SUPPLEMENTARY NOTES ON THE MAGNETIC CLASSIFICATION OF STONY METEORITES

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Abstract: A magnetic classification of stony meteorites on the basis of their saturation magnetization (I_s) and their major magnetic transition temperature (Θ_c) in the cooling process is revised by making use of recently reported chemical and petrographic data. The average values of (I_s in emu/gm, Θ_c in °C) of enstatite chondrites (E), bronzite chondrites (H), hypersthene chondrites (L), carbonaceous chondrites (C) and achondrites (aC) are given by (48.0, 764), (30.9, 653), (12.5, 656), (9.7, 562) and (0.3, 788) respectively.

As either or both I_s and Θ_c values of each groups are distinctly separated from one another, stony meteorites can be classified reasonably well on the $I_s \sim \Theta_c$ diagram.

I. Introduction

In the previous paper (NAGATA and SUGIURA, 1976), the author proposed a scheme to classify stony meteorites on the basis of their saturation magnetization intensity (I_s) and their magnetic transition temperature. The basic principle of this scheme is dependent first on the Urey-Craig-Mason law that the total iron content (the sum of metallic iron and Fe in FeO and FeS) is approximately constant in various kinds of chondrite (*i.e.* E, H, L, LL and C in chemical types), whereas the content of metallic iron and FeS in achondrites is much less than that in the ordinary chondrites though the FeO content in the former is not much different from that in the latter. The second point involved in the proposed scheme is that the magnetic transition with temperature change of magnetites in carbonaceous chondrites is essentially different from that of FeNi alloys in enstatite-, bronzite- and hypersthene-chondrites and in amphoterites. In the proposed scheme, the major magnetic transition temperature (Θ_c) observed in the cooling process is plotted against the saturation magnetization (I_s) for 25 stony meteorites including 13 Yamato stony meteorites. Here, the Θ_c value for carbonaceous chondrites represents their Curie point, whereas Θ_c for other stony meteorites does the $\gamma \rightarrow \alpha$ transition temperature of kamacite phase. In such a diagram of Θ_c versus I_s, it seems that the plots of five different groups of stony meteorites, *i.e.* enstatite chondrites, bronzite ones, hypersthene ones, carbonaceous ones and achondrites are well separated from one another.

In accordance with the progress of chemical, petrographical and magnetic analyses of the Yamato meteorites, however, some provisional results of these studies have become more or less modified. In this supplementary note, the scheme of magnetic classification of stony meteorite will be renewed on the basis of the recently revised data.

2. Urey-Craig-Mason Law

In the Urey-Craig-Mason law, the weight percentage of iron in metal and in FeS, $W(Fe^*)$, is linearly correlated with that of oxidized iron, $W(FeO)$, in chondrites as represented by

$$W(\mathrm{Fe}^*) \simeq W^{\circ}(\mathrm{Fe}^*) - \frac{W^{\circ}(\mathrm{Fe}^*)}{W^{\circ}(\mathrm{FeO})} W(\mathrm{FeO}), \qquad (1)$$

where $W^{\circ}(Fe^*)$ and $W^{\circ}(FeO)$ denote respectively $W(Fe^*)$ at $W(FeO)=0$ and $W(FeO)$ at $W(Fe^*)=0$. $W(Fe^*)$ values of 11 stony meteorites collected by Japanese (given in Table 1) are plotted against their $W(FeO)$ values in Fig. 1. The Urey-Craig-Mason linear relationship between $W(Fe^*)$ and $W(FeO)$ approximately holds for all chondrites except for two achondrites which are shown for comparison. In the diagram of Fig. 1, however, the plot of a bronzite chondrite (Yamato (j)) gets out of the H group domain and enters the L group domain. This behavior should be considered anomalous.

