14. MAGNETIC-MINERALOGICAL STUDIES OF DSDP SITE 323 CORES[1]

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INTRODUCTION

Using Mössbauer and rock magnetism methods, samples of cores from DSDP Site 323 were studied in our laboratory to determine some of their magnetic mineralogical and magnetic physical properties as a means of mineral identification and as a means of gaining some insight into the genesis of their iron forms.

Site 323 sediments were sampled from the ocean floor to a hole depth of 701 meters where basalt was encountered. For chronological purposes the description proceeds from the basalt contact up. Our mineralogical studies resolve three depth intervals: (1) typical deep-sea deposits from 701 to 638 meters; (2) terrigenous deposits with a large amount of mineral alteration from 638 to 506 meters; and (3) terrigenous deposits with little mineral alteration from 506 to 0 meters.

ANALYTICAL PROCEDURES

We studied three aspects of the samples from Site 323: Mössbauer effect, magnetic properties at room temperature, and thermomagnetic effects and properties.

Mössbauer Technique

The Mössbauer methods (Wertheim, 1964) were used mostly on the lower portion of the sediment column. The results are summarized in Table 1, and some Mössbauer spectra are shown in Figure 1. Because of the very limited ferromagnetic constitution of these samples, the ferromagnetic fraction was not satisfactorily measured by Mössbauer spectra. All the samples studied by this method have spectra with one small quadrupole doublet with a splitting value of about 0.054 mm/sec and isomer shift (with respect to Co^{57} [Pd]) of about +0.18 mm/sec. The doublet peaks are sharp and have components of equal intensity and equal line width. The observed characteristics of these parameters indicate fine superparamagnetic particles of goethite FeO(OH) with an average size of about 180Å.

Spectra of the samples from levels higher in the sediment column indicate that iron is mainly contained in the clay minerals either only in the Fe^{3+} state (montmorillonite) or in both the Fe^{2+} and Fe^{3+} states (illite, cronstedtite, chamosite).

Magnetic Properties at Room Temperature

The magnetic investigations at room temperature consisted of the following (see Table 2 for definition of symbols used): Determination of Irs_o as a function of He; a.c. demagnetization of Irs_o; determination of [Hćs] and [He's] and Hes; determination of the ratios Is_o/Irs_o and Irs_o/Irs_{omax} (Table 1). The first parameter (Irs_o as a function of He) characterizes the relative amounts of paramagnetic, superparamagnetic, single domain, and multidomain grains of iron-containing minerals in the samples (Bagin et al., 1969). The second parameter, Irs_o characterizes the relative remanent saturation magnetization of the various deposits. The results of room temperature magnetic determinations are given in Table 1.

Curves of Ir/Ir_{max}. as a function of He were two types: normal (Figure 2) and anomalous (Figure 3). For the curves of normal type (the normal type of deposit) the beginning of the saturation plateau (Hes) varies from 1000 to 3000 oe. For the anomalous type of curve (the anomalous deposit) the beginning of the saturation plateau (Hes) is greater than 7000 oe. For the normal deposit the average value at the maximum slope (He's) is about 250 oe, and for the anomalous deposit the maximum slope (He's) is about 1.5 to 2 times greater.

The ratio Irs_o/Irs_{omax}. varies greatly from sample to sample. The difference between the maximum and the minimum values of the ratio is as much as 1.5 to 2 orders of magnitude. The curves (not shown) for Irs_o as a function of H are typical for deposits of normal type. One-half of Irs_o is usually demagnetized at 100 to 150 oe. Only for the anomalous deposits is one-third of Irs_o not demagnetized at 600 oe. The values of the ratio Is_o/Irs_o vary from 2.7 to 15.0. This means that there is a wide range in grain size of the iron-containing minerals in the deposits.

