2nd Symposium On

"Meteoroids, Meteors and Meteorites: Messengers from Space"

25th November, Thursday

Session-V: Planetary Analogues: Analogues: Similar, but not the same!

Session Chairs: V J Rajesh and Satadru Bhattacharya

Abstract #	Time	Speaker	Title of talk
Invited	16:20-16:50	Alik S Majumdar	Serpentinization of iron-rich olivine and its potential for abiotic methane synthesis in planetary bodies
S5-01	16:50-17:00	Subham Sarkar	Spectroscopic and Planetary Perspectives of Puga Hot Spring Deposits
S5-02	17:00- 17:10	Divyanshi Shukla	Temperature of extremely high silicic magma-fluid system in the Bundelkhand craton (India) and its implications for lunar silicic magmatism
S5-03	17:10-17:20	Neha Panwar	Reflectance spectroscopy of Meteorites
S5-04	17:20-17:25	Preeti Kumari	Sambhar Lake in Rajasthan, India as a Potential Terrestrial Martian Analogue Site for Hypersaline Environments.
S4-05	17:25 - 17:30	Javed Akhter Mondal	Earth without Life: A Global Network Model of Abiotic Phosphorus Cycling on Earth Through Time

Spectroscopic and Planetary Perspectives of Puga Hot Spring Deposits

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Hydrous sulfate minerals like alunite, jarosite, and copiapite have been identified and used to reconstruct the paleoenvironmental condition of Mars due to their specific restricted stability field[1]. In this study, we report an analog locality of the Martian surface at Puga geothermal field, Union Territory of Ladakh, India, which hosts these hydrous sulfate minerals along with sodium borates, i.e., borax and tincalconite, using Visible/Near-Infrared (VNIR) (400-2500 nm) spectroscopy, Mid-Infrared (MIR) (4000-400 cm^{-1}) spectroscopy and X-ray diffraction[2]. A Maiden attempt to characterize Na-borates and hydrous sulfate from Ladakh Himalaya using spectroscopy has been made. In-situ VNIR spectra of natural tincalconite are presented in this study for the first time. Being situated at the suture of the Indian and Eurasian plates, the area is heavily fractured. These fractures act as conduits for hot water, which comes out with dissolved elements like boron and sulfur. Boron is considered an essential element for the formation of life[3], and primordial life on Earth could have evolved in ancient Hot Springs as they provide all the necessary components for life[4]. Still, no borate minerals have been found on Mars so far despite the presence of elemental boron on the planet's surface have been proved[5,6]. Thus, the identification and characterization of hydrous sulfates, commonly found on Mars, along with borate minerals in the hydrothermal setting, has an immense significance in astrobiological studies, especially the search for life and suitable places to find life on the Red planet and also to reconstruct the worlds paleoenvironmental conditions.

References: [1] Baron, D., and Palmer, C. D. (1996). Geochimica et Cosmochimica Acta, 60(2), 185–195. [2] Sarkar, S. et al. (2022). Journal of Geophysical Research: Planets, 127. [3] Kim, H. J. et al. (2011). Journal of the American Chemical Society, 133(24), 9457–9468. [4] Djokic, T. et al. (2017). Nature Communications, 8(1), 1–9. [5] Stephenson, J. D.et al. (2013). PLoS One, 8(6), e64624.[6] Gasda, P. J. et al. (2017). Geophysical Research Letters, 44(17), 8739–8748.

Temperature of extremely high silicic magma-fluid system in the Bundelkhand craton (India) and its implications for lunar silicic magmatism

