Physics of the Earth and Planetary Interiors 187 (2011) 292–300

Contents lists available at ScienceDirect

Physics of the Earth and Planetary Interiors

journal homepage: www.elsevier.com/locate/pepi

Origin of stable remanent magnetization in LL6 chondrite, St. Séverin

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ARTICLE INFO

Article history:
Received 9 December 2010
Received in revised form 8 June 2011
Accepted 8 June 2011
Available online 22 June 2011

Edited by: Keke Zhang

Keywords:
Chondrite
Meteorite
St. Séverin
Tetrataenite
Taenite
Kamacite

ABSTRACT

Thermal demagnetization has been carried out on 20 mutually oriented chips to unravel the stable paleomagnetic record of LL6 St. Séverin. Whereas the higher unblocking fractions (520–560 °C) of natural remanent magnetization (NRM) are directionally scattered, the lower unblocking fractions (<520 °C) are relatively well constrained along a great circle in a stereographic projection. Microscopic analysis revealed St. Séverin to contain paramagnetic troilite and a ferromagnetic Fe–Ni system. A sharp unblocking around 560 °C during thermal demagnetization strongly indicates that tetrataenite is the sole NRM carrier in St. Séverin. The absence of kamacite contribution on NRM and the presence of a scattered higher unblocking fraction (520–560 °C) of NRM imply a sequence of brecciation and a shock-induced metamorphism rather than a thermal origin of NRM.

1. Introduction

To precisely decipher the early stage evolution of the solar system, mineral magnetic investigation is useful in constraining the cooling or metamorphic history of chondritic planetary bodies. Meteorites often contain stable natural remanent magnetization (NRM) of various origins (Stacey et al., 1961; Brecher et al., 1977; Collinson, 1987; Collinson and Morden, 1994; Weiss et al., 2008). Intensive cataloguing and systematic data compilation significantly have improved our understanding of the meteorite magnetism (e.g., Rochette et al., 2003, 2008, 2009a,b; Weiss et al., 2010). Among various types of undifferentiated ordinary chondrites, the LL chondrites have drawn special attention because of their similarity to terrestrial igneous rocks such as relatively poor metal contents, high magnetic stability, and equilibrated mineralogy resulting from a slow cooling (e.g., Rochette et al., 2003).

The LL6 St. Séverin meteorite fell to Earth on June 27, 1966. Five major pieces with a combined total weight of 221 kg were recovered in northern France (latitude: 45°18′N, longitude: 0°14′E). A shock stage S2 (Stöffler et al., 1991) and weathering grade W0 (Wlotzka, 1993) were assigned. Among many LL chondrites, LL6 St. Séverin was used in the present study for two reasons. First, it is one of the few meteorites whose crystallization age has been reliably determined by various radiometric dating techniques, including Pb-Pb (4543 ± 19 Ma, Manhes et al., 1978; 4559 ± 15 Ma, Chen and Wasserburg, 1981; 4553.6 ± 0.7 Ma, Göpel et al., 1994; 4554.9 ± 0.2 Ma, Bouvier et al., 2007), Sm–Nd (4550 ± 330 Ma, Jacobsen and Wasserburg, 1981), Rb–Sr (4510 ± 150 Ma, Dalrymple, 1991), Re–Os (4680 ± 150 Ma, Chen et al., 1998), and Ar–Ar (4430 ± 40 Ma, Dalrymple, 1991). Second, a few previous paleomagnetic investigations have yielded somewhat contradicting outcomes. For example, at an individual specimen level, alternating-field (AF) demagnetization of St. Séverin showed a stable component with a median destructive field (MDF) of 15 mT (Brecher and Ranganayaki, 1975). However, within-specimen comparison failed to link the homogeneity of NRM with MDF > 50 mT in other chips (Brecher et al., 1977). Extremely AF-resistant NRM of St. Séverin was also reported in Sugiura (1977). On the basis of thermomagnetic analysis, it has been suggested that the coexistence of kamacite and tetrataenite is responsible for the extremely high-coercivity fraction of St. Séverin with MDF ∼100 mT (Nagata, 1982). Acquisition of thermoremanent magnetization (TRM) or thermochemical remanent magnetization was considered the origin of the high-coercivity NRM of St. Séverin (Nagata and Funaki, 1982). On the contrary, at least some NRM fractions of St. Séverin were attributed to viscous remanent magnetization or shock-induced remanent magnetization (Morden and Collinson, 1992).

In spite of diverse opinions on the origin of St. Séverin's high-coercivity NRM, rock magnetic descriptions on the NRM carriers are rather similar. The Lowrie–Fuller test (Lowrie and Fuller, 1971) on St. Séverin revealed the presence of fine-grained

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doi:10.1016/j.pepi.2011.06.004

magnetic minerals (Ramana and Rao, 1996). In addition, microscopic observations identified various fine-grained phases, including tetrataenite, kamacite, troilite, and Fe-oxides (Ramana and Rao, 1996). Thermal demagnetization of St. Séverin indicated the dominance of tetrataenite with high heterogeneity in the NRM directions (Morden and Collinson, 1992). Despite the abundance of troilite, kamacite, and taenite, their contribution to NRM was unfavored in some studies (Nagata and Funaki, 1982; Morden and Collinson, 1992). On the basis of thermomagnetic curves and hysteresis behavior, Nagata and Carleton (1989) proposed tetrataenite as the major remanence carrier of St. Séverin. While the origin of the high-coercivity fraction remains disputed, the majority of investigations suggest that either tetrataenite and/or kamacite is the main NRM carrier of St. Séverin.