The results of magnetic investigations at room temperature show that the majority of samples contain magnetic minerals with a moderate value of magnetic hardness. Only for the anomalous deposits were magnetic phases found that require a great coercive field. The large differences between the ratios of Irs_o/Irs_o max. and Is_o/Irs_o in Table 1 only indicate that the deposits contain iron in a number of different forms.

Thermomagnetic Studies

Figure 4 shows curves of Is/Is_o and Irs/Irs_o as a function of temperature. The samples fall into five classes:

Class 1. Magnetite and maghemite determine the thermomagnetic curves of this class (Figure 4a, b). The Curie point is about 575°C. Temperature changes cause mineral alterations of maghemite. The Curie points and the curves indicate maghemite.

Class 2. These thermomagnetic curves (Figure 4c, d) are typical for deep-sea deposits. The curves are indicative of the presence of nonstoichiometrical hematite and hydroxides of iron.

[1]Translated in part from Russian.

TABLE 1
Summary of Results Obtained from the Mössbauer Technique and Magnetic Investigations at Room Temperature

Sample (Interval in cm)	Hes (oe)	Hc's (oe)	$\tilde{H}(\frac{1}{2}Irs_o)$ oe	Is_o/Irs_o	Irs_o/Irs_{omax}	Oxidation State	Isomer Shift (mm/sec)	Quadrupole Splitting (mm/sec)	Ratio Fe^{3+}/Fe^{2+}
1-1, 50-60	1500	260	120	14.5	0.22	–	–	–	–
1-1, 140-150	5000	320	–	8.0	0.054	–	–	–	–
1-2, 34-43	1500	340	120	6.2	0.138	–	–	–	–
1-4, 118-127	2500	400	180	5.8	0.145	–	–	–	–
3-1, 88-94	2500	280	–	13.0	0.155	–	–	–	–
3-2, 14-20	1000	230	–	15.0	–	Fe^{3+}	0.04 ±0.04	0.68 ±0.04	0.54
						Fe^{2+}	0.98 ±0.04	2.53 ±0.04	
3-2, 61-70	>7500	550	220	13.8	0.055	Fe^{3+}	0.15 ±0.06	½ ≅ 1.20	5.0
						Fe^{2+}	1.08 ±0.02	2.12 ±0.04	
4-2,	1500	100	–	4.9	0.606	–	–	–	–
7-2, 105-110	3000	310	–	7.0	0.183	–	–	–	–
7-3, 18-24	3000	320	–	7.2	0.137	–	–	–	–
8-1, 120-121	>7500	270	100	10.0	0.018	Fe^{3+}	0.08 ±0.03	0.58 ±0.04	0.40
						Fe_I^{2+}	0.98 ±0.03	2.00 ±0.04	
						Fe_{II}^{2+}	0.78 ±0.03	2.41 ±0.04	
10-1, 113-122	>7500	500	200	14.0	0.060	Fe^{3+}	0.10 ±0.06	0.71 ±0.06	1.5
						Fe^{2+}	1.25 ±0.06	2.40 ±0.06	
10-2, 75-85	5000	300	–	10.0	0.255	Fe^{3+}	0.15 ±0.06	½ = 1.15	3.8
						Fe^{2+}	1.07 ±0.02	2.08 ±0.04	
10-3, 106-114	3500	320	–	7.0	0.184	–	–	–	–
11-1, 22-32	2500	350	–	10.2	–	–	–	–	–
11-2, 137-148	1500	270	–	9.5	0.311	–	–	–	–
13-5, 106-115	1500	290	–	4.6	0.394	–	–	–	–
13-6, 145-150	1000	300	–	6.6	0.728	–	–	–	–
14-2, 1-8	3000	320	–	5.7	0.260	–	–	–	–
14-2, 128-135	2000	240	120	6.6	0.910	Fe^{3+}	0.18 ±0.02	0.52 ±0.04	–
15-1, 52-60	1000	240	–	6.3	0.910	–	–	–	–
15-2, 91-100	1000	230	–	4.3	1.000	–	–	–	–
15-3, 29-36	1000	230	–	4.7	0.728	Fe^{3+}	0.18 ±0.02	0.54 ±0.04	–
15-4, 51-63	1000	230	–	4.2	0.818	Fe^{3+}	0.18 ±0.02	0.54 ±0.04	–
15-5, 89-98	1000	260	–	5.0	0.458	–	–	–	–
15-6, 19-26	700	240	–	4.8	0.367	–	–	–	–
16-1, 57-62	500	240	–	4.5	0.400	Fe^{3+}	0.18 ±0.02	0.52 ±0.04	–
16-3, 32-37	1000	220	–	4.6	0.848	Fe^{3+}	0.18 ±0.02	0.52 ±0.04	–
16-4, 83-94	500	220	–	4.9	0.734	–	–	–	–
18-2, 80-86	700	300	–	4.5	0.484	–	–	–	–
18-3, 130-139	1000	250	–	2.7	0.734	–	–	–	–
18-4, 115-127	1000	250	–	4.7	0.421	Fe^{3+}	0.18 ±0.02	0.48 ±0.04	–

