Petrogenesis of martian sulfides in the Chassigny meteorite

JEAN-Pierre Lorand1,*†, Sylvain Pont2, Vincent Chevrier3, Ambre Luguet4, Brigitte Zanda2, and Roger Hewins2

1Laboratoire de Planétologie et Géodynamique à Nantes, CNRS UMR 6112, Université de Nantes, 2 Rue de la Houssinère, BP 92208, 44322 Nantes Cédex 3, France
2Institut de Minéralogie, de Physique des Matériaux, et de Cosmochimie (IMPMC)—Sorbonne Université, Muséum National d’Histoire Naturelle, UPMC Université Paris 06, UMR CNRS 7590, IRD UMR 206, 61 rue Buffon, 75005 Paris, France
3W.M. Keck Laboratory for Space and Planetary Simulation, Arkansas Center for Space and Planetary Science, MUSE 202, University of Arkansas, Fayetteville, Arkansas 72701, U.S.A.
4Rheinische Friedrich-Wilhelms-Universität Bonn, Steinmann Institut für Geologie, Mineralogie und Paläontologie, Poppelsdorfer Schloss, 53115 Bonn, Germany

ABSTRACT

The Chassigny meteorite, a martian dunite, contains trace amounts (0.005 vol%) of Fe-Ni sulfides, which were studied from two polished mounts in reflected light microscopy, scanning electron microscope (SEM), and electron microprobe (EMP). The sulfide phases are, by decreasing order of abundance, nickeliferous (0–3 wt% Ni) pyrrhotite with an average composition M_{68.10.01}S (M = Fe+Ni+Co+Cu+Mn), nickeliferous pyrite (0–2.5 wt% Ni), pentlandite, millerite, and unidentified Cu sulfides. Pyrrhotite is enclosed inside silicate melt inclusions in olivine and disseminated as polyhedral or near spherical blebs in intergranular spaces between cumulus and postcumulus silicates and oxides. This sulfide is considered to be a solidification product of magmatic sulfide melt. The pyrrhotite Ni/Fe ratios lie within the range expected for equilibration with the coexisting olivine at igneous temperatures. Pyrite occurs only as intergranular grains, heterogeneously distributed between the different pieces of the Chassigny meteorite. Pyrite is interpreted as a by-product of the low-T (200 °C) hydrothermal alteration events on Mars that deposited Ca sulfates + carbonates well after complete cooling. The shock that ejected the meteorite from Mars generated post-shock temperatures high (300 °C) enough to anneal and rehomogenize Ni inside pyrrhotite while pyrite blebs were fractured and disrupted into subgrains by shock metamorphism. The negligible amount of intergranular sulfides and the lack of solitary sulfide inclusions in cumulus phases (olivine, chromite) indicate that, like other martian basalts so far studied for sulfur, the parental melt of Chassigny achieved sulfide-saturation at a late stage of its crystallization history. Once segregated, the pyrrhotite experienced a late-magmatic oxidation event that reequilibrated its metal-to-sulfur ratios.

Keywords: Mars, meteorite, Chassigny, sulfides, sulfur; Planetary Processes as Revealed by Sulfides and Chalcophile Elements

INTRODUCTION

Mars is an S-rich planet (King and McLennan 2010 and references therein). Oxidized sulfur is a major component of the martian regolith (up to 8 wt% SO2; Foley et al. 2003). Martian sulfates originated from magmatic degassing of SO2 (Tian et al. 2010; Kerber et al. 2015), although a minor contribution from acid weathering of pre-existing Fe sulfides is not unlikely (Dehouck et al. 2012). Owing to their much higher FeO contents, martian basalts are able to transfer twice as much S as dissolved FeS from the mantle to the martian crust compared to terrestrial basalts (Ding et al. 2015 and references therein).

Mars is the only telluric planet of the solar system that can also be studied from meteorites. More than 100 igneous rocks ejected from the martian crust are now available in our collections and are referred to as SNC meteorites, in addition to a few meteorites containing pieces of the lithology of the early martian crust (McSween and Treiman 1998; Treiman et al. 2000). SNC meteorites comprise hypovolcanic porphyritic basalts (shergottites), clinopyroxene cumulates (nakhlites), and dunite cumulates (chassignites) from extrusive flows (McSween 2001; McSween and McLennan 2014 and references therein). Studies of shergottites provided invaluable information on sulfur and sulfides in the interior of Mars. Accessory pyrrhotite was reported as the predominant Fe-sulfide, coexisting with pentlandite and chalcopyrite (Lorand et al. 2005; Gattacceca et al. 2013; Franz et al. 2014; Baumgartner et al. 2017a). It is well known that pyrrhotite phases are oxygen fugacity sensors because trivalent Fe3+ can balances the charge deficiency due the missing Fe2+ in the pyrrhotite structure (Pratt et al. 1994; Mycroft et al. 1995; Mikhlin and Tomashevic 2005; Skinner et al. 2004). The range of metal-to-sulfur atomic ratios (0.99 < M/S < 0.9 where M = divalent metals Fe, Ni, Co, Cu, Mn) published for shergottite