In the present study, the magnetic properties of LL6 St. Séverin are investigated to clarify diverse opinions on the origin of NRM. Because previous studies used only a limited number (at most four) of unoriented chondritic chips, twenty mutually oriented, millimeter-sized chips are used to check whether the magnetic heterogeneity is genuine in multi-specimens level. All the specimens undergo thermal demagnetization because some previous studies have revealed AF demagnetization to be inefficient (e.g., Nagata, 1982; Nagata and Funaki, 1982). It is common to observe that the extraterrestrial materials easily alter during heating (e.g., Fuller, 1974; Cisowski, 1986; Cisowski and Fuller, 1986; Yu and Gee, 2005). However, if successful, thermal demagnetization results are valuable for recognizing the magnetic phase (e.g., Morden and Collinson, 1992; Yu et al., 2009). In this study, twenty mutually oriented chips from LL6 St. Séverin are subjected to stepwise thermal demagnetization. Scanning electron microscopy (SEM) and electron probing microscopic analysis (EPMA) are also conducted to identify potential magnetic phases.

2. Paleomagnetic analysis

Originally acicular chips of LL6 St. Séverin were cut with a diamond wire saw in an alcohol bath, first in two partial acicular slices along the elongated axis. Then each acicular slice was cut into

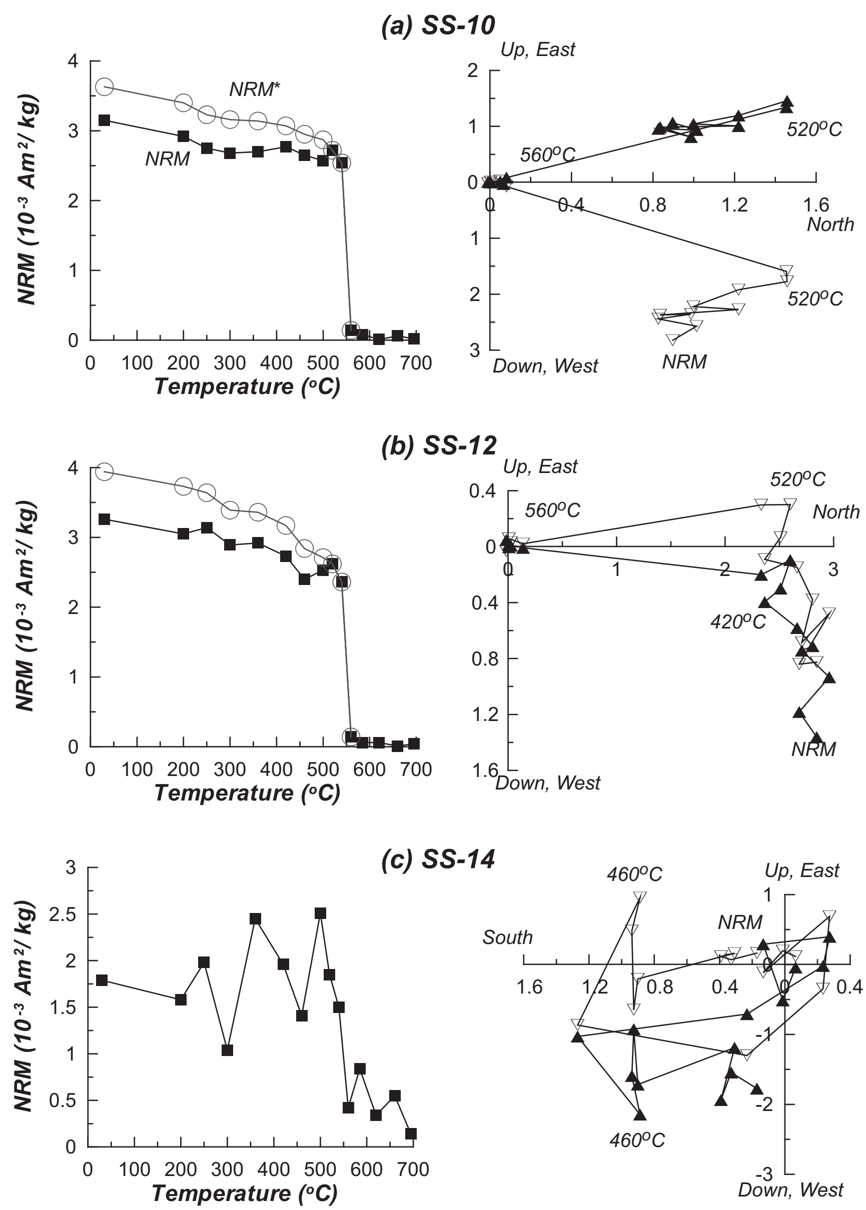

Fig. 1. Thermal demagnetization of (a) SS-10, (b) SS-12, and (c) SS-14. Natural remanent magnetization* (NRM*) was calculated by projecting the low-coercivity fractions towards the direction of high-coercivity remanences. Solid and open triangles represent north versus east and north versus up, respectively.