SPECTROSCOPIC SIGNATURE AND GEOCHEMICAL CONSTRAINTS ON JAROSITE FORMATION AT KACHCHH: IMPLICATIONS FOR MARS. S. Mitra[1], S. Gupta[1], K. Mitra[1], S. Bhattacharya[2], R. Chakrabarti[3], D. Ray[4], S. Banerjee[5], P. Chauhan[2], and G. Parthasarathy[6], [1]Department of Geology & Geophysics, Indian Institute of Technology, Kharagpur – 721 302, India, [2]Space Applications Centre, Indian Space Research Organization, Ahmedabad – 380 015, India, [3]Centre for Earth Sciences, Indian Institute of Science, Bangalore - 560012, India, [4]Physical Research Laboratory, Ahmedabad- 380 009, India, [5]Department of Earth Sciences, Indian Institute of Technology Bombay, Mumbai-400076, India, [6]National Geophysical Research Institute (CSIR), Hyderabad – 500 007, India.

Introduction: The presence of hydroxyl (OH^-) bearing minerals on the Martian surface has been confirmed by several orbiter and rover missions. Since identifying evidence for the presence of water in Martian environments is widely discussed, minerals formed in restricted environments by water rock interaction processes have gained importance for the reconstruction of past Martian environments.

The hydrous sulfate mineral, jarosite, is widely reported from the Martian surface but occurs rarely in natural terrestrial conditions. Several jarosite-bearing sites over the world have been identified to understand the possible mechanism for the appearance of jarosite on Mars, but these studies also indicate differences in the modes of jarosite formation on Earth. Identification of an appropriate terrestrial jarosite analog site is therefore of great importance to reconstruct Martian surface processes.

The recent discovery of a Martian analog site at Matanumadh, Kachchh, India reported jarosite bearing shale layers in a basaltic setting [1] that resembles the Martian sulfate occurrences. Subsequent work has revealed the presence of jarosite in spatially and temporally different settings within the present study area [2]. In order to understand the relationship between hydrous sulfates, and shales this study focuses on spectroscopic and chemical characterization of rocks in and around the jarosite localities.

Geology of the study area: Apart from jarosite

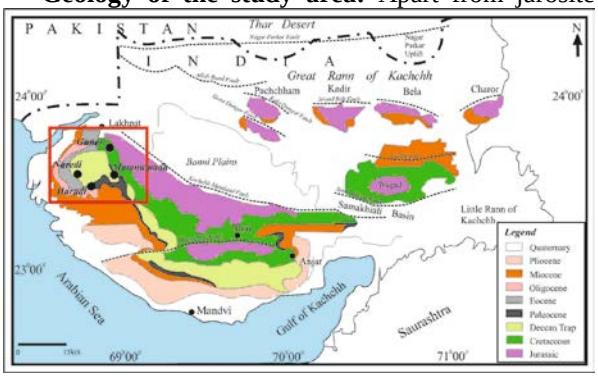

Figure 1: *Location of study area [source 1,3]*

bearing localities that were previously reported from the Matanumadh Formation [1] , Naredi Formation and Harudi Formation[2], also appears in other temporally and spatially different locations of Kachchh (Figure-1). The jarosite occurs as lenticular patches within carbonaceous shales that are ~1 m in length and ~2-3 cm in thickness. In Matanumadh Formation, jarosite appears within both the fractured shale and as clasts in purple sandstone layers [1]. On the other hand in the Naredi Formation that unconformably overlies the Matanumadh Formation, jarosite lenses are confined within shale layers bound by carbonate layers [2]. Similarly, in the overlying Harudi Formation, the jarosite-bearing carbonaceous shale layer is bound by a lower lateritic layer and the overlying Fulra limestone [2]. In addition, jarosite has been

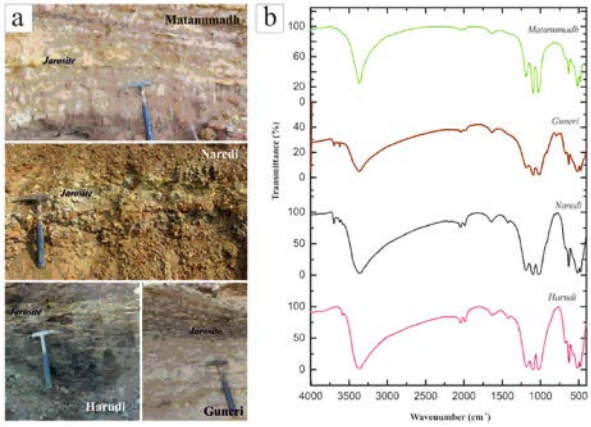

Figure 2: *(a) Field photograph of jarosite from different stratigraphic Formations, (b) FTIR spectroscopy of jarosite from different Formations in Kachchh.*

also found in the Early Cretaceous Bhuj Formation at Guneri, Kachchh, where a systematic repetition of shale and lateritic layers are observed. The thickness of each layer ranges from 1-1.5 m. Like all other formations in this region, lenticular pacthes of jarosite are restricted to shale layers. Figure 2a shows all jarosite bearing locations from which samples of the mineral were collected for analyses.

