A UNIQUE MINERAL ASSEMBLAGE RECORDING SHOCK CONDITIONS IN KAKOWA (L6) ORDINARY CHONDRITE. I. Baziotis[1], L. Ferrière[2], P. D. Asimow[3], M. Anand[4], S. Xydous[1], A. Papoutsa[1], and D. Topa[2]. [1]Department of Natural Resources Management & Agricultural Engineering, Agricultural Univ. of Athens, Iera Odos 75, 11855 Athens, Greece, ibaziotis@aua.gr, [2]Natural History Museum, Burgring 7, A-1010 Vienna, Austria, [3]California Institute of Technology, Division of Geological & Planetary Sciences, Pasadena, California 91125, USA, [4]Planetary & Space Sciences, The Open University, Milton Keynes MK7 6AA, UK.

Introduction: Ordinary chondrites, preserve a record of impact events due to collision(s) among their parent asteroids. In turn, such meteorites help to constrain the shock conditions and hence parameters (e.g., size) of impactors and targets. Shock parameters can be inferred from high-pressure (HP) mineral polymorphs, often found in melt veins (MV). Herein, we report the first discoveries of HP mineral polymorphs in the historical L6 chondrite fall, Kakowa (Romania, 19th May 1858; S5). Three main, sub-parallel MVs, one 300-360 μm wide, and two 20-30 μm wide, as well as a few thinner MVs lying at high angles to the three main ones, are visible within a single 1´´ round section (Fig. 1).

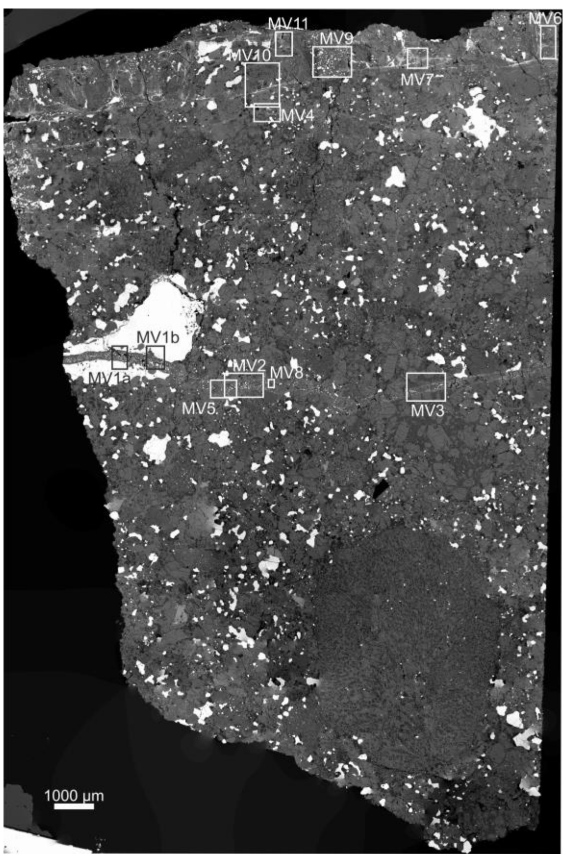

Figure 1: Back-scattered electron (BSE) image mosaic of Kakowa section showing the studied areas within the different MVs. Notable are the two large chondrules, one of them clearly cross-cut by a melt vein (e.g., see MV3).

There is no evidence of cross-cutting relations to suggest that these veins are of multiple generations. The thickest vein contains HP polymorphs of olivine (ringwoodite + wadsleyite), Na-pyroxene (albitic jadeite), and a CAS phase (very likely donwilhelmsite, *don*). Using these observations, we are able to constrain the impact record of this meteorite.

Petrography, mineral chemistry, and Raman spectroscopy: A single polished thin section of the Kakowa meteorite (NHMV-N6231) was examined for shock indicators, in particular HP polymorphs, with a focus on the MVs. We used optical microscopy, a JEOL JSM-IT300LV scanning electron microscope, JEOL JXA 8900 and JEOL JXA 8530F electron probe micro-analyzers, and a dispersive confocal Renishaw inVia Reflex Raman microscope (514 nm laser). Eleven areas located in the three sub-parallel MVs were analyzed for texture and mineral chemistry (MV1 to MV11 in Fig. 1). Two of the regions (MV1 & MV2) were further studied with collocated Raman spectroscopy (RS).

