Magnetite plaquettes are naturally asymmetric materials in meteorites

Queenie H.S. Chan1,*, Michael E. Zolensky1, James E. Martinez2, Akira Tsuchiyama3, and Akira Miyake3

1ARES, NASA Johnson Space Center, Houston, Texas 77058, U.S.A.
2Jacobs Engineering, Houston, Texas 77058, U.S.A.
3Graduate School of Science, Kyoto University, Kitashirakawa Oiwake-cho, Sakyo-ku, Kyoto 606-8502, Japan

ABSTRACT

Life on Earth shows preference toward the set of organics with particular spatial configurations. Enantiomeric excesses have been observed for α-methyl amino acids in meteorites, which suggests that chiral asymmetry might have an abiotic origin. A possible abiotic mechanism that could produce chiral asymmetry in meteoritic amino acids is their formation under the influence of asymmetric catalysts, as mineral crystallization can produce spatially asymmetric structures. Although magnetite plaquettes have been proposed to be a possible candidate for an asymmetric catalyst, based on the suggestion that they have a spiral structure, a comprehensive description of their morphology and interpretation of the mechanism associated with symmetry-breaking in biomolecules remain elusive. Here we report observations of magnetite plaquettes in carbonaceous chondrites (CC) that were made with scanning electron microscopy and synchrotron X-ray computed microtomography (SXRCT). We obtained the crystal orientation of the plaquettes using electron backscatter diffraction (EBSD) analysis. SXRCT permits visualization of the internal features of the plaquettes. It provides an unambiguous conclusion that the plaquettes are devoid of a spiral feature and, rather that they are stacks of individual magnetite disks that do not join to form a continuous spiral. Despite the lack of spiral features, our EBSD data show significant changes in crystal orientation between adjacent magnetite disks. The magnetite disks are displaced in a consistent relative direction that lead to an overall crystallographic rotational mechanism. This work offers an explicit understanding of the structures of magnetite plaquettes in CC, which provides a fundamental basis for future interpretation of the proposed symmetry-breaking mechanism.

Keywords: Magnetite, plaquettes, carbonaceous chondrites, symmetry-breaking, scanning electron microscopy, SEM, electron backscatter diffraction, EBSD, synchrotron X-ray computed microtomography, SXRCT, aqueous alteration, crystal structure

INTRODUCTION

Magnetite (Fe₃O₄), present in most carbonaceous chondrites (CC), has been shown to be an effective catalyst for the formation of the amino acids that are commonly found in these same meteorites (Pizzarello 2012). Magnetite sometimes takes the form of “plaquettes,” or “platelets,” first described by Jedwab (1967). This form consists of barrel-shaped stacks of magnetite disks, with an apparent feature of dislocation-induced spiral growth, that seem to be connected at the center, thus resembling a spiral. Although magnetite plaquettes have been studied for over 50 yr, and the spiral morphology of magnetite has been assumed in many studies (Jedwab 1971; Hua and Buseck 1998), a widely accepted description of the structure and morphology of this particular magnetite form is lacking. However, a detailed description is necessary to confirm or disprove the spiral configuration.

Magnetite plaquettes have been found in various CC, typically in the most carbon-rich Ivuna-like (CI) chondrites, and also in the Renazzo-like (CR) chondrites, ungrouped type 2 carbonaceous chondrites (C2) Tagish Lake and Essebi, and sometimes in unusual Mighei-like (CM) chondrites (for example, Bells; M. Zolensky, personal communication) (Weisberg et al. 1993; Zolensky et al. 1996b, 2002; Hua and Buseck 1998; Greshake et al. 2005). Magnetite does not occur as plaquettes in meteorites from other chondrite classes (e.g., CO, CV, CK, etc.) that show little or no aqueous alteration. The only report of magnetite plaquettes in a CV chondrite was for CV2 MIL 090001 (Keller and Walker 2011), which was later re-classified as a CR2 chondrite based on its whole-rock oxygen isotopic composition (Keller et al. 2012). Magnetite was originally suggested to have formed as a condensate from nebular vapor (Jedwab 1967). However, Kerridge et al. (1979) proposed that the platy morphology of magnetite plaquettes is controlled by nucleation during aqueous alteration on a parent body. A similar conclusion was drawn by Bradley et al. (1998), who observed similar epitaxial growth of magnetite with secondary carbonates. Magnetite in these chondrites often replaces Fe sulfides (Zolensky et al. 1996a; Lipschutz et al. 1999; Trigo-Rodriguez et al. 2013), frequently as pseudomorphs. For example, magnetite framboids replace euhedral pyrrhotite in Tagish Lake, indicating late-stage oxidation (Zolensky et al. 2002; Izawa et al. 2010). Framboidal and acicular magnetite also occurs adjacent to pyrrhotite, and the crystal relationship...