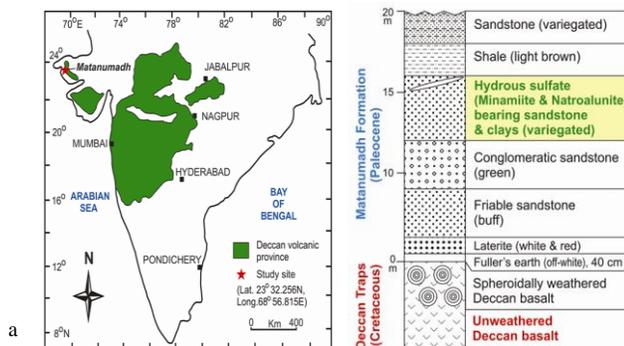


STUDY OF HYDROUS SULFATES FROM THE DECCAN VOLCANIC PROVINCE (DVP) OF KUTCH, INDIA: IMPLICATIONS FOR AQUIOUS ALTERATION PROCESSES ON MARS. S. Bhattacharya¹, N. Jain¹, P. Chauhan¹, G. Parthasarathy², and Ajai¹, ¹Space Applications Centre (ISRO), Ahmedabad, India, ²National Geophysical Research Institute, Hyderabad, India (satadru@sac.isro.gov.in/ Fax: +91-079-26915825).

Introduction: The detection of hydrous sulfates and phyllosilicates in Martian sediments by both space borne orbiter [1-3] and *in-situ* rover experiments [4] have enthused earth scientists to study the Martian analogues on Earth in order to explain the mineralogical and chemical makeup of the Martian surface and also to understand the processes that might have operated on Mars. Recent study by [5] has shown that the presence of jarosite $[K_2Fe_3(SO_4)_2(OH)_6]$, a potassium-bearing hydrous iron sulfate, on Mars has astrobiological implications. Keeping in view of the above, we have conducted spectroscopic and geochemical analysis of hydrous sulfates from the Deccan Volcanic Province (DVP) of Kutch, Gujarat. Matanumadh area of Kutch represents the westernmost part of DVP and is mainly characterized by continental flood basalts of plume origin and hydrous sulfates of secondary origin [6]. DVP of Kutch, therefore, could be considered as a potential analogue site in order to get insights into the hydrous sulfate related aqueous alteration processes on the Mars.

Geology of study area: Geology of the study area (Fig. 1a) is given by [6, 7]. Figure 1b represents the lithological succession of the studied section at Matanumadh. Hydrous sulfates at Matanumadh are found to occur as lenticular bodies in association with Palaeocene sediments that overlies the Deccan Traps [6].



Figures 1a. Location of study area.

Figures 1b. Stratigraphic succession of the study area [Source7].

The Palaeocene sedimentary package of Matanumadh is referred to as Matanumadh Formation and consists of laterites with pockets of bauxite, bright coloured tuffaceous clays, Fuller's earth (bentonite), sandstones and trap-pebble conglomerate with occasional layers of lignite [6].

The upper 1 m of the lateritic crust is hard and massive and grades downward into relatively more brittle type in the lower portion [7]. Locally, pockets and lenses of red or light-purple bauxite have been observed within the laterite horizon, ranging in thickness from 0.5 to 1.0 m. The laterite and bauxite grade downward into a zone of saprolitic clay that ranges in thickness from 2 to 4 m. The clay exhibits different colours, e.g., gray, pinkish white, creamy white, purple, and yellow. These saprolitic clay horizons are individually about 1 m thick and are continuous over the entire extent (0.5 km) of the laterite outcrops in the hill. The saprolite zone merges downward into a zone of spheroidally weathered basalt. Locally, spheroidal boulders of clay display a complete transformation of basalt spheroids to saprolitic clay *in situ* [7].

Methodology: In order to resolve the structure and composition of the iron hydrous sulfates from the Deccan Volcanic Province, we undertook a systematic study on the structure and composition and spectral characteristics of all the iron bearing hydrous sulfates from this area, which are relevant to the understanding of the presence of jarosite in the Martian Surface. Sampling has been done from the unweathered and weathered Deccan basalts, laterite horizons and the sediments belonging to the Matanumadh Formation. In-situ spectra has been obtained using FieldSpec3 ASD spectrometer in the spectral range of 0.35-2.5 μm and the powders of the same samples have been analyzed by XRF and XRD methods. Reflectance spectra of the minerals as obtained from the study area have been compared with the mineral spectra from USGS spectral library. A quantitative approach has been adopted to match the unknown spectra with the standard reference. ENVI based Spectral Feature Fitting (SFF) and Spectral Angle Mapper (SAM) have been utilised to generate a score between 0 to 1 for each unknown mineral giving an weightage of 0.8 to SFF and 0.2 to SAM, where a score of 1 indicates a complete match between the mineral in question with that of a reference.

Results: Spectral analysis: It has been observed that the spectra of hydrous sulfates are found to match with that of spectra of Jarosite of USGS spectral library (Fig. 3) and Natroalunite with alunite (Fig. 4).

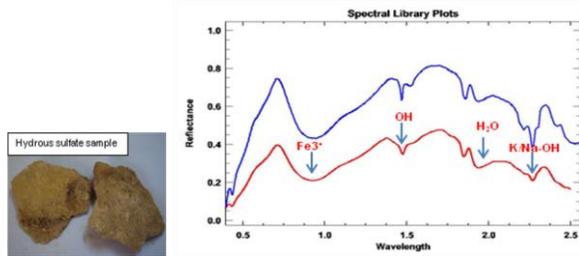


Figure 3. Reflectance spectra of jarosite from DVP (Red) and pure jarosite spectra from USGS spectral library (blue).

