A New Spinel in Martian Meteorite SaU 008: Implications for Martian Magnetism

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Abstract: Martian meteorites are the only available Martian Materials on Earth. A suite of demagnetization experiments, temperature dependence of saturation magnetization, scanning electron microscopy, and electron microprobe analysis were carried out to characterize the remanent magnetization carriers of Martian meteorite SaU 008. A stable paleomagnetic record of SaU 008 originates from a newly found spinel ((Fe, Cr, Ti)-spinel) whose composition has never been documented (or identified as magnetic.)

Keywords: Spinel, Mars, SNC, Magnetism

1. INTRODUCTION

Mars currently shows no sign of a core-source magnetic field. The observed daily magnetic field on Martian surface is ~ 1 nT (Acuna et al., 2001), which is about four orders of magnitude smaller than the present-day geomagnetic field. Instead, anomalously strong surficial field (about 10 times stronger than the Earth surface) was observed on certain locations in Martian southern hemisphere (Acuna et al., 1999; Nimmo and Stevenson, 2000). Although magnetic anomalies within the southern highlands are large (~ 1000 nT), neither the Hellas nor the Argyle impact basins shows a surficial magnetic field > 100 nT at ~100 km altitude. The absence of crustal magnetism in large basins and their surroundings implies that the Mars dynamo had already ceased to operate when these impact basins were formed, about 3.9 Ga (Acuna et al., 1999). However, the exact timing on the onset and decay of Martian dynamo is still a matter of debate (Purucker et al., 2000; Schubert et al., 2000). For instance, previous relative age determination based on the surface-crater-countings is ambiguous, often yielding conflicting outcomes (Wyatt et al., 2001; Frey et al., 2002; Rogers and Christensen, 2003).

To date, Martian meteorites (known as SNC meteorites) are the only available Martian material on Earth. They provide pivotal information on the evolution of Martian dynamo, by implication, Martian tectonics in the past. Based on the rock types, SNCs are classified into four groups: Shergottites, Nakhlite, Chassignite, and Orthopyroxenite. Among these four types, Shergottites are the most abundant. Shergottites are subdivided to basaltic and lherzolic according to the mineral compositions. In particular, the basaltic shergottites are similar to terrestrial basalts consisting mostly of pyroxenes (augite and pigeonite) and relict plagioclase. The high degree of shock that the shergottites underwent at ejection from Mars changed the structure of the plagioclase into glass (known as maskelynite) (e.g., Nyquist et al., 2001).

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2. SAMPLES AND EXPERIMENTS

On November 26, 1999, a total of 9923 g of SaU 005/008 was collected at Sayh al Uhaymir desert, Oman (20°59.76'N, 57°19.55'E). Compared to other Shorgottites, SaU is unique because it shows the least terrestrial weathering (Gnos et al., 2002). In addition, SaU shows chemical composition somewhat between gabbros and peridotites, suggesting its plutonic origin (Gnos et al., 2002). The K/Ar crystallization age is 1.01 ± 0.11 Ga (Park et al., 2004). Amount of cosmogenic nuclei reaction is fossilized on meteorite depending on the duration of space-traveling time, known as exposure age. The exposure age of SNC is 1.27-1.50 Ma (Paetsch et al., 2000).

In the present study, three mm-sized meteorite chips and 20 individual opaque separates of SaU 008 was used. Conventional paleomagnetic demagnetization, intensive scanning electron microscopy (SEM), and electron microprobe analysis were carried out. In addition, temperature dependence of magnetization was monitored both at low-temperature (2-300 K) and high-temperature (20-700°C) ranges in order to precisely determine the magnetic properties.

3. RESULTS

Under the microscope, most of the augite grains are cumulus, some of the olivines are xenocrysts (i.e., grains carried into the melt from pre-existing mineral assemblages). Chromites are usually less than 50 microns and are located either within the olivine or in the mesostasis, similar to what has been previously documented in a sister meteorite SaU 005 (Zipfel, 2000; Brotoschewitz and Appel, 2003). Four opaque minerals were identified from SEM and electron microprobe analysis: Fe-sulfide, ilmenite, (Fe, Cr, Ti)-spinel, and (Cr,Fe)-spinel. Of these, ilmenite is paramagnetic, thus cannot contribute to the remanent magnetization. Composition of Fe-sulfide shows Fe/S ratio of 0.926. Note that Fe-sulfide is magnetic at room temperature for Fe/S ratio < 0.86. In addition, temperature dependence of saturation magnetization shows no low-temperature variation at 30-34 K, a hallmark for the presence of magnetic Fe-sulfide. Overall, we can safely exclude the possibility that ilmenite or Fe-sulfide contributes to the stable remanent magnetization in SaU 008.

Comparison of paleomagnetic data between the mother chip and 20 individual grains clarifies the magnetic carrier of SaU 008. Eight individual grains show virtually identical demagnetization trend to the mother chip. These eight chips show identical chemical composition of (Fe, Cr, Ti)-spinel, indicating that (Fe, Cr, Ti)-spinel is responsible for the stable paleomagnetic record of SaU 008 (Yu and Gee, 2005). It is noteworthy that (Fe, Cr, Ti)-spinel has never been reported on Earth as a stable paleomagnetic carrier.

4. DISCUSSIONS

Minerals in the spinel group have 32 oxygen ions and 24 cations in a single unit cell. Spinel compositions are usually plotted in a spinel prism where 6 end-members are chromite ($FeCr_2O_4$), hercynite ($FeAl_2O_4$), magnesiochromite ($MgCr_2O_4$), magnesioferrite ($MgFe_2O_4$), magnetite (Fe_3O_4), and spinel ($MgAl_2O_4$). Of the end member spinel compositions, it has been documented that two end members (Fe_3O_4 and $MgFe_2O_4$) are magnetic. While the observed data suggest that the (Fe, Cr, Ti)-spinel is responsible for the stable remanence in Sau 008, we lack detailed knowledge about the magnetic properties of intermediate composition in solid-solution series. Thus, investigating the detailed mineralogical and magnetic properties of intermediate compositions of spinel is an urgent request.

Retrieving information on the ancient planetary magnetic field is essential in understanding the evolution of planets and asteroids in solar system. Despite such merit, magnetic studies on meteorites remain relatively unpopular and unsuccessful. Such scarcity mainly results from the fact that meteorites are easy to alter and they are subject to stringent curation regulation (Yu, 2006). For instance, a newly identified (Fe, Cr, Ti)-spinel shows chemical alteration on heating at > 350°C (Yu and Gee, 2005). Another obstacle in meteoritic investigation is an instrumental limitation. For example, a single-crystal or single-chip often yields a weak magnetic signal, requires a delicate modification of conventional instrument (Yu et al., 2007).

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