

DISCOVERY OF A POSSIBLE CM2 CARBONACEOUS CHONDRITE PARENT BODY IN THE NEAR-EARTH ASTEROID POPULATION. Matthew R. M. Izawa¹, Vishnu Reddy², Lucille Le Corre³, Allison McGraw², J. A. Sanchez³, Edward A. Cloutis⁴, Katsuyuki Yamashita⁵, Andrew P. Jephcoat¹, Daniel M. Applin⁴, Brendon J. Hall⁶ ¹Institute for Planetary Materials, Okayama University, Misasa, Japan, ²Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA; ³Planetary Science Institute, Tucson AZ, USA ⁴Department of Geography, University of Winnipeg, Winnipeg, MN, Canada; ⁵Department of Earth Sciences, Okayama University, Okayama, Japan, ⁶Enthought Inc., Austin TX, USA

Introduction: The Mukundpura CM chondrite fell on June 6th 2017 and many fragments were recovered shortly after. Mukundpura was classed as a CM2 chondrite based on its petrographic, geochemical and mineralogical characteristics [1,2]. We have conducted a multi-technique investigation of several new fragments of Mukundpura with the aim of placing it in the context of known CM chondrites and their potential parent bodies.

Petrographic analysis: Polished surfaces of two Mukundpura chips were analyzed using a Cameca SX-100 electron probe microanalyzer with natural and synthetic standards. Mukundpura shows considerable heterogeneity, and may show multiple (though related) lithologies. These include a predominant CM2 lithology with cataclastic texture and no apparent fabric, where most primary anhydrous nebular phases such as olivine, orthopyroxene, and Mg-spinel remain unaltered. Some regions represent a more heavily-altered lithology where primary nebular minerals are extensively replaced by secondary phases. The heavily-altered materials may have a weak foliated petrofabric. A third possible lithology is extremely rich in pyrrhotite and pentlandite, possibly reflecting local sulfidation. Figure 1 shows a backscattered electron map of one of the Jaipur polished sections showing the three possible lithologies.

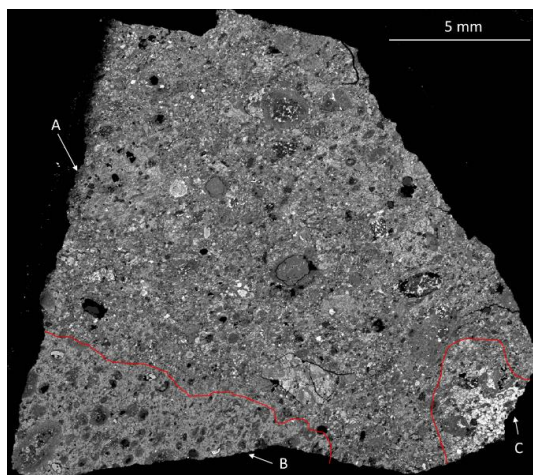


Figure 1: Backscattered electron image showing three possible lithologies in Mukundpura. A) Predominant

CM2 lithology with cataclastic texture and limited alteration. B) Possibly foliated, more heavily altered lithology. C) Sulfide-rich lithology.

Modal mineralogy: Powder X-ray diffraction was conducted at the Diamond Light Source, Beamline I-11 on a <45 μm grain size powder in 500 borosilicate glass capillary using monochromatic radiation with a wavelength of 0.824883 \AA . The powder aliquot was taken from a bulk powder prepared by homogenizing a 150 mg sample of Mukundpura using an agate mortar and pestle. Minerals were identified by pattern matching using the Crystallography Open Database. Modal abundances were determined using Rietveld refinement in the Bruker TOPAS5 software package in fundamental parameters mode [3]. Modal abundances of the minerals identified are summarized in Table 1. The modal mineralogy of Mukundpura is broadly consistent with other CM2 chondrites.

serpentine	63.0 ± 0.9
cronstedtite	9.0 ± 0.7
magnetite	0.16 ± 0.08
tochilinite	8.7 ± 0.4
pyrrhotite	1.62 ± 0.14
mackinawite	0.21 ± 0.05
pentlandite	0.73 ± 0.09
olivine (Fo90)	8.9 ± 0.3
orthopyroxene (En93Fs6Wo1)	0.5 ± 0.2
calcite	4.9 ± 0.2
dolomite	1.7 ± 0.4

Table 1: Modal abundances determined by Rietveld refinement with 1-sigma uncertainties.

Reflectance Spectroscopy: Visible and near IR (0.35-2.5 μm) reflectance spectra were acquired with an Analytical Spectral Devices FieldSpec Pro HR spectrometer with a viewing geometry of $i = 30^\circ$ and $e = 0^\circ$ with incident light being provided by an in-house 150 W quartz-tungsten-halogen collimated light source. Sample spectra were measured relative to a Spectralon®

~100% diffuse reflectance standard and corrected for minor (less than ~2%) irregularities in its absolute reflectance. Ultraviolet reflectance spectra (200-400 nm) were acquired using an Ocean Optics Maya spectrometer equipped with a bifurcated cable (giving a viewing geometry of $i=e=0^\circ$), and an AIS D2 25 W deuterium light source.

