SCIENTIFIC LEGACY FROM THE SPIRIT ROVER'S EXPLORATION OF GUSEV CRATER.

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Introduction: NASA's Spirit Rover landed in Gusev crater on 1/4/04 (sol 1) and maintained communication with Earth until 3/22/10 (sol 2208), when winter reduced solar power and prevented further communications. Spirit traveled 7.73 km to Bonneville crater, across the basaltic plains to the Columbia Hills (CH), over West Spur and Husband Hill (HH), down into Inner Basin and to Home Plate (HP) (Fig. 1). This abstract highlights the scientific legacy from analyses of the data acquired by the instrument payload [1].

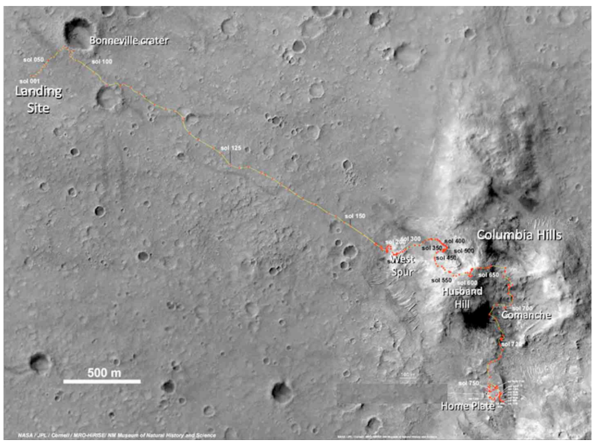

Fig. 1: HiRISE image of the path from the landing site, to Bonneville crater, West Spur, Husband Hill and Home Plate.

Volcanism and Impacts. When Spirit landed, the expectation of 'Gusev lake' sediments [2] yielded to the reality of basaltic plains modified by impacts and aeolian activity. The uppermost ~ten m is impact-churned regolith, and evidence for extremely slow erosion rates indicates that the plains experienced dry and desiccating conditions since the Hesperian (~3 Ga) [3]. The CH are older than the plains basalts and had been uplifted perhaps by Gusev crater's central peak or ring or through mutual interference of overlapping crater rims [5]. HH was later draped by impact and volcaniclastic deposits (Fig. 2) [4,5]. West Spur's distinct rock compositions indicate a spatially isolated depositional event [5]. Basalt compositions reveal that the Gusev magmatic province is alkaline and therefore distinct from the subalkaline rocks thought to be pervasive across Mars [6]. Contrasting compositions between plains and CH basalts imply a local magma source beneath Gusev crater [6]. HP (Fig. 3) is dominated by volcanic tuff deposits, indicating energetic explosive emplacement, and it exhibits cut and fill structures, cross bedding, and an embedded volcanic 'bomb' [7].

Soils: Finer-grained components of soils at Gusev crater and Meridiani Planum are similar, indicating that they are a distinct global unit and products of wind distribution [8]. Minimal oxidative weathering indicates relatively limited interactions with water [8].

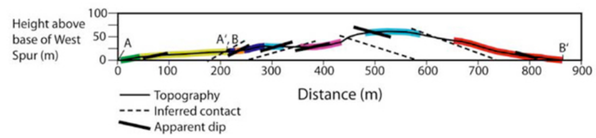

Fig. 2: Transect W to E (L to R) across Husband Hill (adapted from [5]) shows bedrock dips indicating draped deposits. Also, strata were correlated across this transect [4].

Dust devils: Dust devils erode surficial bright dust deposits, creating numerous dark tracks on the plains [9]. These arise from inherently unstable superadiabatic profiles that develop in daytime and drive convection in the lower atmosphere [10].

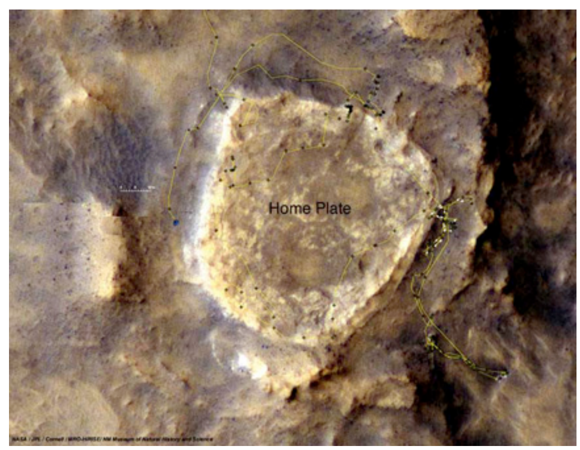

Fig. 3: HiRISE image of Home Plate, which is ~80 m across, ~2 m high and consists of wind-reworked volcanic ash overlying a poorly sorted, layered pyroclastic base-surge deposit.