In the groundmass of Kakowa, olivine grains show strong mosaicism and planar deformation features. A large fine-grained chondrule 6.1 mm in diameter and a porphyritic chondrule 3.5 mm in diameter dominate the studied section; the porphyritic chondrule is bisected by the thickest MV. The three main sub-parallel MVs and minor MVs with other orientations are presumed to be the result of a unique shock event; they are predominantly in contact with olivine but occasionally also with pyroxene and metal grains. The width of the thickest MV is nearly constant (from ~300 to 360 μm), while the thinner MVs are variable in width. The MVs consist of glass, silicate clasts (olivine, pyroxene, and plagioclase), sulfides, chromite, and Fe-Ni metal. The MVs are zoned from glass-bearing rims to metal-rich layers to silicate clast-rich cores.

HP polymorphs. We have observed different HP polymorphs including ringwoodite (*rw*), wadsleyite (*wd*), albitic jadeite (*jd*), and possible *don* (Fig. 2).

MV1-1a: The MV matrix is mostly a crystallized assemblage of garnet + *rw* + magnesiowüstite (Fig. 2A). *Rw* clasts in the MV are composed of small recrystallized crystals, locally coexisting with *wd*. Matrix olivine in contact with the MV is converted to polycrystalline *rw*, followed outwards by *rw* lamellae, and then by "normal olivine". The *rw* zone in some places extends more than 25 μm into the matrix.

EPMA analysis of a dark elongated crystal, 15 × 7 μm in size (Fig. 2B) yields a formula $Ca_{0.97}Na_{0.03}Fe^{3+}_{0.06}Al_{3.92}Si_{2.01}O_{11}$, close to the *don* formula recently discovered in the lunar meteorite Oued Awlitis 001 [1]. The verification of the structure of this mineral is pending; if confirmed it would be the first report of *don* in a chondrite.

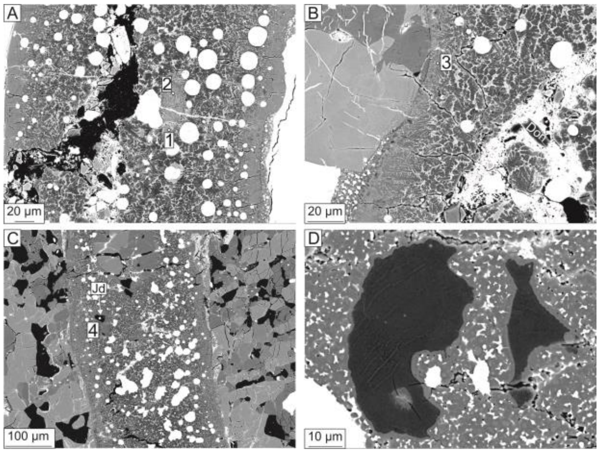

Figure 2: (A) MV1-a with *rw* (1) in close association with *wd* (2). (B) MV1-b with *wd* (3) near the edge of the MV. EPMA analysis indicates possible *don* in the center of the MV. (C) MV2 hosting albitic jadeite (4). (D) Plagioclase melt pool with *jd* lamellae. RS are shown in Fig. 3. All images are rotated by 90º clockwise relative to Fig. 1.

MV2: EPMA analysis of irregularly shaped crystals, up to ~20 µm (Fig. 2C), yield the formula $(Na_{0.65}Ca_{0.08}K_{0.05}\square_{0.22})(Al_{0.81}Si_{0.17}Fe_{0.02})Si_2O_6$, with Ca# [100×Ca/(Ca+Na)] of 10.49. With ~25% vacant M2 sites and 17% Si on M1, this is albitic jadeite; it is beam-sensitive, like other published cases [2,3]. It commonly shows sub-µm parallel lamellae (Fig. 2D). The RS of Kakowa albitic jadeite has a distinct major peak at 698 cm^{-1} and minor peaks at 201, 376, 387, 432, 521, 574, 988, and 1035 cm^{-1} (Fig. 3). The two peaks near 1000 cm^{-1}, related to vibration of $[Si_2O_6]^{4-}$ groups, are resolved but not as distinct or well-separated as in the ideal *jd* spectrum. The RS of near-endmember *jd* has major peaks at 700, 991, and 1040 cm^{-1} and minor at 204, 375, 385, 433, 525, 575 cm^{-1} (RRUFF R050220.2), which is an exceptionally good match even though our EPMA analysis plainly shows that the Kakowa material is *not* near-endmember *jd*.

