Colour Cathodoluminesence study of forsteritic Olivine in Mukundpura (CM2) meteorite. S. Baliyan[1,2], D. Ray[1], [1]Physical Research Laboratory, Ahmedabad 380009, India, [2]Indian Institute of Technology, Gandhinagar 382355 (E-mail: shivanib@prl.res.in).

Introduction: Mukundpura is one the eye witnessed falls in recent times (June 6, 2017 at 5:15 IST), fell near Jaipur, Rajasthan, India. It has been reported as one of the primitive chondrites and classified as CM2 based on petrographic, mineralogical, isotopic studies and bulk chemical composition [1]. A few relict chondrules (highly forsteritic porphyritic olivine, barred olivine and porphyritic pyroxene type), isolated olivine grains (both forsteritic and fayalitic type) are recognised while "poorly characterised phases" in the form of phyllosilicates are common in the matrix. Matrix occupies majority (>70% vol) of the studied sections. Other minor and accessory phases include carbonates and sulphides. Cathodoluminescence (CL) has been used to reveal growth textures in crystals, due to high detection sensitivities for structural defects and activator elements, with high spatial resolution. In this study, we have used colour cathodoluminescence imaging technique to characterise the forsteritic olivine in order to explain the aqueous alteration in the parent asteroid.

Samples: The Mukundpura meteorite was collected by PRL researchers immediately after the reported fall. However, the main mass was kept in the Geological Survey of India, Kolkata repository. Three polished thick sections of Mukundpura were investigated in this study.

Methodology: Colour CL imaging study was done using Gatan Inc. Chroma CL2, which is installed in Cameca SX100 Electron Probe Micro Analyser (EPMA) at Physical Research Laboratory, Ahmedabad, India. EPMA has been used to quantitatively analyse the major and minor elemental concentrations of CL-active phases, hence forsteritic olivine. Quantitative elemental determination was performed using Wavelength Dispersive Spectroscopy (WDS) technique. The longer counting times are preferred especially to improve the detection limits for the minor elements of olivine (Ca, Mn, Ti, Cr, Ni). Operating conditions were 15 kV accelerating voltage, sample current 80 nA an 1μm beam diameter. Natural mineral standards (for silicates) were used for normalisation of data were corrected using a routine PAP procedure. Uncertainties (2σ) in our measurement for the most of the elements were better than 5%.

Results and Discussion: Mukundpura chondrite appears as various clast and matrix-rich (a variety of phyllosilicate, Mg-serpentine, Fe-cronstedtite, tochilinite) CM2 type, however a few relict chondrules with fine grained accretionary rim are likely to be survived despite the pervasive alteration it has undergone [1]. Highly forsteritic ($Fo_{98.74-99.66}$) and fayalitic (Fa_{50}) olivines both occur as isolated, subhedral, grains within matrix (figure 1a).

CL Analyses: The isolated fayalitic olivines are CL - negative. Instead, forsterite shows a wide range of behaviour which includes the zonation in CL intensity in isolated olivine grains and relict chondrules. It is observed that highly forsteritic olivines show blue CL emission at core, while at the marginal area the luminescence became gradually red to dark red. The CL colour variation is mostly intrinsic and likely attributed to structural defects. However, a patchy, heterogeneous and complex CL zoning are

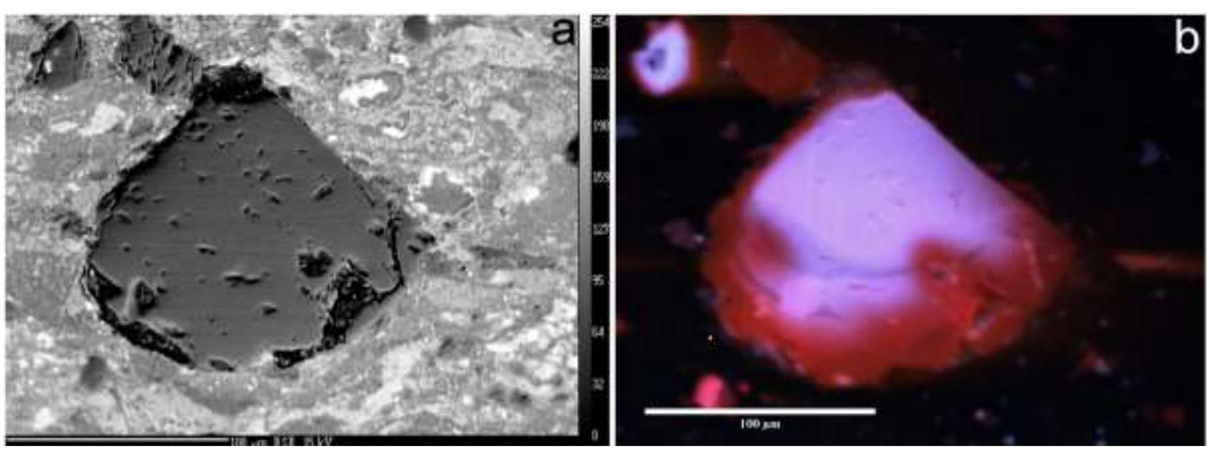

Figure 1: (a) BSE image of an isolated forsteritic olivine grain surrounded by some poorly characterised phases, **(b)** Colour Cathodoluminescence image showing patchy zoning in the same grain.