Fig. 2 shows the correlation between I_s and the content of metallic Fe of

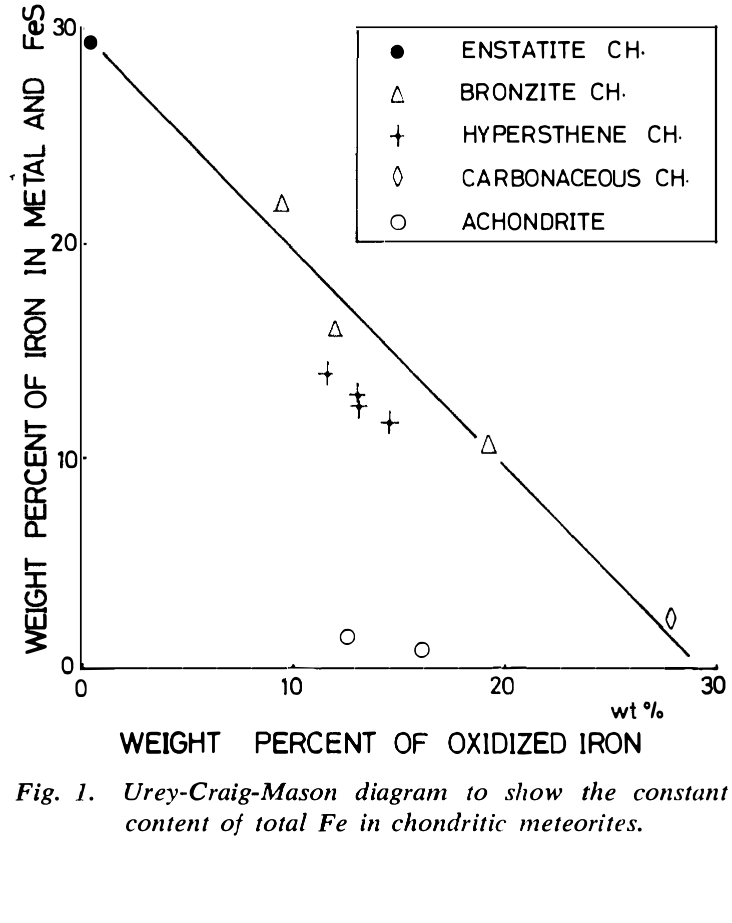

Fig. 1. Urey-Craig-Mason diagram to show the constant content of total Fe in chondritic meteorites.

11 meteorites given in Table 1. Except for a carbonaceous chondrite (Yamato (c)), a proportional relationship approximately holds between I_s values and the metallic iron contents. This result indicates that the I_s value can approximately

Table 1. Major chemical elements in stony meteorites.

Meteorite sample	Classification	Saturation magnetization (I_s) (emu/gm)	Chemical component			
			Fe in metal (wt %)	Ni in metal (wt %)	Fe in (FeS) (wt %)	FeO (wt %)
Yamato (a)	E	48.0	22.18	1.86	7.20	0.48
(b)	Diogenite	0.19	0.66	0.004	0.85	12.58
(c)	C_3	10.8	0.15	1.32	2.30	27.84
(d)	H	32.3	12.69	1.52	3.38	12.02
(j)	H_4	15.5	7.33	0.78	3.26	19.22
(k)	L_5	14.3	7.64	0.96	4.81	13.10
(l)	Howardite	0.53	0.39	0.012	0.48	16.00
(m)	L_5	17.5	7.50	0.83	5.36	13.02
Kesen	H	34.4	18.23	1.59	3.68	9.47
Fukutomi	L	22.9	9.83	1.33	4.05	11.62
Mino	L	11.0	7.86	1.16	3.73	14.48

