Platinum Jubilee

Physical Research Laboratory

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Symposium on *Meteoroids, Meteors and Meteorites: Messengers from Space*

Programme

29th November, Monday

Session-2: Chondrites & Micrometeorites: Events and Processes

Session Chairs: Sujoy Ghosh & Anil D. Shukla

Abstract #	Time	Speaker	Title of talk
Invited	13:50-14:05	Sandeep Sahijpal	Chondrites overview.
S2-01	14:05-14:15	Sujoy Ghosh	Natural bridgmanite in the Katol meteorite
S2-02	14:15-14:25	N.G Rudraswami	Micrometeorites: samples of chondritic components.
S2-03	14:25-14:33	Dipak K. Panda	AOA (Amoeboid olivine aggregates): Nebular and Parent body Processes in Mukundpura.
S2-04	14:33-14:41	Arindam. Dutta	Petrochemical and shock characterization of four Indian meteorite (chondrite) finds / falls
S2-05	14:41-14:49	Dafilgo Fernandes*	Investigating micrometeorites from Antarctica and deep-sea sediments of the Indian Ocean: Particulate asteroid and comet matter on the Earth.
S2-06	14:49-14:57	Mayank Pandey*	Preliminary results of micrometeorites collected From Maitri Station Antarctica
S2-07	14:57-15:05	Dipankar Pathak*	Understanding impact volatilization events in meteorites and their parent bodies, through volatile stable isotope systematics.
S2-08	15:05-15:13	Shristi Sharma*	Calcium Isotopic Compositions of Ordinary Chondrites.
S2-09	15:13-15:21	Shreeya Natrajan	The origin and evolution of insoluble organic matter in CMs- A NanoSIMS study.
S2-10	15:21-15:29	Shivani Baliyan*	Carbonates in meteorites and asteroids: Implications for aqueous alteration.
S2-11	15:29-15:37	Kishan Tiwari*	Shocked induced phase transformations and melting textures in Kamargaon L6 chondrite:

			Evidence for multiple impacts and constraints on shock conditions and thermal history
S2-12	15:37-15:42	Avadh Kumar	Meteorite-Asteroid relation using Cosmic ray exposure ages in Ordinary chondrites
S2-13	15:42-15:47	Malika Singhal*	Luminescence Characterization of Minerals from Murchison and Murray

Natural bridgmanite in the Katol meteorite

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Bridgmanite, the most abundant mineral of the Earth's lower mantle, has been reported in only a few shocked chondritic meteorites; however, the compositions of these instances differ from that expected in the terrestrial bridgmanite. Here, we report the first natural occurrence of Fe-bearing aluminous bridgmanite in shockinduced melt veins within the Katol L6 chondrite with a composition that closely matches those synthesized in high-pressure and temperature experiments over the last three decades. The Katol bridgmanite coexists with majorite and metal-sulfide intergrowths. We found that the natural Fe-bearing aluminous bridgmanite in the Katol L6 chondrite has a significantly higher $Fe3+/\Sigma Fe$ ratio (0.69 ± 0.08) than coexisting majorite (0.37 ± 0.10), which agrees with experimental studies. The Katol bridgmanite is arguably the closest natural analog for the bridgmanite composition expected to be present in the Earth's lower mantle. Textural observations and comparison with laboratory experiments suggest that the Katol bridgmanite formed at pressures of ~23 to 25 gigapascals directly from the chondritic melt generated by the shock event. Thus, the Katol L6 sample may also serve as a unique analog for crystallization of bridgmanite during the final stages of magma ocean crystallization during Earth's formation.

Micrometeorites: samples of chondritic components

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Micrometeorites (MMs) are extraterrestrial material in the size range of ~50–2000 µm collected by various methodology in deep sea, Polar Regions and space. These particles get detached from their parent bodies as dust and eventually spiral inwards towards the Sun over geologically timescales [1-6]. The unmelted micrometeorites (UMMs) as the name suggest preserve the mineral phases similar to that prior to atmospheric entry. The study of these UNMs has the potential to provide direct insights into the astrophysical conditions operating during the early solar system and the geological history of their parent bodies [1-3]. In spite of the benefits of studying UMMs, there are far fewer research on unmelted particles than on cosmic spherules [3]. This is predominantly due to highly friable nature of UMMs as well as the effort in recognizing UMMs and the challenges associated with analyzing the small particles.

The present study report high-precision analyses using secondary ion mass spectrometer for oxygen isotope systematics on micrometeorites collected from Antarctica. The study population focuses on unmelted coarse-grained (Cg) varieties. The study also analyzed relict minerals in porphyritic cosmic spherules and the relict matrix in a single scoriaceous fine-grained (Fg) MM. The minerals investigated are olivine and spinel. The textural, chemical and isotopic data on the mineral phases of MMs confirm that both olivine and spinel grains have retained their pre-atmospheric O-isotope compositions, indicating about their history beginning from breaking up with parent bodies, followed by Earth's entry and parent body affinities.

The olivine grains in spinel-free MMs have oxygen isotope composition that follow a slope-1 line on oxygen three isotope plot. They may represent most probable fragmented chondrules, with both type I and type II. The observed Mg#–Δ17O distribution is best explained by a mixture of CM and CR chondrules, Tagish Lake chondrules or WILD2 cometary particles [3]. One of these chondrule-like MMs has oxygen isotope composition that are heterogeneous that are ^{16}O-rich linking it to relict silicate fragment of AOA material probably fused into the chondrule precursor or CAI type material [1]. The present work supports earlier O-isotope studies signifying that small MMs significantly sample material from CC parent bodies and that CgMMs sample from chondrules and, to a lesser extent, CAI material. The further studies will provide insights into the primitive O-isotope reservoirs of the early solar system.

