SURFICIAL GEOLOGY OF THE SPIRIT ROVER TRAVERSE IN GUSEV CRATER: DRY AND DESICCATING SINCE THE HESPERIAN. M. P. Golombek[1] and the Athena Science Team, [1]Jet Propulsion Laboratory, Caltech, Pasadena, CA 91109.

Introduction: The Spirit rover landed successfully in a low albedo portion of Gusev crater at 14.5692°S, 175.4729°E on January 3, 2004 and has traversed about 3.5 km over 180 sols through cratered plains to Bonneville crater and the Columbia Hills [1]. Gusev, a 160 km diameter Noachian crater that lies at the terminus of the 900 km long Ma'adim Vallis, was selected as a landing site to search for evidence of previous liquid water flow and/or ponding [2]. Although no clear evidence of fluvial or lacustrine activity has been identified in the cratered plains (excepting rocks in the Columbia Hills), their surficial geology strongly limits any warmer and/or wetter period of Mars history (e.g., observed at Meridiani Planum [3]) to be pre-Late Hesperian. This paper will review the surficial geology of Gusev crater as observed along the traverse by Spirit with special reference to the derived gradation history that strongly argues for a dry and desiccating environment since the Late Hesperian.

Columbia Memorial Station: The landing site is a generally low relief somewhat rocky plain dominated by shallow circular depressions and low ridges [4]. The Columbia Hills ~2 km to the east are over 100 m high and the rim of Bonneville crater (200 m diameter) form the horizon 240 m to the northeast.

Preliminary rock counts suggest ~5% of the surface is covered by rocks >1 cm diameter (± a factor of two in the scene) near the lander, which is substantially less than at any of the 3 previous landing sites, although the size-frequency distribution follows a similar exponential [5]. Boulder and cobbles are rare; the largest rock within 20 m of the lander is <0.5 m diameter and the area covered by rocks >10 cm is about 50% of the total area. Most rocks are angular to sub-angular of variable sphericity, and almost none display obvious rounding [4].

A vast majority of the rocks appear dark, fine grained, and pitted. Many appear to be ventifacts, with flutes and grooves formed by impacting sand in saltation [6]. Most rocks appear coated with dust and some lighter toned rocks have weathering rinds whose formation may have involved small amounts of water. The chemistry and mineralogy of the rocks described elsewhere (and the pits as vesicles) appear to be consistent with olivine basalts [7] and the soil appears similar to soil elsewhere on Mars [1].

Hollows: Shallow circular depressions, called hollows generally have rocky rims and smooth soil filled centers. Perched, fractured and split rocks are more numerous around hollows than elsewhere and lighter toned (redder) rocks are often closer to eolian drifts [4]. Hollow morphology and size-frequency distribution strongly argue that they are impact craters rapidly filled in by eolian material. Excavation during impact would deposit ejecta with widely varying grain sizes and fractured rocks, which would be in disequilibrium with the eolian regime. This would lead to deflation of ejected fines, exposing fractured rocks, and creating a population of perched coarser fragments. Transported fines would be trapped within the depressions creating the hollows. Trenching in Laguna hollow near the edge of the Bonneville ejecta exposed unaltered basaltic fines capped by a thin layer of brighter, finer, globally pervasive dust. The dust-free nature of sediment in the hollows coupled with their uniformly filled appearance implies rapid modification to their current more stable form.

Bonneville Crater: Several lines of evidence suggest Bonneville is a relatively fresh crater that was formed into unconsolidated blocky debris [4]. Rock abundance and the largest block size increases by a factor of 2-4 from the discontinuous ejecta, through the continuous ejecta to the rim, suggesting a relatively pristine ejecta blanket. The rim is ~3 m high and although the crater is shallow (~10 m deep) the rubble walls show no signs of mass wasting and eolian material deposited inside is limited to 1-2 m thickness by protruding boulders. No bedrock is exposed in the walls, even where impacted by smaller craters in the wall. The low depth to diameter ratio of Bonneville and other small craters in and on its walls suggest that they formed as secondary craters [8].

