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REMANENT MAGNETISM IN METEORITES

by

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CONTENTS

ILLUSTRATION

TABLES

REMANENT MAGNETISM IN METEORITES [1/]

By

Robert L. DuBois[2/] and Donald P. Elston

INTRODUCTION

Thirty-three new measurements of natural remanent magnetism (NRM) are reported for several classes of chondrites and achondrites. The new data are tabulated (table 1) with published NRM values for chondrites, irons, and one stony-iron, and are arranged to reveal possible interrelationships among some of the classes. Data for the stony meteorites are grouped by chondrite and achondrite classes, and data for the stony-irons and irons are arranged with respect to gallium-germanium (Ga-Ge) groups (table 1). Classes for the chondrites and achondrites are after Mason (1962); the Ga-Ge groups are after Lovering and others (1957). Suggested correlations between chondrite classes and the Ga-Ge groups (after Elston, 1967, 1968) are outlined in table 2. The NRM data are presented graphically in figure 1, and average NRM values for the meteorite classes or groups are summarized in table 3.

The new remanent magnetic data were obtained from measurements made with an astatic magnetometer. For measurement, the specimens were affixed within a plastic cube, unmodified from their field or museum condition, and eight measurements of the X-, Y-, and Z-components of the remanence were made, from which intensity and direction of the natural magnetism were calculated. Total natural remanence was determined for 17 specimens of calcium-rich achondrites; for 5 hypersthene, 2 bronzite, and 2 pigeonite chondrites; for 3 hypersthene and 2 enstatite achondrites; and for 2 carbonaceous chondrites.

[1/] Submitted to Earth and Planetary Science Letters for publication.

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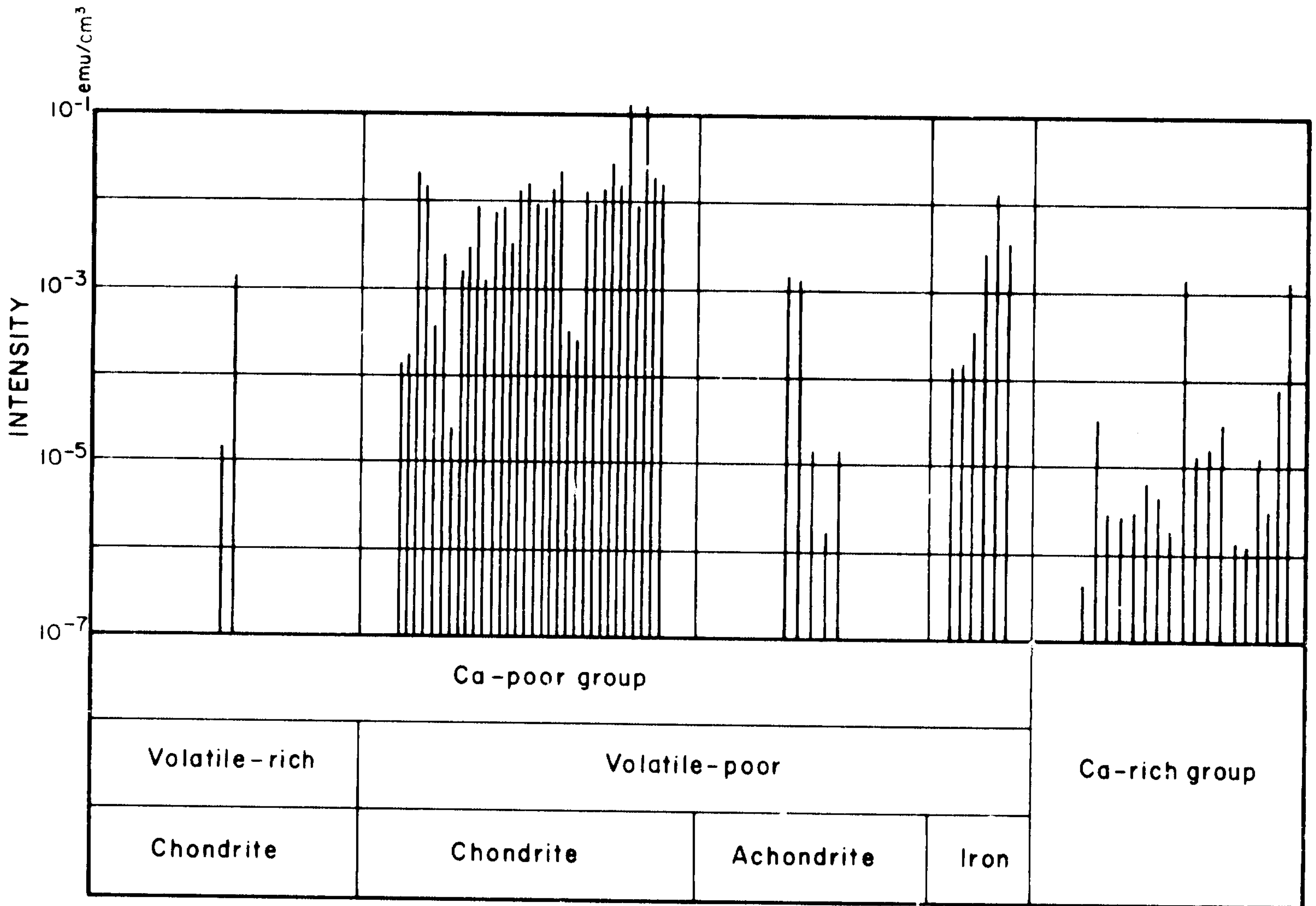

