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HIGH PRESSURE POLYMORPHS IN THE CHÂTEAU-RENARD (L6) ORDINARY CHONDRITE: IMPLICATIONS FOR COLLISIONS ON ITS PARENT BODY

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Introduction: We report the first discoveries of high-pressure mineral polymorphs in the historical L6 chondrite fall Château-Renard. Within a single polished thin section there is a network of melt veins ranging from ~40 µm up to ~200 µm in width. There is no evidence of cross-cutting to suggest that these veins are of multiple generations. However, veins less than ~50 µm wide contain no high-pressure polymorphs whereas the wider veins contain the high-pressure assemblages ringwoodite + wadsleyite, ringwoodite + wadsleyite + majorite-pyrope$_{ss}$, ahrensite + wadsleyite, and ringwoodite + wadsleyite + tuite. In association with the latter assemblage we find a sodic pyroxene with the composition and structure of omphacite but whose Raman spectrum is indistinguishable from that of jadeite. Using these observations, we are able to constrain the impact record of this meteorite and to extend it to the L-chondrites in general. We also call attention to the fact that Raman spectra alone are apparently inadequate to identify jadeite or to provide constraints on shock pressure history based on the stability field of jadeite [1-3].

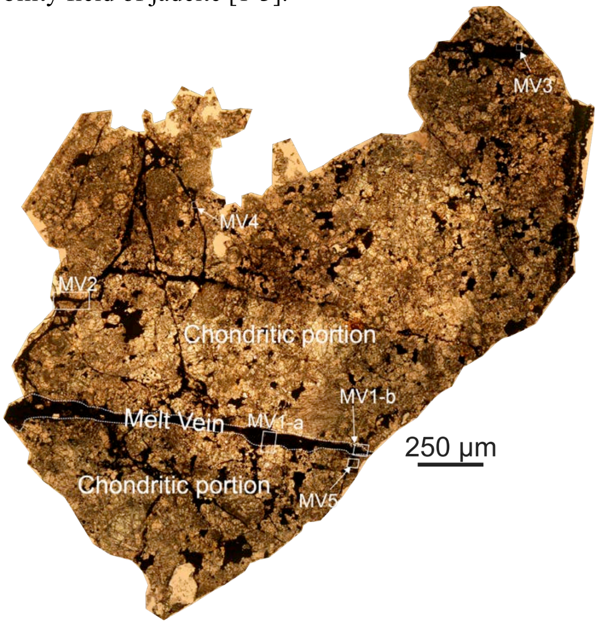

Figure 1: *Transmitted light image of Château-Renard (L4361) showing the complex network of melt veins. Areas MV1-a, MV1-b, MV2, MV3, MV4 and MV5 are called out.*

Context: Meteorites, especially ordinary chondrites, preserve a record of impact events due to (possibly multiple) collisions among their parent asteroids. As such, meteorites showing evidence for impact metamorphism constrain the pressure (*P*) – temperature (*T*) – time (*t*) conditions and hence the relative velocity, size, and density of impactors and targets. Shock parameters can be inferred from the occurrence and textures of high-pressure (HP) mineral polymorphs often found in melt veins (MV).

Highly-shocked L6 ordinary chondrites contain a variety of HP polymorphs. The French historical fall Château-Renard is a highly shocked (shock stage S5) L6 chondrite. Château-Renard was an important highly shocked type specimen in early studies of the petrography, shock metamorphism and impact geochronology of meteorites. However, no verifiable occurrence of any HP mineral in this meteorite has been reported in the literature. Here, we report new textural, compositional, diffraction, and micro-Raman spectroscopy data documenting HP phases in this historical meteorite.

Results:

Petrography. In the groundmass of Château-Renard, olivine grains show strong mosaicism and planar fractures and plagioclase is converted to plagioclase glass. There are numerous pervasive veins presumed to be the result of shock; they are predominantly in contact with olivine but occasionally also with pyroxene (Fig. 1). The MVs have variable thickness (from ~40 to ~200 µm), are mostly crystalline and are made up of silicate clasts (mostly olivine stoichiometry), sulfides, and Fe-Ni metal grains, with gradation from glass-bearing rims, to segregated metal-rich layers, to silicate clast-rich cores. We analysed several of the silicate clasts within six selected regions of interest in melt veins from a single polished thin-section of Château-Renard (NMHV-L4361).

Characterization of HP polymorphs: We have observed within the melt veins a number of HP polymorphs including ringwoodite (rw), ahrensite (ahr), wadsleyite (wd), majorite-pyrope$_{ss}$, and tuite. Within clasts and grains displaying olivine stoichiometry, there are clear correlations between the fayalite content (Fa) and the occurrence of HP structures. We found: in MV1-a, rw + wd (Fig. 2a); in MV1-b, rw + wd + majorite-pyrope$_{ss}$ (Fig. 2b); in MV3 and 5, ahr + wd; and in MV4 sodic pyroxene + rw + wd + tuite (Fig. 2c,d).