References: [1] Genge M. J. et al. (2008) *MAPS*, ***43***, 497–515. [2] Engrand and Maurette,(1998). [3] Suttle et al. (2019) GCA 245, 352–373. [4] Plane J. M. C. (2012) Chem. Soc. Rev. 41, 6507–6518. [5] Rudraswami N G et al. (2020) Meteorit. Planet. Sci. 55, 2256-2266. [6] Taylor S et al. (1998) Nature 392, 899–903.

AOA (Amoeboid olivine aggregates): Nebular and Parent body Processes in Mukundpura.

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Introduction: Amoeboid olivine aggregates (AOAs) are the most common type of refractory inclusions in chondritic meteorite. It looks like AOAs have escaped extensive heating/melting and hence must have preserved the evidence for condensation from solar nebula gas [1,2]. In primitive carbonaceous chondrites, AOAs are mostly consisting of forsterite, Fe, Ni-metal, Al-diopside, spinel, anorthite, and very rare melilite. Mukunpura is a highly altered CM2 type meteorite. The present work aims to study the mineralogy of AOA in Mukundpura to understand the physiochemical condition of nebular gas.
Analytical Techniques: X-Ray mapping and mineral composition for the thick section of Mukundpura were carried out with JEOL IT300 scanning electron microscope coupled with an OXFORD EDS operated at 20 keV 500pA.
Results: The petrography study shows that all the chondrule and the matrix of in the meteorite are highly altered. Few partially altered chondrule with isolated olivine grains are fayalitic in composition [3]. The matrix is mainly clast of phyllosilicates or poorly crystallized phases (PCP) along with presence of carbonates and very rare presence of refractory inclusion [3, 4]. Only in two thick sections, presence of AOA has been observed. The EDS analysis shows the AOA are mainly composed of forsterite ($Fa_{<3}$), high Ca-pyroxene with average Wo 48.7, En 48.4 and Fs 2.8, low Ca pyroxene with average Wo 0.8, En 93.5 and Fs 5.7, Al-rich pyroxene (Al_2O_3 12-16 wt %) with average Wo 46.8, En 47.6 and Fs 5.6, Fe-Ni metal (Fe 92 wt %, Ni 6 wt %, Co ~1 %). AOA's in Mukundpura are mostly aggregates of irregular shaped olivine arranged in band like structure. The metal droplets are within the Ca-Al rich pyroxene. The high_ca pyroxene are coupled within the forsterite grains while low_Ca pyroxenes are occurring as individual grain. Spinel are also occurring as individual grain in AOA.
Discussion: From the geochemical analysis, it appears that Mukundpura is poor in refractory inclusion with highly altered matrix [4]. Only two AOA observed in two thick section (one in each section). AOA's in Mukundpura are mainly composed of forsterite, hi_Ca pyroxene, CAI (Al-rich pyroxene, Spinel), Fe-Ni metal. Forsterite in AOA of Mukundpura are coarse-grained and compact which indicate the possibility of thermal processing but may not be complete melting. Presence of CAI (Ca_Al- rich pyroxene) within olivine suggests that melilite was not physically isolated from the nebular gas. Hence, it can be implicit that during fast cooling the melilite might have altered to Al-Ca pyroxene [5].
Conclusion: AOA are common refractory found in chondritic meteorite and only two AOA observed in Mukundpura. AOA's in Mukundpura are consist of forsterite ($Fa_{<3}$), CAI (in the form of spine, Ca-Al-diopside), Fe-Ni metal. CAI (malilite) might have altered to Ca-Al pyroxene during the fast cooling in AOA of Mukundpura.
Reference: [1] Weber D.and Bischoff A. (1997) Chem. Erde, 57, 1–24. [2] Krot et al., (2002) Meteorit. Planet. Sci., 37, 1451–1490, [3] Panda et al (2018) 81st Annual Meeting of The Meteoritical Society #6270 [4] Panda and Shukla (2019) IPSC; [5] Krot et al., (2004) Chemie der Erde 64 185–239

Petrochemical and shock characterization of four Indian meteorite (chondrite) finds / falls

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In this study four (04 nos.) Indian meteorite (chondrite) finds / falls, e.g. *Bhanupratappur (L4)*, *Jalangi (L5/6)*, *Karimati (L5)* and *Natun Balijan (L4)* (earlier referred as Sadiya by [1]), have been registered in the Meteoritical Bulletin Database (http://www.lpi.usra.edu/meteor/metbull) for the first time based on their chemical and petrological types [2,3]. These ordinary chondrites of varying petrologic types (L4 to L5/6) with shock grades/stages ranging from S2 – S5 have been studied to evaluate relative degree of shock metamorphism and its characteristic features. Moreover, relatively higher equilibration temperatures (720-1109°C) have been estimated for these L-Group chondrites which can be correlated with their shock stages with increasing petrologic types, though at many instances the shock effects have been annealed to some extent with increasing temperature. Characteristic Raman peaks exclusively represent the presence of wadsleyite (718 cm^{-1} and 917 cm^{-1}) and ringwoodite (795 cm^{-1} and 842 cm^{-1}) fragments confined within shock melt veins (SMVs) as observed in *Jalangi (L5/6)* and *Bhanupratappur (L4)* chondrites. Presence of plagioclase melt glass along the interstitial /intergranular spaces of olivine and pyroxene chondrules, and within matrices suggests escalation of shock pressures at above ~ 45 GPa, involved in volume expansion and generating radial cracks in *Jalangi (L5/6)* chondrite. These recent fall / find, e.g., *Jalangi (L5/6)*, *Karimati (L5)*, *Bhanupratappur (L4)* and *Natun Balijan (L4)* chondrites exhibit comparable mineralogy, textures, and mineral chemical data (see Table -1), suggesting similar parental source component.

