Cathodoluminescence Microscopy and Spectroscopy of Forsterite from the Tagish Lake Meteorite: An Implication for Luminescence-Based Astromineralogy. A. Gucsik[1,2] and H. Nishido[3], K. Ninagawa[4], I. Gyollai[1], M. Izawa[5] and C. Jäger[6]. [1]Konkoly Thege Miklós Astronomical Institute, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences; [2]Department of Geology, University of Johannesburg, Johannesburg, 2600 Auckland Park, South Africa, (E-mail: argu1986@hotmail.com). [3]Department of Biosphere-Geosphere System Science, 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]University of Winnipeg, 515 Portage Avenue, Winnipeg, Manitoba R3B 2E9, Canada; [6]Max Planck Institute for Astronomy, Helmholtzweg 3, Jena, D-07745, Germany

Introduction:

The Tagish Lake meteorite fell by fireball event in January 2000 [1]. This meteorite is an intermediate between CM and CI chondrite, original preatmospheric weight was 200 kg [1], classified as CI2 chondrite [2]. Tagish Lake meteorite has a brecciated, matrix-dominated material, which contains chondrules with less than 1 mm diameter, altered Calcium-Aluminium-rich (CAIs) up to 2 mm in diameter, magnetite, individual grains of olivine, Ca-Fe-Mn carbonates (mainly mixture of magnesite and siderite), Fe-Ni sulfides including pyrrhotite (Brown et al. 2000). The purpose of this study is to classify forsterite from the Tagish Lake meteorite by means of Cathodoluminescence Microscopy and Spectroscopy as well as Micro-Raman Spectroscopy in order to understand more about the crystallization processes in early Solar System.

Experimental Procedure:

A systematic cathodoluminescnce investigation was done at Okayama University of Science (Okayama, Japan), as follows. CL colour imaging was carried out using a Luminoscope (ELM-3R) consisting of a cooled charge-coupled device (CCD) camera, a cold cathode discharge tube and a vacuum chamber. A SEM-CL system containing a SEM (JEOL: JSM-5410LV) combined with a grating monochromator (OXFORD: Mono CL2), having a retractable parabolic mirror coated with aluminium (collecting efficiency of 75 %), provided the CL spectral measurements for this study. Further details of the CL equipment and analytical procedure can be found in Kayama et al. (2010). Corrected CL spectra in energy units were deconvoluted into the Gaussian components corresponding to each emission center. A peak-fitting software (Peak Analyzer) in OriginPro 8J SR2 was used for the correction and deconvolution of each emission center.

Raman spectral measurements were carried out using a LabRam Confocal Spectrometer (632 nm excitation) for the single spectrum at Max Planck Institute for Astronomy (Jena, Germany) and for the Raman mapping by a WITec Alpha 300 spectrometer (532 nm) at Department of Geology, University of Johannesburg (South Africa).

Results:

The analyzed chondrules are less altered, which is an intermediate between granular and barred texture (Fig. 1). The mesostasis composed of both of phyllosilicates and carbonaceous material. In both of chondrules, olivines show zoned mosaicism, which may correspond to inhomogenity.

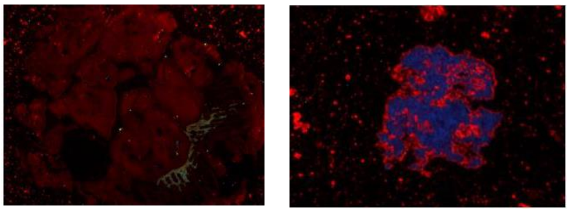

Figure 1. *Cathodoluminescence imaging of the analyzing area of "Tla" (left) and "Tlb" (right).*

The major part of the selected grain is composed of a mineral-fragment rich groundmass, which contains a strongly altered forsterite chondrule. Cathodoluminescence spectral features have broad luminescence centres at 400-460, 600-650 and 700 nm. In some parts of the selected grain, peak intensities at 600-700 region are relatively high (Fig.2). After correction of CL spectra, a peak at 400 nm, shoulders at 600-650 and 700-800 nm can be identified as follows. In energetic CL spectra, broad shoulders occur at 0-2 eV region, and broad peak appears at 2.5-3.5 eV region (Fig. 3).

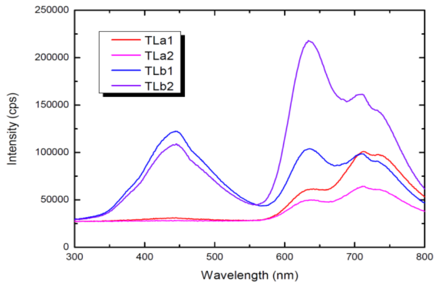

Figure 2. *Cathodoluminescence spectral properties of Tla and Tlb are in the Tagish Lake meteoric forsterite showing three major regions centered at 400-460, 600-650 and 700-800 nm reimaging of the analyzing area of "Tla" (left)d "Tlb" (right).*