Eolian Activity: The red soils appear to be cemented fines and sand (coarse and fine) and granules have been sorted into eolian bedforms. Bedforms consist primarily of meter-size ripples in which the crests have a surface layer of well-rounded coarse sands and the troughs consist of poorly size-sorted sands with a bimodal size distribution, with modes centered on fine sand (0.1 to 0.3 mm in diameter) and coarse sand to granules (1-3 mm in diameter) [6]. The larger grains are sub-angular to rounded and appear to be lithic fragments. The sand does not appear to be currently active, based on the presence of surface crusts on the deposits and bedforms, the inclusion of dust on the bedforms, and the absence of sand dunes and steep slip faces. Many small rocks appear embedded and cemented in the soil, suggestive of a crusted gravel armor or lag.

Many of the rocks at Gusev show evidence for partial or complete burial, followed by exhumation [4, 6]. These include the two-toned rocks with a redder patination along the base, ventifacts that originate from a common horizon above the soil (suggesting that the lower part of the rock was shielded), rocks that appear to be perched on top of other rocks, and some undercut rocks, in which the soil has been removed from their bases. These observations suggest that surface deflation, perhaps highly localized, of 5 to 60 cm has occurred.

Landing Site Predictions: Landing site evaluation during selection predicted that both landing sites would be safe for the landing system and trafficable by the rovers [2]. At Gusev crater, available data suggested it would look generally similar to the Viking Lander (VL) and Mars Pathfinder (MPF) landing sites, but would be less rocky. High-resolution images indicated a cratered plain. These general predictions were correct and the specific remote sensing data at the actual landing locations are consistent to the surface characteristics observed by the rovers [5].

The landing location has a bulk TES thermal inertia of 300-350 J m^{-2} $s^{-0.5}$ K^{-1}, suggesting a surface dominated by duricrust to cemented soil-like materials or cohesionless sand and granules, which is consistent with the observed thermal inertias and soil characteristics at Gusev [5]. Spirit landed in the darkest portion of the Gusev landing ellipse (albedo ~0.19) characterized by dust devil tracks, and then traversed into a higher albedo area that included Bonneville (albedo ~0.26). The albedo measured by Pancam is comparable, suggesting that albedo in Gusev can be used as a proxy for the amount of bright atmospheric dust on the surface. Rock abundance derived from orbital thermal differencing techniques at the Gusev landing site (7%) is similar to rock counts within 10 m of the Columbia Memorial Station (~5%), although the abundance of rocks has varied by perhaps a factor of 2-4 along the traverse. Orbital estimates of slope at 1 km and 100 m scales from MOLA topography and 5 m from MOC stereogrammetry and photoclinometry and radar roughness indicate Gusev is comparable to or smoother than the Viking Lander 1 and Mars Pathfinder sites at all three scales, consistent with the relatively flat and moderately rocky plain seen in the Pancam and Navcam images [5].

Implications for the Climate: The observation that the landing site looks as predicted from orbital remote sensing data has important implications for the climate that has acted on the cratered plains since they formed. High-resolution MOC images showed a cratered surface and Spirit observations indicate a surface dominated by impact and eolian activity. Mapping and crater counts of Gusev show that the cratered plains are Late Hesperian/Early Amazonian in age [9]. The history of gradation and modification of the surface thus represents the cumulative change of the surface since ~3.0 Ga [10].

The gradation and deflation of ejected fines of 5-60 cm and deposition in craters to form hollows thus provides a measure of the rate of erosion measurable in an average vertical removal of material per unit time typically measured on Earth in Bubnoff units (1B=1 m/yr) [11]. The exhumation of rocks at Gusev suggest of order 10 cm average deflation of the site in 3 Ga, which yields extremely slow erosion rates of order 0.1 nm/yr or 10^{-4} B. Erosion rates this slow are comparable to those estimated at the Mars Pathfinder landing site (~0.01 nm/yr in [12]) and at the Viking Lander 1 site (~1 nm/yr in [13]) and argue that a dry and desiccating environment similar to today's has been active throughout the Hesperian and Amazonian [12] or since ~3.7 Ga [10].

By comparison, erosion rates estimated from changes in Noachian age crater distributions and shapes are 3-5 orders of magnitude higher [see refs in 12] and comparable to slow denudation rates on the Earth (>5 B) that are dominated by liquid water [11]. The erosion rates derived from the cratered plains of Gusev therefore yield a sharp contrast to the results from the Noachian age evaporates from Meridiani Planum [3] and the erosion rates for other Noachian terrains in which water was present and the climate may have been warmer and wetter. The erosion rates from Gusev as those from Viking 1 and Pathfinder strongly limit this warmer and wetter period to the Noachian, pre-3.7 Ga and a dry and desiccating climate since.

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