Table-1: Mineral chemical data, textural variants, and shock grade of studied chondrites

Chondrite	Mineralogy*	Textural variants	Chondrule: Matrix	X_{Mg}	Equilibration T in °C#	Shock Stages
Bhanupratappur (L4)	Olivine ($Fa_{25-29}Fo_{71-75}$)	PO, GO, POP chondrules and matrix component	~ 70 : 30	0.71 – 0.75	720-1020	S4 – S5
	Opx ($En_{72-77.5}Fs_{20.6-26.3}Wo_{1-4}$)	PP, POP, GP chondrules and matrix component		0.72 – 0.775		
	Cpx	Present as matrix component, rarely as mesostasis within PO and POP chondrules		$Wo_{42.7-48.3}En_{44.5-47}Fs_{7-12}$		
Jalangi (L5/6)	Olivine ($Fa_{24-27}Fo_{73-76}$)	BO, PO, GO, POP chondrules and matrix component	~ 60 : 40	0.73 – 0.76	825-1109	S4 – S5
	Opx ($En_{74.8-77}Fs_{21-23.4}Wo_{1-2}$)	PP and POP chondrules and matrix component		0.748 – 0.770		
Karimati (L5)	Olivine ($Fa_{24-26}Fo_{74-76}$)	BO, PO, GO, POP chondrules and matrix component	~ 60 : 40	0.74 – 0.76	720-950	S2 – S3
	Opx ($En_{74-77.1}Fs_{21.4-25.8}Wo_{\leq 2}$)	GP and POP chondrules and matrix component		0.748 – 0.771		
Natun Balijan (L4)	Olivine ($Fo_{73-75}Fa_{25-27}$)	BO, PO, POP, GO chondrules and matrix component	~ 70 : 30	0.73 – 0.75	750-930	S2 – S3
	Opx ($En_{69-76.7}Fs_{22-30}Wo_{1-4}$)	PP, POP chondrules and matrix component		0.689 – 0.767		
	Cpx	Present as matrix component, within mesostasis of BO and POP chondrules and rarely as rock/mineral clasts		$Wo_{27-48.8}\ En_{43.7-59}\ Fs_{7.3-13.4}$		

* Apart from olivine, orthopyroxene, clinopyroxene and feldspathic glass, Fe-Ni metals (kamacite and taenite), ± magnetite ± troilite ± chromite ± merrillite ± apatite are also present in these studied chondrites.
Equilibration temperatures of studied chondrites have been calculated after Brey and Köhler (1990); Witt Eickschen and Seck (1991); Wood and Banno (1973); Lindsley and Anderson (1983) and others, compiled with PTMAFIC data. Calculation error limit in PTMAFIC software: ± 25-60ºC.

References: [1] Saikia B. J. et al. (2017) *Journal of Astrophys Aerospace Technol.*, **5**, 2. [2] Dutta A. and Raychaudhuri D. (2019) *GSI Unpublished Report*, FS 2017-19. [3] Gattacceca J. et al. (2020) Meteoritical Bulletin, no. 108, *Meteorit. Planet. Sci.*, **55(5)**, 1146-1150.

Investigating micrometeorites from Antarctica and deep-sea sediments of the Indian Ocean: Particulate asteroid and comet matter on the Earth

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Micrometeorites are micrometers to millimeters in size heated extraterrestrial particles and are primarily derived from asteroid bodies and comets that are collected from the Earth's surface [1,2,3,4,5]. Extraterrestrial dust, estimated to be ~40,000 tonnes per year, enters the atmosphere and is by far the most abundant extraterrestrial material accreting to the Earth [6]. Although 90% of the dust that directly enters the atmosphere is lost due to ablation during the entry process only 10% is recovered as micrometeorite on the surface of the Earth [7]. Micrometeorites have undergone significant chemical changes as a result of heating and ablation, making it difficult to determine their precursors [8]. Despite this, the previous study shows their chondritic elemental ratios preserved with the least changes [9]. For this study micrometeorites, were obtained from Antarctica ice and deep-sea sediments of the Central Indian Ocean Basin [10,11]. Scanning electron microscope and electron microprobe were used to examine and investigate the petrology and chemical composition of micrometeorites. The texture, mineralogy, and chemical composition of partially melted micrometeorites and unmelted Antarctica fine-grained micrometeorites indicate dominant fine-grained carbonaceous chondritic precursors. Some of the relict grains found in micrometeorites appear to represent type I and type II chondrule fragments from carbonaceous and ordinary chondrites. The major and minor elements for relict olivine and pyroxenes are compared with those from carbonaceous and ordinary chondrites to assert the nature of chondritic precursors that contribute to relict grains in micrometeorites. Unmelted Antarctica coarse-grained micrometeorites that are studied are similar to chondrules from many carbonaceous chondrites. In addition, evidence of intact subspherical domains of chondrules has been found in a few composite micrometeorites, which constraints the chondrule features of micrometeorites parent bodies [12]. The petrology, mineralogy, and chemical composition of these Antarctic and deep-sea micrometeorites suggests carbonaceous chondrites as the dominant source, with a modest fraction of ordinary chondrite-like parent bodies contributing a minimal fraction.

