MAPPING CARBONATES AND ASSOCIATED MINERALS ON MARS: A NEW FUZZY SYSTEM BASED APPROACH. S. Dhoundiyal[1], A. Porwal[1] and G. Thangjam[2], [1]Indian Institute of Technology, IIT, Bombay, India , [2]National Institute of Science Education and Research, NISER, HBNI, Bhubaneshwar, India (sdhoundiyal@iitb.ac.in).

Introduction: Carbonates are key to understanding the ancient Martian environment as well as the geologic evolutionary history. Their presence indicates liquid water with neutral-to-alkaline pH and a thick CO_2 rich atmosphere. The Martian atmosphere is < 10mbar and is dominated by CO_2. However, in the past, Mars had a much thicker atmosphere, between 100mbar-2bar. This atmospheric pressure would have allowed liquid water to exist on the Martian surface. Evidence of this exists in the form of widespread sulphate and phyllosilicate deposits[1,2,3]. Thus, a thick CO_2 rich atmosphere and the presence of liquid water would imply a widespread distribution of carbonate deposits. However, few such deposits have been found.

We present our progress in understanding the geochemical and environmental conditions that led to the formation of carbonates across Equatorial Mars. In this effort, we also present an overview of our proposed algorithm to detect carbonates and associated minerals and quantify their abundance from CRISM hyperspectral data.

Previous work: A global study using hyperspectral data from the OMEGA instrument found no carbonate deposits on Mars[4]. It was suggested that either conditions necessary for their formation never existed, or any deposits that did form were eroded in the early Martian acidic environment [5].

CRISM higher spatial resolution data led to the discovery of multiple carbonate deposits on Mars. This finding though in few localized areas indicates that the environment necessary for the formation of carbonates existed and the acidic conditions characteristic of the Hesperian era were not prevalent globally [6-13]. Further carbonate deposits were observed in geologic outcrops of the Hyugen's basin and Noachis Terra. These deposits suggest that conditions conducive to the formation of carbonates were more widespread than had been previously thought [14]. This raises the question of how widespread these carbonate supporting conditions were.

The aforementioned studies have relied on spectral band parameters (band depth, band centre, etc) for the detection of carbonates. In general, the spectral parameters for carbonate detection using CRSIM data can broadly be divided into two groups: those relying on the 3.4μm and 3.9μm absorption features, and those relying on the 2.3μm and 2.5μm absorption features. The 3.4μm and 3.9μm features are diagnostic of carbonates, however, they are problematic because CRISM's SNR is four times lower for wavelengths >2.7μm. The second set of parameters that rely on the 2.30μm and 2.50μm absorption features are best suited for Mg-rich carbonates while the 2.33μm and 2.53μm features are for Fe-Ca-rich carbonates. However, these characteristic features could be affected by intimate mixing and the association with other minerals and impurities. In addition, absorption features in this wavelength range could also be caused by hydrated silicates, zeolites, and serpentinites, making spectral identification of carbonates difficult[15,16].

Therefore, a careful analysis of the spectral parameters is important and an automated method can be developed that is robust enough to detect minerals of interest. Expert Systems have been used to address these problems and generate mineral abundance maps from remotely sensed data in a terrestrial context [17].

Methodology: The reflectance spectra of the minerals of interest are studied and characteristic absorption features are identified. Spectral subsets corresponding to these spectral features are extracted. Continuum removal is applied to each of the spectral datasets and relevant band parameters are calculated. These parameters act as inputs to the Expert system which consists of three sections. The fuzzifier converts the summary parameters to linguistic values corresponding to 'High', 'Medium' and 'Low'. The inference engine combines these linguistic values with logical operators to establish an input-output relationship. The defuzzifier turns the fuzzy value into the mineral abundance.

Expert System for Carbonate Detection: The Band centres for the two absorption features expected at 2.3μm and 2.5μm, and the inter band gap are calculated. These variables are fuzzified. Fuzzy If-then rules form the inference engine whose output is a fuzzy value indicating the carbonate abundance for the given spectra. Defuzzifier converts this fuzzy value into a numerical value corresponding to the carbonate content for the given spectra.

Initial Results: Mineral spectra from the PDS spectral library were resampled to CRISM wavelengths and used to evaluate two standard spectral parameters: MIN2295_2480, MIN2345_2537 [15].

A simple parallelepiped classifier was used with the proposed spectral parameters to detect carbonates. Table 1 summarises results for both sets of spectral parameters for different types of carbonates, and Table 2 summarises results for both sets of spectral parameters for 9 other associated mineral types.

Discussion and future work: The standard spectral parameters correctly classified all carbonate samples. However this method also yields false classification eg. phyllosilicates, etc.

The standard spectral parameters have higher false-positives for carbonates and false-negatives for other minerals. The proposed spectral parameters had a higher false-negative rate for carbonates and a higher true-positive rate for other minerals.

Further works are underway to improve the accuracy of the spectral parameters. The improved parameters would be incorporated into an expert system for better true detection of the minerals of interest and their quantitative analysis.

Other associated minerals, especially phyllosilicates and others, as listed in Table 2 can be similarly processed and incorporated into the expert system.

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TABLE 1: Classification results for carbonate minerals

Mineral	Total no. of samples	Accuracy of standard parameters	Accuracy of proposed parameter
Ankerite	6	1	0.83
Aragonite	6	1	1
Calcite	28	1	0.93
Dolomite	2	1	0.50
Hydromagnesite	12	1	0.33
Magnesite	14	1	0.36
Mangano Calcite	6	1	1
Northupite	2	1	0
Siderite	11	1	0.91
Toral	87	1	0.73

TABLE 2: Classification results for other minerals

Mineral	Total no. of samples	Accuracy of standard parameters	Accuracy of proposed parameters
Inosilicates	146	0.46	0.67
Nesosilicate	50	0.56	0.62
Nitrate	6	0.67	0.16
Oxide	90	0.78	0.86
Phosphate	2	0.50	0.50
Phyllosilicate	128	0.43	0.58
Sorosilicates	10	0.70	0.60
Sulphate	52	0.5	0.79
Tectosilicates	48	0.83	0.73
Total	532	0.56	0.69