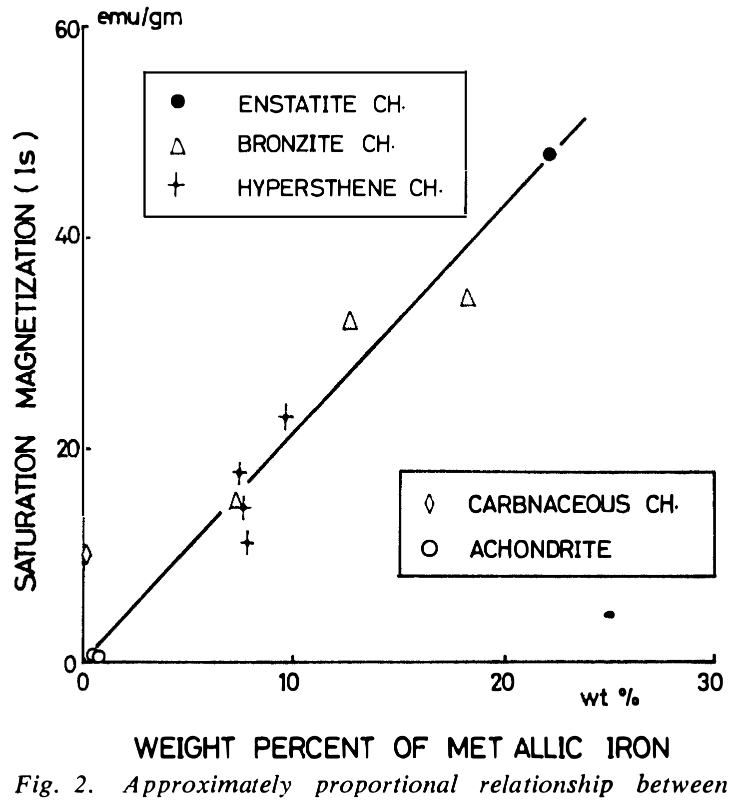

Fig. 2. Approximately proportional relationship between the saturation magnetization (I_S) and the metallic iron content in stony meteorites except for carbonaceous chondrites.

represent the abundance of metallic iron in achondrites and chondrites except carbonaceous chondrites, the major ferromagnetic constituent of which is magnetite. It is observed in Fig. 2 again that a bronzite chondrite (Yamato (j)) is anomalous, being plotted in the middle of the L group in the diagram. It may be generally concluded from Fig. 2, however, that since the I_s value can approximately represent the metallic iron content in stony meteorites except for carbonaceous chondrites, the linear relationship between I_s and the metallic iron content ($W(\mathrm{Fe}^\circ)$) is expressed as

$$I_s = 210 \cdot W(\mathrm{Fe}^\circ) \text{ emu/gm.} \qquad (2)$$

The numerical value of the coefficient (*i.e.* 210 emu/gm) is in a reasonably good agreement with the saturation magnetization of pure iron and kamacites of (0~10%)Ni.

3. Magnetic Classification of Stony Meteorites—$I_s \sim \Theta_c$ Diagram—

The magnetic data reported in the previous paper (NAGATA and SUGIURA, 1976) contain no considerable errors. However, chemical data and petrographic classification of some Yamato stony meteorites have been considerably modified by recent studies of these samples in detail. The saturation magnetization (I_s) and the main magnetic transition temperature (Θ_c) in the cooling process, given for the newly reclassified 25 stony meteorites, are summarized in Table 2, where those samples having asterisk marks have recently been studied particularly in detail. The Θ_c values are plotted against the I_s values for these 25 stony meteorites in Fig. 3. Comparing Fig. 3 with the similar unrevised diagram (Fig. 5 in the previous paper), it is noted that the L group plots are much more sharply separated from the H group plots in the revised $\Theta_c \sim I_s$ diagram, if an anomalous sample (Yamato (j)) is ignored. Probably Yamato (j) sample could be rejected from the H group, because the FeO content and the FeO/(FeO+MgO) ratio of this sample are 19.22% and 44.8% in weight respectively, which are far beyond the limits of those of the olivine-bronzite chondrite group but are rather in the middle composition between the olivine-hypersthene chondrites and the olivine-pigeonite ones (*e.g.* MASON, 1962)*. Excluding Yamato (j) chondrite, then, the average values of I_s and Θ_c for the five groups are given in Table 3, where the error estimate after ± represents a simple average of deviations in absolute value from the mean value. As shown in the table, the I_s values are well separated from one another except a slight overlapping of the L group on the C group, and the Θ_c values also are well separated from one another except an almost overlapping of the H group with the L group.

As already demonstrated in Fig. 2, the systematic dependence of I_s value on

* Yamato (j) chondrite is extremely weathered, containing $H_2O(+)$, NiO and CoO, and consequently much oxidized.

Table 2. Saturation magnetization (I_S) and the major magnetic transition temperature (Θ_c) in the cooling process of stony meteorites.