Figure 1.--Remanent magnetic intensities in meteorites.

PRELIMINARY RESULTS OF SOME DEMAGNETIZATION STUDIES

Preliminary thermal demagnetization and artificial thermoremanent magnetism (TRM) studies were carried out on the Murray carbonaceous chondrite (Type II of Wiik, 1956). Magnetic studies of the fresh ablation crust have shown that the chondrite's relatively strong remanence (table 1) resides in its crust, and thus that most of Murray's remanence may have been acquired during and immediately after its passage through the atmosphere. Within Murray the NRM is a low-temperature moment, similar to that reported for the Mokoia pigeonite chondrite by Stacey and others (1961). The low-temperature moment probably resides in the iron-rich hydrous matrix material that forms more than 80 percent of Murray. Paragenetic and textural relations (Elston, 1968) show that the matrix accumulated at low temperatures and pressures at the time of chondrite accretion.

Preliminary artificial TRM studies of pyroxene-plagioclase (eucrite) achondrite have shown that the remanent magnetism of this "basaltic" material is strengthened by cooling in the Earth's magnetic field. The low remanent moments in the pyroxene-plagioclase achondrites may, therefore, be of extraterrestrial origin.

DISCUSSION

The NRM data are intrinsically interesting because certain averages of NRM values appear to characterize individual meteorite classes and groups (table 3). Evaluation of the new NRM data (table 1) must await the results of additional studies of thermal demagnetization, artificial TRM, susceptibility, remanence associated with fusion crusts, and the effects of brecciation. Natural remanent magnetic moments in meteorites have been measured by Stacey and Lovering (1959), Lovering (1959), Stacey and others (1961), Weaving (1962), Gus'kova (1963), and DuBois (1965); all concluded that at least some of the moments studied are of extraterrestrial origin.

Thermal demagnetization experiments on two chondrites led

Stacey and Lovering (1959) to conclude that the remanence was induced in extraterrestrial fields that originated in the chondrite parent bodies. Furthermore, they suggested that the bodies had fluid conducting cores, or alternatively, that fluid cores are not necessary for the generation of magnetic fields of a terrestrial type.

Investigations by DuBois (1965) on oriented specimens of Canyon Diablo and Odessa octahedrites collected in the field have indicated a lack of correlation between the direction of natural remanent magnetism of _in situ_ irons and the direction of the Earth's field; such discordance may indicate that at least part of the remanent magnetism of these iron meteorites is of extraterrestrial origin.

Lovering (1959) considered that the Moore County eucrite probably acquired its remanent magnetization by cooling while still forming part of the outer mantle of its parent body. Preliminary res lts of our studies on eucrite material support Lovering's conclusion that remanence in the pyroxene-plagioclase achondrites is of extraterrestrial origin.

The NRM data (table 1), when assembled according to meteorite classes and Ga-Ge groups, appear to display some characteristic values of intensities (fig. 1, and table 3). The chondrites that exhibit the higher remanences are in classes that have greater average nickel-iron contents. The bronzite chondrites, about 18 weight percent nickel-iron, commonly exhibit stronger remanence than the hypersthene chondrites, about 8 weight percent nickel-iron. The lowest moments in chondrites may reside in the carbonaceous chondrites (Type II), as measured in a specimen of Mighei that lacks a well-developed fusion crust.