References: [1] Bradley et al. (1998), *In Meteorites and the Early Solar System*, 861-898. [2] Maurette et al., (1991), *Nature,* **351**, 44–47. [3] Brownlee et al. (1993), *24th LPSC*, 205-206. [4] Taylor et al. (1998), *Nature*, **392**, 899–903. [5] Genge et al. (2008), *Meteorit. Planet. Sci.,* **43**, 497–515. [6] Love and Brownlee (1991), *Icarus*, **89**, 26-43. [7] Taylor et al. (2000), *Meteorit. Planet. Sci.* **35**, 651–666. [8] Rudraswami et al. (2015), The Astrophysical J., **814**, 78. [9] Brownlee et al. (1997), *Meteorit. Planet. Sci.* **32**, 157–175. [10] Rudraswami et al. (2020), *Meteorit. Planet. Sci,* **55**, 2256-2266. [11] Prasad et al. (2013), *JGR*, **118**, 2381–2399. [12] Fernandes et al. (2021), *52nd LPSC* (LPI Contrib. No. 2548).

Preliminary results of micrometeorites collected From Maitri Station Antarctica

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Micrometeorites are the largest fraction of extraterrestrial material reaching to the earth's surface and represent a broader spectrum of Solar System bodies as compared to meteorites. Here we will discuss preliminary results obtained from ~3000 cosmic spherules collected from Antarctica Blue ice region located approximately 8 km from the permanent Indian station Maitri (70°45S and 11°44E) [1]. These cosmic spherules are classified based on the scheme given in [2]. All the selected particles were mounted in epoxy, carbon-coated, examined, and analysed using SEM and EPMA respectively. The MMs are dominated by porphyritic (~36.9%) and barred (~36.5%). The other textural types comprises cryptocrystalline ~7.4%, glass~4.5%, RGB ~2.9%, scoriaceous ~4.5%, I-type ~6.1%, and G-type ~1.2%. When compared with particles collected from deep sea it is found that they are better preserved as lots of particles are lost due to interaction with sea water. Bulk major oxide data is obtained and elemental ratios of non-volatile elements shows that majority of them align with carbonaceous chondrites. Also lack of chondrules in majority of the particles impose important question on the nature of progenitors. We have also started to separate and analyze unmelted particles and some of which are also included here. They can be broadly divided into Coarse grained and fine grained and provide direct window to their precursors. Their mineralogy is also discussed briefly. Further analysis of Antarctica samples is continuing, and preliminary findings indicate that both melted and unmelted micrometeorites could be recovered. In the future, a thorough examination will be carried out to elucidate the sources of cosmic dust and better understand the early solar system

References: [1] Rudraswami et al. (2020), *Meteoritics and Planetary.Science.*, **55**, 2256-2266. [2] Genge M. J., Engrand C., Gounelle M. and Taylor S. (2008) *Meteoritics and Planetary.Science.*, **43**, 497– 515.

Understanding impact volatilization events in meteorites and their parent bodies, through volatile stable isotope systematics

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Introduction: Impact events on terrestrial planets and other rocky bodies like asteroids are crucial in understanding their geological past. Impact events were responsible for delivering materials toward inner solar system, during the late heavy bombardment period that provides an insight to the lunar evolution. Such processes are also considered to be important in delivering volatiles to Earth at different times during its formation, and shortly or during its early differentiation. In this abstract, we present K and Sn stable isotope data of two ordinary chondrite falls from India, Dergaon (H5) and Mahadevpur (H4/5), to 1) Explain the anomalously low potassium content of Dergaon amongst ordinary chondrite [1], and 2) Constrain a probable impact event in the history of Mahadevpur parent body that could have caused a disturbance in the $^{87}Rb/^{86}Sr$, due to Rb volatilization [2].

Method: The major and trace elements data for both Dergaon and Mahadevpur fragments, together with the Nd and Sr isotope data were obtained using a quadrupole ICP-MS (X-Series II, Thermo Scientific) and a TIMS (Triton plus, Thermo Scientific) at the Center for Earth Sciences, Indian Institute of Science, India, respectively. The K and Sn stable isotopes were measured with a MC-ICP-MS at the Department of Earth and Planetary Sciences, Washington University in St. Louis, USA and Institute of Geological Sciences, University of Bern, Switzerland, respectively.

Result and Conclusion: Two fragments of Mahadevpur (one collected from Mahadevpur, and other from Pengeri) shows almost identical major and trace elements pattern, including $^{143}Nd/^{144}Nd$, suggesting that they are paired meteorites belonging to the same parent-body. However, the fragments show distinct elemental Rb/Sr and $^{87}Sr/^{86}Sr$. Based on the calculation of initial $^{87}Sr/^{86}Sr$ and a modelled Rb loss age ($\Delta t \rightarrow$ time since formation of CAIs), such an impact volatilization event is estimated to have occurred on the Mahadevpur parent body between 4.09-4.137 Ga. Given this hypothesis is correct, the same differences should be observed in the isotopic composition of volatile elements. The $\delta^{41}K$ as well as their $\delta^{122}Sn$ analysis shows a distinct isotope composition, indicating a possible change due to evaporation/condensation processes. Sn being more volatile compared to K, shows a much greater degree of fractionation by a factor of ~0.6 ‰ between the two fragments of Mahadevpur.