Class 3. The thermomagnetic curves (Figure 4e, f) are characteristic of iron oxide forms, and they are typical for nonstoichiometrical hematite.

Classes 4 and 5. It is presumed that the curves of Figures 4g, h, i are likely to be determined by temperature transitions of cronstedtite. The 525°C temperature corresponds to the beginning of the temperature transition of cronstedtite as revealed by differential thermal analysis.

MAGNETIC-MINERALOGICAL DEPTH ZONATION OF SITE 323

Interval 701 to 638 Meters; Typical Deep Sea Deposits

The magnetic-mineralogical data delineate three zones in this interval.

Zone A, 701 to 675 meters: Samples 16-1, 57-62 cm; 16-3, 32-37 cm; 16-4, 83-94 cm; 18-2, 80-86 cm; 18-3, 130-139 cm; 18-4, 115-124 cm. The thermomagnetic and other magnetic characteristics are typical of deep-sea deposits. The iron is mostly contained in the superparamagnetic grains of $\alpha FeOOH$. The ferromagnetic fraction contains the nonstoichiometrical hematite.

Zone B, 675 to 660 meters: Samples 15-3, 29-36 cm; 15-4, 54-63 cm; 15-5, 89-98 cm; 15-6, 19-26 cm. The thermomagnetic data are typical for highly altered terrigenous deposits. The iron is contained in nonstoichiometrical hematite. The hydroxide iron forms are less common here than in Zone A.

Zone C, 660 to 638 meters: Samples 13-6, 145-150 cm; 14-2, 1-8 cm, 128-135 cm; 15-1, 52-60 cm; 15-2, 91-100 cm. Zone C is similar to Zone A.

Interval 638 to 506 Meters; Terrigenous Deposits With Highly Altered Minerals

We used Samples 10-1, 113-122 cm; 10-2, 75-85 cm; 10-3, 106-114 cm; 11-2, 137-148 cm; 13-5, 106-115 cm. Except for Sample 10-1, 113-122 cm, the magnetic properties of the deposits are similar to those of Zone B at 675 to 660 meters below the sea floor. Cronstedtite is