Characteristic although possibly partly overlapping ranges in values of remanence also may exist in the iron meteorites when they are arranged according to Ga-Ge groups. If the differences in remanence between individual volatile-poor chondrite classes and the Ga-Ge groups of irons were generated extraterrestrially, they may represent moments developed in the magnetic fields of different parent bodies.

Low to very low remanent moments were found in one hypersthene and two enstatite achondrites, which contain only very sparse metal. The lowest moments in the calcium-poor achondrites reside in the essentially iron-free enstatite achondrites. Relatively strong remanence was found in metal-free, calcium-poor pyroxene (hypersthene) extracted from the Bondoc Peninsula mesosiderite. This remanence approaches that of the hypersthene chondrites.

The calcium-rich pyroxene-plagioclase achondrites (eucrites and howardites) exhibit low to very low values of remanence. As in the hypersthene and enstatite achondrites, the low moments may be due to the presence of only small amounts of magnetic minerals, principally metal. The remanence of the Washougal howardite is higher than the remanence of the eucrites (table 1). Howardites are commonly more highly brecciated than eucrites, and they contain less metal. Urey and Craig (1953) reported that eight howardites contained an average of 0.45 weight percent nickel-iron, and that 13 eucrites contained 1.18 weight percent nickel-iron. The small specimen of howardite that was measured for remanence lacked both fusion crust and apparent metal. In contrast, the eucrites that were measured characteristically were partly enclosed by fusion crusts, and metallic nickel-iron was obviously present in several. Thus, the higher moment measured for Washougal cannot be attributed to metal, fusion crust, or the lack of brecciation. For this reason, there may be a real and significant difference in remanence between the howardites and eucrites.

The effects of brecciation need to be evaluated. Except for the Moore County eucrite and the diopside-olivine achondrite, Lafayette, all the calcium-rich achondrites listed in table 1 exhibit various degrees of brecciation. Brecciation that occurs after the acquisition of remanence can result in a diminution of remanence because fragmented materials carrying the remanence almost certainly become diversely oriented during brecciation. The value of remanence of the Moore County eucrite, which is essentially unbrecciated, is the highest of the eucrites (with the exception of Pasamonte No. 2, an unbroken specimen that displays an anomalously high remanence). The remanence of Moore County, however, is not much greater than that of several eucrites which are highly brecciated.

The high remanence of unbrecciated Lafayette may be representative of the diopside-olivine achondrites. It appears to be significantly greater than that of the pyroxene-plagioclase achondrites. The relative importance of the remanence that may reside in the narrow portion of fusion crust of the specimen that was measured, and the magnetic character of the interior material, will be investigated.

Because eucritic material acquires a stronger remanence when heated and cooled in the Earth's magnetic field, the pyroxene-plagioclase achondrites are inferred to have crystallized in a parent body whose magnetic field was substantially weaker than that of the Earth. The diopside-olivine achondrite, Lafayette, may have crystallized in a stronger magnetic field than that associated with the formation of the magnetism of the pyroxene-plagioclase achondrites, and thus possibly in a different parent body.

Table 1.--Remanent magnetic intensities in meteorites

Source: 1, this report[a/]; 2, Stacey and others (1961); 3, Lovering (1959); 4, Gus'kova (1963); 5, DuBois (1965)

Class Type Name (specimen no. and weight)	Intensity (emu/cm^3)	Source
Carbonaceous		
Chondrite		
Mighei	1.5×10^{-5}	1
Murray (635.1; 24.82 g)	1.2×10^{-3}	1
Olivine pigeonite		
Chondrite		
Karoonda	1.3×10^{-4}	1
Mokoia[b/]	$\sim 2.5 \times 10^{-4}$	2
Mokoia	3.4×10^{-2}	1
Olivine hypersthene		
Chondrite		
Chateau-Renard	1.4×10^{-2}	4
Farmington (48.5; 9.6 g)	6.0×10^{-4}	1
Farmington	$\sim 2.8 \times 10^{-3}$	2
Holbrook No. 1 (M819; 336.4 g)	2.9×10^{-5}	1
Holbrook No. 2 (8338; 41.53 g)	1.2×10^{-3}	1
Holbrook No. 3 (8338; 25.15 g)	4.8×10^{-3}	1
Homestead	$\sim 9.1 \times 10^{-3}$	2
Homestead (M822; 409 g)	1.0×10^{-3}	1
L'Aigle	8.1×10^{-3}	4
Mocs	8.8×10^{-3}	4
Mordvinovka[c/]	5.6×10^{-3}	4
Rakovka	1.1×10^{-2}	4
Saratov No. 1	2.1×10^{-2}	4
Saratov No. 2	9.8×10^{-3}	4
Sevryukovo	8.8×10^{-3}	4

