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Magnetic study of meteorites recovered in the Atacama desert (Chile): Implications for meteorite paleomagnetism and the stability of hot desert surfaces

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ABSTRACT

We conducted a detailed paleomagnetic study of 18 ordinary chondrites recovered in a hot desert (the Atacama desert, Chile) to clarify the significance of the natural remanent magnetizations of weathered meteorites. We show that the more weathered meteorites (weathering grade W3) possess a stable magnetization unblocked over two temperature intervals (140–320 °C, and 500–550 °C). This magnetization was acquired on Earth as indicated by the paleomagnetic directions of large meteorites (>150 g) that are in the direction of the terrestrial field. Rock magnetic data suggest that this stable magnetization is a chemical remanent magnetization acquired by maghemite and magnetite upon their formation as weathering products. On the other hand, the natural remanent magnetization of ordinary chondrites showing little or no weathering (weathering grades W0 and W1) are much weaker, and very unstable upon demagnetization, a similar behavior to the magnetization of meteorite falls. Therefore, up to the weathering grade W1, weathering does not largely overprint the original extraterrestrial magnetization of these meteorites. This is confirmed at microscopic scale by magnetic imaging: tetrataenite and kamacite have randomly oriented magnetization at mineral scale that is canceled out at larger scale (>1 mm^3), whereas a small fraction of the weathering products has a weak but unidirectional magnetization that masks the weak extraterrestrial magnetization. This suggests that extraterrestrial magnetization can survive mild weathering (below weathering grade W2), and that such meteorites remain worthwhile targets for study of extraterrestrial paleomagnetism. For meteorites with weathering grade W3 or more, the extraterrestrial signal can only be studied at microscopic scale. These data also show that over a time scale of several kyr to several tens of kyr, large stones (>150 g) have remained still at the surface of the Atacama desert whereas smaller ones have moved only by rotation around vertical axes, evidencing the fine scale stability of this desertic surface.

1. Introduction

Meteorite paleomagnetism is a unique source of information about the ancient magnetic fields in the solar system (e.g., Weiss et al., 2010). However, after the fall of a meteorite on Earth, the magnetic carriers of meteorites, which are FeNi metallic alloys in most cases, start weathering, which may hinder the measurement and interpretation of their paleomagnetic record. The best solution to this problem is to work on freshly fallen meteorites (e.g., Gattacceca et al., 2003), though the opportunity is rare. Another solution is to work on meteorites that were collected soon after their witnessed fall and have since been curated in museums (these meteorites are called "falls"). However, falls account for only 3% of the total number of known meteorites, and some meteorite groups are poorly or not at all represented by falls. For instance, there are no falls for lunar meteorites, CH3 chondrites, or brachinites, a single one for angrites or Rumuruti chondrites, two for CK chondrites, three for CR chondrites, etc. On the other hand, meteorites found a long time after their fall (up to several tens or hundreds of ka, e.g., Jull, 2006) account for 97% of the whole meteorite collection. These meteorites are called "finds". Most meteorite finds in collection come from Antarctica (72%), and from hot deserts (24%; mostly from Sahara, Arabic peninsula, Australia, and southwestern USA).

Meteorite finds are therefore potentially an important source of paleomagnetic information. However, there are possibilities of overprinting of the original extraterrestrial magnetization by secondary terrestrial magnetizations through weathering of the initial magnetic carriers, crystallization of ferromagnetic weathering products, or acquisition of viscous magnetization during long-term stay in the Earth's magnetic field. In most meteorites, the

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Table 1
Magnetic properties and paleomagnetism of meteorites from the Atacama desert.