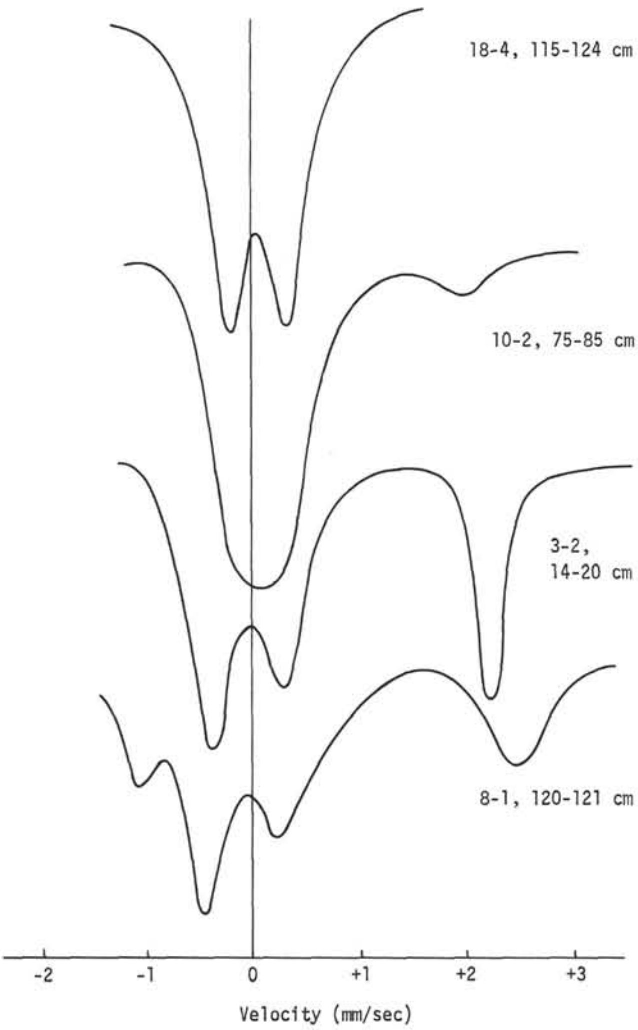

Figure 1. *Some Mossbauer spectra of Site 323 sediment samples.*

likely present in Sample 10-1, 113-122 cm. Samples 10-1, 113-122 cm and 10-2, 75-82 cm correspond to the intermediate zone (638 to 506 m) in the terrigenous deposits. Hematite is found in the samples from 638 to 506 meters.

Interval 506 to 0 Meters; Terrigenous Deposits With Little Alteration of Minerals

Based upon magnetic-mineralogical characteristics, this interval can be divided into many zones. For simplicity we divided the interval into three groups of magnetic-mineralogical characteristics regardless of the sample's depth in the interval 506 to 0 meters.

Group 1: Samples 1-1, 50-60 cm; 1-3, 78-88 cm; 3-1, 88-94 cm; 4-2. The ferromagnetic fraction consists of low-temperature oxidation magnetite (magnetite and maghemite). The material of these samples was likely derived from pre-existing rocks, with little mineralogical alteration during transportation.

Group 2: Sample 3-2, 61-70 cm. In contrast to the samples of Group 1, magnetite and maghemite were not found. Only nonstoichiometrical hematite was found here, which may indicate a highly oxidizing regime at the time of the material's formation.

TABLE 2
Definition of Symbols Used in this Report

Irs	–	remaining Irs_o at a particular temperature as the sample is heated or cooled
Irs_o	–	initial saturation remanence
Irs_{omax}	–	maximum value of Irs_o for given collection of samples
Is	–	magnetization in a strong field at a particular temperature
Is_o	–	initial saturation magnetization
Ir	–	normal remanence
Ir_{max}	–	maximum normal remanence for each sample
He	–	artificial magnetic field to which a sample is subjected
$H_c's$	–	reverse d.c. magnetic field required for complete demagnetization of Irs_o
Hes	–	minimum amount of magnetic field required to reach the beginning of the saturation plateau (Figure 2)
$He's$	–	The magnetic field at a point of maximum rate of change of Ir/Ir_{max} on the Ir/Ir_{max} versus He curve of Figure 2
oe	–	oersteds
$\tilde{H}$	–	a.c. field
a.c.	–	alternating current
d.c.	–	direct current
Is_1	–	Is_o
Is_2	–	saturation magnetization at 20°C after first heating
$\approx$	–	approximately equal to
$\tilde{H}(\frac{1}{2} Irs_o)$	–	median destructive a.c. field

Group 3: Samples 1-1, 140-150 cm; 1-2, 37-43 cm; 1-4, 118-127 cm; 7-2, 105-110 cm; 7-3, 18-24 cm; 8-1, 120-121 cm. According to the literature (Betekhtin, 1950), cronstedtite formation occurs soon after deposition. The low values of remanent saturation magnetization and high values of the ratio Is_o/Irs_o require that the iron is mainly contained in paramagnetic silicate minerals.