Reflectance spectra of Mukundpura are similar to other CM chondrites [4]. In the ultraviolet, Mukundpura shows a red spectral slope with a superimposed local maximum in reflectance near 232 nm (Figure 2A), possible a Fresnel peak related to carbon $sp^2 \pi-\pi^*$ transitions in organic compounds [5]. a marked red slope in the ultraviolet, a local maximum in reflectance near 550 nm, and broad local minima near 700 nm and 900 nm superimposed on a red-sloped NIR spectrum (Figure 2B). The overall reflectance is low (0.055 at 550 nm). Features near 700 nm and 900 nm are ascribable to Fe-bearing serpentine. The feature near 700 nm is attributable to $Fe^{2+}-Fe^{3+}$ charge transfers and the feature near 900 nm is ascribable to Fe^{2+} d-d crystal field transitions.

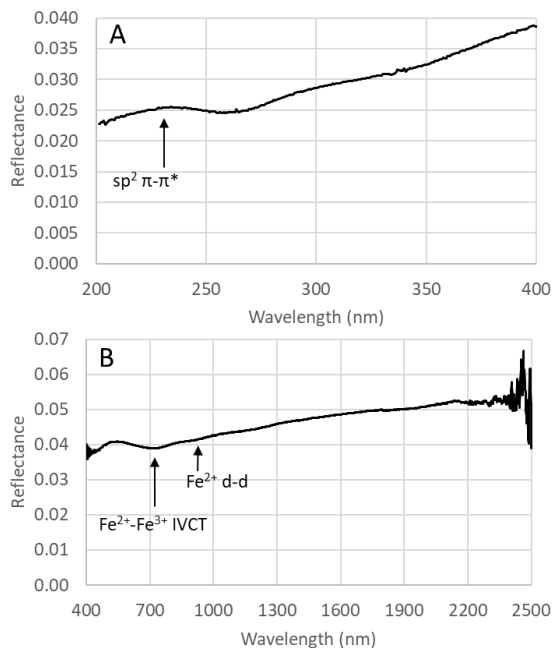


Figure 2: Reflectance spectra of Mukundpura <45 μm bulk rock powder.

Chromium isotopic composition: A 20 mg aliquot of bulk Mukundpura was analyzed for whole-rock Cr isotopic composition using the same methods as [6]. Bulk Mukundpura has a composition similar to other CM2 chondrites yielding $\epsilon^{53}Cr$ 0.10 ± 0.05 and $\epsilon^{54}Cr$ 0.87 ± 0.08 (both 2 standard error), with $^{55}Mn/^{52}Cr = 0.654 \pm 0.020$ (3% error).

Implications for Parent Body: CM2 carbonaceous chondrites have been proposed to be meteorite analogs for primitive, low albedo C-complex asteroids in the main belt and near-Earth asteroid (NEA) population. We conducted an unsupervised survey of C-type NEAs from our NEA characterization survey [7] to find the best spectral match to Mukundpura laboratory reflectance spectrum (Fig. 2). Figure 3 shows the spectral match between NEA 1999JV6 (orange line) and Mukundpura (black line). As seen in the plot, the spectra match perfectly across the entire telescopic wavelength range (700-2500 nm). The increase in reflectance beyond 2300 nm is due to the thermal tail of the Planck curve that has been pushed to NIR wavelengths due to the low albedo of the NEA and close heliocentric distance. We suggest NEAs such as 1999 JV6 as plausible parent bodies for meteorites such as Mukundpura.

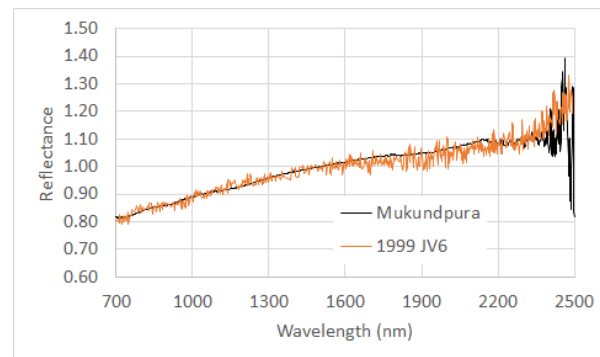


Figure 3: Near-IR reflectance spectra of NEA 1999 JV6 (orange) from the NASA IRTF and laboratory spectrum of Mukundpura CM carbonaceous chondrite. The spectra match perfectly in this wavelength range (700-2500 nm). The data are normalized to unit at 1.5 microns.

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References: [1] Ray D. and Shukla A.D., *Pl. Sp. Sci* 151, 149-154 (2018). [2] Rudraswami N.G. *Geoscience Frontiers* 17 Feb. 2018. [3] Thompson S.P. et al., *Rev. Sci. Instrum.* 80, 075107-1 (2009). [5] Applin et al., *Icarus* 307 40-82 2018. [6] Yamakawa A. et al., *Astrophys. J.* 720(1) 2010.