CATHODOLUMINESCENCE CHARACTERIZATION OF THE FORSTERITE IN KABA METEORITE: AN ASTROMINERALOGICAL APPLICATION.

A. Gucsik[1,2], T. Endo[3], E. Nakazato[3] H. Nishido[3], K. Ninagawa[4], M. Kayama[3], Sz. Bérczi[5], Sz. Nagy[6], P. Ábrahám[2], Y. Kimura[7], I. Gyollai[8], I. Simonia[9], P. Rózsa[10], J. Posta[10], M. Nagy[10], K. Mihályi[10], D. Apai[11] & P. Futó[12] [1]Abteilung Geochemie, Max-Planck-Institut für Chemie, Joh-J.-Becherweg 27, Universitätcampus, Mainz, D-55128, Germany (E-mail: a.gucsik@mpic.de); [2]Konkoly Observatory of the Hungarian Academy of Sciences, H-1121 Budapest, Konkoly Thege Miklós út 15-17., Hungary; [3]Research Institute of Natural Sciences, Okayama University of Science, 1-1 Ridai-cho, Okayama, 700-0005, Japan; [4]Department of Applied Physics, Okayama University of Science, 1-1 Ridai-cho, Okayama, 700-0005, Japan; [5]Institute of Physics, Department of Material Physics, Eötvös University, Pázmány P. s. 1/a, Budapest, H-1117, Hungary; [6]Eötvös University, Dept. Petrology and Geochemistry, H-1117 Budapest, Pázmány Péter sétány 1/c, Hungary; [7]Department of Earth and Planetary Materials Science, Graduate School of Science, Tohoku University, Sendai 980-8578, Japan; [8]Department of Lithospheric Research Center for Earth Sciences, University of Vienna, Althanstrasse 14, A-1090 Vienna, Austria; [9]School of Graduate Studies of Ilia Sate University, Tbilisi, Georgia; [10]University of Debrecen, Egyetem tér 1., Debrecen, H-4032, Hungary; [11]Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA; [12]Enese, Radnóti utca 7, H-9143, Hungary.

Introduction: Kaba carbonaceous chondrite is the most primitive unshocked CV fall (in 1857) collected nearby the Kaba village, East Hungary. It contains many types of chondrules associated with porphyritic, granular, radial and barred olivine, which have a variety of composition including almost end members of forsterite and fayalite occasionally with normal or reversed zoning. Cathodoluminescence (CL) has been used to characterize meteorititic minerals such as olivine and feldspar for the investigation of thermal history and shock pressure effect due to high detection sensitivities of structural defects and activator elements with high spatial resolution. In this study, CL imaging and spectroscopy have been conducted to clarify formation mechanism of luminescent forsterite of Kaba meteorite.

Experimental Procedure: CL color imaging was carried out using Luminoscope (ELM-3R). CL scanning images at high magnification were recorded by a Mini-CL detector (Gatan) installed in a Scanning Electron Microscopy (SEM). CL spectroscopy was made by a SEM-CL system, which is comprised of SEM (JEOL: JSM-5410) combined with a grating monochromator (OXFORD: Mono CL2). All CL spectra were corrected for total instrumental response, which was determined using a calibrated standard lamp. This correction prevents errors in the peak position of emission bands and allows quantitative evaluation of CL intensity. Raman spectra were recorded with a Renishaw Rm-2000 Raman spectrometer attached to a Leica DM/LM microscope with a 1-µm diameter focused beam in the 100-1300 cm^{-1} region using a CCD camera, the accumulations lasted during 100 sec.

Results and Discussion: Petrographical investigation shows the following modal abundances in %: matrix (55.2), chondrule (27.7), CAI (3.4), aggregated olivine (2.5), and isolated coarse grained olivine (0.8).

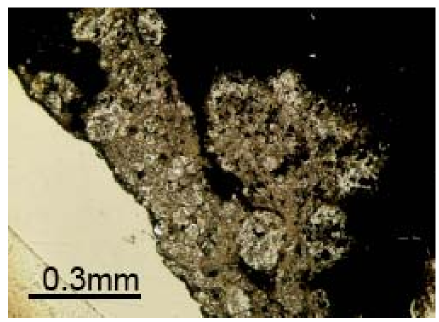

Figure 1. *Aggregates of olivine grains.*

Aggregates of the olivine vary between 0.5–1.7 mm in their grain size (Fig. 1). The composition of olivine shows 99.5–94.4 % (Fa) and 84.3–99.5 % (Fo). In general, fayalite (Fa) coexisted with forsterite (Fo), which contacted with enstatite (En), occasionally associated with iron oxide and troilite. The composition of olivine shows 99.5–94.4 % (Fa) and 84.3–99.5 % (Fo) (Fig. 2).