Table 1.--Remanent magnetic intensities in meteorites--continued

Class Type Name (specimen no. and weight)	Intensity (emu/cm^3)	Source
Olivine hypersthene--Continued		
Chondrite--Continued		
Slobodka	1.4×10^{-2}	4
Zavetnoye	3.5×10^{-2}	4
Achondrite		
Bondoc pyroxene (3.8 g)	1.9×10^{-3}	1
Bondoc pyroxene (2.6 g)	1.3×10^{-3}	1
Johnstown (125.5x)	1.8×10^{-5}	1
Iron (Ga-Ge group II)[d/]		
Mt. Stirling[e/] (coarse octahedrite)	1.6×10^{-4}	3
Olivine bronzite		
Chondrite		
Beardsley (19; 54.525 g)	4.8×10^{-4}	1
Borodino	3.7×10^{-4}	4
Mt. Browne[f/]	$\sim 1.0 \times 10^{-2}$	2
Okhansk No. 1	9.9×10^{-3}	4
Okhansk No. 2	1.4×10^{-2}	4
Okhansk No. 3	4.4×10^{-2}	4
Pultusk No. 1	2.0×10^{-2}	4
Pultusk No. 2	1.1×10^{-1}	4
Pultusk (M-821; 36.30 g)	9.6×10^{-4}	1
Ställdalen	1.1×10^{-1}	4
Zhovtnevyy Khutor No. 1350	2.9×10^{-2}	4
Zhovtnevyy Khutor No. 199	2.2×10^{-2}	4
Pallasite (Ga-Ge group III)[d/]		
Bendock (metal phase only; 9.20 percent Ni)[g/]	7.0×10^{-4}	3

Table 1.--Remanent magnetic intensities in meteorites--Continued

Class Type Name (specimen no. and weight)	Intensity (emu/cm^3)	Source
Olivine bronzite--Continued		
Iron (Ga-Ge group III and IV)[d/]		
Kyancutta (medium octahedrite; 8.28 percent Ni)	2.2×10^{-4}	3
Mungindi No. 2 (fine octahedrite; 12.36 percent Ni)	6.0×10^{-4}	3
Santa Catharina (Na-rich ataxite; 33.60 percent Ni)	4.4×10^{-3}	3
Enstatite		
Achondrite		
Norton County	2.9×10^{-6}	1
Peña Blanca (509.1)	2.9×10^{-5}	1
Iron (Ga-Ge group I)[d/]		
Canyon Diablo (octahedrite; 10 specimens)	$1.5\text{-}28.4 \times 10^{-3}$; avg. 1.16×10^{-2}	5
Odessa (octahedrite; 14 specimens)	$2.6\text{-}19.4 \times 10^{-3}$; avg. 6.6×10^{-3}	5
Calcium-rich achondrites		
Pyroxene-plagioclase		
Pigeonite-anorthite (eucrite)		
Juvinas (65; 22.31 g)	6.9×10^{-7}	1
Moore County	5.0×10^{-5}	3
Moore County (294.a; 42.21 g)	4.2×10^{-6}	1
Pasamonte No. 1a (197; 17.67 g)	4.1×10^{-6}	1
Pasamonte No. 1b (197; 11.30 g)	4.7×10^{-6}	1

Table 1.--Remanent magnetic intensities in meteorites--Continued

Class Type Name (specimen no. and weight)	Intensity (emu/cm^3)	Source
Calcium-rich achondrites--Continued		
Pyroxene-plagioclase--Continued		
Pigeonice-anorthite (eucrite)--Continued		
Pasamonte No. 1c (197; 41.91 g)	7.9×10^{-6}	1
Pasamonte No. 1d (197; 63.9 g)	6.5×10^{-6}	1
Pasamonte No. 1e (197; 8.8 g)	2.6×10^{-6}	1
Pasamonte No. 2[h/] (197.55; 104.00 g)	1.5×10^{-3}	1
Pasamonte No. 3 (197.84; 116.03 g)	1.2×10^{-5}	1
Pasamonte No. 4 (197.98; 41.94 g)	2.8×10^{-5}	1
Pasamonte No. 5 (197uu; 37.0 g)	4.8×10^{-5}	1
Sioux County No. 1 (198.8; 164.16 g)	1.5×10^{-6}	1
Sioux County No. 2 (53.60 g)	1.1×10^{-6}	1
Sioux County No. 3 (198a; 206.85 g)	1.1×10^{-5}	1
Stannern (15.43 g)	5.3×10^{-6}	1
Hypersthene-anorthite (howardite)		
Washougal	8.5×10^{-5}	1
Diopside-olivine (nakhlite)		
Lafayette (23.60 g)	1.6×10^{-3}	1