Samples and analytical method:

To understand the formation process(es) of jarosite in various formations at Kachchh, fifteen samples of jarosite and the host shale layers were chosen from the study area and subsequently investigated through FTIR spectroscopy and ICP-MS analyses. The collected samples were initially identified through FTIR spectroscopy.

All the samples were pressed into KBr pellets and analyzed in Mid-IR range (400-4000 cm^{-1}) (Figure 2b). The identified jarosite samples and respective host shale layers were analyzed in ICP-MS. The Rare Earth Element (REE) patterns have been normalized to North American Shale Composite (NASC).

Results and Discussion:

Field observations reveal that jarosite at Kachchh appears across a wide spatial and temporal range in the stratigraphic sequence. However they are invariably resticted to the shale layers. Jarosite is known to preferably form in highly acidic and oxic conditions. Discovery of jarosite on Mars [4] therefore implies acidic water activity on Mars. Spectroscopic identification techniques have been preferred for the samples becaue of their fine grain size and the amorphous nature of the samples collected from the field. In this study, the fine grained, amorphous yellow material within the shale layers have been identified to be composed of jarosite. In Figure 2b the absorbance band of asymmetric vibrations (two v3 and two v4) are consistently present in all spectra. Gypsum and goethite are also found in minor amount in association with the jarosite lenses in different Formations.

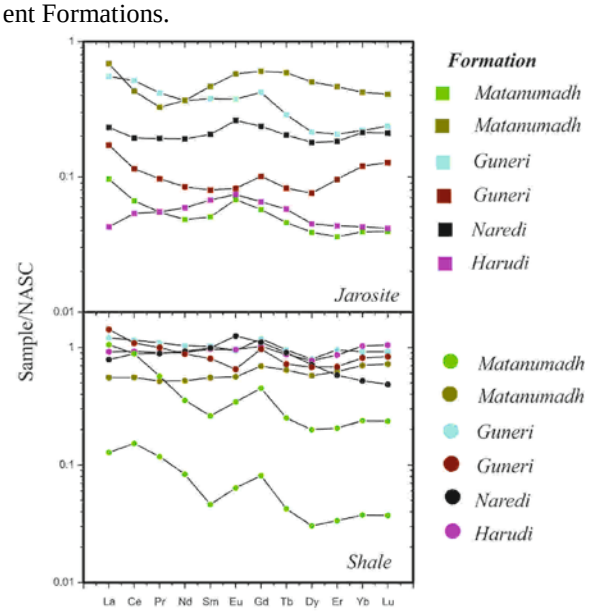

Figure 3: *REE in the shale and associated jarosite of Guneri, Matanumadh, Naredi. and Harudi Formations, normalized to North American Shale composite.*

Due to their similar geochemical behavior, Rare Earth Elements are often used to understand the source of formation elements of the concerned minerals. Shale samples and associated jarosite samples from different stratigraphic ages of Kachhch were analyzed to understand the host rock control on jarosite chemistry. Shale layers of different ages have characteristic REE patterns that differ from each other. In addition, REE patterns of jarosite samples of different locations also show variations. Despite the variation within the samples, the REE pattern for the jarosite samples show similarity with those of the hosting shale layers (Figure-3).

Implication for Mars: According to [1,5], the Matanumadh Formation at Kachchh could be considered as an appropriate Martian analog site for investigating the formation of jarosite on Mars. In this study, we show that apart from Matanumadh, other Formations in Kachhchh also contain striking resemblance to Martian jarosite localities. It can therefore be inferred that a major part of present-day Kachchh could be considered as a Martian analog site. Although, jarosite bearing assamblages appear in formations of different stratigraphic ages, it is very unlikely that all the different formations formed jarosite at different times. It is much more likely that jarosite in Kachchh formed during the final phase of marine regression, symbolizing ther disappearance of a standing water body over the Kachchh region. In addition, the dry environment of Kachchh is suitable for the formation and preservation of jarosite Similar to our area of study, Matian jarosite outcrops are detected on sparsely scattered areas on the planet. The presence of jarosite not only indicates the presence of acidic and oxidizing water on the surface, but also indicates its ephemeral nature. Jarosite therefore could constrain termination of water activity on Mars and might be indicative of the final period of water-rock interation on the Martian surface.

References: [1] Bhattacharya, S. et al. (2016) *JGR, 121, 402-431.* [2] Gupta, S. et al. (2016) *AGU Fall Meeting, P21C-2131.* [3] Karanth, R.V. and Gadavi, M.S. (2007) *CURR SCI., 93, 1271.* [4] Klingelhöfer, G. et al. (2004) *Science, 306, 1740-1745.* [5] Bhattacharya, S. et al. (2012) *LPSC XXXXIII, #1468.*