

SPIRIT AT GUSEV CRATER: PRELIMINARY OBSERVATIONS, POTENTIAL PROCESSES AND HYPOTHESES. N. A. Cabrol¹, D. Des Marais¹, J. Farmer², L. Crumpler³, E. A. Grin¹, K. Milam⁴, J. Grant⁵, R. Greeley², R. C. Anderson⁶, J. Grotzinger⁷, R. Arvidson⁸, M. H. Sims¹, Geoffrey Landis⁹, D. Blaney⁶, Z. A. Learner¹⁰, P. A. de Souza, Jr.¹¹, C. Weitz¹², and the Athena Science Team ¹NASA Ames, Moffett field, CA; (ncabrol@mail.arc.nasa.gov); ²Arizona State University, Tempe, AZ; ³New Mexico Museum of Natural History and Science, Albuquerque, NM; ⁴Department of Earth and Planetary Sciences, Univ. Tennessee, Knoxville, TN; ⁵Smithsonian Institution, Washington, D.C.; ⁶Jet Propulsion Laboratory, Caltech, Pasadena, CA; ⁷Massachusetts Institute of Technology, Cambridge, MA; ⁸Washington University, St. Louis, MO; ⁹NASA Glenn, Cleveland, OH; ¹⁰Cornell University, Ithaca, NY; ¹¹CVRD Group, Vitoria, Brazil; ¹²NASA Headquarters, Washington, DC

1.0 General Morphology and Observations:

Spirit landed in a flat plain in Gusev crater with local undulations at meters scales generated by ridges covered with blocks, some of them looking rounded. Several, flat-topped, mesas are visible in the far field in direction of Ma'adim Vallis. A set of north/south oriented hills reaches ~150 m elevation to the east of the landing site (LS). A dipping brighter unit with possibly some scarps is associated with it. This setting could be consistent with layering observed on the MOC images of the hills, local exposure of material with variable dust cover, or deflated or allochthonous material. Numerous small depressions are visible from LS referred to as "Columbia Memorial Station"* (CMS). Floors are partially filled with finer-grained, high albedo material. At least one of them, nicknamed "Sleepy Hollow"* (~30 m diameter) may be an eroded secondary impact crater. It is unclear if they can all be related to small impact structures. Some of them are elongated and aligned with the ridges.

1.1 Rocks Shape, Size & Color: The floor of the plain consists of notably smaller rocks than in the three previous landing sites at VL 1 and 2, and Pathfinder. The shape of rocks and clasts range from angular to rounded.

- Rounded: As a first level survey, the bigger blocks appear to be the most rounded. They are generally less red to dark in color and many are sitting on top of longitudinal ridges. There are exception with large (~30 cm) white rocks. Some of the darker rocks have patches of what appears to be a varnish or reflective coating that suggests the coating formed before the rock was emplaced at the current site.

- Tabular/Flat: Other large rocks are tabular. A class of these rocks consist of small clasts of a few cm and only few mm in thickness. The largest are several tens of cm in diameter and most share similar thicknesses. The larger flat rocks sit flat at the surface or protude from the dust with a geometry consistent with a flat subsurface orientation. Smaller flat rocks can be high-albedo and often display a less red tone. They are also consistent in thickness, very thin (thus likely inconsistent with impact products).

- Angular: There are a significant number of angular rocks exposed at the surface of the plain. Their shape and setting suggest that these rocks may represent impact ejecta, recently-exhumed rocks, and/or rocks more resistant to weathering as compared to the rounded type.

At least two populations of rock colors are observed: dark rocks and higher albedo rocks which could be of the same type but with various degrees of weathering. There could be also two distinct populations of rocks: angular/sub-angular dark rocks and flat white rocks. Mixtures may lead to the intermediate colors observed.

Some of the rocks have a socketed aspect to them, especially near Sleepy Hollow*, while others are fractured. Possible processes of fracturing could include impacts from other rocks (with a limit with respect to smaller size rocks) and freeze/thaw cycle. Most of the rocks have a polished aspect which could be attributed to abrasion of rock faces by wind-blown sand.

1.2 Soil: The first soil analysis yield results showing unusual properties, resisting deformation by applied forces associated with deployment of the the IDD and the rover wheels. This points to development of a hard crust. Analysis of the crust with the Microscopic Imager shows evidence of lithification of dust particles through precipitation of minerals as possible meniscus cements, within interstitial void space. The cement may also be developed as sub-mm scale capillary tubes, revealed by ring-shaped cross-sections. These cements and tubes may have been formed by condensation of water vapor to form dew, followed by evaporation and mineral precipitation. Other soils, particularly beneath and around rocks like Adirondack, are darker, have a pebbly appearance, and also appear cemented.

