

# HYDROTHERMAL ALTERATION OF VISTA ALEGRE BASALTS: IMPLICATION FOR THE SEARCH FOR LIFE ON MARS

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**Introduction:** Hydrothermal systems have long been studied for their potential role in the origins and evolution of life on Earth [1]. The formation of an active hydrothermal system requires a thermal gradient, high permeability and a fluid reservoir [2]. A hypervelocity impact into a solid planetary body results in shock heating, melting, and elevated geotherms resulting from the target rock uplift [3], the extent of which depends on the size of the impact and the target lithology. Though small terrestrial impact craters generate short-lived local fluid circulation (i.e. 1500-4500 years in the 4 km diameter Kärddla Crater [4]), complex craters in the 10's of km diameter size range form hydrothermal systems that can remain active for tens to hundreds of thousands of years [5]. The Mars Reconnaissance Orbiter's (MROs) discovery of hydrated silicates associated with large impact craters on Mars indicates that these structures may have sustained long-lived hydrothermal systems in the past, and consequently could have provided habitats for putative Martian life [6].

Hydrothermal alteration occurs most efficiently in highly porous rock [3], and thus can be well documented in impacted lithologies which can attain porosities >60% as a result of the extreme shock pressures from the impact event [7]. Secondary minerals, chemical alteration of primary materials, and the occurrence of fluid inclusions are accepted indicators of past hydrothermal activity [3], however the challenge remains in determining whether that alteration was pre or post-impact, as well as correlating the level of alteration with the extent of hydrothermal activity. Given that impact-generated hydrothermal alteration on Mars would have occurred primarily within basaltic rocks, we have focused our research on terrestrial basaltic craters in basaltic target rocks. In this contribution we provide the first documentation of hydrothermal alteration within the Vista Alegre impact structure and provide evidence for its impact associated origin.

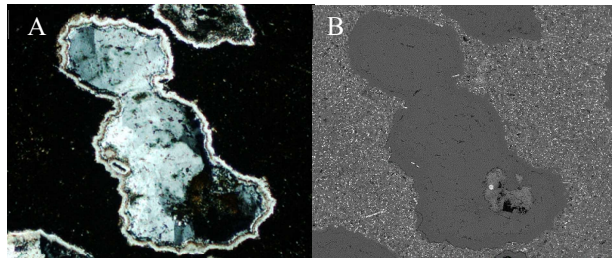
**Field Site:** There are five known impact craters on Earth formed in basaltic lithologies, of which the Vista Alegre impact structure (25° 57.0' S, 52° 41.5' W) is one of the best preserved. This poorly studied, 9.5 km diameter, complex crater is located in the western portion of the Paraná Basin flood basalts of Brazil [2, 8]. Though the structure has not been dated, its location within the Serra Geral Formation places its origin after the basaltic magmatism episodes which

formed the volcanic province at 134 Ma [2, 9]. Before being covered by the thick basaltic flows of the Serra Geral formation, Jurassic-age sandstones were deposited under an arid climate [2], presenting Vista Alegre as an excellent analogue structure for Mars. The Mercosul aquifer system underlies the Paraná volcanic pile in the deeper levels of sandstone. A hydrothermal system triggered by an impact event but has since weathered and eroded away as the superegene environment developed [10].

**Methods:** Representative samples were collected at various locations within the Vista Alegre structure in February 2017. For this study, nine samples from that suite were selected for further study based on shock level and visible hydrothermal alteration. Hydrothermal alteration was determined through optical and electron microscopy; thin sections were analyzed for mineral alteration, veining and other evidence consistent with hydrothermal alteration using a Nikon Eclipse LV100POL compound petrographic microscope. A JXA-8350F Field Emission Electron Probe Microanalyzer (FE-EPMA) was used to determine the chemical composition and alteration textures in the Vista Alegre samples.

