SULFATE MINERAL FROM HOT SPRINGS IN COLD DESERT (LADAKH, INDIA):ANALOGUE TO MARTIAN SULFATE DEPOSIT? A. D. Shukla[1], D. Ray[1] and S. Bhattacharya. [1]Physical Research Laboratory, Ahmedabad 380009, India (anilds@prl.res.in); [2]Space Application Centre, Ahmedabad-380015

Introduction: Discovery of sulfates by Mars Orbiter instruments and rover (Mini-TES, Opportunity) is important for understanding the aqueous geochemistry in the early geologic history (late Noachian-early Hesperian) of Mars [1,2]. Sulfates are also have great astrobiological implications for past habitability on Mars [3]. The different mode of ocurrences of variety of sulfates (Fe-Mg-Ca sulfate) account for different hypothesis to exolain their formation process. These include mainly evaporative or sulphide oxidation. The discovery of sulfate veins further triggers possible hydrothermal origin. However, due to lack of definitive information especially for Ca-sulfate, the origin remains elusive. Therefore, studies on Mg-Ca sulfates from different terrestrial setting are more compelling as compared to Fe^{3+} sulfates due to restricted occurrences of the later.

Ladakh in Jammu and Kashmir State, India is known for manifestation of several hot springs, viz. Puga, Chumathang and Panamik (Fig. 1). Ladakh is benefitted by its geographical location (rain shadow zone of the Great Himalayan Range), regional elevation (relative relief of 1000-2000 m, with few peaks >7000 m), and insolation conditions (minimum winter temperature of -40°C) that elucidate well its contemporary arid to hyper-arid climate. Additionally, low precipitation (rain shadow zone) enable to maintain the pristinity (minimally affected by terrestrial processes) of this area. In this study, we report the sulfate mineralogy and S isotope of Puga hot spring and this could provide suitable mineralogical and petrological information for remote sensing technique.

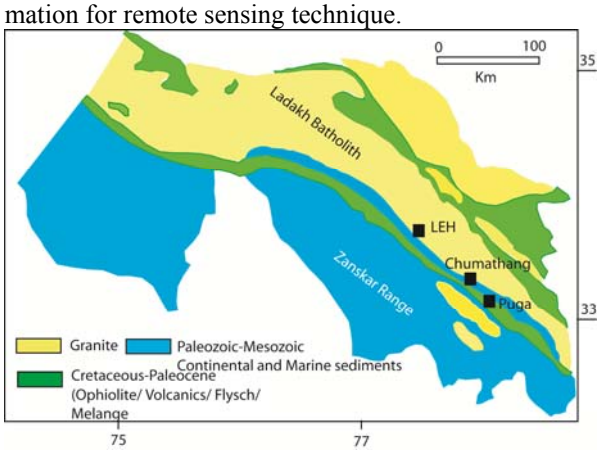

Fig. 1. Geological map of Ladakh region showing locations of Puga and Chumathang hot springs

Geological setting: The hot springs of Ladakh are most likely to be tectonically controlled (and associated igneous activities) especially the Indus Tsangpo suture zone plays a crucial role for maintaining a sustained boiling spring, geyser or hydrothermal mineral deposits.

Puga (altitude ~4400m, surface temp at discharge ~30-84°C) is located in Tso Morari region, south of Indus Tsangpo suture zone. Several faults appear to crosscut the Puga valley. Numerous occurrences of active hotsprings were identified at Chumathang area (altitude ~3950 m, surface temp at discharge ~85-87°C). Water and steam discharging with hissing sound are quite common. Geologically, the Puga and Chumathang comprise several tectonic belts. The sedimentary-metasedimentary sequences were intruded by Ladakh granite, Chumathang granite and often by Indus Tsangpo suture zone. Moreover Mahe and Zildat faults are found to occur adjacent these two hotsprings and caused more conducive for fluid percolation.

Fig. 2 Sulfate mineral deposits at Puga hot spring. Note the sulfate minerals precipitate along fractures.

