SWIR DATA FROM BRAZILIAN IMPACT STRUCTURES FOR UNDERSTANDING IMPACT-GENERATED HYDROTHERMAL SYSTEMS ON MARS

D. Dieperink¹, J. Alsemgeest¹, F. van Ruitenbeek², F.M. Brouwer¹, ¹Geology and Geochemistry Cluster, Faculty of Science, Vrije Universiteit, De Boelelaan 1085, Amsterdam 1081HV, The Netherlands (j.alsengeest@vu.nl), ²Department of Applied Earth Sciences, Faculty of Geo-Information Science and Earth Observation, University of Twente, Hallenweg 8, 7522NH, Enschede, The Netherlands

Introduction: Impact-generated hydrothermal systems are considered a possible habitat for early life and are therefore of importance not only for life on Earth but also for the search for life on other planets [1]. Our nearest neighbor, Mars, is currently the focus of the search for life, and the prevalent occurrence of impact craters on this planet makes impact-generated hydrothermal systems a compelling target [2]. Moreover, hydrous minerals have been found within impact structures on Mars, but it remains unclear whether these are formed through impact-generated hydrothermal systems, or if these are pre-existing minerals simply excavated by impacts [3]. There is no direct evidence available from Mars to distinguish between the two causes, and therefore, analog impact structures on Earth may be used to better understand such hydrothermal systems. The Vista Alegre and Vargeão Dome impact structures in Brazil are formed in basaltic targets, similar rock to the Martian crust, and therefore exhibit a chemically similar alteration process to that of Martian impact craters [4,5].

In this work, indications of hydrothermal alteration from the Vista Alegre and Vargeão Dome impact structures were used as analogs to study four Martian impact craters of comparable size, accounting for gravity differences between Mars and Earth [6]: Toro, Auki, Laylá, and Canso [7–9]. Hyperspectral imagery from samples from the two structures on Earth were compared with hyperspectral remote sensing data from Mars, to verify if signals from both the impact-generated and the excavated hydrothermal systems on Earth can be related to signatures from craters on Mars.

Methods: Vein-forming hydrothermal alteration was analyzed in a sample set from the Brazilian analog craters. First, available literature data on the different vein-forming stages was complemented by optical and scanning electron microscopy data, to create an overview of the hydrothermal mineral assemblages. Second, the samples were prepared into slabs and measured using a Specim Hyperspectral camera in the Short-Wave Infrared range (SWIR, 1000-2500 nm), and, representative spectra were subsequently selected for each mineral. Then, based on the representative spectra a decision tree was developed to classify individual minerals, which was tested on the data from the slabs. Finally, this decision tree was applied to hyperspectral remote sensing data, specifically openly available CRISM Map-Projected Targeted Reduced Data Record [10], of the Martian craters.

Results: The type of vein-forming hydrothermal alteration differs by crater. In the Vista Alegre impact structure, two different vein types were confirmed, which consisted predominantly of zeolites and calcite, respectively. In Vargeão Dome, the vein-forming alteration consisted of zeolite, quartz, and phyllosilicate-bearing white veins, as well as Fe-oxide enriched, fragment-bearing red veins. Throughout both structures, the zeolites chabazite and heulandite, as well as the phyllosilicates celadonite and beidellite, provided clear spectral signatures in the SWIR range (Fig. 1).

The decision tree identifies the distribution of the different minerals throughout the terrestrial samples but is not able to distinguish the two zeolite types (Fig. 2). From the selected craters on Mars, hydrous mineral signals are notably present in the Toro crater, but largely absent in the others (Fig. 3). The mineral maps indicate the presence of illite, celadonite, and possibly beidellite.

Discussion: The lack of hydrous mineral signatures in Auki, Laylá, and Canso craters may be related to differences in the processing methods between the CRISM data, different data quality, or different degrees

Fig 1 Representative reflectance spectra in the SWIR range of the main alteration minerals in the Vargeão Dome and Vista Alegre impact structures. Note that the spectra of chabazite and heulandite are very similar, inhibiting discrimination without complementary techniques
of dust cover. However, as the craters are relatively fresh and hydrous spectral features are identified using the same data types in other structures, it is more likely that hydrous minerals do not occur in sufficient amounts to be detected, at least with the applied spatial resolution. The Toro crater, which is the largest of the four craters [7–9], shows some of the same mineral types as observed in the white veins in the terrestrial structures. As the terrestrial white veins are typically not impact-related, a preliminary hypothesis is that the hydrous minerals in the Toro crater represent an excavated hydrothermal system. However, considering that other spectral signatures are different, specifically the occurrence of illite and the absence of zeolites, the hydrothermal system may not be directly comparable to that on Earth, meaning that an impact origin cannot be excluded. This would, in turn, suggest that craters at least the size of the Toro crater, ~42 km, are needed to observe a sufficient hydrous mineral signal.

**Conclusion:** Within the limitations of this study, the minimum crater size for an impact-generated hydrothermal system to occur on Mars is estimated at around 40 km. It is, however, more likely that hydrous minerals within this type of structure are excavated, rather than impact-related.

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**Fig 2** Mineral classification of typical examples of the white veins in Vargeão Dome, the dominant alteration type. A: sample with two different zeolites. B: Sample with predominantly celadonite. Note that red veins could not be distinguished within the SWIR range.

**Fig 3** Mineral classification of the Toro (A) and Auki (B) craters on Mars. Note that hydrous mineral signals are present in the Toro crater, but are not limited to the representative minerals from the terrestrial analogs.