**Results:** The microprobe results from the nine representative samples show that the target basalts mostly consist of labradorite (~55-70%), hornblende and augite (25-35%) and ulvöspinel (5-10%). Electron dispersive X-ray spectroscopy (EDS) spectra show that the main secondary phases are carbonates (calcite), Fe-Mg clays (smectite and celadonite), Al-clays (montmorillonite), zeolites, quartz and Fe-oxides (ulvöspinel and ilmenite). Glass in the sample set was rare and restricted to highly shocked rocks. Minimal amounts of copper were identified in sample VA-2017-1B associated with a hornblende clast partly replaced with clays. This sample set also contained several white vein-like structures that appear to be filled with varying amounts of calcite, phyllosilicates, Fe-oxyhydroxides and subordinate quartz and zeolite. Veins composed of zeolites have needlelike and spherulitic textures; whereas calcite-filled veins have polycrystalline textures. Calcite is also found in large vesicles lined with phyllosilicates. Most of the phyllosilicates had a composition compatible with smectite, montmorillonite, and celadonite. Backscattered electron (BSE) imagery results revealed the presence of single and double rims surrounding calcite vesicles. Both rims were composed of calcite,

but EDS spectra revealed that each layer had a slightly different composition (**Fig 1**). The textures are comparable to hydrothermal textures that have been observed at the Ries crater in Nördlingen, Germany [11]. Petrographic analyses of the Vista Alegre samples has demonstrated that all of the shocked basalts are heavily altered (e.g., they contain amygdules and veins full of carbonates and clays).

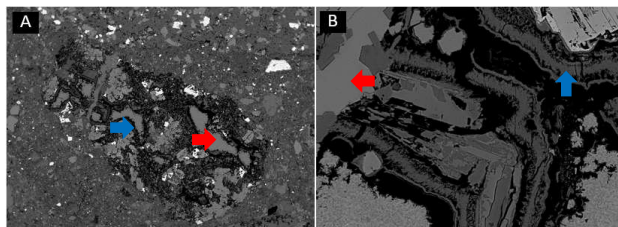


**Figure 1:** Irregular calcite spherule enveloped by double secondary calcite rims. **A-** Cross polarized light. **B-** Backscattered electron image.

**Discussion and Conclusions:** Comparisons of the alteration products found in Vista Alegre samples with similar occurrences in previous studies of active geothermal systems allows us to establish a non-ambient temperature range of 130-200°C [12,13].

Optical and mineralogical investigations revealed that calcite is widely distributed in our samples, replacing primary phases such as plagioclase, pyroxenes and volcanic glass in high permeability zones such as fractures and veins. Calcite is the most common late cooling stage mineral in Vista Alegre. The alteration of basalts to calcite requires high partial pressures of CO<sub>2</sub> [12]. The single and double rims lining calcite-filled vesicles suggest multiple stages of hydrothermal fluid passing through the sample.

The majority of cavities are lined with a mixture of phyllosilicates. Montmorillonite generally forms at low temperatures, and thus is not necessarily directly related to impact-induced hydrothermal alteration, but smectite forms at higher than 100°C and celadonite precipitates as the temperature decreases, in line with the temperature gradient caused by the impact event [10].



**Figure 3:** Backscattered electron images of widespread hydrothermal alteration. EDS spectra indicate the presence of calcite (red arrow) and smectite (blue arrow).

As described in Utada's 2001 reaction sequence [14], impact-generated melt products react with water from the pre-existing aquifer causing the rapid formation of glass. Glass is often created or modified by impacts of meteorites but is nearly absent in Vista Alegre impact structure. This can be explained by the reaction of glass with water resulting in dissolution and secondary phase precipitation where plagioclase glass is replaced with hydrothermal fluids, promoting the formation of secondary alteration products by the release of preferential cations [2, 15].

Copper, a metal likely derived from the hydrothermal alteration of mafic igneous minerals is often associated with smectites, zeolites, quartz, and calcite. This is consistent with having been formed at low temperatures (100-150°C) [13].

Whether the Cretaceous Paraná basaltic target rocks were intensely altered by hydrothermal fluids prior or post impact is a controversial topic. However, based on our textural and mineralogical study, we suspect the occurrence of alteration phases within the basaltic impact samples from Vista Alegre are largely a consequence of an impact-generated hydrothermal system. This is most clearly demonstrated by the alteration of glass clasts in impact breccias, which rules out a pre-impact origin. This is also indicated by the deposition of calcite in the presence of high partial pressure CO<sub>2</sub>, also supporting the use of Vista Alegre as an analog for craters on Mars where a high partial pressure of CO<sub>2</sub> is more likely. As seen with copper and phyllosilicates in the Vista Alegre crater, the order of alteration products filling amygdules and veins is consistent with temperatures found within an impact-induced hydrothermal system. Understanding the efficacy of basaltic impact substrate as a microbial habitat together with the biological potential of hydrothermal systems will help guide the selection of sites for future Mars life detection missions.

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