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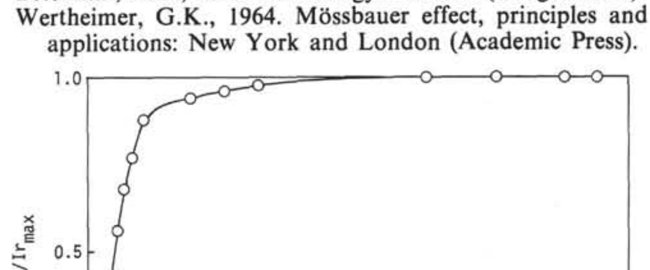

Figure 2. *A plot typical of normal (more common) samples of Ir/Ir_{max}. as a function of the magnetic field. Note the positions of Hes and He's.*

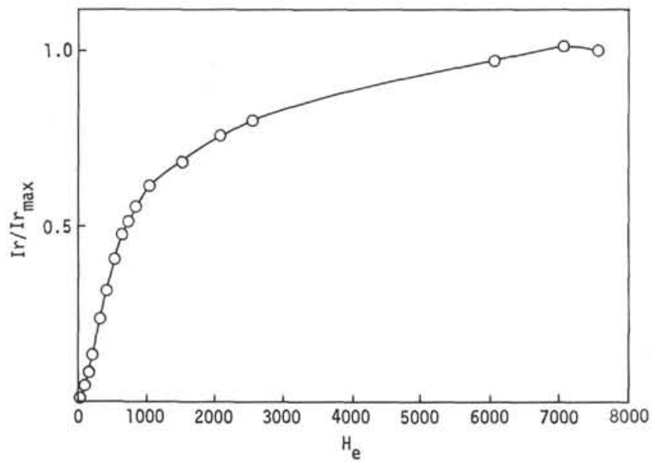

Figure 3. *A plot typical of anomalous samples of Ir/Ir_{max} as a function of the magnetic field. Note the positions of Hes and He's.*

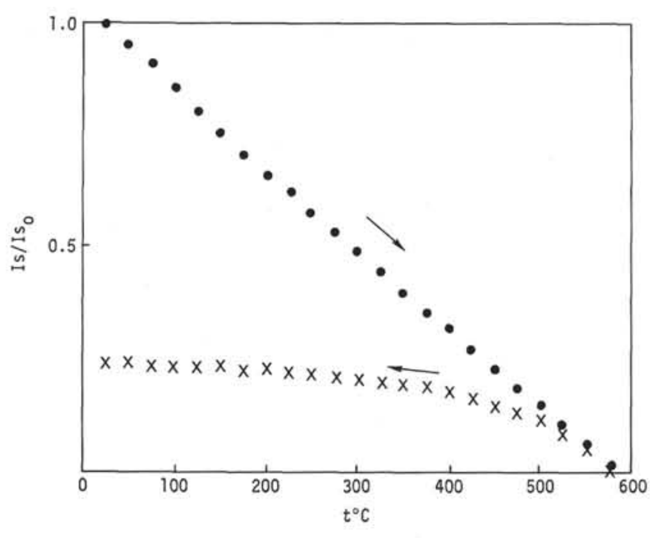

Figure 4a. *A plot of the saturation magnetization in a 5000 oe field as a function of progressive and regressive temperature for class 1 samples. Note the difference between the heating curve and the cooling curve due to mineral alteration during heating.*