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The Earth is considered a natural laboratory and potential analogue to test and understand the Lunar and Martian geological environments. Recent planetary explorations programs, such as the "Curiosity" and the sample return Apollo mission in late nineties have confirmed the presence of silicic magmatism on Moon and Mars [1]. The occurrence of igneous rocks with SiO_2 >75wt% is rare and unusual, both in terrestrial and lunar rock records. One such rare occurrence is the ~2.0 Ga extremely high silicic quartzolites in the Bundelkhand craton, northcentral India, having SiO_2 contents varying from 85 wt% to as high as 96 wt% (e.g., [2,3]). Quartzolites (commonly referred as quartz reef in the Bundelkhand literature) apparently, have similar chemical makeup (SiO_2 ≥90 wt%; TiO_2 ~1wt%; FeO ~1.61wt%) to high silicic fragments/ tridymite from the Apollo 11 samples/Si-rich melt inclusions, as reported in various lunar studies (e.g. [4,5,6,7]).
Understanding of silicic magmatism has garnered scientists' interests ever since. It is crucial in deciphering planetary evolution, differentiation of crust, crustal characteristics and to put constraints on the Moon and Martian evolution vis-a-vis Earth's geochemical evolution. However, such studies at present are carried out through multi-disciplinary approach using simulated petrological modelling of silicic magma reservoirs, geophysical surveys, satellite data etc. Quartzolites (SiO_2 ≥90 wt%) of Bundelkhand craton, India represents one such potential terrestrial analogue to have a first-hand experience in drawing key petrological constraints for Moon and Martian rocks/minerals and help understand lunar and martian magmatic environments.
Quartzolites of the Bundelkhand craton represent a widely distributed (modest aerial estimate: 40000 m×50 m) extremely silicic terrestrial rock record. There are more than 1540 mappable quartzolite veins/reefs exposed [8] intermittently within the vast expanse of the 29,000 km^2 area of the craton. The Bundelkhand quartzolites (SiO_2 ≥ 90wt%) have variable concentrations of iron, aluminium and titanium oxides (Al_2O_3 ≥3.8 wt%; TiO_2 ~1wt%; FeO ~1.61 wt%; Na_2O+K_2O ~2 wt%). A plausible source and/or the processes producing a magmatic rock with ~95wt% SiO_2 is still unknown. Our limited study on microstructures and quartz textures developed in the quartz veins/reefs suggest that these rocks may have originated in the brittle-ductile transition zone (BDTZ) at middle crustal depth [9].
A comparative study of the published major element compositions of high silica volcanic and magmatic rocks/minerals/melt inclusions (in various rocks and minerals) of Moon with those mof the Bundelkhand quartzolites bring out some interesting results. The Al_2O_3 content of quartz reefs overlap with the Al_2O_3 present in immiscible Si-rich melt inclusions encountered within ~4.3Ga old lunar zircon. On the TiO_2 wt% vs SiO_2 wt% diagram, the TiO_2 concentrations are found to be in agreement with that of the immiscible silicate melt inclusion encountered within the same ~4.3Ga lunar zircon [4], and with tridymite encountered within basalt sample 10045-29 of Apollo 11 returned samples [5]. The FeO concentrations of quartzolites also surprisingly overlap with those of immiscible Si-rich silicate melt inclusion within the ~4.3Ga old zircon [4]. On plotting the normalized values of FeO and TiO_2 contents from the published literatures of quartzolites and other high silicic rocks/melts on Moon in a compositional phase equilibrium of FeO-TiO_2 [10] liquidus temperatures varying between

1330˚C-1440˚C, sometimes even going upto 1600˚C, are obtained. The liquidus temperatures obtained in rhyolite-MELTS_v1.0x program are also comparable within a range of 1200˚C to 1600˚C.

Liquidus temperatures yielded from the compositional phase diagrams of FeO-TiO_2 and the MELTS program are in agreement with each other. The significant overlap in major element chemical compositions of the samples from Lunar rocks/meteorites/silicate melt inclusions and the Bundelkhand samples indeed intriguing. Whether extremely high silicic rock in Bundelkhand and in Moon and Mars having comparable major element compositions are products of magma or silicate-dissolved deep fluid remains an open question and deserves further critical examination.