Mineralogy and S isotope: Mineralogical studies were carried out Scanning Electron Microscope (SEM, JEOL Ltd) equipped with Energy Dispersive Spectrometer (EDS, OXFORD Inc). $\delta^{34}S$ of bulk samples were determined using Elemental Analysis - Isotope Ratio Mass Spectrometry (EA-IRMS). During the analysis the reference material IA-R061 (Barium sulfate, $\delta^{34}S_{V\text{-}CDT}$ = +20.33 ‰) and IAEA-SO-5 was used for reproducibility and accuracy.

Fig. 3 Chumathang Sulfur hot spring with shimmering water

The most common type of sulfate mineral include prismatic gypsum. Chemical composition of sulfate mineral ranges Ca:20-31 wt% and S:21 to 42 wt% respectively.

$\delta^{34}S$ of Puga sulphate yielded almost an uniform value of 4.1‰.

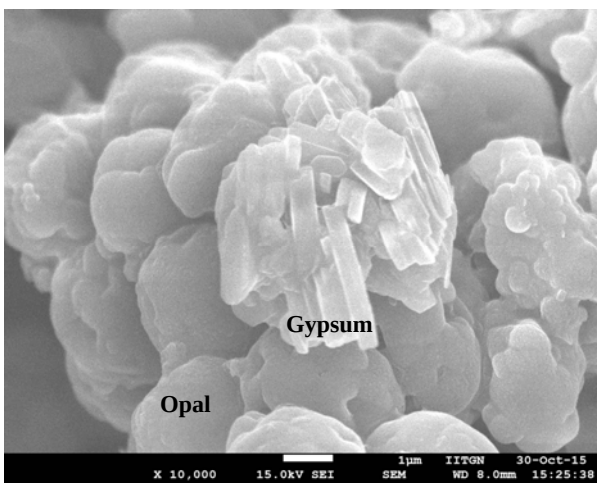

Fig. 4 Occurences of prismatic gypsum associated with opal

Discussion: Sulfur most commonly occur in Mars either as sulphide or sulfate minerals and it is understood that Mars is a S-rich [4]. It is understood that hot spring and hydrothermal mineral deposits were presumably common on Mars when numerous shield volcanoes were active complemented by many large igneous provinces or even proliferations of impact-induced hydrothermal activities. Water was also stable at that point of time before it has frozen permanently with time.

The geological setting especially the presence of suture zone and several faults with different orientation facilitate the conduits of hotwater in Puga and Chumathang area in Ladakh. The mineralogical association of sulfate (gypsum) and silica (opal) suggest their precipitation from alkaline sulfate hotspring. We did not notice any organic matter associated with Gypsum. Gypsum can precipitate with or without microbial mediation. Recent sudy also document that gypsum morphology commonly influenced by biota [5]. However, gypsum in present study show only lamlaae, prismatic type and appears to be abiotic in origin.

This can be further confirmed by the sulfur isotope ratio of gypsum. The relatively low and restricted $\delta^{34}S$ value also well resemble sulfate mineral precipitated from alkaline geothermal fluid. Positive $\delta^{34}S$ value also suggested for greater inputs of inorganic sulfur. Biogenic samples generally carry the distinct negative $\delta^{34}S$ values. Earlier work on Oxygen and hydrogen isotope studies implied long term residence of groundwater at Puga and Chumathang and therefore meteoric in origin [6]. In view of scanty rainfall, snow melt probably contributed the most water to be heated up due to geothermal gradient. The water chemistry of hotsprings regulated due to melting of snow also contributed for fluid mixing and dilution process and held responsible for water with high-pH, high-sulfate and low chloride chemistry.

Alkaline springs dominate in terms of number of occurences, discharge rate and longevity. Also the mineralogical associations favor high water-rock interaction. Studies on modern continental hotspring sulfate depoits suggest gypsum is likely precipitated in non acidic condition. Understanding of martian sulfate mineralogy, texture, capability to become potential biomarker carrier will be further explored and achieved by future Mars 2020 rover and sample return mission.

References:

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