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"Lucky Strike": A terrestrial analog for hydrothermal fields on ancient Mars with implications for the ExoMars rover

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Abstract

If hydrothermal systems developed on ancient Mars they are likely to have hosted favorable conditions for life and its emergence. Thus, the identification and study of hydrothermal contexts on Mars by robotic exploration (e.g., ExoMars) is currently a high priority. Here we use terrestrial submarine hydrothermal fields as analog to investigate the morphological and mineralogical characteristics of putative hydrothermal deposits developed during the Early- to Middle-Noachian periods of Mars and their potential preservation up to recent times.

1. Introduction

The environment of Mars during the Early- to Middle-Noachian periods was characterized by a higher internal heat flux and denser atmosphere relative to today's Amazonian Mars, likely producing temperatures around 273 K at the surface [1]. The internal radiogenic heat was probably dissipated through the young crust along tectonic systems and, at the surface, in spatially limited areas such as volcanic centers. Water from magmatic outgassing and exogenous delivery by impacts was probably globally abundant and interacted with the volcanic centers. The subsurface and surface interaction led to the development of geologic features that, as proposed below, were not dissimilar to current submarine hydrothermal fields on Earth. During the Hesperian, the diminishing availability of surface water and intensity of volcanism has possibly limited hydrothermalism to impact craters [2].

This inferred context has been determined to be one of the most likely ancient habitable environment of Mars [1, 3], based on the fact that hydrothermal systems of the Archean Earth are recognized as a very favorable environment for the concentration of organics and subsequent emergence of life [4]. For example, the analysis of a 3.3 Ga old Archean Earth chert sample belonging to a hydrothermal, shallow-marine depositional setting revealed that hydrothermal fluids can sustain a high biomass [5]. For this reason, the candidate landing sites of the ExoMars rover are on Noachian-aged terrains [1].

Current submarine hydrothermal fields in volcanic areas on Earth are reasonable analogs for some type of environment on ancient Mars. The exact geological properties of hydrothermal sites that might have existed on Noachian Mars are unknown and might have been diverse, including settings such as subaerial, shallow submarine and deep submarine, and with morphologies such as diffuse or focused outflow. Here we focus on a particular site with the following characteristics [6, 7]: (i) a submarine context different from subaerial systems [8]; (ii) strongly influenced by tectonics in a low-spreading context, (iii) a relatively well studied area for which remote sensing observations have been recently acquired. (iv) is currently active with pristine features. We first review the geomorphology and mineralogy of this site and then consider the modification of a similar putative hydrothermal field on Mars during the Hesperian and Amazonian periods on the base of additional terrestrial analogs.

2. The Mid-Atlantic Ridge hydrothermal field "Lucky Strike"

The Lucky Strike segment on the low-spreading Mid-Atlantic Ridge is located at ~37°2' N/~32°2' W, about 400 km southwest from the Azores Islands. The hydrothermal site was discovered in 1992 on the 13-km wide Lucky Strike volcano, itself found within an axial rift valley of the ridge [9, 10]. The hydrothermal vent field extends over 1 km^2 (Figure 1) with both low and high temperature venting, diverse

outflow morphologies, various substrata and faults [7]. Outflow morphologies include active sulfide mounds 1-20 m wide and several meters high with associated highly-porous chimneys and flanges; extinct mounds composed of sulfide blocks and rubble; patches of diffuse venting with no topographic relief, and networks of cracks. The substrate is primarily basalt covered by sulfide deposits, hydrothermally cemented breccia or talus material. Active venting is observed to be generally within 10 m from fault scarps, indicating that the extensive fault system is controlling the hydrothermal discharge [6, 7]. In addition to faults, the outflows are associated with volcanic morphologies such as a lava lake and volcanic cones.
Several of the geologic properties of this field are identifiable in the local topography at a 1-m spatial resolution (Figure 1). Morphological detection of diffuse venting and surface cracking, instead, requires optical imagery at a sub-meter spatial resolution.

3. Post-formation modification of a putative hydrothermal field

In order to understand the post-formation modifications occurred during the Hesperian and Amazonian periods of a putative, Noachian-aged hydrothermal field, we consider massive sulfide deposits on Earth [12]. The deposits are remnants of hydrothermal fields after burial by sediments, diagenesis and exhumation. They are the only large-scale remnant feature that might be identified with remote sensing data without relying on in situ chemical analysis. Massive sulfide deposits correspond to Archean or younger sulfide mounds and consist of a massive lens of variable shape (mound, sheet), configuration (single, stacked, disseminated), and size (10-100s m) in a host rock of a different lithologic property [12]. The massive lens is associated with concordant exhalites and a discordant zone of veins in a host rock altered into clays and chlorites [12].
During burial, the mineralogy of massive sulfide deposit will not exceed the greenschist facies on Mars, corresponding to <10 km burial material. Chemical weathering, however, will probably replace sulfides with oxides, sulfates and quartz (gossan) [12, 13]. On Mars, the original context of formation of massive sulfide deposits could be modified by impact excavation and ejecta emplacement, rather than subduction and orogenesis.

We will discuss the differences between the Noachian context and today's spreading ridges on Earth, in particular the effect of the absence of plate tectonics (e.g., rift systems, subduction, orogenesis) on the factors controlling the small-scale geology of a hydrothermal field (heat source and permeability). We will further discuss the preservation of Noachian-aged hydrothermal deposits, and whether future in situ measurements by the ExoMars rover might be able to identify and assess ancient hydrothermal conditions.

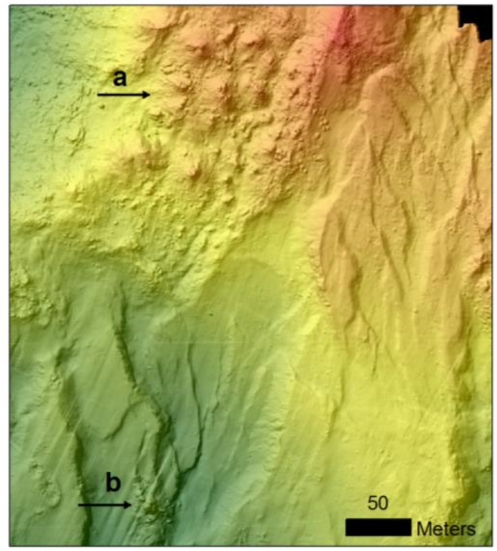

Figure 1: Hill-shaded map with color-coded topography (red: -1600 m, blue -1700 m) of an area within the Lucky Strike hydrothermal field. Mounds clusters (labelled a and b) are identified as isolated topographic peaks. Figure modified from [6].

4. References

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