The Dergaon meteorite shows a normal Nd and Sr isotope ratios, and the calculated initial $^{87}Sr/^{86}Sr$ shows a composition similar to ordinary chondrites. The $\delta^{41}K$ isotopes composition of Dergaon meteorite is unique amongst the other ordinary chondrites [3].

Here, we evaluate the possibility of evaporative or condensation processes at kinetic or equilibrium conditions (Fig.1). The $\delta^{41}K$ of Dergaon falls under a $P_i/P_{i,\,sat} < 1$ (0.97-0.98) while both the fragments of Mahadevpur falls under the region where $P_i/P_{i,\,sat} > 1$. Here, $P_i/P_{i,\,sat}$ is the saturation pressure of a species i. The magnitude of K isotope fractionation in Dergaon is equivalent to HED groups of meteorites, however the Ca/K doesn't explain a K loss due to evaporation or condensation process.

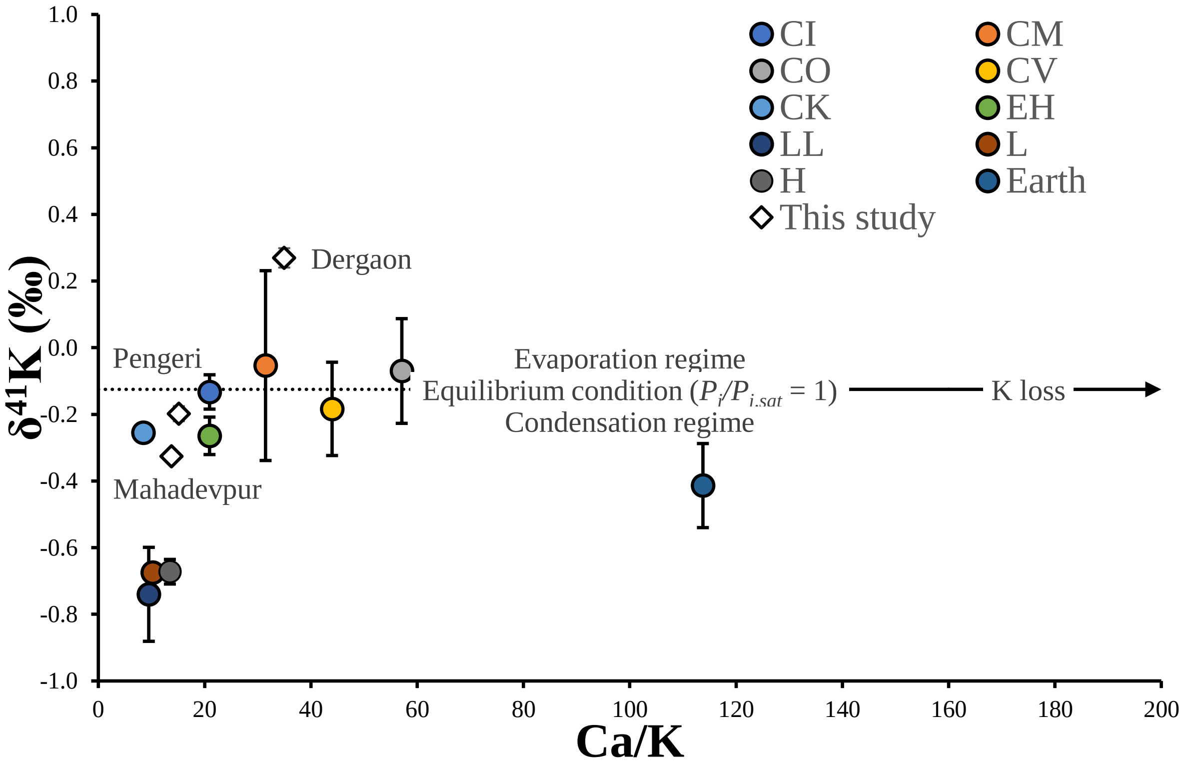

Fig. 1 Relation of K isotope variation with a possible evaporation/condensation process.

References:

[1] Shukla PN, Shukla AD, Rai VK, Murty SV, Bhandari N, Goswami JN, Mazumdar AC, Phukon P, Duorah K, Greenwood RE, Franchi IA. MAPS 40, no. 4 (2005): 627-637.

[2] Pathak, Dipankar, and Ramananda Chakrabarti. MetSoc 2017, 51, no. 1, SI (2016): A509.

[3] Ku, Y., and S. B. Jacobsen. Science advances 6.41 (2020): eabd0511.

Calcium Isotopic Compositions of Ordinary Chondrites

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Abstract: Mass-dependent isotopic differences between bulk meteorite samples can provide an insight into initial heterogeneity, processes within the disk that fractionated isotopes during nebular condensation and planetary accretion, and/or differentiation processes within the planets after they formed.[1] Calcium is an abundant refractory lithophile element (RLE) and therefore, can provide information about high-temperature condensation processes and the initial heterogeneity of the early solar system.[2]

In this study, we measured the calcium isotopic composition of 16 ordinary chondrites using a Thermo Scientific™ Triton Plus Thermal Ionization Mass Spectrometer (TIMS) at CEaS, IISc.[3] The measured data is compared to literature data for ordinary chondrites and different meteorite groups in Figures 1 and 2, respectively.