References:

1. Morris, R.V., Vaniman, D.T., Blake, D.F., Gellert, R., Chipera, S.J., Rampe, E.B., Ming, D.W., Morrison, S.M., Downs, R.T., Treiman, A.H., Yen, A.S., Grotzinger, J.P. Achilles, C.N., Bristow, T.F., Crisp,T.F., Des Marais, D.F., Farmer,J.D., Fendrich, K.V., Frydenvang, J., Graff, T.F., Morookian, J.M., Stolper, E.M., Schwenzer, S.P. (2016). *Earth, Atmos., and Planet. Sci*. **113(26)**, 7071-7076.
2. Pati, J.K., Patel, S.C., Pruseth, K.L., Malviya, V.P., Arima, M., Raju, S., Pati, P. And Prakash, K., (2007). *Journ. Earth Sys. Sci.* **116**, 497-510.
3. Sensarma, S., Matin, A., Paul, Madhesiya, A.K., Sarkar, G. (2021). *Pre. Res*. **352**, 105951.
4. Zeng, X., Joy, K.H., Li, S., Lin, Y., Wang, N., Li, X., Li, Y., Hao, J., Liu, J., Wang, S. (2020). *Geophys. Res. Lett.* **47(4)**. doi: 10.1029/2019GL085997.
5. Keil, K., Bunch, T.E., Prinz, M. (1970). *Proc. of the Apollo 11 Lunar Science Conf.* **1**, 561-598.
6. Roedder, E. and Weiblen, P.W. (1971). *Proc. of the 2nd Lunar Science Conf.*, 507–528.
7. Roedder, E. and Weiblen, P.W. (1972). *Earth and Planet. Sci. Letters*. **13**, 272-285.
8. Das, D., Mondal, T.K., Hossain, M.S., (2019). *Journal of Geol. Soc. of India*. **94**, 227-237.
9. Shukla, D., Sensarma, S. (2020). Abstract In the *36th I.G.C.* 1643-1644.
10. Eriksson, G., Pelton, A.D. (1993). *Metal. Trans. B.* **24B**, 795.

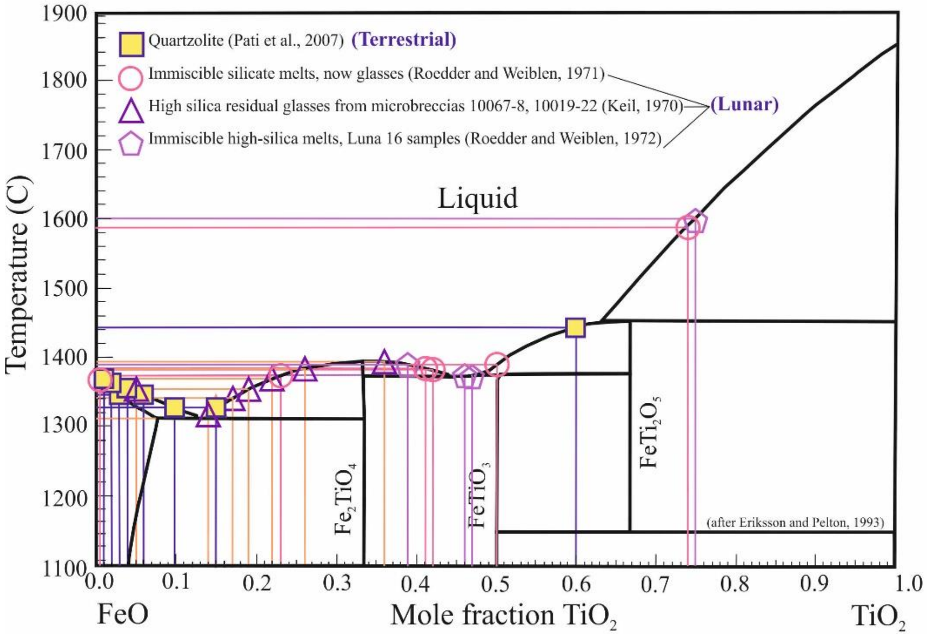

Fig. 1: Liquidus temperatures of terrestrial and lunar samples estimated from FeO-TiO_2 phase diagram (modified after Eriksson and Pelton, 1993)

Reflectance spectroscopy of Meteorites

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Reflectance spectroscopy is a non-destructive technique that can be used to derive the mineralogical composition and physical properties such as grain size, surface roughness and porosity [e.g., 1, 2, 3, 4] of particulate surfaces. In this study, reflectance spectra of the Balcare, Berduc and Realico Meteorites has been obtained in the spectral range 0.35-2.5 microns using ASD Fieldspec 4 Hi-Res. The measurements have been acquired for bulk samples of the meteorites using bifurcated optical fiber assembly. This arrangement enabled us to acquire reflectance spectra of very small meteorites under normal incidence and emission angles, and thereby zero-degree phase angle. These spectra were then used to characterize the mineralogy of the meteorites by estimating the various band parameters such as band centers, band area etc. for the visible 1000nm and 2000nm bands [5,6]. This is an efficient lab-based technique that can be used to establish the asteroid-meteorite relationship with aid from satellite and telescope based remote sensing datasets.

