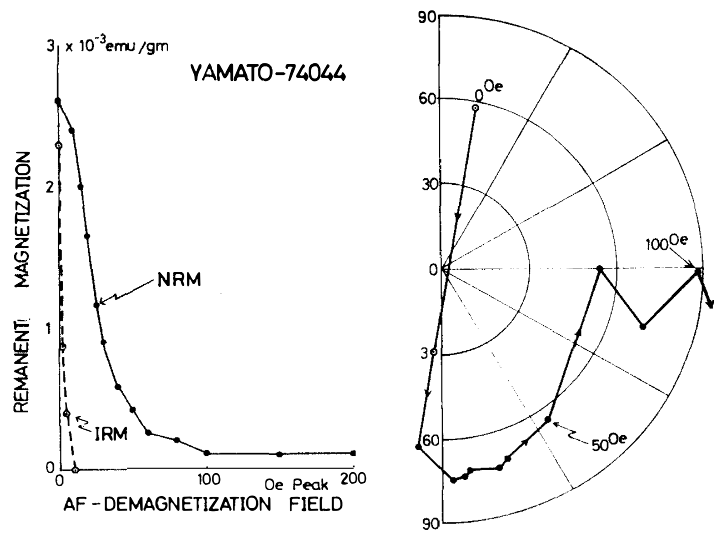


*Fig. 5. AF-demagnetization curve of NRM of Yamato-74044 pallasite in comparison with that of its IRM.*

evidence of a reheating process is noted in this sample (FISHER *et al.*, 1978), it seems very likely that the observed NRM is attributable to the thermoremanent magnetization acquired on entry into the earth's atmosphere.

## 4. Concluding Remarks

As far as the thermomagnetic characteristics of the matrix phase of Yamato-

75031 and that of the metal part of Yamato-74044 are concerned, results of the present magnetic studies are in approximate agreement with those of the metallographic studies on the same samples; namely, the major magnetic component of Yamato-75031 matrix is 15% Ni plessite, while that of the metal part of Yamato-74044 is 6.6% Ni kamacite. As the matrix of Yamato-75031 is mostly the plessites comprising 15% Ni plessite and 20–30% Ni taenite and partially the Widmanstätten kamacites, the thermomagnetic curves of this sample indicate the presence of a small amount of 8% Ni kamacite phase also. It can be concluded thus that the thermomagnetic analysis method is fairly useful for the purpose of identifying the three-dimensional bulk composition of ferromagnetic constituents. This is sufficiently true in the case of stony meteorites, in which the fine ferromagnetic grains are almost uniformly distributed. In the case of iron meteorites, however, only a very small piece of iron can be examined by use of an ordinary magnetometer, even though its bulk magnetic composition is measureable by this method. It has been observed that a number of large grains ($\sim$1 mm in mean diameter) of completely different compositions, such as schreibersite, are included in the metallic part of the two Yamato iron meteorites. It should be pointed out therefore that the magnetic examination must be made on an exactly same iron sample whose chemical and metallographic analyses have been completed with respect to one of its surfaces. In the present preliminary work, only the matrix phase of the two meteorite samples has been magnetically examined, whence the magnetic characteristics of schreibersites and their kamacite enveloped in Yamato-75031 have not yet been clarified. In the future studies in detail, the magnetic measurements will have to be made on individual metallographic phases in iron meteorites.

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