

CONSTRAINING SPECTRAL SIGNATURE OF PUGA HOT SPRING DEPOSIT. S. Sarkar¹, H. Moitra², S. Bhattacharya^{2,3}, D. Ray¹, A. Dagar³, S. Gupta², A. Chavan¹, A. D. Shukla¹, S. Bhandari⁴, ¹Physical Research Laboratory, Ahmedabad 380 009, Gujarat, India, ²Department of Geology and Geophysics, Indian Institute of Technology Kharagpur, Kharagpur- 721302, India, ³Space Applications Centre, Indian Space Research Organization, Ahmedabad- 380015, Gujarat, India, ⁴Department of Earth and Environment Science, Krantiguru Shyamji Krishna Verma Kachchh University, Bhuj-370001, Gujarat, India (subhamrajsarkar@gmail.com).

Introduction: 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. There has been a paradigm shift in the Martian science community from ‘follow’ the water to ‘search’ for habitability in recent years. Thus, finding suitable analog localities of astrobiological significance having different geological settings will be beneficial for the search for alien life on Mars.

Boron is considered an essential element for the formation of life, and primordial life on Earth could have evolved in ancient Hot Springs as they provide all the necessary components for life. A recent discovery of alunite, jarosite, copiapite, gypsum, and native sulfur, along with hydrated Na borates such as Borax and Tincalconite from Puga hot spring, Ladakh, India [1], has established the region as a suitable analog of Mars from an astrobiological perspective.

Although the mineralogical identification of the Martian surface has been made using orbiter based Visible Near-Infrared [VNIR] spectroscopic sensors [OMEGA and CRISM instruments], it is now being used in rover instruments [IR spectrometer in SuperCam Suite of Mars 2020 Perseverance rover] for mineralogical characterization. In this study, we are trying to highlight the limitation of spectroscopy for mineralogical identification using samples from the abovementioned Martian analog location.

Geological Setting: The Puga geothermal field is part of the Upper Indus valley and comprises loose valley fill material, aeolian sediments, glacial moraine

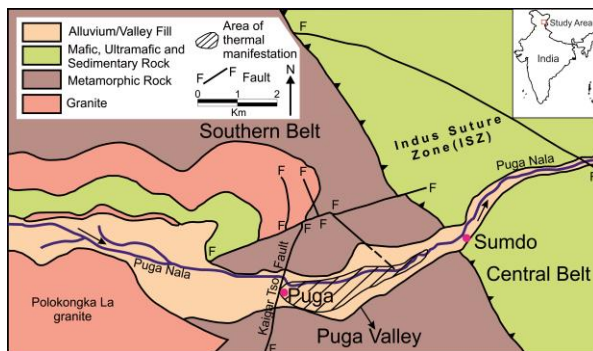


Figure 1: Geological and structural map of the study area showing location of the site investigated (modified after [2]; taken from [1])

deposits, and scree [Figure 1]. The basement rock

contains paragneiss and schists of the Paleozoic age. While the borate deposits are directly precipitated due to the evaporation of hot spring water, sulfates of this region may have formed due to the water-rock interaction of the basement gneisses and the geothermal water. A more detailed description of the geological setting of the study area is given in [1, see supplementary material for detailed site-wise



Figure 2: Satellite [Google Earth] image showing 3D perspective view of location PUG-18-08 (looking northward; taken from [1]).

description and photographs].

Samples and analytical method: Samples were collected from the loose valley fill materials consisting mainly of borate deposits and from a small mound beside the Sumdo-Pologongka La Road and the road cut section on the other side of the road, both comprising sulfate deposits. In this study, we present data from two samples, one collected from the mound and the other from the road cut section [Figure 2], namely, PUG-18-05-C and PUG-18-08-C, respectively.

In situ VNIR measurements were taken using A FieldSpec® 4 Hi-Res spectroradiometer [Analytical Spectral Devices, Boulder, CO, USA]. The spectra were then matched with the USGS and RELAB spectral library to identify the consisting minerals [Figure 3]. This mineralogical characterization was then corroborated using the X-Ray Diffraction technique [XRD] using Bruker D2 Phaser Table top XRD system [Figure 4].

Results and Discussion: Complete VNIR, Mid-IR, and XRD characterization of the minerals from the study area have been presented in [1]. The basis of the mineral identification was VNIR and Mid-IR spectral parameters; the mineral characterization was then corroborated with XRD analysis. The major Sulfate and borate minerals were identifiable by all three techniques. But some minerals are featureless, or have very minute spectral features in VNIR or

Mid-IR, or are masked by more prominent spectral features of other minerals. Here we present two such samples which have such discrepancies in their spectral and X-ray data.