References: [1] Hapke, B., JGR 86, B4, 3039-3054, 1981; [2] Hapke, B., Icarus 157, 523–534, 2002; [3] Shkuratov Y. et al., Journ. Quant. Spectrosc. Rad. Transfer., 113 (18) 2431-2456, 2012; [4] Sun, Z. et al., J. Quant. Spectrosc. Ra. 163, 102–119, 2015; [5] Adams, J. B., JGR, 79(32), 4829-4836, 1974; [6] Gaffey, M. J. et al., AIP Conf Proc., 1386, 189-169, 2002

Sambhar Lake in Rajasthan, India as a Potential Terrestrial Martian Analogue Site for Hypersaline Environments

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Sambhar lake, India's largest inland salt playa is situated in Sambhar town, Jaipur district of Rajasthan is an elliptical, shallow (max depth 3m) hypersaline lake. The area falls in a semi-arid region with a maximum temperature of 45ºC and is rain shadowed. The basement of the lake is made up of Delhi and Aravali Supergroup comprising the Sandmata Gneissic Complex of Bhilwara Supergroup which is overlain by an arkose-pelite-greywacke suite of Ajmer formation of South Delhi fold Belt (Mesoproterozoic) [3]. Sambhar lake is rich in evaporites, including carbonates- (calcite, dolomite), chlorides (halite, sylvite, carnalite), and sulfates (gypsum, thenardite, anhydrite, etc.) [2]. The extensive occurrence of evaporite deposits in the study area makes them interesting for comparison to the Martian surficial geology. Various sulfate minerals like jarosite ($K_2Fe_6(SO_4)_4(OH)_{12}$) and gypsum ($CaSO_4.2H_2O$) and halite have also been reported from different parts of Mars such as Juventae Chasma, the rim of Endeavor crater, Cape rock, etc. Therefore studying the terrestrial gypsum and associated evaporites will help in understanding geological processes for its origin and evolution, on the surface of Mars. Among all the minerals present in the study area, gypsum plays a significant role, since it can be formed by evaporation in diverse depositional environments. Gypsum ($CaSO_4.2H_2O$) is formed when water reduces by evaporation to nearly 20% of the original volume after carbonates are precipitated. It can transform into another mineral with further evaporation and change in water conditions (temperature, pH, or salinity). The spectral signatures of gypsum and associated evaporites provide information regarding the molecular structure and the chemical composition, which in turn help us to understand the physico-chemical conditions and transformations that lead to the formation of the mineral assemblage. Through the oscillating conditions between evaporation, precipitation, and dissolution during the formation of gypsum, some organic molecules get entrapped within the mineral. The present study also focuses on characterizing the possible organic molecule found along with the minerals. We have carried out a detailed spectral characterization using techniques such as FTIR, Laser Raman, and Hyperspectral analysis of gypsum and other evaporites from this region. The preliminary observations from the study indicate the presence of sulfates and hydroxides. FTIR spectral signatures show characteristic absorption bands at ~1639 nm and 1000nm, which attributes to the symmetric and asymmetric stretching of H-OH bonding. The absorption feature at or near ~693 nm indicates asymmetric vibration of SO_4^2. Similarly, the Raman shifts are also confirming the chemical composition of the samples as sulfate., by the distinctive peaks attributing the sulfate and hydroxide ions. Laser Raman shows signatures of halite in a few of the samples with some impurity of lead and NH_4. These spectral signatures are correlated with the H-OH vibration of 1000 nm observed by CRISM on Mars at the rim of Cape rock for sulfate-rich veins [1]. In addition to this, morphological observations shows that polygonal cracks of Gale Crater's center and dunes from Olympia Undae from the North Polar region of Mars are similar to the polygonal dissection cracks and dunes from Sambhar Lake.