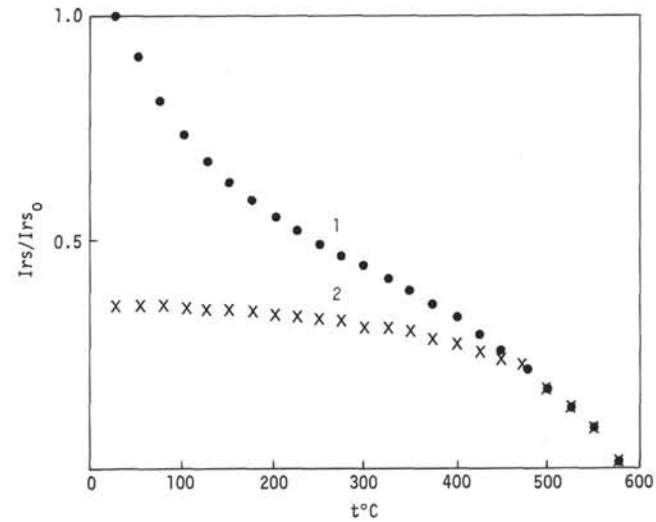

Figure 4b. *Remanence magnetization of class 1 samples as a function of temperature for progressive heating and then for progressive cooling.*

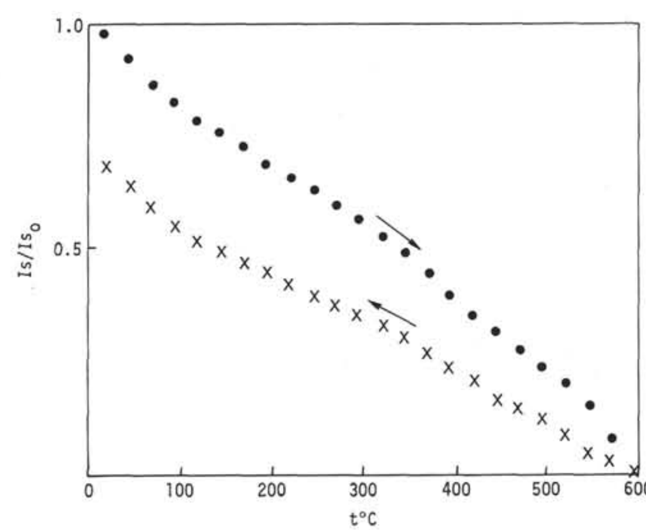

Figure 4c. *A plot of the saturation magnetization in a 5000-oe field as a function of progressive and regressive temperature for class 2 samples. Note the differences between the heating curve and the cooling curve due to mineral alteration during heating.*

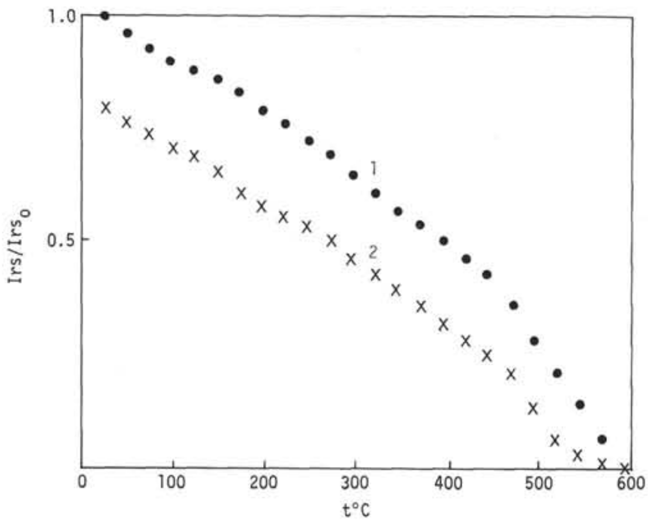

Figure 4d. *Remanence magnetization of class 2 samples as a function of temperature for progressive heating then for progressive cooling.*