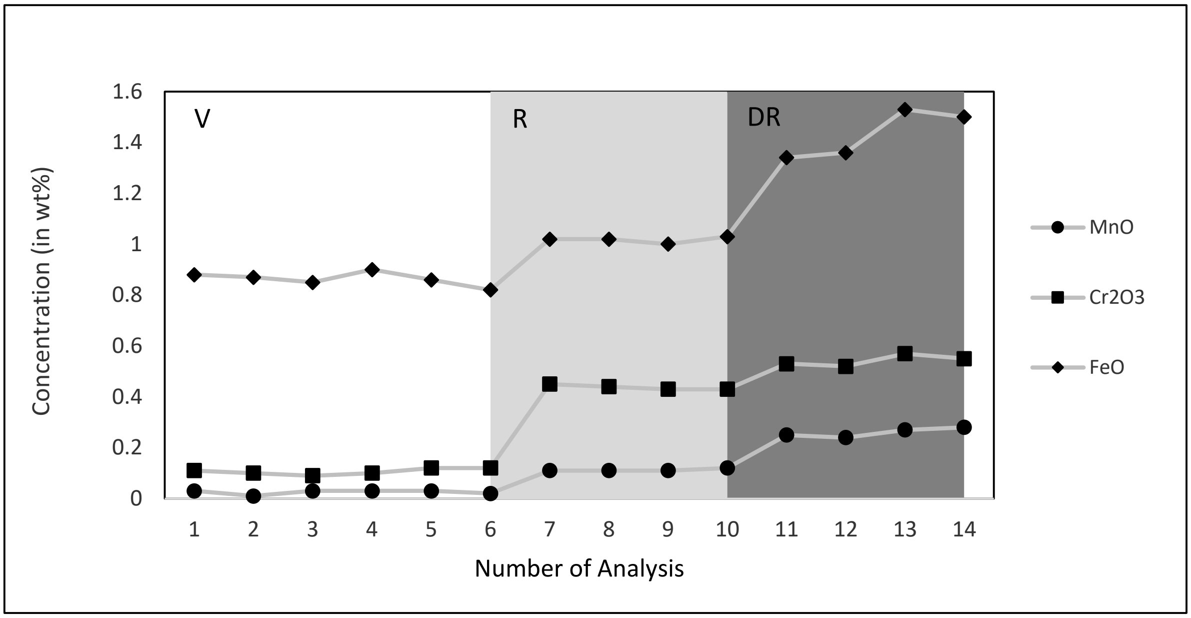

Figure 2: Variability of MnO, Cr_2O_3, FeO in different sectors of CL zoning as shown in forsteritic olivine. V: Violet, R: Red, DR: Dark Red.

also common (figure 1b). Additionally, forsteritic olivines within altered chondrule clasts appear dull red CL luminescent as compared to the isolated forsterite grains in matrix.

EPMA analyses: The detailed quantitative analysis using EPMA corresponds to the colour zonation observed in CL imaging. All CL active phases are observed as Mg-rich and nearly Fe-free. The innermost, unaltered core of forsterite is CaO (0.40 - 0.55wt%), Al_2O_3 (0.13 – 0.19wt%) and TiO_2 (0.03 – 0.07wt%) rich as compared to margin. Instead, the margins show differential enrichment in FeO (1.02 – 1.50 wt%), Cr_2O_3 (0.51 – 0.57wt%) and MnO (0.24 – 0.28 wt%). The Progressive variations of concentration is observed for MnO, Cr_2O_3 and FeO in different sectors as identified with colour CL zonation is shown in figure 2. Interestingly, majority of them show an increasing pattern from violet, red and dark red regions.

The isolated fayalitic olivine does not show any CL luminescence (CL negative) because of the presence of quenching effect of diavalent Fe ions. Red luminescent is the most prominent feature in the highly forsteritic grain. However, in some other grains, CL zoned forsterite shows blue luminescence in the central region while red luminescence is common in the rim. This luminescence can be attributed to impurity center of divalent Mn ion as an activator or trivalent Cr ions, which possess two components of Cr activator and/or structural defect caused by interstitial Cr ions. However, intrinsic structural defect can also produce blue emission because it can be detected in pure synthetic forsterite, whereas minor quadrivalent Ti ions are slightly activated [2].

Plausibly, the emission of blue CL luminescent at pristine core of forsteritic olivine might correspond to rapid cooling and crystallisation of mineral [3], whereas, the migration of diffusible elements can be linked with aqueous alterations occurred within the asteroidal parent body. Hydrothermal alteration is often proposed to explain the luminescent variability in CM chondrite [4]. Nevertheless, the high abundance of luminescent forsteritic olivines in Mukundpura and variegated zoning within them unarguably suggest intense, multiple phases of complex aqueous activities are common in the parent body.

Our study, therefore, suggests that Colour CL imaging is unique, powerful tool to assess the growth structures like colour zonation (insensitive to optical microscope), crystal-chemical properties and to elucidate the unusual minor element distribution manifested by complex CL textures to unravel asteroidal parent body process. This novel technique deserves definite application in detection of forsterite in protoplanetary and planetary nebula or even cosmic dust and may also aid in mineralogical investigations for the future planetary missions.

References: [1] Ray, D. and Shukla, A.D. (2018) *Planet. Space Sci.*, 151, 149-154, [2] Guscik et. al. (2011) *LPSC 42nd*, abstract #1157, [3] Guscik et.al. (2016) *Int. Journal of Spectroscopy*, 2016, 1751730, [4] Guscik et. al. (2013) *Meteoritics & Planet. Sci.*, 48, 2577-2596.