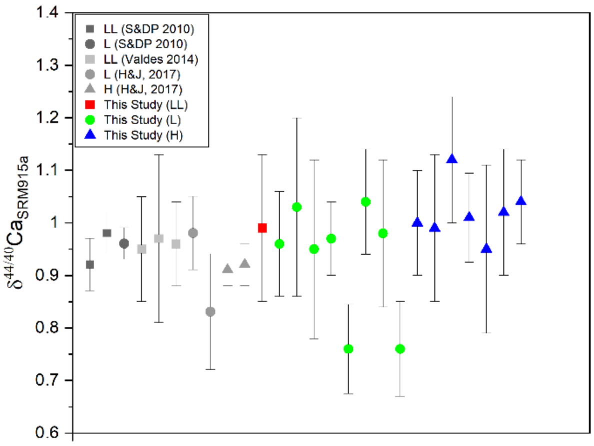

Fig. 1. Mass-dependent $\delta^{44}Ca/^{40}Ca$ compositions of ordinary chondrites measured in this study along with literature data. [2,4,5]

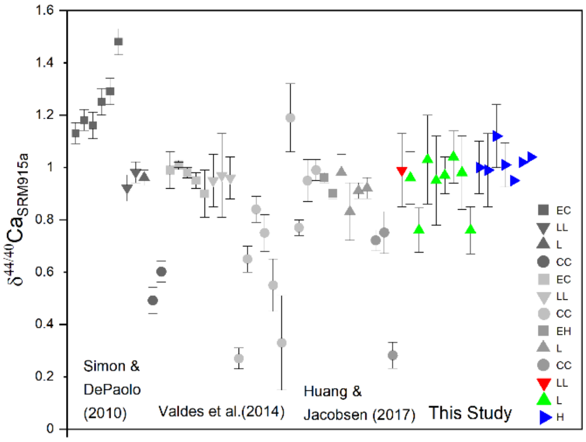

Fig. 2. $\delta^{44}Ca/^{40}Ca$ compositions of ordinary chondrites compared to different chondrite groups. [2,4,5]

Earlier studies have shown some variation in $\delta^{44}Ca/^{40}Ca$ between chondrite groups and Earth, at the <0.1‰ level of precision. The maximum variability was observed in carbonaceous chondrites (+0.10‰ to +1.19‰), and least variability in ordinary chondrites (+0.91‰ to +1.16‰). We show however, that variability in ordinary chondrites is larger than previously measured and that resolvable differences also exist between same meteorite samples measured by different groups-indicating sample heterogeneity. The isotopic composition does not seem to correlate with degree of thermal alteration in the samples. Previous studies have postulated that parent body aqueous alteration [6] and low-temperature alteration [7] play a significant role in establishing variability in calcium isotopic composition. Future studies therefore require a greater number of samples belonging to chondrite groups displaying different stages of alteration.

References: [1] DePaolo D.J. (2004) *Rev. in Mineralogy & Geochemistry Vol.* ***55****, 255-288.* [2] Simon J. I. and DePaolo D. J. (2010) EPSL, ***289****, 457–466.* [3] Mondal S. and Chakrabarti R. (2018) JAAS, ***33****, 141.* [4] Valdes M. C., Moreira M., Foriel J. and Moynier F. (2014) EPSL, ***394****, 135–145.* [5] Huang S. and Jacobsen S. (2017) GCA, ***201****, 364–37.* [6] Lundberg L.L., Zinner E. and Crozaz G. (1994) Meteorit. Planet. Sci. 29, 384–393. [7] Bermingham K.R., Gussone N., Mezger K. and Krause J. (2018) GCA, 226, 206–223.

The origin and evolution of insoluble organic matter in CMs- A NanoSIMS study

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The majority of carbon and nitrogen abundances found in chondrites is usually associated with macromolecular organic component. The fraction of this component that survives acid demineralization is termed as "insoluble" organic matter (IOM). The ^{13}C and ^{15}N isotopic ratios measured in IOM extracted from carbonaceous chondrites generally show large enrichments [1,2]. These provide clues to the origin , formation and the effects of nebular and parent body processing on the organic matter

^{15}N anomalies of the order of ~2000–3000‰ have been reported in carbonaceous chondrites[3,4,5,6]. These enrichments termed as hotspots are reported to be a result of ion molecule reactions at very low temperatures in the outer portion of the nascent solar nebula or the ISM [7,8]. Alternatively, these enrichments can also be explained by UV irradiation self-shielding similar to that of oxygen, self-shielding model [9,10,11] indicating they could have occurred in the outer solar nebula.

On the other hand, ^{15}N isotopic anomalies also manifest in terms of 15N poor signatures, termed as "cold-spots". Although not commonly observed they have been reported in Sahara 97096 [12] , DOM 08006 [13] and Maribo[14]. They are an intriguing feature as the organic matter in primitive chondrites as well as IDPs are predominantly enriched. The local ISM [15,16] and several molecular clouds [17,18,19] show depleted nitrogen isotopic ratios. Moreover the solar value of $\delta^{15}N_{air}$~ -380 ‰ calculated based on the data from Genesis [20] and atmospheric composition of Jupiter [21] also indicated a lower abundance of ^{15}N.

As advanced analytical techniques are used to study these samples the case for both nebular and ISM origin of organic matter becomes stronger. Thus in order to add to the understanding of C, N isotopic anomalies and their link to the origin of organic matter we performed a nanoSIMS analysis on IOM extracted from Murchison, Murray and Mukundpura. We observed a large variation in $\delta^{13}C$ and $\delta^{15}N$ ranging from hotspots to coldspots. Another interesting observation was that a contrast was seen in the ^{15}N isotopic anomalies between samples extracted in air as compared to the samples extracted in argon (inert) environment, which could be a result of contamination due to atmospheric nitrogen during the extraction.

