PHASE TRANSFORMATION MECHANISMS OF CA-MAJORITE IN THE SHOCKED VILLALBETO DE LA PEÑA ORDINARY CHONDRITE: CLUES TO COOLING PATHS IN SHOCKED METEORITES

M. Martínez-Jiménez[1] and A. J. Brearley[1], [1] Department of Earth & Planetary Sciences, The University of New Mexico, Albuquerque, NM 87131, USA (mmartinezjimenez@unm.edu).

Introduction: Villalbeto de la Peña (hereafter, VP) is a heavily shocked L6 ordinary chondrite that fell in Spain in 2004 [1]. Although its shock stage is classified as S4, recent analyses suggest that it was shocked to a higher degree than previously reported, as indicated by the presence of a large shock-melt vein (hereafter, SMV) [2]. The major mineral constituents of the host VP meteorite are olivine (Fo_{75}), enstatite (En_{77}), diopside ($En_{47}Fs_8Wo_{45}$), maskelynite ($Ab_{79}An_{15}Or_6$), metallic iron-nickel, troilite, and phosphates [2]. The SMV considered in this work is ~10 mm long and ~4 mm wide, and contains numerous high pressure phases including ringwoodite, Ca-poor and Ca-rich majorite, maskelynite, jadeite, pyroxene glass, chromite, merrillite, and eutectic FeNi-troilite. In this study, we have focused on the phase-transformation mechanisms of diopside to Ca-rich majorite.

Analytical Procedure: The textural and mineralogical characteristics of the VP meteorite were characterized using Scanning Electron Microscopy (SEM/EDS), Light Optical Microscopy, Focused-Ion-Beam (FIB)/Transmission Electron Microscopy (TEM), Raman Spectroscopy, and Electron Probe Micro-Analysis (EPMA).

Results: A relatively rare Ca-rich silicate phase, identified as Ca-rich majorite, based on Raman spectroscopy [2], with a composition consistent with diopside, occurs in the SMV associated with ringwoodite, Ca-poor majorite and jadeite. Optical microscopy shows that this phase is anisotropic suggesting that it has tetragonal, rather than cubic symmetry. We extracted one FIB section from a region of this anisotropic Ca-rich majorite to investigate its structure and chemistry in detail (Fig. 1A). The Ca-rich majorite in the FIB section has a complex structure, consisting of a single crystal (3x1 μm) embedded within a symplectic intergrowth of Ca-rich majorite and glass (Fig. 1B,C). STEM X-ray mapping shows that the Ca-rich majorite is, however, Mg-rich and Ca-poor compared with the single crystal Ca-rich majorite and the glass shows the inverse relationship, being Ca-rich. Currently, we only have [111] zone axis electron diffraction patterns from the single crystal of Ca-rich majorite, which are insufficient to unambiguously demonstrate that the garnet has tetragonal ($I4_1/a$) instead of cubic ($Ia\bar{3}d$) symmetry. However, based on the optical anisotropy of the grains, we infer that these grains must be tetragonal.

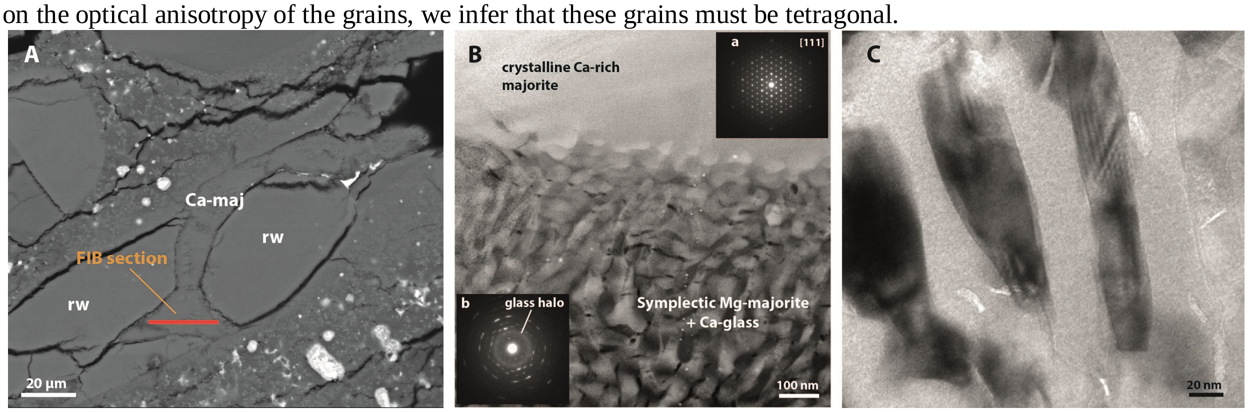

Fig. 1. A) SEM image of the Ca-rich majorite. B) and C) Dark-field STEM images of crystalline tetragonal Ca-rich majorite and its dissociation into a symplectic Mg-rich majorite plus glass [diffraction patterns shown as insets].

Discussion: Our TEM data show that diopside in the SMV in VP has undergone two distinct transformation processes during the shock event. First, diopside transformed directly through a solid-state transformation mechanism to tetragonal Ca-rich majorite. In addition, these grains underwent a dissociation reaction to form a symplectite of more Mg-rich majorite and a Ca-rich glass, which may represent $CaSiO_3$-perovskite that vitrified during decompression [3]. This observation suggests that Ca-rich majorite is metastable and decomposed to a more stable, lower Ca majorite during cooling. The presence of tetragonal Ca-rich majorite in the SMV suggests that either (i) the cooling rate was sufficiently slow to allow the transformation from cubic to tetragonal (see [4]), or (ii) that the shock pressures were higher locally, resulting in tetragonal symmetry. The temperature profile in the melt-pocket was likely heterogeneous causing localized differences in the cooling rate. In conclusion, the transformations of Ca-rich majorite may provide important constraints on the cooling rates and P-T-t conditions of shocked meteorites.

References: [1] Llorca, J. et al. (2007) *Meteoritics & Planetary Sciences* 42:A117–A182. [2] Martínez-Jiménez, M. et al. *in prep.* [3] Tomioka, N. and Kimura, M. (2003) *Earth and Planetary Science Letters* 208:271-278. [4] Heinemann, S., Sharp, T. G, Seifert, F. and Rubie, D. C. (1997) *Phys Chem Minerals* 24:206-221.