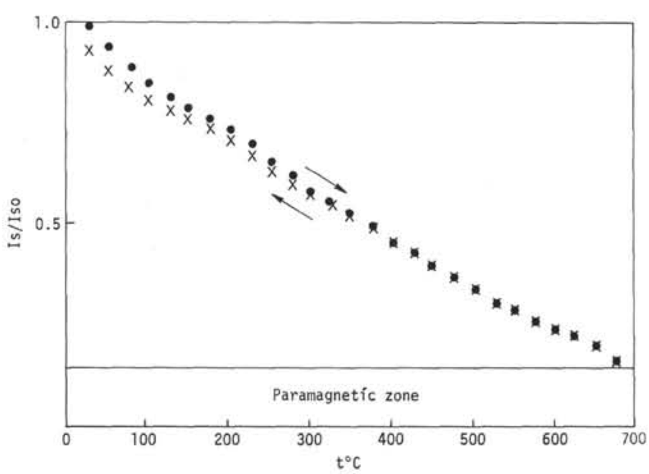

Figure 4e. *A plot of the saturation magnetization in a 5000-oe field as a function of progressive and regressive temperature for class 3 samples. Note the differences between the heating curve and the cooling curve due to mineral alteration during heating.*

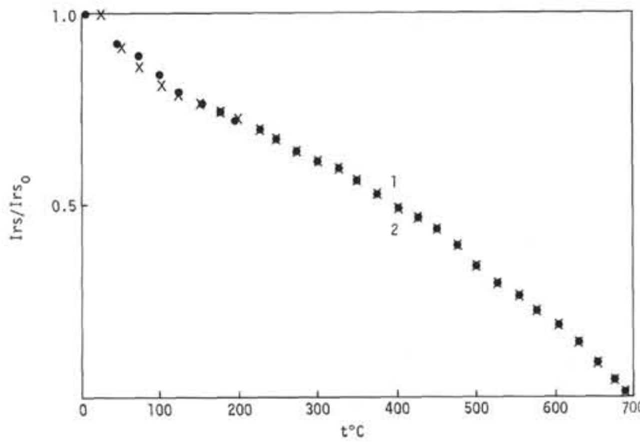

Figure 4f. *Remanence magnetization of class 3 samples as a function of temperature for progressive heating and then for progressive cooling.*

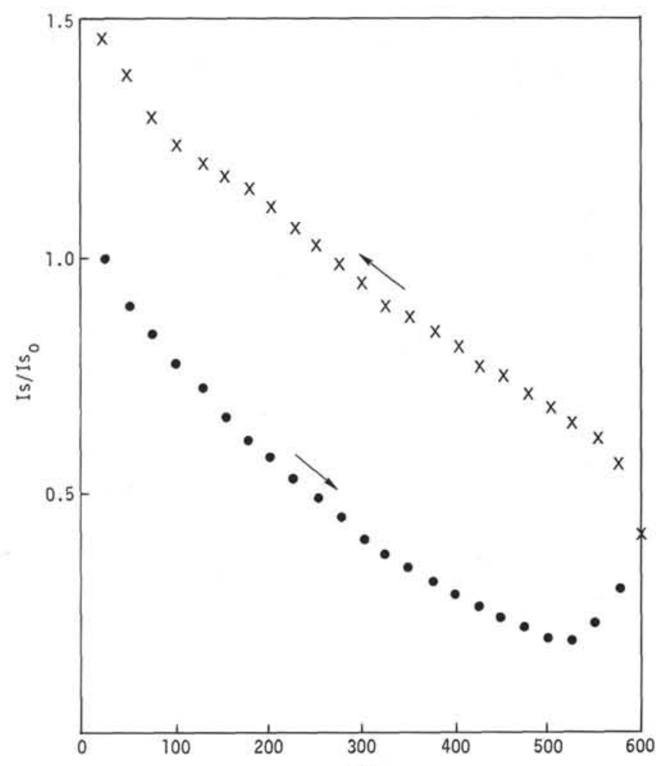

Figure 4g. *A plot of the saturation magnetization in a 5000-oe field as a function of progressive and regressive temperature for class 4 samples. Note the differences between the heating curve and the cooling curve due to mineral alteration during heating.*