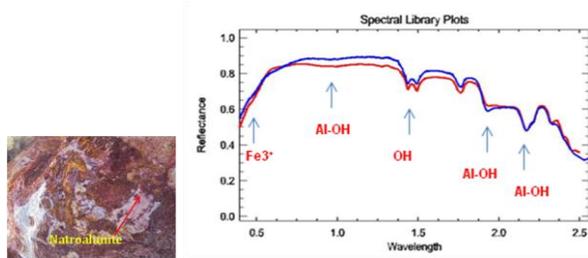


Figure 4. Reflectance spectra of Natroalunite from DVP (red) and pure natroalunite spectra (blue) from USGS spectral library.

The spectra of white coloured soft and powdery clay minerals closely match with that of Kaolinite spectra of USGS spectral library (Fig. 5).

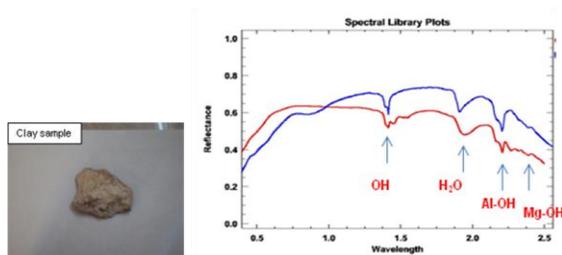


Figure 5. Reflectance spectra of Kaolinite from DVP (red) and pure Kaolinite spectra (blue) from USGS spectral library.

Other minerals include limonite, gibbsite, dipyrre and nontronite as identified through the spectral matching technique.

Geochemistry: The samples collected from field area exhibit three distinct compositions range. The composition analyses were carried out by using XRF analyses. The uncertainties involved are typically +/- 0.01 wt %. The total iron content is measured as Fe_2O_3 . The first compositional class represents hydrous silicates without sulphur and the composition is close to saprolite clay mineral $[\text{Ca}_{0.3}(\text{Si}_{3.0}\text{Al}_{1.0})_4.0(\text{Al}_{2.0}\text{Mg}_{0.2})_{2.33}\text{O}_{10}(\text{OH})_2]$. The second class represents sodium-bearing iron hydrous sulfate ($\text{SO}_3 \sim 33\text{-}34$ wt %; $\text{Na}_2\text{O} \sim 6.40\text{-}6.50\text{wt}\%$; $\text{Fe}_2\text{O}_3 \sim 49\text{-}$

50 wt % and $\text{H}_2\text{O} \sim 10$ wt %), i.e., natrojarosite. The third one is Al-rich sodium-bearing hydrous sulfate known as natroalunite ($\text{Al}_2\text{O}_3 \sim 37\text{-}38.5$ wt %; $\text{Fe}_2\text{O}_3 \sim 1.10\text{-}1.20$ wt %; $\text{Na}_2\text{O} \sim 7.20$ wt %; $\text{SO}_3 \sim 39$ wt %; $\text{CaO} \sim 0.07$ wt % and $\text{H}_2\text{O} \sim 14.5$ wt %). Most of the dark yellowish samples (Fig. 3) are natrojarosite and purple coloured samples (Fig. 4) represent natroalunite. White coloured sample is saprolite (Fig. 5).

Implications for Mars: According to [8], the lateritisation in the Matanumadh basin took place in the Palaeocene. The basin was later on submerged during the Middle Eocene giving rise to the depositions of lignites and black shales rich in pyrite. During the post-Pliocene uplift, the shales and lignites were eroded exposing again the underlying laterites as capping the basalts. According to [7], oxidation of pyrite-rich Eocene lignite beds and black shales overlying the laterite horizon was responsible for the formation of Fe- and Al-rich hydrous sulfates at Matanumadh. Oxidation of pyrite yielded sulphuric acid rendering the percolating water acidic. The sodium concentration in the percolating water was probably increased due to the scavenging of sodium by the acidic solution from the Na-bearing minerals in the Eocene sediments. The downward moving acidic meteoric water charged with Na^+ reacted with some of the kaolinite in the laterite crust as also with the underlying saprolite clay horizon depositing natrojarosite and natroalunite. Similar explanation has been given by [9] in order to explain the presence of hydrous sulfate-rich layered deposits at Opportunity landing site in the Meridiani Planum. According to their hypothesis, regional heating in the Meridiani Planum caused a release of sulfide-rich hydrothermal waters, giving rise to the formation of pyrite-rich regional deposits in a depression. Subsequently, aqueous oxidation of these deposits by atmospheric O_2 created an acidic environment leading to the formation of hydrous sulfates and goethite. From the present study, it can thus be concluded that the laterite horizons of Matanumadh, Kutch area belonging to DVP can act as a potential analogue site to better understand the Martian aqueous alteration processes.

References: [1] Wray, J.J. et al. (2009) *GRL*, 36, L21201. [2] Farrand, W.H. et al. (2009), *Icarus*, 204, 478-88. [3] Carter, J. Et al. (2011) *LPSC*, #2593. [4] Farrand, W.H. et al. (2007), *JGR*, 112, E06S02. [5] Kula, J. & Baldwin, L.S. (2011) *EPSL*, 310, 314-18. [6] Siddaiah, N.S. & Kumar, K. (2009) *Curr. Sci.*, 97, 1664-1669. [7] Chitale, D.V. & Guven, N. (1987) *Clays and Clay Minerals*, 35(3), 196-202. [8] Biswas, S.K. (1971) *Quart. J. Geol. Mining and Metallurgical Soc. India*, 43, 223-35. [9] Zolotov, M.Y. & Shock, E.L. (2005) *GRL*, 32, L21203.