Implications: *P-T-t constraints*. The occurrence of *wd* suggests *P*>13 GPa to at most 22 GPa (depending on *T* and Fe content), whereas *rw* suggests higher *P*, 18-23 GPa. The presence of *don*, if confirmed, may suggest minimum P of 13 GPa [4] and maximum *P* exceeding the stability field of *rw*, up to ~26-30 GPa [5,6]. Coexistence of all three HP phases indicates small-scale spatial or temporal heterogeneity of the *P* field. The *P* for growth of albitic jadeite is currently uncalibrated.

Wd can grow at linear velocities ≤1 m/s; the observed *wd* requires the MV to spend a few µs in the *wd* field before quenching. Thermal models of MV cooling suggest cooling times, for the thickest vein, of $\sim10^{-3}$ s. Preservation of *rw* at the center of MV1 suggests cooling < 1273 °K while *P* remained > 18 GPa.

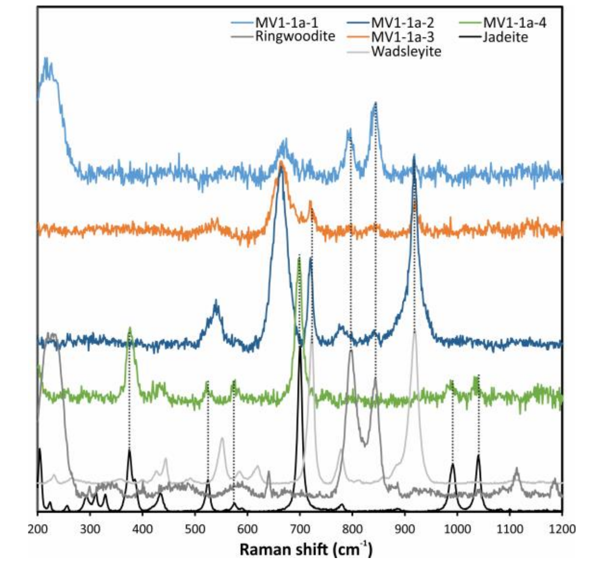

Figure 3: Selected RS obtained for Kakowa. Reference: ringwoodite (RRUFF R070079), wadsleyite (RRUFF R090004), and jadeite (RRUFF R050220.2).

"*Jadeite*". RS from a Na-Si-rich melt pool (Figs. 2D,3) suggest a jadeite-like pyroxene. Setting aside the preservation question, the absence of lingunite suggests maximum *P* < 21 GPa and the absence of Ca-ferrite, Ca-perovskite, or Ca-rich garnet suggests, at least locally, *P* ≤ 15.5 GPa. The presence of jadeite-like pyroxene near the center, and *rw* at the rim of the widest MV again suggests spatial or temporal *P* gradients. We aim to confirm the structure of the jadeite-like pyroxene by in-situ electron diffraction techniques.

Pending further analyses, it is already clear that Kakowa hosts a unique record of high-*P*,*T* and, if confirmed, the first chondritic occurrence of donwilhelmsite. The presence of discrete veins indicates heterogeneity of the *T* field, likely the result of collapse of spatially variable porosity during shock compression or slip along localized shear bands. We cannot presently assign a global peak condition or *P*,*T* path for the meteorite or rule out recording of multiple shock events on its parent body.

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References: [1] Fritz J. et al. (2020) *Am. Min.*, 105, 1704–1711. [2] Ma C. et al. (2020) *LPS LI*, Abstract #1712. [3] Xydous S. et al. (2020) EPSC2020–932, 14. [4] Akaogi M. et al. (2009) *Phys. of the Earth &Planet. Int.* 173(1-2), 1-6. [5] Hirose K. & Fei Y. (2002) *GCA* 66, 2099–2108. [6] Nishi M. et al. (2018) *Geosci. Frontiers*, 9, 1859–1870.