Aqueous alteration and element mobility: Plains materials experienced limited but unequivocal aqueous alteration [11]. Rock interiors are soft and have elevated S, Cl and Br relative to terrestrial basalts and martian meteorites. S, Cl and Fe^{3+} are enriched in various rock coatings. Abundances of Mg, S, and other salt components are correlated in soil profiles, consistent with aqueous mobility. Compared to the plains, HH rocks are enriched in alteration phases, including goethite, hematite, and nanophase iron oxides [12,13,14]. Fe-bearing phases were identified (olivine, pyroxene, ilmenite, magnetite, nanophase ferric oxide (npOx), hematite, goethite, and Fe^{3+}-sulfate) [12]; their relative abundances indicate the oxidation states of deposits.

Certain HH rocks ('Independence-class') are iron-poor (equivalent FeO ~4 wt%), have high Al/Si ratios, and can be enriched in trace elements (e.g., Cr, Ni, Cu, Sr, and Y), consistent with phyllosilicates or their compositional equivalents [15,16]. Spirit broke through a thin sulfate-rich soil crust W of HP and became embedded in underlying sulfates and basaltic sands. The presence of near-surface sulfate-rich deposits here and elsewhere in CH implies that aqueous dissolution and precipitation have operated on an ongoing basis [17].

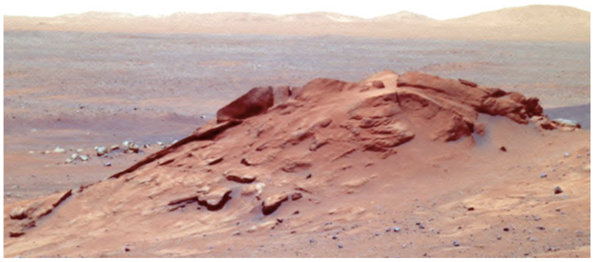

Fig. 4: Pancam image of Comanche carbonate-rich mound.

Hydrothermal activity: Comanche (Fig. 4), a mound on HH's SE flank, has Mg,Fe-rich carbonate (16-34 wt%) resembling carbonates in the martian meteorite ALH84001 [18]. Carbonate may have precipitated from hydrothermal carbonate-bearing solutions at near-neutral pH during the Noachian. Several soils have elevated S abundances [14,19]. Soils on HH (Paso Robles, [19]) and also ~250 m to the N (Samra) and ~50 m to the E (Tyrone) of HP have hydrated ferric sulfates [19,21]. That Fe^{3+} was mobile under apparently oxidizing conditions, leading to ferric sulfate and oxide deposits, implies hydrothermal acid-sulfate conditions [19,22]. HP sustained localized higher- and lower-temperature alteration on its E and W sides, respectively [23]. Opaline silica occurs as bedrock and light-toned soils beside the E and N edge of HP with up to 91% SiO_2 [20]. Its origin is attributed to acidic leaching of volcanic rocks or to deposition as sinter from mildly alkaline thermal waters [20].

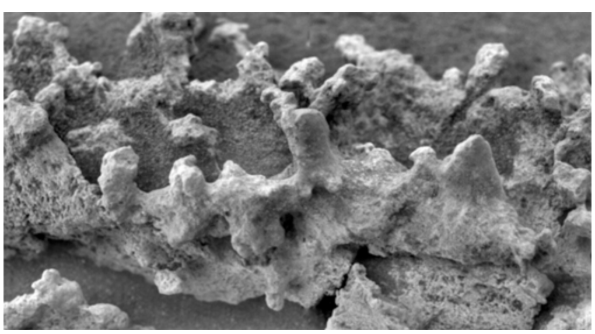

Fig. 5: Microscopic Imager scene (~6 cm wide) showing the Elizabeth_Mahon siliceous hydrothermal deposit.

A habitable ancient environment: Hydrothermal systems provide favorable environments for microbial life on Earth, and perhaps on Mars [24]. Hot springs satisfy habitability requirements due to the presence of water, nutrients, useful light or redox chemical energy, and favorable conditions [24]. Features of the HP silica deposits (Fig. 5) strongly resemble hot spring sinters on Earth that host microbial communities [25].

Legacy: Spirit found extensive aqueous alteration in CH. This alteration was obscured from orbit due to dust and because key outcrops were too small to be spatially resolved [26]. These findings indicate that aqueous alteration of older terrains might have been pervasive, increasing the likelihood that Mars was once habitable at certain localities and that evidence of ancient environments was preserved. Subsequent missions have validated this scenario elsewhere on Mars.

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