All this study will help in understanding various geological processes such as fluid-rock interaction, alteration processes, and importantly the presence of water activity on earth as well as on early mars and its astrobiological significance. Therefore, the Sambhar Lake of Rajasthan can be considered a potential terrestrial analogue for the geomorphological, chemical, mineralogical, spectral, and astrobiological studies of Mars.

Keywords: spectral analyses, Gypsum, Sambhar Lake, evaporites, terrestrial analogues.

References

[1] Cabrol, Nathalie A., and Edmond A. Grin, eds. *From Habitability to Life on Mars*. Elsevier, 2018.

[2] Mukherjee, Pralay, and Prabal Rakshit. "Late Quaternary climatic vicissitudes as deciphered from the study of lacustrine sediments of Sambhar Lake, Rajasthan, India." *Indian Journal of Geosciences* 66.4 (2012): 213-224.

[3] Sinha, R., and B. C. Raymahashay. "Evaporite mineralogy and geochemical evolution of the Sambhar Salt Lake, Rajasthan, India." *Sedimentary geology* 166.1-2 (2004): 59-71.

Earth without Life: A Global Network Model of Abiotic Phosphorus Cycling on Earth Through Time

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Abstract: We present here a dynamic abiological global box model for Earth's P reservoir and flux evolution, built from an ensemble of smaller models for the distinct geochemical processes we know P is subject to during its cycle combined – from deep Earth reservoirs to surface processes and extraterrestrial delivery – obtaining a "best guess" baseline for model parameters, aiming to model what an Earth-like planet where life never expanded to form the planetary-wide biosphere we are part of today. Yet, given the significant uncertainties on initial P distribution through global geochemical reservoirs, a set of simulations with randomized original P mass distribution across planetary reservoirs was run. Its combined results suggest that given enough reservoir connectivity, final state reservoir masses were practically independent of original P distribution on reservoirs post-core formation. Similarly, uncertainties related to some past or present-day P fluxes between reservoirs or associated with possibly varying timescales of geochemical P cycling processes during long-term planetary evolution led us to assess how long-term P mass distribution over planetary reservoirs was affected by some of the parameters related to effectiveness or associated timescales of several geochemical or geophysical processes associated with P geochemical cycle. This model's results suggest that in the absence of widespread biological activity, long-term planetary geochemical cycling on planets similar to Earth, with respect to geodynamism, tends to bring P to surface reservoirs. In contrast, generalized biological activity tends to move P to subductable marine sedimentary reservoirs, depleting the surface crustal and sedimentary reservoirs of inorganic Phosphorus.

References: [1] Jusino-Maldonado, M., Riançо-Silva, R., Mondal, J.A. et al. A global network model of abiotic phosphorus cycling on Earth through time. Scientific Reports **12**, 9348 (2022). [2] Laneuville, M., Kameya, M. & Cleaves, H. J. (2018) Astrobiology, **18**, 897-914. [3] Rudnick, R. L. & Gao, S. (2014). In Treatise on Geochemistry Volume 3: The Crust, eds. [4] Stern, R. J. & Scholl, D. W. (2010) International Geology Review, **52**, 1-31. [5] Filippelli, G. M. (2008). Elements, **4**, 89-95. [6] Pasek, M. & Lauretta, D. (2008) Origins of Life and Evolution of Biospheres, **38**, 5-21. [7] Stewart, A. J. & Schmidt, M. W. (2007) Geophysical Research Letters, **34**. [8] Paytan, A. & McLaughlin, K. (2007) Chemical Reviews, **107**, 563-576. [9] Pasek, M. A. & Lauretta, D. S. (2005). Astrobiology, **5**, 515-535. [10] Benitez-Nelson, C. R. (2000). Earth-Science Reviews **51**, 109-135. [11] McDonough, W. F. & Sun, S. S (1995) Chemical Geology, **120**, 223-253.