IMPACT-GENERATED HYDROTHERMAL ACTIVITY AT GUSEV CRATER: IMPLICATIONS FOR THE SPIRIT MISSION.

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Introduction: Gusev crater is the landing site of the Spirit rover, the fourth spacecraft to successfully land on Mars. The crater is ~160 km in diameter; however, its original rim-to-rim diameter might have differed from the present due to post-impact erosion and partial crater rim collapse. Estimates for the age of the crater place it in the early to mid-Noachian, and there are indications of hydrogeologic activity in the crater up until ~0.7 Ga [1]. The crater basin is largely filled with post-impact material including lacrustine, fluvial, aeolean deposits, ejecta from nearby impacts, and collapsed material from the crater wall [2,3]. The thickness of the crater fill is likely a kilometer or more. Current estimates put the Spirit landing site 6 to 8 km south of the center of the crater (Fig. 1). This mission is part of the "follow the water" Mars exploration initiative. In this report, we explore the possibility of impact-generated hydrothermal activity and associated mineral signatures in Gusev crater.

Impact-generated hydrothermal activity: Several hydrothermal systems generated at terrestrial impact craters have been identified based on a wide array of mineralogical evidence [4-7], and impact-induced hydrothermal activity at Martian craters has been suggested [8,9]. The primary heat sources driving a hydrothermal system associated with a complex impact crater are the central uplift and melt sheet, with the latter contributing ~10 to 100 times more energy [10]. The combined thermal energy of the Gusev crater melt sheet and central uplift was ~1.4×10^{23} Joules, which is 56 times the amount of heat released at Yellowstone over a 15,000 year period [3]. Initial temperatures, based on hydrocode modeling by Ivanov and Deutsch [11] for a similarly-sized Sudbury crater, were ~1700°C in the central melt sheet, ~400 to 500°C in the peak ring, and ~100°C in the crater rim. If there was water in the subsurface at the time of the impact, the heat would have caused fluid circulation, initiating a hydrothermal system. Craters with fluidized ejecta blankets in the vicinity of Gusev crater suggest that water was present in the region during a substantial part of its history.

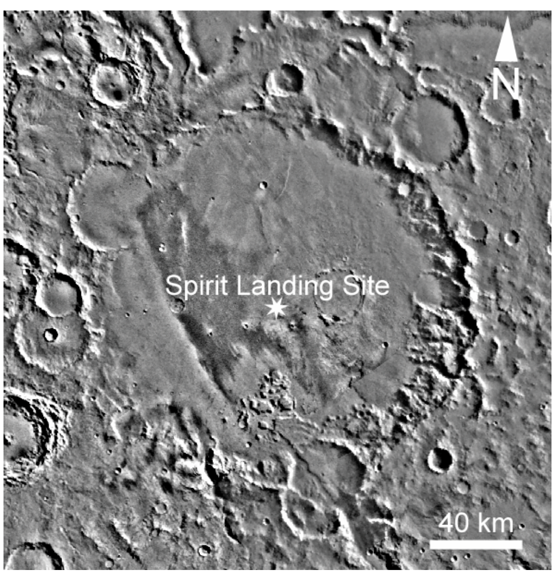
Evolution of a hydrothermal system at Gusev: Our numerical modeling [12] of a similarly large complex crater suggests the evolution of a post-impact hydrothermal system at the Gusev crater developed along the following lines. The first step was gravity-driven rapid draining of the rim and the flooding of the crater cavity by groundwater. The interaction between the incoming water and the hot interior of the crater would have produced large quantities of steam. Eventually, a crater lake should have formed in the bowl of the crater, changing the flow of water from a gravity-driven to a hotspot-driven state. Newsom et al. [9] showed that the thermal energy of the impact melt and the central uplift can keep a lake from completely freezing for thousands of years under a thick sheet of ice, even under the current climatic conditions. Over time, long-lived upwellings would have developed, most notably in the annular trough and the peak ring. Because the boiling point of water increases rapidly with pressure, steam generation was probably limited to near-surface regions, except for production of supercritical fluid deep below the surface. Therefore, once the near-surface cooled there was probably no steam emission from the ground. The lifetime of the hydrothermal system at Gusev crater was probably between several hundred thousand and over 1×10^6 years, depending on assumed ground permeability.

Mineralogy: A long-lived hydrothermal system at Gusev crater would have produced a wide variety of minerals via the hydrothermal alteration of Martian basalts. Temperatures in this hydrothermal system would have ranged from ~360°C early in its evolution to near-ambient towards the end. Experimental studies of hydrothermal alteration in analog Martian basalts by [13] produced numerous alteration products, including opal-CT, quartz, carbonates, and hematite. All of these should be easily detectable by the mini-TES instrument [14]. However, most of these minerals were also generated in low-temperature (23 and 75°C) experimental runs and thus may be indistinguishable from minerals formed by fluvial and lacrustine activity subsequent to the hydrothermal system. Nonetheless, several minerals – vesuvianite, sepiolite, richterite, and biotite – formed only during high-temperature (200 and 400°C) runs and could be indicative of a high-temperature impact-induced hydrothermal system in Gusev crater if found by Spirit. Additionally, the fluid used in the experimental study was simply CO_2-saturated H_2O, while proposed Martian brines [15] would further chemically interact with the basalts in a high-temperature environment. One example is the replacement of Ca^{+2} in plagioclase by Na^{+} in the fluid, which is generally called albitization and occurs at temperatures higher than 65°C.

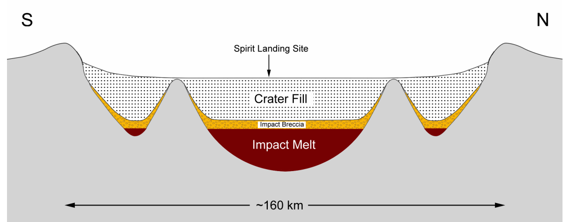
Implications for Spirit: Our model simulations and observations at terrestrial impact sites suggest hydrothermal alteration would occur in the peak ring and in the modification zone where fluid flow is further facilitated by faults. While the peak ring is currently covered at Gusev, samples of that hydrothermally altered material may have been excavated by later impact events.

Hydrothermal alteration in the modification zone and original rim of the crater may still be exposed, particularly in the eastern half of the crater. Later impact events into this part of the Gusev basin could have also launched debris towards the center of the Gusev basin where Spirit is located. Furthermore, Ma'adim Vallis, spilling into Gusev from the south, eroded portions of the rim sequence and carried that material towards the Spirit landing site. We note, however, that the temperature of the hydrothermal system in the vicinity of the rim was probably never above 100 °C and, thus, any hydrothermal alteration in rim lithologies would be associated with relatively low temperatures.

The Spirit rover is well-equipped to detect minerals associated with hydrothermal activity. Pancam can detect unusual coloration associated with hydrothermal alteration, Mini-TES can detect a wide range of hydrothermal deposits [16], and the Mössbauer spectrometer can detect iron-bearing minerals associated with hydrothermal environments [17]. Also, the Microscopic Imager might be able to detect mineral veins within individual rocks indicating water circulation.



a.



b.

Figure 1. (a) Location of the Spirit landing site in Gusev crater. (b) Schematic cross-sectional view of Gusev crater, with the Spirit landing site shown. Vertical exaggeration is about 10 X. Later impact events that excavated material from the uplifted peak ring and crater rim, where hydrothermal alteration occurred, may have deposited hydrated lithologies at the Spirit landing site. Furthermore, Ma'adim Vallis, the channel that flowed into the crater from the south (a), eroded debris from the rim and carried it to the Spirit landing site (or points in the sediment below Spirit).

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