1.3 Wind: Evidence for aeolian action is visible at CMS* through high albedo wind tails behind rocks. Dark streaks behind rocks seem to be deflation marks. Although no large dune formations have yet been observed at the landing site, several small localized drifts of material have been observed. Pitting and fluting, in addition to basal marking and

coating on rocks may have resulted from aeolian activity..

2.0 Processes and Hypotheses: Categories of observations (topography, morphology, rocks, soil and surficial material) are tested against hypotheses (aeolian, volcanic, aqueous, glacial, impact) that have been proposed to explain the depositional history of material in Gusev [1,3]. The combination of observations shows that the local topography could have been the result of a variety of geological processes (e.g., volcanic and/or aqueous), which makes the topography a poor discriminating factor. It could either mean that any of these processes could be individually responsible for most of what is observed or that the local topography is the result of a combination of processes acting at the same time or successively over time.

2.1 Fluvial hypothesis: Round boulders (if confirmed) and longitudinal ridges could be a pointer to fluvial activity in Gusev. The position of the sub-rounded to rounded boulders on top of the ridges could be consistent with bars. Minor observations that could also be consistent with the fluvial hypothesis are longitudinal markings at the base of some of the ridges.

2.2. The lacustrine hypothesis. As yet, no observation unequivocally supports the presence of an ancient lakebed at LS. This is consistent with pre-mission mapping [3,4] that suggests that CMS* is potentially resting on a later stage non-lacustrine flow unit from Ma'adim Vallis known as the Plains Unit [3]. The presence of very fine flat tabular is consistent with a sedimentary setting and may represent the Plains Unit. They could be part of an older formation involving a lake episode and have been exposed relatively recently. In the same perspective, the abundance of small flat clasts of consistent (thin) thickness sitting at the surface is also consistent with sedimentation in lakes and/or exfoliation of a surficial crust.

2.3 The glacial hypothesis: The presence of glaciers in the Gusev region, especially channeled by Ma'adim Vallis is unlikely based on comparison of the Gusev landscape with terrestrial analogs. There is no evidence of glacial erosion in the regional setting. Some observations at LS are (e.g., large isolated sub-rounded to metric blocks that are standing isolated in the plain) are, however, intriguing in that respect. In terrestrial glacial environments, such large boulders are deposited as erratics. On Earth, glacial erratics show signs of significant transport and vary in lithology from the local bedrock. Potential examination of these boulders by MER instruments may provide a means of testing this hypothesis. Sinuous lines of boulders are perpendicular to the

ridges covered by round to sub-round blocks and in a glacial setting could be associated with frontal ice push.

A possible best fit of observations involving both water and ice a playing role at LS (2.1 to 2.3) could have involved the sudden release of an ice-covered flow, or the release of a flow, or a series of flows highly loaded in sediments which froze upon deposition in the crater and/or contain ice.

2.4 The volcanic hypothesis: The identification of basalt with Mini-TES and the presence of vesiculated rocks show that volcanic material has been deposited in Gusev crater. This material may have been derived from within Gusev or outside the crater itself. If rocks present at CMS* were derived from ejection of material during local impact events, then this suggests that the Plain Units [3] may be partially or completely dominated by volcanic lithologies originating from the crater itself (through fractures in the basin basement) or from outside the crater (e.g., volcanoes). On the other hand, if the volcanic material was derived from a Ma'adim Vallis flow, then rocks exposed at CMS* could represent highlands material.

2.5 The aeolian hypothesis: Orbital observations over the past 25 years of spacecraft operations have shown dynamic aeolian activity at work within Gusev [3, 5]. CMS* is located in a very dynamic aeolian setting that, from orbit, shows evidence of low albedo dust devil tracks, intracrater deposits, and possible wind streaks. LS appears to be located in a large, relatively low albedo streak that provides an opportunity to examine active aeolian processes. Initial observations at CMS* show some localized drifts that are oriented perpendicular to the prevailing rocks, which may represent aeolian activity. While such orbital and ground data support present day aeolian activity, no textures have been observed in rocks that indicate ancient wind action.

References: References: [1] Cabrol N. et al., 1996, *Icarus* 123, 455-464; [2] Grin E. and Cabrol N., 1997, *Icarus* 130, 461-474; [3] Milam, K.A. et al. (2003), *JGR*, [4] Kuzmin R. O. et al. (2000) USGS Geol. Inv. Ser. Maps MTM-15182 and 15187; [5] Greeley R. et al., Greeley, R. et al., 2003. *J. Geophys. Res.*, Vol. 108, No. E12, 8077

*: tentative designation not formally adopted by the International Astronomical Union.