References

[1]Alexander, C.M.O'D., et al., (2007) GCA, 71 4380-4403. [2] Alexander, C. M. O`D., et al., (2017) Chem. Erde 77, 227–256 (2017).[3] Busemann, H., et al., (2006) Science 312, 727–730.

[4] Busemann, H., et al., (2007 MAPS. 42, 1387–1416.[5] Floss, C., et al., (2014). GCA 139, 1–25.[6] Hashiguchi, M., et al., (2015). Geochem. J. 49, 377–391 [7] Wirström, E. S., et al., (2012) Astrophys J 757, L11–L14 .[8] De Gregorio, B.T., et al., (2013).MAPS. 48, 904–928.[9] Chakraborty, S. et al., (2014) Proc. Natl. Acad. Sci. 111, 14704–14709. [10] Muskatel, B. H et al., (2011) Proc. Natl. Acad. Sci. 108, 6020–6025. [11] Visser, R. et al., (2018),A&A. 615, A75-91.[12] Piani, L. et al., (2012) MAPS. 47, 8–29 . [13] Nittler, L. R. et al., (2018), GCA, 226, 107–131 (2018).[14] Vollmer, C. et al., (2020), Sci. Rep 10:20251. [15] Adande, G. R. & Ziurys, L. M.(2012), ApJ, 744, 194–208. [16] Hily-Blant, P et al., (2019) A&A. 632, L12 (2019).[17] Daniel, F. et al. (2013). A&A 560, A3. [18] Redaelli, E. et al., (2018) A&A. 617, A7.[19] Kahane, C. et al. (2018) ApJ, 852, 130–142.[20] Marty, B et al., (2011) Science 332, 1533–1536.

[21] Meibom, A. et al., (2007) ApJ 656, L33–L36.

Carbonates in meteorites and asteroids: Implications for aqueous alteration

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Carbonates, even though occurring as a minor phase (generally < 3%) in primitive Carbonaceous (C) chondrites (commonly in CM (Mighei like) and CI (Ivuna like) chondrites), is ubiquitously present in meteoritic matrix. The carbonates are also important because they are the direct precipitate from the aqueous fluid and thus provide insights on the geologic history (first 5 Ma) of the early Solar System [1]. Carbonates are detected in exposure scale in the surface of asteroids Bennu and Ceres, while majority of carbonates are micron to sub-micron sized (rare veins and vein fragments) within the C-chondrites. The nature of carbonate minerals also varies with the extent of alteration; e.g. complex carbonates are generally common in the highly altered chondrite types. The activity of ion also has a fair control on carbonate chemistry, e.g. in higher aqueously altered meteorite due to decreasing Mg^{2+} activity, dolomite destabilises and facilitate precipitation of calcite. The carbonate mineral chemical composition also varies within a single meteorite and corroborate changes in the microenvironment. This also endorses precipitation of carbonate due to multiple events rather single episode. Thereof, the microstructure, texture and chemical composition of carbonate potentially record the diverse scenarios of aqueous alterations in the parent body.

Carbonates in B-type asteroid Bennu occur as centimetre-thick, meter-long vein suggesting for fluid-flow into the fractures conducive for open system, hydrothermal alteration [2]. The carbonates appear to be more abundant and complex in Ceres as compared to CM/CI chondrites and thus arguing for advanced and pervasive alteration [3].

Future scopes include *in situ* VIS-NIR spectroscopy of carbonate in C-chondrite to better understand the intricacy of spectra obtained remotely from the carbonates on asteroidal surface. The in situ C-O isotopic study of chemically zoned carbonates are also prerequisite to understand crystal growth and isotopic evolution of aqueous fluid.

References: [1] Fujiya, W., Sugiura, N., et al. (2012) Nature Comm. 3, 627. [2] Kaplan H. H., et al. (2020) Science 370. [3] McSween et al. (2018) MAPS, 53, 1793-1804.

Shocked induced phase transformations and melting textures in Kamargaon L6 chondrite: Evidence for multiple impacts and constraints on shock conditions and thermal history

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Contents of Abstract: We report high-pressure mineral assemblages and microtextures in a up to 1.6 mm-wide shock melt vein (SMV) in heavily shocked Kamargaon L6 chondrite to constrain the shock conditions and thermal history. The chondritic portion mainly consists of olivine (Fo_{73-74}), low-calcium pyroxene ($En_{77-80}Fs_{19-22}Wo_{1-2}$), high-calcium pyroxene ($En_{45-46}Fs_{9-10}Wo_{44-46}$), plagioclase ($Ab_{62-70}An_{18-23}Or_{12-15}$), Fe-Ni metal alloy (kamacite and taenite), troilite and a minor amount of phosphate and chromite. The feldspar grains in the SMV have been transformed into maskelynite and lingunite and their texture and heterogenous composition suggest that they crystallized from isolated feldspar melt pockets at high-pressure. The parental pyroxene around some of the maskelynite grains are transformed into majorite. We also observed three distinct textures in olivine grains from the SMV: (i) segmented texture; (ii) vesicular texture; and (iii) dissociated texture. The segmentation may have developed due to the formation of sub-grain boundaries during the recovery process when the grains were subjected to localized shear stress. Many textural and compositional features indicate that the polycrystalline assemblage of segmented olivine is the product of back transformation from ringwoodite or wadsleyite. Dissociation of olivine has been proposed to be the result of incongruent melting of olivine into magnesiowüstite and liquid. We propose that the vesicular texture possibly formed due to localized melting during a shock event and subsequent degassing of volatiles after decompression when the post shock temperature was sufficiently high. Our finding is the first report of vesicular olivine and pyroxene grains in an ordinary chondrite.

