

DISCOVERY OF CHENMINGITE, FeCr_2O_4 WITH AN ORTHORHOMBIC CaFe_2O_4 -TYPE STRUCTURE, A SHOCK-INDUCED HIGH-PRESSURE MINERAL IN THE TISSINT MARTIAN METEORITE. Chi Ma^{1,*}, Oliver Tschauner², John R. Beckett¹, Yang Liu³; ¹Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA; ²Department of Geoscience and High Pressure Science and Engineering Center, University of Nevada, Las Vegas, NV 89154, USA; ³Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA; *chi@gps.caltech.edu.

Introduction: The Tissint martian meteorite is a highly-shocked, olivine-phyric shergottite. Olivine is often transformed to ringwoodite or ahrensite and, in melt veins or pockets, to bridgmanite plus wüstite [1]. Plagioclase is transformed to maskelynite or even melted and partially crystallized to tissintite [2]. These responses to shock conditions on Mars provide clues to the nature of the ejection events for martian meteorites and to local shock conditions. Where new-to-science high-pressure phases are discovered, meteoritic occurrences can also inform the study of deep earth systems at high pressures and temperatures.

During an ongoing nanomineralogy investigation of the Tissint shergottite, we have discovered the new high-pressure minerals ahrensite [1] and tissintite [2]. Here, we report a third new high-pressure mineral from Tissint, FeCr_2O_4 with a *Pnma* orthorhombic CaFe_2O_4 -type (CF) structure. It occurs within chromite grains in contact with shock melt pockets (Figs. 1-3) and is named “chenmingite”. We characterized the composition, structure and petrography using high-resolution scanning electron microscope (SEM), electron back-scatter diffraction (EBSD), electron probe microanalysis (EPMA), and synchrotron X-ray diffraction (SXRD). The mineral and name have been approved by the Commission on New Minerals, Nomenclature and Classification of the International Mineralogical Association (IMA 2017-036) [3]. The name is in honor of Ming Chen, a cosmochemist and mineralogist at the Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, for his contributions to high-pressure mineralogy of meteorites, shock metamorphism and impact crater research. Among his contributions is the discovery of natural FeCr_2O_4 with a CF structure in the Suizhou meteorite, a moderately shocked L6 chondrite [4]. Synthetic FeCr_2O_4 with a CF structure has been synthesized at high pressures and moderate temperatures [e.g., 4,5].

Occurrence, chemistry, and crystallography: In Tissint, type chenmingite occurs in the interior of two chromite grains exposed to melt pockets (Fig. 1). Xieite (FeCr_2O_4 in a CaTi_2O_4 -type (CT) structure [e.g., 6]) and a previously unknown Fe,Cr,Ti-oxide with a bixbyite-related structure occur in the same chromite grains but these phases are in direct contact with shock melt pockets (Figs. 1-2), whereas the chenmingite is always in the interior of the host chromite. The shock

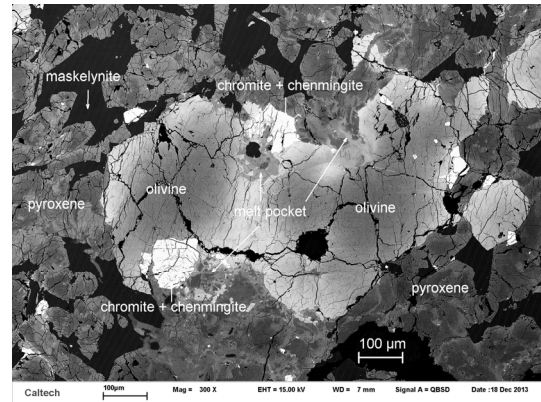


Fig. 1. Backscatter electron (BSE) image showing the chenmingite-bearing chromite grains next to shock melt pockets in Tissint.

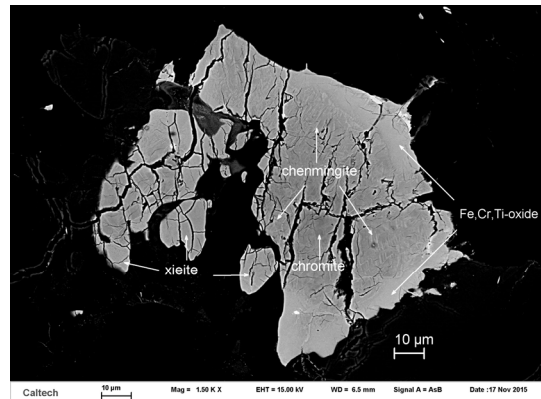


Fig. 2. Enlarged BSE image revealing chenmingite in chromite with xieite and Fe,Cr,Ti-oxide.

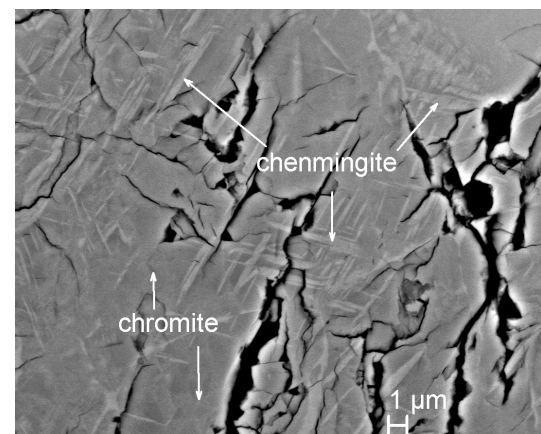


Fig. 3. Further enlarged BSE image showing chenmingite lamellae in chromite.

melt pockets are surrounded by olivine and ‘maskelynite’. The host rock consists mainly of pyroxene (mostly zoned pigeonite), ‘maskelynite’ (An₅₈₋₆₉), and olivine (typically ~Fa₃₀ but ranging from Fa₂₀ to Fa₆₀), with minor ilmenite and chromite and trace pyrrhotite, magnetite, and merrillite, plus melt pockets and veins.

