Visible/Near Infrared (VNIR) spectral characterization of borates from Puga hot spring deposit, Ladakh, India and its implications for Mars.

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Introduction: Boron may have played a major role in the origin of life by controlling the reactivity of various prebiotic organic compounds and thus helping carbohydrates and ribose to be stabilized [1]. Significant amount of boron is found in martian meteorite MIL 090030 [2] and this element has recently been detected in calcium-sulfate-filled fractures in Gale crater [3] using NASA's Curiosity Rover's ChemCam instrument. This discovery of *in situ* boron in a long-lived hydrologic system on Mars has immense significance so far as the search for life on Mars is concerned.

Borate minerals are most commonly found in evaporite deposits related to hot springs [4]. Previous researchers[5,6] have already found evaporite deposits on Mars with the aid of Mars Global Surveyor Thermal emission spectrometer (TES) and Mars Odyssey Thermal Emission Imaging System (THEMIS). Despite the identification of boron as well as the geological locality favorable for finding it on Mars, no mineral species containing boron have been identified till date on the surface of the Red Planet. But considering the oxidizing conditions of martian clay it has been proposed [2] that borate minerals may be present on Mars. In this context, the extensive study of suitable borate mineralization zones will help us to understand, in a better way the possibility of finding the same on Mars. Identification of microbial fossils from Puga hot spring area [7], a part of the extensive Ladakh-Tibet borax spring zone has notable implications in astrobiological research, especially for searching palaeo-life on Mars.

Regional Geology: Regionally the Puga geothermal field is a part of the upper Indus valley which comprises of three distinct tectonic belts, namely, northern, central and southern tectonic belts [8,9]. The basement of the northern tectonic belt is the Ladhakh Granite, above which sedimentary rocks belonging to Indus group lie nonconformably. Mahe fault is situated to the north of central tectonic belt and separates it from the northern belt [8,9]. The central tectonic belt is termed as the 'Indus Suture Zone' (ISZ), along which Indian and Eurasian plates collided during Himalayan orogeny[10]. This belt comprises of basic, ultrabasic and sedimentary rocks belonging to Sumdo group[8,9]. Zildat fault marks the southern extremity of the central belt and separates it from the southern and southeastern tectonic belt. The southern belt is characterized by thick successions of sedimentaries, metasedimentaries and metamorphics which have been intruded by at least two phases of granitic activity from Upper Cretaceous to Upper Tertiary age [8, 9]. The area shows a gradual increase in intensity of deformation and metamorphism from north to south and thus, the rocks of the southern belt are highly deformed subject to medium to high-grade metamorphism [8, 9].

Figure 1: The Puga geothermal field.

The Puga geothermal field, situated just south of the 'Indus Suture Zone', is placed within the southern tectonic belt and bounded by two roughly N-S trending faults, namely, Zildat fault and Kaigar Tso fault to the east and west, respectively. The Puga geothermal field covers an area of about 5 sq. km in the eastern part of the east-west trending Puga valley which lies between Sumdo town in the east and Polokongka La in the west, having a length of about 15 km with a maximum width of 1 km. Recent and subrecent glacial morain deposits along with aeolian sand and scree, which are encrusted with borax, sulfur and other hotspring deposits are found as valley fill materials that continue up to 15–65 m depth. The upper hard reconsolidated breccia layer is present up to the depth of the basement rock composed of paragneisses and schists. Sumdo formation marks the eastern boundary of this Paleozoic basement known as Puga formation and in the west Polokongka La granite intrudes it [8, 9].

Puga valley hosts the only known borate deposit of economic significance in India [11]. Although mining of borate minerals (especially borax) from Puga has a long history but the deposit was first scientifically described by Cunningham [12] followed by his visit in the year 1845 [4]. The primary borate mineral found in the area is kernite ($Na_2B_4O_6(OH)_2.3H_2O$) which, by absorbing water, converted to borax

($Na_2B_4O_5(OH)_5.10H_2O$) in the summer and finally dehydrated to tincalconite ($Na_2B_4O_5(OH)_5.3H_2O$) [18]. In his study, we report the Visible/Near Infrared (VNIR, ~400-2500 nm) spectral characterization of natural borax from Puga hot spring deposit and its derivative mineral tincalconite for the first time and its possible martian implications have been discussed.

