Chenmingite, FeCr$_2$O$_4$, in the CaFe$_2$O$_4$-type structure, a shock-induced, high-pressure mineral in the Tissint martian meteorite

Chi Ma$^{1,*}$, Oliver Tschauner$^2$, John R. Beckett$^1$, Yang Liu$^3$, Eran Greenberg$^4$, and Vitali B. Prakapenka$^4$

$^1$Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California 91125, U.S.A.
$^2$Department of Geoscience, University of Nevada, Las Vegas, Nevada 89154, U.S.A.
$^3$Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109, U.S.A.
$^4$GSECARS, University of Chicago, Argonne National Laboratory, Chicago, Illinois 60637, U.S.A.

ABSTRACT

Chenmingite (FeCr$_2$O$_4$; IMA 2017-036) is a high-pressure mineral, occurring as micrometer- to submicrometer-sized lamellae within precursor chromite grains along with xieite and Fe,Cr-rich ulvöspinel next to shock-induced melt pockets, from the Tissint martian meteorite. The composition of chenmingite by electron probe analysis shows an empirical formula of (Fe$_{0.73}$Mg$_{0.27}$Mn$_{0.02}$)($Cr_{1.60}$Al$_{0.29}$Fe$_{0.61}$Fe$_{0.05}$Ti$_{0.08}$)$_{2.03}$O$_4$. The general and end-member formulas are (Fe,Mg)(Cr,Al)$_2$O$_4$ and FeCr$_2$O$_4$. Synchrotron X-ray diffraction reveals that chenmingite has an orthorhombic $Pnma$ CaFe$_2$O$_4$-type (CF) structure with unit-cell dimensions: $a = 9.715(6)$ Å, $b = 2.871(1)$ Å, $c = 9.497(7)$ Å, $V = 264.6(4)$ Å$^3$, and $Z = 4$. Both chenmingite and xieite formed by solid-state transformation of precursor chromite under high pressure and high temperature during the Tissint impact event on Mars. The xieite regions are always in contact with melt pockets, whereas chenmingite lamellae only occur within chromite, a few micrometers away from the melt pockets. This arrangement suggests that chenmingite formed under similar pressures as xieite but at lower temperatures, in agreement with experimental studies.

Keywords: Chenmingite, FeCr$_2$O$_4$, high-pressure mineral, shock-induced phase, Tissint martian meteorite, shergottite

INTRODUCTION

The Tissint martian meteorite is a fresh, highly shocked, olivine-phyric shergottite (e.g., Baziotis et al. 2013; Ma et al. 2015, 2016). Around shock-generated melt pockets and veins in this meteorite, olivine is often transformed to ringwoodite or ahrensite and, in the immediate vicinity of the melt veins or pockets, to bridgmanite plus wüstite (Ma et al. 2016). Plagioclase is transformed to maskelynite, locally melted and partially crystallized to tissintite (Ma et al. 2015) and zagamite-stishovite assemblages. These responses to shock conditions on Mars provide clues to the nature of the ejection events for martian meteorites and to local shock conditions. Novel high-pressure minerals can narrow constraints on shock metamorphism in meteorites and the scale of impact events on their parent bodies. As natural phases, they contain minor chemical components that can guide experimental research about deep mantle mineralogy and provide constraints in assessing chemical or textual signatures that survive retrograde transformation in ultrahigh-pressure terrains.

Here, we describe a new high-pressure mineral chenmingite, FeCr$_2$O$_4$, with a $Pnma$ orthorhombic CaFe$_2$O$_4$-type (CF) structure. It occurs in Tissint within chromite grains in contact with shock melt pockets (Fig. 1). Chen et al. (2003a) first reported FeCr$_2$O$_4$-CF in the Suizhou meteorite along with xieite. It has also been synthesized at high pressures and moderate temperatures (e.g., Chen et al. 2003a; Ishii et al. 2014). Preliminary results of this work were given by Ma et al. (2018).

The mineral chenmingite (FeCr$_2$O$_4$; IMA 2017-036) has been approved by the Commission on New Minerals, Nomenclature and Classification of the International Mineralogical Association (Ma and Tschauner 2017). It is one of thirteen newly approved high-pressure minerals discovered in shocked meteorites since 2013 (Ma 2018). The name is in honor of Ming Chen, a cosmochemist and mineralogist at the Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, for his outstanding contributions to research on high-pressure mineralogy of meteorites, shock metamorphism, and terrestrial impact craters. Among his contributions is the discovery of natural FeCr$_2$O$_4$ with a CF structure and xieite (the natural CaTi$_2$O$_4$-type polymorph of chromite) in the Suizhou meteorite, a highly shocked L6 chondrite (Chen et al. 2003a, 2003b; 2008).

SAMPLE AND ANALYTICAL METHODS

The Tissint meteorite, which fell at Tata, Morocco on 18 July 2011, is a martian meteorite (olivine-phyric shergottite). The type material is in Tissint section UT2 deposited in the Meteorite Collection of the Frank H. McClung Museum at the University of Tennessee, Knoxville, Tennessee 37996, U.S.A. Section UT2 also hosts type ahrensite (IMA 2013-028; Ma et al. 2016) and type tissintite (IMA 2013-027; Ma et al. 2015). Tissint consists mostly of olivine (microphenocrysts and magneisian mackrocrysts with thin ferroan rims), pyroxene (mostly pigeonite with some subcalcic augites), maskelynite (An$_{30-40}$), with minor chromite and ilmenite, and accessory pyrrhotite, merillite, and magnetite. The meteorite contains scattered shock melt pockets and rare melt veins, and associated high-pressure phases.

Field-emission scanning electron microscope (SEM), electron backscatter diffraction (EBSD), electron probe microanalysis (EPMA), and synchrotron X-ray diffraction (SXRD) were used to characterize the composition, structure, and petrography of chenmingite and associated phases. Backscatter electron (BSE) imaging was performed using a Zeiss 1550VP field emission SEM. EBSD analyses were