Table 1. EPMA data for chenmingite.

| Constituent wt% | Chenmingite n=15 | SD |
|--------------------------------|------------------|------|
| Cr ₂ O ₃ | 57.49 | 0.45 |
| FeO | 28.68 | 1.41 |
| Al ₂ O ₃ | 7.05 | 0.11 |
| MgO | 4.37 | 0.99 |
| TiO ₂ | 0.70 | 0.05 |
| MnO | 0.62 | 0.03 |
| Total | 98.91 | |

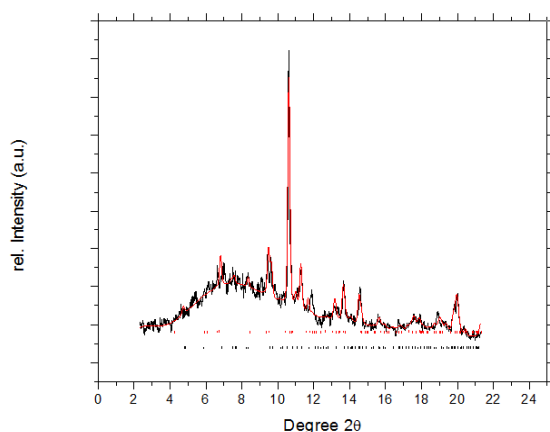


Fig. 4. SXR powder pattern of chenmingite and bixbyite-like Fe-oxide (black) and the corresponding modeled pattern (red), with tick marks indicating chenmingite (red) and Fe-oxide (black) reflections. The primary beam wavelength was 0.4959 Å.

Chenmingite occurs as lamellae, < 1 μm in width and up to 4 μm in length set in arrays within the host chromite (Fig. 3). Its composition (Table 1; SD = one standard deviation of the mean) gives rise to an empirical formula based on 3 cations and 4 oxygens *apfu* of $(\text{Fe}^{2+}_{0.75}\text{Mg}_{0.23}\text{Mn}_{0.02})(\text{Cr}_{1.60}\text{Al}_{0.29}\text{Fe}^{3+}_{0.06}\text{Fe}^{2+}_{0.04}\text{Ti}_{0.02})_{\Sigma 2.01}\text{O}_4$, where $\text{Fe}^{2+}/\text{Fe}^{3+}$ was defined by the ratio needed to produce the required stoichiometry. The composition of chenmingite is the same, within error, as the host chromite as is that of xieite from the same host grains. Chenmingite has a general formula of $(\text{Fe,Mg})(\text{Cr,Al})_2\text{O}_4$ and an end-member formula of FeCr_2O_4 . SXR, which was conducted on regions free

of xieite, reveals that chenmingite has the orthorhombic *Pnma* CF-type structure with unit cell: $a = 9.715$ (6) Å, $b = 2.87$ (1) Å, $c = 9.49$ (7) Å, $V = 264.6$ (4) Å³, and $Z = 4$ (Fig. 4). Chenmingite’s calculated density is 5.29 g/cm³, which is consistent with the density of material synthesized by [5]. Chenmingite is isotypic with harmunite (CaFe_2O_4).

Origin and significance: Phase relations for FeCr_2O_4 [5] show that chromite, the stable low pressure spinel-structured phase, breaks down to form $\text{Fe}_2\text{Cr}_2\text{O}_5$ plus eskolaite (Cr_2O_3) with increasing pressure (12-16 GPa, decreasing with increasing temperature). At higher pressures (16-18 GPa), this phase assemblage yields to single phase fields of CF-structured (lower temperature) and CT-structured (higher temperature) phases. In the end-member system, the CF and CT phases are quenchable but it is possible that the high Al_2O_3 content of the host chromite in Tissint also helped to stabilize these phases and enhanced their survival probability following shock.

The texture (Figs. 2-3) and EPMA analyses showing no significant difference in chemistry between host chromite and either xieite or chenmingite suggest that both chenmingite and xieite formed by solid state transformation from precursor chromite under high pressure and temperature during the Tissint impact event on Mars. These features are consistent with expectations based on phase relations for the FeCr_2O_4 system [5] provided that time at elevated pressure and temperature was insufficient to allow the nucleation and growth of eskolaite and $\text{Fe}_2\text{Cr}_2\text{O}_5$. It is also important to note that xieite regions (aggregate of sub-micrometer-sized crystals) are always in contact with melt pockets, whereas chenmingite lamellae only occur within chromite, a few μm away from the melt pockets. This arrangement suggests that chenmingite formed under similar pressures as xieite but at lower temperatures. Since CF- and CT-structured FeCr_2O_4 in Suizhou [4] display similar textural relationships, they are also consistent with comparable formation pressures but different temperature regimes. Since the structures of both xieite and chenmingite form channels that can accommodate large cations, they may also be significant carriers of trace elements in the Earth’s mantle.

References: [1] Ma C. et al. (2016) *Geochimica et Cosmochimica Acta* 184:240–256. [2] Ma C. et al. (2015). *Earth and Planetary Science Letters* 422:194–205. [3] Ma C. & Tshauer O. (2017) *Mineralogical Magazine* 81:1037. [4] Chen M. et al. (2003) *Proceedings of the National Academy of Sciences* 100:14651–14654. [5] Ishii T. et al. (2014) *American Mineralogist* 99:1788–1797. [6] Chen M. et al (2003) *Geochimica et Cosmochimica Acta* 67:3937–3942.