Method: The soft colorless samples (PUG-18-6-A and PUG-18-6-B) were collected from a hot spring deposit in the Puga geothermal area (Figure 1). A FieldSpec® 4 Hi-Res spectroradiometer (Analytical Spectral Devices, Boulder, CO, USA) having spectral resolutions of 3 nm for VNIR and 8 nm for SWIR-1 (shortwave infrared) and SWIR-2, respectively, has been used for characterization of the samples in 400–2500 nm range of the electromagnetic (EM) spectrum. A contact probe equipped with a high-intensity light source, provided with the FieldSpec® 4 instrument, has been used to collect the *in situ* spectra due to bad ambient light condition. The probe contains a 100 W halogen reflectorized lamp, with a fiber-optic input socket. The angle between the halogen lamp and the fiber-optic input socket is kept at 30°. All the spectra collected have been standardized using a Spectralon panel (Labsphere, North Sutton, NH, USA).

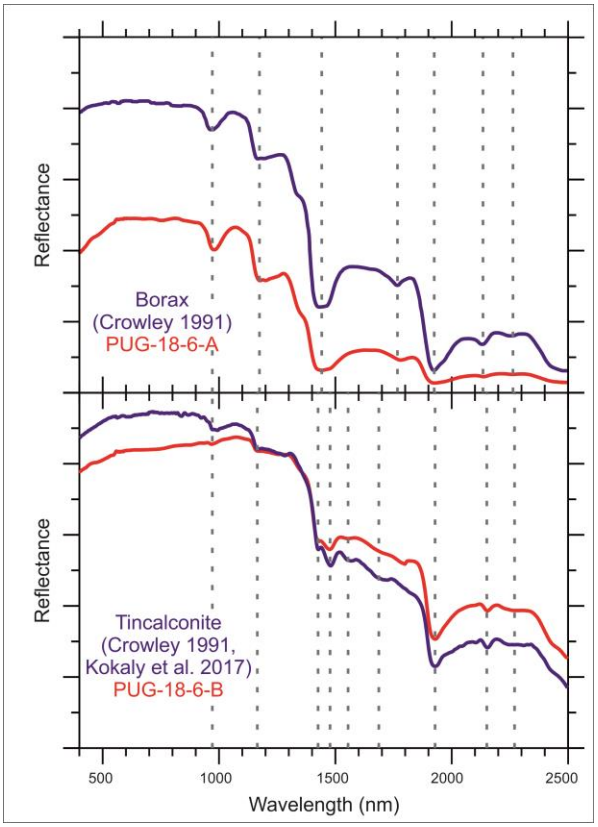

Figure 2: Representative VNIR reflectance spectra of published Borax and Tincalconite (Blue line) along with spectra of PUG-18-6-A and PUG-18-6-B (Red line), respectively. Dotted vertical lines are given for visual aid.

The acquired spectra of PUG-18-6-A and PUG-18-6-B were identified to be of borax and tincalconite, respectively, by comparing them with the published spectra of those minerals from previous work [13]. Final identification of PUG-18-6-B was done by matching it with freely available predefined mineral spectra of the United States Geological Survey (USGS) Spectral Library version 7 [14]. In VNIR region (400-2500 nm), only various combinations and overtones of B–O and water fundamentals are found. We have identified H_2O-related features [15, 16] at 982, 1172, 1432, 1481 and 1927 nm of VNIR reflectance spectra of PUG-18-6-A and for PUG-18-6-B reflectance spectra, those absorption bands are situated at 972, 1161, 1424, 1476 and 1929 nm (Figure 2). The absorption features related to overtones and combinations of different B–O fundamental stretching and bending [17] are marked at 1777, 2140 and 2261 nm for PUG-1-I and 1555, 1802, 2155 and 2222 nm for PUG-1 (Figure 2).

Discussion: Tincalconite will prove extremely useful in the search for boron on Mars as this dehydrated sodium borate has the best potential to be stable in martian atmospheric conditions which is consistent with the simulation experiment carried out by Poritas *et al*. [18]. Puga hot spring thus serves as an excellent analogue for studying the martian evaporites with special reference to possible borate mineralization on Mars. Future Mars missions will be equipped with high-resolution VNIR spectroscopic instruments on both orbiter as well as rover-based platforms and they may possibly be able detect different borate minerals which may have a significant role in facilitating primordial life on the Red Planet. Thus, the present study involving borates from Puga hot spring will help in the identification of similar kind of palaeo hot spring deposits on Mars.

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