The Mukundpura (CM2) chondrite:A new carbonaceous meteorite fall in India

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Introduction: The Mukundpura chondrite is the fifth carbonaceous meteorite fall in India since 1890 [1,2]. This rare type of meteorite fell on June 6, 2017 in Mukundpura village near Jaipur, India (05:15 IST for details of fall see [3]). It fell as a single stone, however, was subsequently fragmented into several pieces once the stone hit the ground and made a ~10 cm deep pit. The total recovered mass is ~2 kg. A few of the fragments are fusion crusted (~ 2 mm thick) with well developed regmaglypts.

Analytical Techniques: Small slices are cut from the main mass and at least four thick sections were studied for petrography and mineral chemistry; powdery samples for XRD, XRF, ICP-MS analyses and rest fragments were kept for cosmogenic and noble gas isotopic studies. Mineral compositions were carried out using a Cameca SX 100 electron microprobe (15 kV, 15nA). Colour Cathodoluminescence studies were conducted using a Gatan Chroma CL2 imaging system (15kV, 80nA). Trace elements of olivine was determined using longer counting times (30-40s) to improve the detection limits. Bulk major and trace element compositions were determined using method described in [3].

Results: We focus here on the petrography, mineralogy, cathodoluminiscence properties and assess aqueos alteration of the meteorite. Under microscope, Mukundpura appears as a clast-rich texture including few chondrules (porphyritic olivine, barred olivine), mineral clasts (olivine and poorly crystallized phases) set in a relively fine grained matrix. Fine grained accretionary rims are visible around chondrule or even around mineral clast aggregates. The matrices host abundant poorly crystalised phases (PCP), Mg serpentine, carbonate, trace metals and sulphides. Typical calcium-aluminium rich inclusion (CAI) are apparaently uncommon except sporadic occurenecs of a few spinel and diopside grains. The minerals apparently show no evidence of shock. XRD spectra of bulk powder samples yields characteristic peaks for Fe-cronstedtite, tochilinite, Mg-serpentine, olivine, carbonate and minor magnetite. Olivines are highly forstertic (~Fo_{99}), occur as porpyhritic chondrule and more frequently as isolated mineral megaclast (~500µ across) within matrix. Fayalitic olivines (~Fa_{40-50}) are common as isolated clast within the matrix. The diopside average is ($Wo_{38-41}En_{57-60}Fs_{1.2}$, n=7). Carbonates are mostly pure calcite and found frequently intergrown with Mg/Fe serpentine. The Mineralogical Alteration Index and FeO/SiO_2 and S/SiO_2 of PCP are 0.48-0.66, 1.14-1.56 and 0.01-0.1, respectively (also see [4,5]). Both Fe-cronstedtite (FeO~up to 50 wt%) and Mg serpentine (MgO~ 29 wt%) occupy majority of matrix. Highly forsteritic olvine (>Fo_{98}) typically gives off bright red CL emission and appear as homogeneous mineral phase under BSE. However, patchy/ sector zoning (violet and different shades of red) and oscillatory zoning are not uncommon. The violet CL emission in a few of olivines as compared to red rim are dependent on differential FeO (< 1 versus 1.02-1.5 wt%), Cr_2O_3(<0.15 versus 0.43-0.55 wt%), MnO (<0.02 versus 0.12-0.28 wt%) content. Calcites typically display the blue CL emission.

Discussion: The clast dominat lithology suggests active regolith gradening process and clumps of serpentinite-tochiline further refers to active aqueous alteration of matrices in parent body. The dominant phyllosilicates and calcite commonly interpretated to have formed during asteroidal aqueous process and testifies presence of Ca and CO_2. The various mineralogy of phyllosilicate and intergrowth of cronstedtite and tochilinite within serpentine and calcite suggests complex aqueous alteration history. However, alteration was not presumed to be pervasive as a few fresh forsteritic-rich olivine chondrule and relict chondrule are still identifiable. CL emission in red region of forsteritic olivine is attributed to different site occupencies of Mn^{2+} and Cr^{3+}. The variations in CL intenstity of forsteritic olivine are mainly associated with variations of Al_2O_3 and TiO_2 contents. The relatively lesser CL intensity of olivine in altered chondrule and Fe, Cr, Mn-rich rim are often attributed to diffusion caused due to aqueous and or hydrothermal alteration.

Conclusion: The Mukundpura is classified as CM2, based on textures, mineralogy and extent of aqueous alteration. Additionally, alteration escaped some of the silicate minerals including forsteritic olivine chondrules whereas matrix suffered extensive, though incomplete, aqueous alteration. Bulk chemical composition of Mukundpura also correspond to CM type. Further isotopic studies of this eye-witnessed meteorite fall are in progress to understand nebular and asteriodal process and aqueous environment of water-rich asteroid.

References: [1] Meteoritical Bulletin no. 107 (2018) *MAPS* (in preparation). [2] Mason B. (1962-1963) *Space Sci. Rev.* 1:621-646. [3] Ray D. and Shukla A.D. (2018) *Planet. Space Sci.* 151:149-154. [4] Browning L.B. et al. (1996) *Geochim. Cosmochim. Acta* 60:2621-2633. [5] Rubin A.E. et al. (2007) *Geochim. Cosmochim. Acta* 71:2361-2382.