[a] Values of remanence, which were determined in emu/gm, were converted to emu/cm^3 by using values of specific gravity in Wood (1963, table 3). Specific gravity data for Murray are from Horan (1953); for Karoonda, Mighei, and Mokoia from Mason (1963a); and for Norton County from Beck and La Paz (1951). Ordinary chondrites were assigned to the bronzite and hypersthene classes on the basis of Fe_2SiO_4 contents of their olivine as reported by Mason (1963b). Specimens are in collections at Arizona State University, Tempe, and the University of Arizona, Tucson.

[b] Stacey and others (1961) reported that the remanent moment disappears at 200° C., and they interpreted it as an isothermal moment that was induced in the Earth's field. From paragenetic and textural studies on Murray and Mokoia (Elston, 1968), we conclude that "low-temperature" hydrated iron-rich carbonaceous material, which encloses and is included in "accretionary" chondrules, contains the observed low-temperature remanence.

[c] Classification as a hypersthene chondrite uncertain.

[d] Ga-Ge group assignments are from data in Lovering and others (1957). The groups are correlated with the various chondrite classes for reasons discussed by Elston (1967, 1968).

[e] Ga-Ge group II is indicated on basis of Ga content, but Ga-Ge group I on basis of Ge content (Lovering and others, 1957).

[f] Referred to as a bronzite chondrite by Anders (1964).

[g] Ga-Ge group III; Lovering and others (1957).

[h] The reason for the anomalously high value is unknown. It may be the result of the presence of a large fragment of metal in the breccia within this unbroken specimen, or it may be a low-temperature isothermal moment that was artificially induced by magnetic "testing" of this meteorite during its early handling, or both.

Table 2.--Suggested genetic classification of the meteorites (adapted from Elston, 1967, 1968)

		CHONDRITE (Ni-Fe)[1/]	ACHONDRITE	STONY-IRON	IRON
Calcium-poor	Volatile-rich	Carbonaceous (0.15)	Carbonaceous	----------	----
Calcium-poor	Volatile-poor	Pigeonite (5)	Chassignite Pigeonite	----------	----
Calcium-poor	Volatile-poor	Hypersthene (8)	Hypersthene	Siderophyre	Ga-Ge II
Calcium-poor	Volatile-poor	Bronzite (19)	Bronzite	Pallasite (Ga-Ge III) Lodranite	Ga-Ge III Ga-Ge IV(?)
Calcium-poor	Volatile-poor	Enstatite (21)	Enstatite	?	Ga-Ge I
Calcium-rich	Volatile-poor	----------	Pyroxene-plagioclase Diopside-olivine Augite	----------	----

1/ Approximate average weight percent from data in Wiik (1956), Wood (1963), and Mason (1965).

Table 3.--Summary of average values of remanent magnetism in various meteorite classes

Class/Type	Intensity (emu/cm^3)	Number Used In Estimate
Carbonaceous chondrite	1.5×10^{-5}	1
Olivine pigeonite		
Chondrite	1.9×10^{-4} a/	3
Olivine hypersthene		
Chondrite	9.2×10^{-3}	17
Achondrite	1.1×10^{-3}	3
Iron (Ga-Ge group II)	1.6×10^{-4}	1
Olivine bronzite		
Chondrite	3.1×10^{-2}	12
Pallasite	7.0×10^{-4}	1
Iron (Ga-Ge group III)	4.1×10^{-4}	2
Iron (Ga-Ge group IV)	4.4×10^{-3}	1
Enstatite		
Achondrite	1.6×10^{-5}	2
Iron (Ga-Ge group I)	8.7×10^{-3}	24
Calcium-rich achondrites		
Pigeonite-anorthite	1.2×10^{-5} b/	15
Hypersthene-anorthite	8.5×10^{-5}	1
Diopside-olivine	1.6×10^{-3}	1

a/ This value excludes one specimen of Mokoia.

b/ This value excludes Pasamonte No. 2.

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