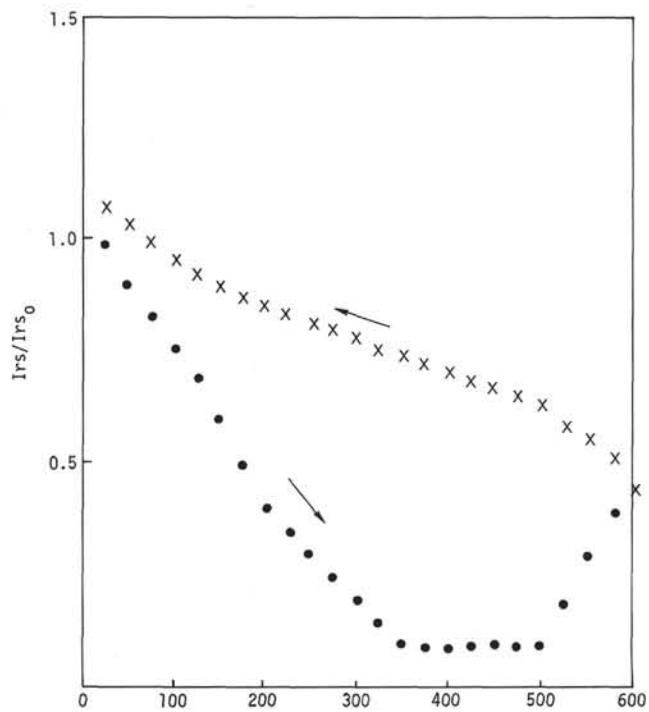

Figure 4h. *Remanence magnetization of class 4 samples as a function of temperature for progressive heating and then for progressive cooling.*

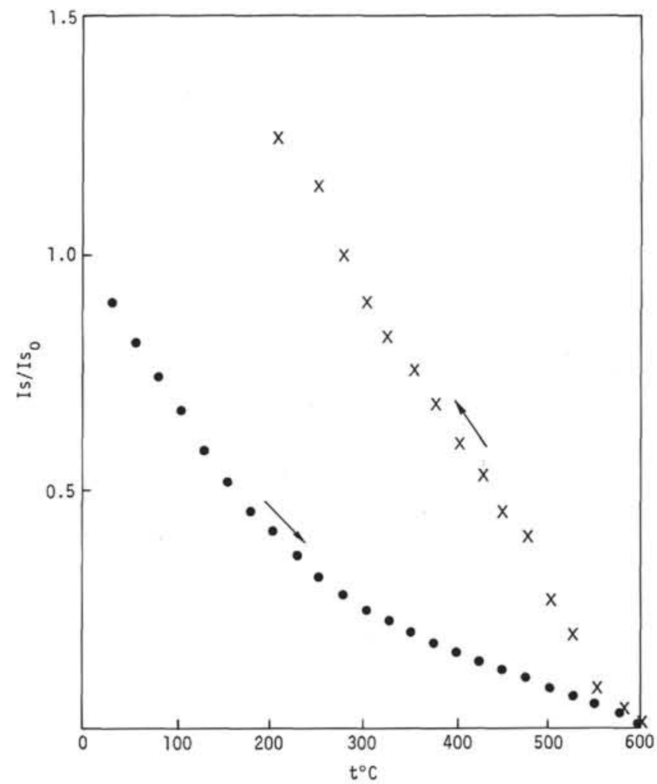

Figure 4i. *A plot of the saturation magnetization in a 5000-oe field as a function of progressive and regressive temperature for class 5 samples. Note the differences between the heating curve and the cooling curve due to mineral alteration during heating.*