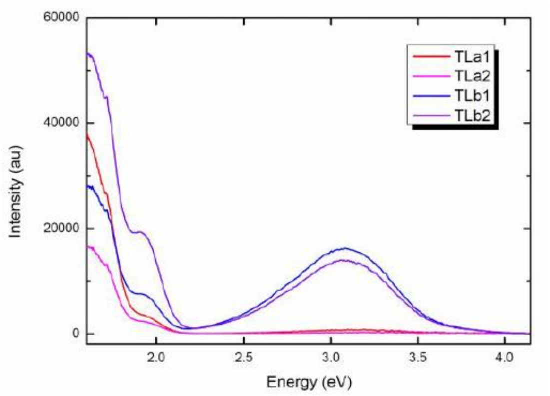

Figure 3. *Intensity vs energy plot of the Tagish forsterite.*

Raman spectral features of the selected forsterite grain (Tlb) contain several very weak (vw) positions at 232, 302, 390, 433, 537, 598, 668, 730, 912, 964 cm^{-1}, five medium peaks (m) at 633, 1189, 1226, 1287 cm^{-1}, and a strong band centered at 1618 (s). The spectrum is dominated by a very strong (vs) doublet peak at 816 and 851 cm^{-1}. Broad bands at around 3000 cm^{-1} would be related to the OH-groups delivered from the epoxy (Fig. 4).

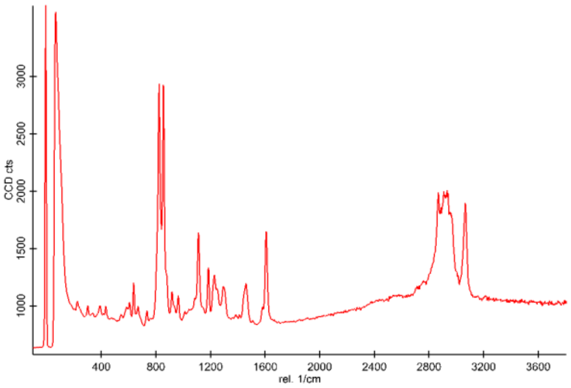

Figure 4. *Raman spectrum of forsterite showing a dominant doublet peak at 816 and 851* cm^{-1}.

Discussion:

The broad luminescence center at 400 nm corresponds to structural defect. The variation of luminescence intensity in chondrule, determine chemical inhomogenity due to low degree of thermal metamorphism [3]. At duller red luminescence centers, the olivine has fayalitic component, whereas light luminescent patches are purely forsterites.

The fractures in chondrules are non-luminescent, which is driven by either enrichment of divalent Fe due to terrestrial weathering, or shock-driven lattice defect. The blue luminescence centre at several areas is addressed to instrinsic defect centre. This defect centre associated by either Al^{3+} substitution for Si^{4+} ions or lattice deformation due to Ca and Ti ions [3,4].

The broad emission at 650 nm is assigned to Mn^{2+} impurity centre in M2 position of forsterite [3]. The broad emission bands at 720 nm and also in higher wavenumber range are attributed to Cr^{3+}activator in the M1 and M2 sites and interstitial positions of forsterite [3].The activation energies for red emissions are centered at 0.8 and 1.74 eV, where the 1.74 eV peak corresponds to Cr^{3+}, 1.94 Mn^{2+}. The activation energies in blue region appear as broad band at 3.15 eV, which of FWHM is 1 eV, which corresponds to defect centre [3].

Raman spectral properties of the selected forsterite grain show a well-crystalline background of sample. According to Chopelas [5] the SiO internal stretching and bending modes, which were assigned to the highest frequencies at 816 and 851 cm^{-1}. There is no any polarization effect obsereved in this sample. Bands at around 1600 cm^{-1} might be related to the organic material.

Conclusions:

The CL zonation corresponds to thermal quenching, chemical inhomogenities in chondrules. The blue CL emission is caused by lattice defect. The CL properties of Tagish Lake forsterite depends on distribution of activator elements (Cr, Mn), and quenching element (Fe^{2+}), and crystal lattice defect. Raman spectroscopy of the selected sample shows that this sample was not suffered a high-grade metamorphism as it is indicated in its well-crystalline background.

ScanningElectronMicroscope-Cathodoluminescence (SEM-CL) microscope and spectrscope provide an adequate background for the analysis of different Earth and Planetary materials that require the non-destructive, easy-to-use, and relatively rapid analysis. In this case, SEM-CL would provide a powerful method for the study of the the above-mentioned samples, which can aid to understand more about the crystallization environment of minerals in the Early Solar system, for instance.

References:

[1] Brown, P.G. et al. (2000) *Science*, *290/5490*, 320-325. [2] Grady, M.M., et al. (2002) *MAPS*, *37*, 713-735. [3] Nishido, H. et al. (2013) *Geochronometria 40/4*, 239-243. [4] Steele, I.M. (1986): *American Mineralogist*, 71, 966-970. [5] Chopelas, A. (1991) *American Mineralogist*, 76, 1101-1109.