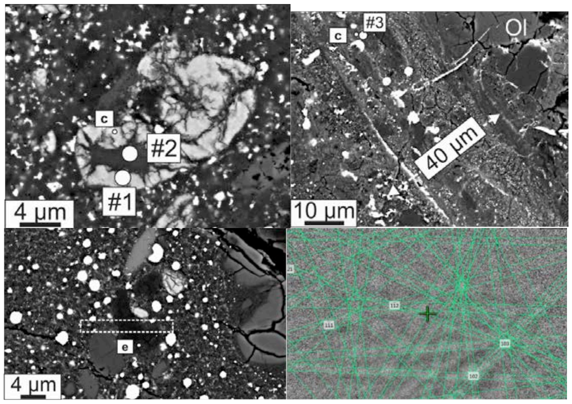

Figure 2. (a) MV1-a. (b) MV1-b. (c) MV4. (d) EBSD pattern of grain with jadeite Raman bands, omphacite composition, and unclear pyroxene structure.

MV1-a: Zoned grains with olivine stoichiometry show dark cores surrounded by bright rims. The Raman spectra from the bright rim are assigned to rw with bands at 784-789 cm^{-1} and 840-846 cm^{-1}. The dark regions display typical Raman spectra of olivine. EBSD/EDS shows dark cores are olivine structure and Fa$_{20}$. Bright rims index with spinel structure (*Fd*-3*m*) and are about Fa$_{38\text{-}44}$, hence rw. One very bright rim is Fa$_{67\text{-}69}$, hence ahr.

MV1-b: Raman spectra display characteristic 928 cm^{-1} and ~592 cm^{-1} majorite peaks. EBSD patterns show garnet structure. Compositions include near end-member orthopyroxene stoichiometry with 3.96 to 4 Si apfu and also 3.58-3.62 apfu Si; we label this phase majorite-pyrope$_{ss}$.

MV3 and MV5: Bright rims of olivine in these veins show Raman spectra that combine features of ahr and wd. EBSD patterns index with spinel structure and are ahrensite with Fa$_{\sim 60}$. Wd spectra occasionally show olivine peaks at ~820 cm^{-1} and 852 cm^{-1}, indicating incomplete reaction or partial back-transformation.

MV4: The distinctive sodic pyroxene displays the peaks considered characteristic of jadeite at ~700, ~990, and ~1037 cm^{-1}, as reported from simulated and experimental data on near-endmember jadeite. However, the composition is $(Ca_{0.07\text{-}0.10}Fe_{0.16\text{-}0.19}Na_{0.25\text{-}0.46}Mg_{0.35\text{-}1.12}Al_{0.29\text{-}0.57})Si_{2.01\text{-}2.04}O_6$. Although jadeite component is present, no points have Na formula units above 0.8. Using IMA nomenclature, this is not jadeite but omphacite. The EBSD pattern quality (Fig. 2d) is not adequate to distinguish between jadeite (*C2/c*) and omphacite (*P2/n*), so we turned to transmission electron microscopy (TEM). SAED patterns of the pyroxene are consistent with omphacite (*P*2/*n*). In the TEM foil, we also observed rw and wd as intergrown grains crystallized from the melt. The two phases have a topotaxial relationship, with the [100] zone-axis of wadsleyite parallel to ringwoodite [110].

Discussion

P-T-t constraints. Topotactic intergrowth of rw and wd imply a solid-state transformation at high enough temperature to allow Fe-Mg interdiffusion. Fe-depleted forsterite olivine cores with moderately Fe-enriched wd, moderately Fe-enriched rw, and highly Fe-enriched wd-ahr intergrowths suggest a range of pressures from 13-18 GPa. Different olivine polymorphs in each MV reflect different cooling rates rather than large variations in pressure. The observed majorite suggesting growth conditions of 17-20 GPa and 1800-2100 °C.

Wd grains can grow at linear velocities up to <1 m s^{-1} and hence the observed 1-3 µm wd require the MV to spend only a few microseconds in the wd stability field before quenching. Thermal models of MV cooling suggest cooling times of ~0.7 msec. Preservation of Fa$_{40}$ rw at the center of the MV suggests cooling below ~1273 °K at P > 13 GPa in order to prevent complete back-transformation.

"Jadeite". Raman spectra from the Na-Si-rich melt suggests the occurrence of a jadeite-like pyroxene. However, analytical TEM confirms that the pyroxene has the composition and structure of omphacite. Addition of 50 mol% Di to jadeite lowers the low-*P* limit for a homogeneous cpx phase by about 0.5 GPa and also lowers the upper-*P* limit for homogeneous cpx by about 5 GPa (from 21 GPa Jadeite → Ca-ferrite to ~16 GPa Clinopyroxene → Majorite + Ca-perovskite). Although preservation of the highest-*P* indicator minerals might be problematic, the presence of sodic clinopyroxene and the absence of Ca-ferrite, Ca-perovskite, or Ca-rich garnet suggests, at least locally, $P \leq 15.5$ GPa in the pyroxene-bearing regions.

Château-Renard records variable apparent pressure and temperature conditions. Possibly each vein records a different time along a common *P*-*T* path. On the other hand, the presence of discrete veins directly proves heterogeneity of the temperature field, which is likely the result of collapse of spatially variable porosity during shock compression or slip along localized shear bands Still, we lack a sound basis for asserting that a global peak *P*-*T* condition or global *P*-*T* path can be defined for the meteorite. Different veins may be recording altogether different shock events.

References: [1] Ozawa, S. *et al*. (2014) *Sci. Rep.* **4**. [2] Bazhan, I. S. *et al.* (2017) *Russian Geol. Geophys.* **58**:12-19. [3] Zhang, A. *et al.* (2006) *Eur. J. Mineral.* **18**:719-726.