Assessing Shock Levels of Enstatite-Rich Meteorites by Raman Spectroscopy

Bidong Zhang[1], Audrey Bouvier[1], and Sean Shieh[1]
[1] University of Western Ontario, Department of Earth Sciences, Centre for Planetary Science and Exploration, London, Ontario N6A 3K7, Canada

Introduction: Stöffler and collaborators set up a criterion for estimating shock stages of ordinary chondrite using petrographic observations[1]. The classification scheme was adapted for enstatite chondrites[2]. However, (1) opaque minerals darken silicates and obsecure their petrologic textures, which makes the classification of shock stages challenging; (2) the shock stages based on orthopyroxene and olivine (within a single sample) can be inconsistent[3]; (3) high-pressure phase studies indicated much lower pressure (18 GPa) than the petrologic assessment (45-90 GPa)[4]. The full width at half maximum ($FWHM_\chi$) of Debye rings of micro X-ray diffraction (μXRD) technique was used to assess the shock stages of enstatite chondrites[5], and the $FWHM_\chi$ have a positive linear relationship with shock stages. Yet, μXRD's beam size (>200 μm) cannot provide representative data for small grains and impurities. Therefore, we aim to examine the meteoritical enstatites by Raman spectroscopy and calibrate enstatite compositions and shock levels simultaneously using one selected peak of Raman spectra.

Materials and Methods: Enstatite chondrites: LaPaz Icefield (LAP) 02225, MacAlpine Hill (MAC) 02837, Pecora Escarpment (PCA) 91020; Enstatite achondrite: Itqiy; Aubrites: Larkman Nunatak (LAR) 04316, Khor Temiki, Allan Hills (ALH) 84008; Ureilite: Sayh al Uhaymir (SaU) 559. The Raman spectroscopy is equipped with a 514.5-nm argon-ion laser source. The system was calibrated by a neon lamp and silicon chip. Frequency precision is estimated as ±1 cm^{-1}. The laser beam size is about 2 μm. Aquisition time varied from 30 to 360 s. Raman shifts and their FWHMs were obtained via PeakFit program.

Results and Discussion: The shock level assessment by Raman is based on the process that the equilibrium shock effects are recorded by bulk mineral grains[1]; moreover, the FWHM of Raman spectra at peak ~343 cm^{-1} (ν_3, M-O stretch) was selected to evaluate the degree of crystal disorder induced by different shock stages. The enstatite grains were randomly selected from thin sections or separated minerals from chips. Raman spectra of 23 to 30 random points for each sample were collected. Raman shifts of ν_3 (calibrated from Raman measurements) and Fe^*-derived shifts (calculated by the linear relationship between shifts of ν_3 and $Fe^*=Fe/(Mg+Fe)$ (mol%)[6]) have negligible differences, which means the ν_3 hardly shifted under different shock levels. The FWHMs of ν_3 varied from 7.77 to 16.40 cm^{-1}. Shock stages of meteorites were constrained by orthopyroxene (OPX) (LAP 02225: S1[7]; MAC 02837: S3[2]; LAR 04316, Khor Temiki and ALHA 84008: S4[3]; PCA 91020: S5[7]). Our linear regression fitting between the FWHMs and corresponding shock stages (excluding the unknown, Itqiy and SaU 559) showed a linear relationship (r^2=0.96) (Figure 1). The "shock-stage values" of Itqiy and SaU 559 calculated by the fitted linear equation suggested to be 7 and 10, respectively, which exceed the range of the conventional classification scheme. Neither of them had whole-rock melting features. Hence, these two meteorites might have experienced much higher shock levels and/or require another plausible mechanism of deformation to explain their abnormal degree of crystal disorder.

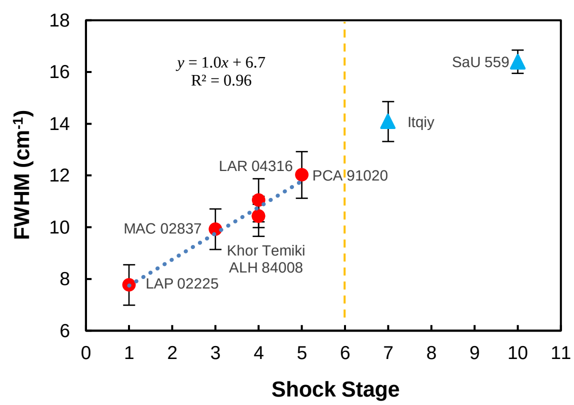

Figure 1. Linear regression fitting of known shock stages (red dots) and FWHMs. Red dots denote determined shock levels from OPX; blues triangles denote the undetermined, but their coordinations were calculated by the fitting. The yellow dash line is the highest shock stage (S6) defined by the petrologic scheme. Itqiy and SaU 559 were estimated to have the shock stage values of 7 and 10, respectively.

Conclusion: The enstatites from different shock stages have negligible differences in the Raman shifts of ν_3. The FWHMs of ν_3 increase with the shock stages, and notably, they have a linear relationship (r^2=0.96). Based on petrographic descriptions, this non-descructive method could be used to assess relative shock levels of enstatite-rich meteorites, which are important to constrain the formation history of these meteorites and their parent bodies.

References: [1] Stöffler, D. et al. (1991) *Geochimica et Cosmochimica Acta* 55: 3845-3867. [2] Rubin A. E. et al. (1997) *Geochimica et Cosmochimica Acta* 61: 847-858. [3] Rubin, A. E. (2015). *Meteoritics & Planetary Science* 50: 1217-1227. [4] Rubin, A. E. (2015) *Chemie der Erde - Geochemistry* 75, 1-28. [5] Izawa M. R. et al. (2011) *Meteoritics & Planetary Science* 46: 638-651. [6] Huang, E. et al. (2000) *American Mineralogist* 85: 473-479. [7] Rubin, A. E. (1997) *American Mineralogist* 82: 1001-1006.