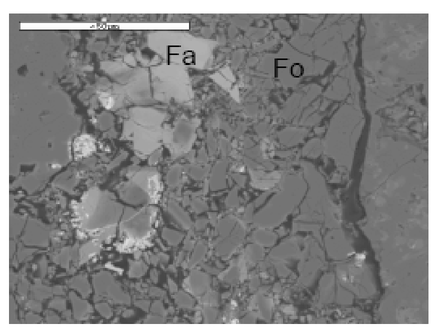

Figure 2. *BSE image of olivine aggregates showing the texture of clastic Fo and Fa grains.*

Highly forsteric olivine (Fo: 99.2–99.7) emits bright CL, whereas the olivine containing fayalitic composition, even if only slight, shows no luminescence due to quenching effect of divalent Fe ions. Red luminescent forsterite is predominant, and occasionally zoned forsterite shows blue in the core and red in the rim. CL spectra of red luminescent forsterite have two broad bands at approximately 630 nm in red region and over 700 nm in red–IR region (Fig. 3). The former band can be assigned to impurity center of divalent Mn ion as an activator. The latter one shows a magnificent red emission in a wide range of wavelength responsible for trivalent Cr ions, which possess two components of Cr activator and/or structural defect caused by interstitial Cr ions. CL spectra from blue luminescent area in the core of forsterite give a characteristic broad band emission at approximately 400 nm, also associated with minor red emissions related to Mn and Cr ions [1,2]. This blue emission is attributed to intrinsic structural defect because it can be detected in pure synthetic forsterite, whereas minor quadrivalent Ti ions are slightly activated. EPMA analysis of the forsterite reveals that minor elements of Mn (0.01–0.08 wt%), Cr (0.11–0.34 wt%) and Fe (0.22–0.86 wt%) are concentrated in red luminescent rim, but Ca (0.60–0.88 wt%) and Al (0.19–0.46 wt%) in blue luminescent core.

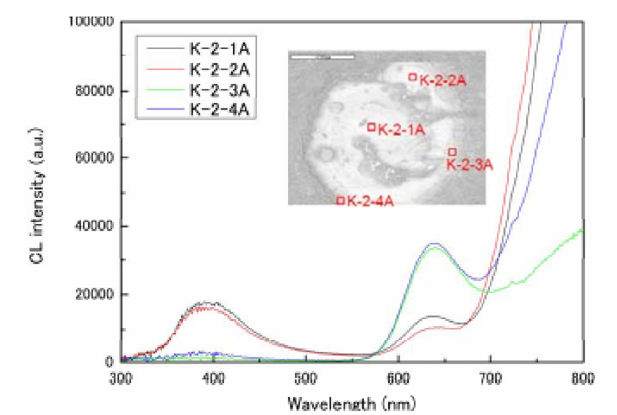

Figure 3. *CL spectra of Kaba forsterite.*

In this case, the quenching effect of divalent Fe ions on CL might be slight and homogeneous over a forsterite grain due to low and unvaried concentration of Fe. Therefore, CL color variation observed in Kaba forsterite should be attributed mostly to an intrinsic structural defect, of which distribution cannot be detected by any other methods. It implies that aqueous alteration on the forsterite might eliminate intrinsic structural defects progressively from the rim of the grain to the core, accompanied by the migration of diffusible ions of Mn, Cr and Fe to the rim where Ca and Al ions might still lie in the core. This process could proceed at low temperatures (<300˚C) over a short reaction time.

Raman spectra of most olivine in Kaba CV3 chondrite corresponds well to those of the forsterite previously reported. The strongest peaks are a doublet at 822 and 854 cm^{-1}, which can be assigned to SiO_4 tetrahedral symmetric and antisymmetric vibrational modes, respectively. A shoulder peak appears at 879 cm^{-1}, which may be related to a T_2g mode. The other characteristics peaks at 299, 423, 600, and 957 cm^{-1} correspond to A_1g mode of MgO_6 octahedra, and additionally SiO_4 bending mode, respectively (Fig. 4).

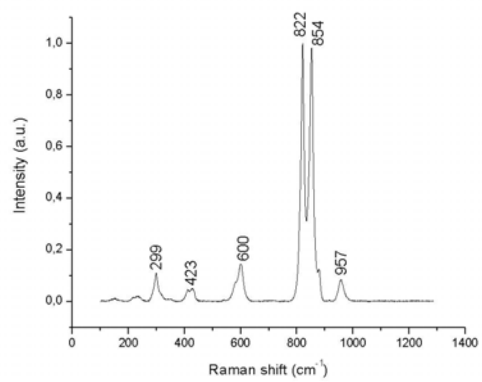

Figure 4. *Raman spectral features of Kaba forsterite.*

In this spectrum, there is no evidence appearing as a molten olivine or glassy material, which was suggested by Ábrahám et al. [3], whereas weak signs for Fe-enriched halo around forsterite grains as presented by Hua and Buseck [4] were observed. However, it cannot be ruled out that some forsterite grain contain glassy material, which is in a good agreement with the models coming from Ábrahám et al. [3] because the temperature is a very important factor to conserve the original conditions within the solar nebulae.

Consequently, CL of the forsterite micro-particles might be detected in the circumstellar dust including dust of B stars and objects of late spectral type. For revealing of forsterite CL in the astronomical objects, it is necessary to obtain optical spectra of such objects with high spectral resolution and high signal/noise ratio. At low temperature, we can detect narrow and enhanced CL emissions of forsterite as a component of circumstellar dust substance.

References: [1] Klerner et al. (2000) *LPSC XXXI,* abstract #1689. [2] Pack et al. (2002) *65th Ann. Met. Soc. Meeting,* abstract #5218. [3] Ábrahám et al. (2009) *Nature, 459, 224-226.* [4] Hua and Buseck (1998) *GCA 62, 1443-1458.*