Based on textures, melting features and high-pressure polymorphs, we have estimated average shock pressure and temperature in the shock-melt veins of Kamargaon L6 chondrite to be ~19-22 GPa and ~2433-2633 K. The maskelynization of feldspar (An_{18-23}) in the SMV indicates that the Kamargaon L6 chondrite has experienced peak pressure of up to ~30 GPa. Taking the peak thermal metamorphic temperature of 1073 K as initial temperature, the calculated shock and post shock temperature are ~1390 K and ~1226 K, respectively. The thermal model to estimate the cooling history of the shock-melt vein gives the crystallization time of ~50 ms. The SMV reaches the temperature of 1226 K in ~2 s. The shock pulse duration must have been less than ~2 s for the back transformation of high-pressure polymorphs to occur. Calculated values of impact velocity and the parent body size of the Kamargaon L6 meteorite, using these shock conditions, is envisaged ~2.06-2.3 km/s and at least ~6.4 km across respectively. Textures observed in the investigated sample indicate that they were formed as a result of multiple impact events on the parent body of Kamargaon L6 chondrite.

Meteorite-Asteroid relation using Cosmic ray exposure ages in Ordinary chondrites

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Abstract: Meteorites are the space rocks that coming from the outer space due to continuum impacts, collisions and gravitational perturbation on its parent asteroid body. Class of meteorites can be categorized into two types, on the basis of the genesis: *Chondrites* (undifferentiated) and *Achondrites* (differentiated). Further Chondrites can be subdivided as- *Ordinary*, *Carbonaceous* and *Enstatite* based on mineralogy and petrological properties. The ordinary chondrites are the largest class of meteorites in our collection; it had almost 87% of available meteorites. The group of H chondrites (high iron content, approx. 28%), L chondrites (low iron content, approx. 22%) and LL chondrites (low iron and low metallic iron) are together known as Ordinary chondrites. The cosmic ray exposure age of the meteorite is defined as how much time it spends after ejection from parent body. It is also known as ejection age [1].

After ejection from its parent body to their fall on the Earth as meteorites, as they are in continuum exposed to the Solar Wind(SW), Solar cosmic rays (SCR) and Galactic cosmic rays(GCR). During this process interaction of Galatic Cosmic Rays (GCR, energy in GeV range) with the ejected material, resulting in the production of cosmogenic nuclides [2,3]. We calculated ^{21}Ne cosmic ray exposure ages of these meteorites to understand the number of meteorite producing ejection events and constraints of its parent asteroid body. After analyzing the histogram of exposure age of the ordinary chondrites, it depicts influx of meteorite to Earth and its time dependence. Number of peaks also constraint the number of parent bodies which depicts Meteorites-Asteroid relations. [4,5].

References:

[1] Grady M. Monica et al. (2014) *Atlas of meteorites.*
[2] Kumar A. et al. *52nd LPSC LPI Contrib. No*. 2548
[3] Kerridge John F. et al. 1993, *ICARUS* 106, 135-150
[4] Kumar A. et al. (2020) *IPSC_0055*
[5] Dalcher et al. (2013) *Meteorit. Planet. Sci.* 48, 1841-1862

Luminescence Characterization of Minerals from Murchison and Murray

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Thermoluminescence (TL) and optically stimulated luminescence (OSL) are widely used to study the terrestrial and extra-terrestrial materials. Natural TL and OSL signals reveal the thermal, radiation and terrestrial history of meteorites[1]. Additionally, investigating the induced luminescence signals can decode the metamorphic history of the meteorites. However, most of the techniques used are framed for quartz and feldspar. In the present study, we are trying to explore the luminescence properties of new minerals.The luminescence properties of minerals as olivine, spinel, and quartz are being explored which are separated from Murchison and Murray meteorites. The measurements were done on single grains hand picked under optical microscope after physical[2] and chemical processing[3]. The traps responsible for luminescence are characterized using UV and BG-39 filters and stimulated with Blue, Infrared LED and heat[4]. The analyzed grains of olivine show only a low-temperature TL peak near 80-100℃, a significant BSL signal in UV emission. A very feeble IRSL response was observed in UV emission. Spinel also showed a dim luminescence signal and will be subjected to further studies. OSL results of quartz are similar to terrestrial quartz but the TL results are very feeble.

References:

[1] Sears, Derek WG, Kiyotaka Ninagawa, and Ashok K. Singhvi. "Luminescence studies of extraterrestrial materials: Insights into their recent radiation and thermal histories and into their metamorphic history." *Geochemistry* 73, no. 1 (2013): 1-37.
[2] Clarke A. The Extraction and Study of Interstellar Grains. The University of Manchester (United Kingdom); 2018.
[3] Amari S, Lewis RS, Anders E. Interstellar grains in meteorites: I. Isolation of SiC, graphite and diamond; size distributions of SiC and graphite. Geochimica et Cosmochimica Acta. 1994 Jan 1;58(1):459-70.
[4] Yukihara EG, McKeever SW. Optically stimulated luminescence: fundamentals and applications. John Wiley & Sons; 2011 Feb 16.