Sample	I_s (emu/gm)	Θ_c(°C)
(*Enstatite chondrite*)		
Yamato (a)	48.0	764
(*Bronzite chondrite*)		
Yamato (d)	32.3	685
*Yamato (j)	15.5	660
*Yamato-74371	33.5	635
Kesen	34.4	670
Yonozu	24.2	654
Seminole	24.3	627
Mt. Brown	40	640
(*Hypersthene chondrite*)		
*Yamato (k)	14.3	624
*Yamato (m)	17.5	644
Yamato-74191	6.8	671
Yamato-74362	8.1	645
Fukutomi	22.9	700
Mino	11.0	658
Dalgety Downs	9.7	648
Bjurböle	13	660
Barratta	12	655
Homestead	10	650
(*Carbonaceous chondrites*)		
Yamato (c)	10.8	540
Leoville	10.3	575
Mokoia	8	570
(*Anchondrite*)		
Yamato (b)	0.19	780
*Yamato (l)	0.53	792
Yamato-74013	0.17	792

stony meteorite types, E, H, L and achondrite, is attributable to the characteristic difference in their metallic iron contents, whereas the I_s value of C group represents their magnetite content of about 10% on the average. The average values of I_s in Table 3 indicate that the average content of metallic iron is about 15%, 6% and 0.15% in weight respectively in H and L chondrites and achondrites.

On the other hand, the Θ_c value represents the average composition of the major ferromagnetic constituent in each group. The highest value of Θ_c of the achondrite group indicates that the metallic phase in them is almost pure metallic iron. The high Θ_c value for the enstatite chondrite also represents the same situation. The average value of Θ_c about 655°C for the H and L groups represents that their major ferromagnetic constituent is kamacite of 5.5%Ni on the average, whereas the Θ_c value of the C group can surely be identified to Curie point of magnetites or slightly substituted magnetites.

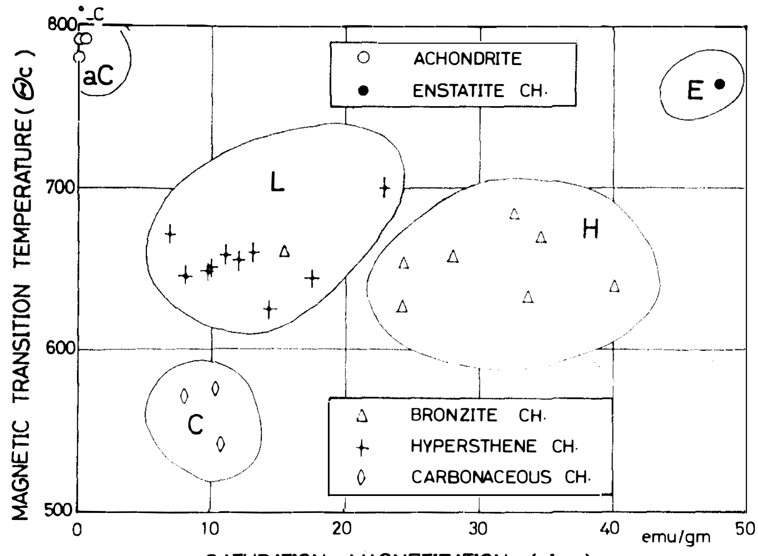

Fig. 3. The saturation magnetization (I_S) versus the major magnetic transition temperature (Θ_c) diagram to classify stony meteorites into petrologically and chemically classified groups.

Table 3. Average values of I_S and Θ_c for five groups of stony meteorites.

Group	I_s (emu/gm)	Θ_c (°C)
E(n=1)	48.0	768
H(n=7)	30.9±4.7	653±16
L(n=10)	12.5±3.5	656±13
C(n=3)	9.7±1.1	562±14
Achondrite (n=3)	0.30±0.16	788±5

4. Concluding Remarks

The five groups of stony meteorites, enstatite-, bronzite-, hypersthene- and carbonaceous-chondrites and achondrites, are grouped reasonably well separately from one another in the $\Theta_c \sim I_s$ diagram of Fig. 3. When similar data of I_s and Θ_c for olivine-pigeonite chondrites or amphoterites become available in the near future, their I_s values will come to fall between those of the L group and those of the achondrite group, though no accurate prediction may be made at present on the Θ_c value which is probably almost the same as that of the L group or lies between those of the L group and the achondrite one.

Since we still have a large number of Yamato stony meteorite which have not yet been precisely examined, the coordinated chemical, petrographical and magnetic analyses of these new stony meteorites are expected to reveal their characteristics in detail, and the observed data are hoped to establish a more reliable magnetic classification diagram for the stony meteorites.

References

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