								Stable component during AF demag										
	Group	Mass (g)	Age (kyr)	Ox% (vol%)	NRM$_0$ (A m^2/kg)	NRM$_{6mT}$ (A m^2/kg)	SIRM (A m^2/kg)	AF range (mT)	Intensity (A m^2/kg)	Direction Decl./Incl.	α_{95}	n	REM' ($\times10^{-3}$)	M_r/M_{rs} ($\times10^{-3}$)	B_c (mT)	B_{cr} (mT)	S_d (Am^2/(kg T log$_{10}$s))	VRM/NRM (%)
W0–1 find																		
SJ031	L3	218	–	3	3.51E−4	7.24E−5	5.49E−2	Unstable						5.6	1.3	13.7	8.90E−2	7
SJ028	H5	151	–	14	4.91E−4	6.01E−4	4.01E−1	Unstable						13	1.29	60.07	–	10
SJ024	L6	15.2	–	15	4.83E−4	4.25E−4	7.08E−2	Unstable						12.0	2.7	23.7	2.01E−1	15
SJ030	H5	25.5	–	18	2.50E−3	6.38E−4	3.19E−1	Unstable						15	2.13	34.44	–	2
W2 find																		
SJ019	L6	68.9	7.3±1.3	23	5.96E−4	5.78E−4	8.01E+0	Unstable						14.0	1.8	14.9	1.69E−1	7
SJ015	L6	349	39.8±10	28	1.03E−1	1.02E−1	6.51E+0	16–100	8.13E−2	299/−32	8.3	3	420	4.6	6.3	45.6	–	0
PdM-14	H4	3650	–	28	1.29E−4	1.30E−4	1.30E−1	0–80	1.02E−4	17/−34	–	1	0.45	45	14.4	208	–	36
SJ048	H5	10.6	–	33	3.20E−3	4.86E−4	5.76E−1	Unstable						27	3.48	24.99	–	2
SJ011	H4	33.7	11.2±1.8	36	1.04E−3	1.17E−3	–	12–90	6.10E−4	215/−19	–	1	–	–	–	–	–	4
SJ026	L6	*94*	–	46	7.04E−4	1.99E−4	1.49E−1	Unstable						26.0	7.6	106.6	1.04E−1	5
W3 find																		
SJ029	H3	399	13.9±1.5	50	3.41E−3	3.15E−4	2.14E−1	12–55	1.06E−4	5/−52	–	1	1.35	–	–	–	–	1
SJ017	H6	56.4	17.5±2.0	67	1.13E−3	1.30E−3	7.75E−1	14–90	8.48E−4	76/4	53.9	3	4.98	85.0	9.3	29.2	2.33E−1	6
SJ036	L6	27.6	–	67	6.37E−4	1.37E−4	2.40E−1	36–120	2.10E−5	137/4	–	1	0.53	33	8.9	247.8	–	7
SJ014	L6	134	32.2±6.2	68	9.96E−4	2.87E−4	2.05E−1	6–120	2.20E−4	38/−8	8.3	3	2.46	38	9.2	190.7	–	5
SJ005	H6	*50*	37.8±17	71	8.65E−4	2.62E−3	5.08E−1	18–90	1.29E−3	232/−57	10.3	3	3.19	227.0	13.7	25.8	1.90E−1	2
SJ021	H4	174	20.6±2.2	73	3.58E−3	3.06E−3	2.81E−1	15–90	1.29E−3	3/−29	14.4	4	4.96	130.0	9.0	19.8	1.90E−1	1
SJ039*	L6	38.5	–	79	6.57E−4	5.84E−4	3.53E−1	18–120	3.33E−4	–	–	1	1.87	69	9.3	28	–	7
PdM-13	H6	46	–	96	7.01E−3	5.67E−3	–	20–100	3.17E−3	137/4	–	1	–	172	14.1	28.7	–	1

When the meteorite was found in several fragments, the mass (in italics) is the mass of the studied fragment. Terrestrial ages are from Gattacceca et al. (2011). Ox% is the ratio oxide/(oxide + metal + troilite) derived from image analyses and point counting. S_d is the VRM decay constant normalized by mass and applied field. The ratio VRM/NRM is estimated from the terrestrial age and S_d. We use 40 kyr for samples without age, and the average Sd for samples without VRM experiments.

*Sample SJ039 was not oriented when collected in the field.