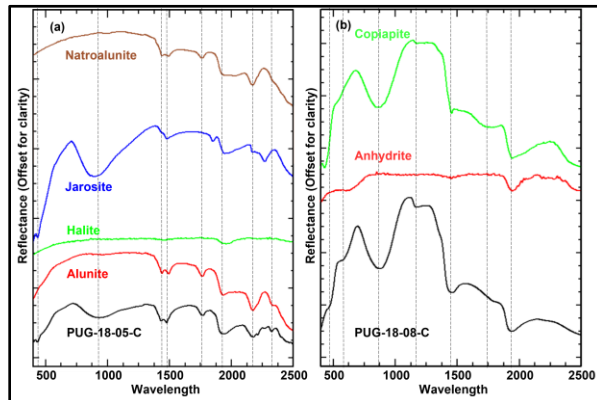


Figure 3: (a) VNIR spectra of PUG-18-05-C and USGS library spectra of natroalunite, jarosite, halite, and alunite. (b) VNIR spectra of PUG-18-05-C and USGS library spectra of copiapite and anhydrite. The dotted lines are for visual guidance.

The VNIR data of sample PUG-18-05-C closely resembles that of jarosite and alunite because of the presence of 433 and 930 nm feature diagnostic of jarosite [2,3] and

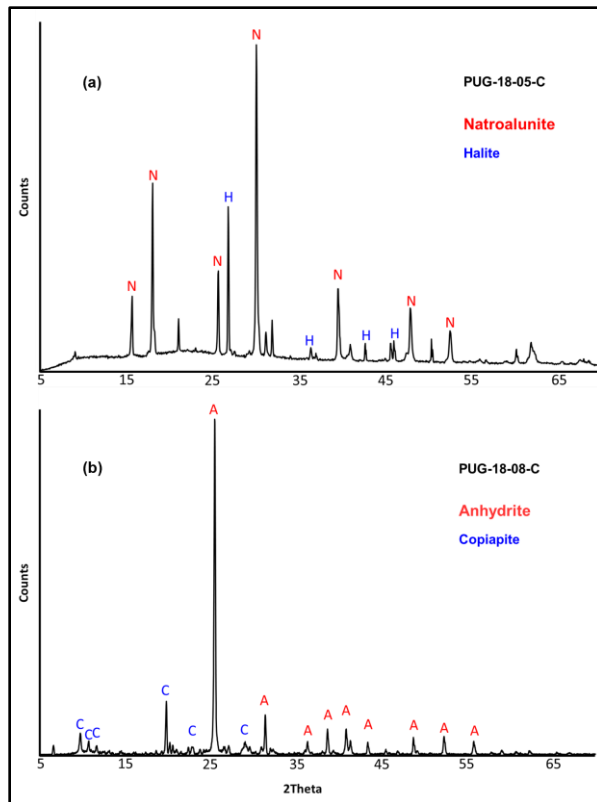


Figure 4: XRD results of samples (a) PUG-18-05-C, and (b) PUG-18-08-C

1450 nm doublet feature, 1775, 1940 nm absorptions and features near 2200 and 2300 nm regions diagnostic of alunite

[3,4,5,6] [Figure 3(a)]. Whereas, the XRD data confirms the presence of natroalunite and halite in the sample owing to the presence of characteristic d spacing values compared with those listed by [7,8] [Figure 4(a)]. VNIR spectra of natroalunite is strikingly similar to that of alunite, and halite spectra is almost featureless [Figure 3(a)].

VNIR spectra of sample PUG-18-08-C confirms the presence of copiapite by displaying diagnostic absorption feature of the mineral at 550, 860, 1170, 1360, 1750, and 1940 nm region [6] [Figure 3(b)]. On the other hand, XRD data confirms the presence of anhydrite in the sample as the major constituent mineral by comparing the d spacing values given by [9] along with a minor amount of copiapite as confirmed by matching with ICDD-PDF2 (2016) crystallographic database copiapite (sample ID 00-035-0583). [Figure 4(b)]. The almost featureless VNIR spectra of anhydrite can explain the non-detection of the mineral by spectroscopic technique.

Thus, one must rely on compositional and/or mineralogical analysis techniques to identify these minerals in an unknown sample.

Implication for Mars: VNIR and Mid-IR spectroscopic techniques have been widely used for the mineralogical identification of extraterrestrial planetary bodies [as well as mars] due to their simple working principles involving reflectance and transmittance of light and their usability in satellite and rover-based platforms. This study clearly shows the limitations of the VNIR spectroscopic technique for identifying unknown mineral phases with no or minute spectral features. Thus, to better understand the mineralogy of Mars, more rover-based observations comprising spectroscopic [VNIR, Mid-IR] and mineralogical [XRF, XRD] are needed to be studied in the future.

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