**Introduction.** Since landing at the Columbia Memorial Station (CMS) the analysis of soil sedimentology at Gusev has produced a database that currently represents data on over 7,600 soil particles [1-3]. The diversity of sizes, textures and individual particle morphologies observed with the Microscopic Imager (MI) hints at the complex geological history experienced by the crater basin over nearly 4 billion years and supports the existence of impact, volcanic, aeolian, and aqueous processes over time. The conclusions that can be drawn from the soils surveyed by the MI are limited by the relatively small number of samples collected (vs. terrestrial sampling) and biased by instrument’s constraints such as resolution and field of view [4]. MI can only provide a stamp-size snapshot of soils that are sampled at a frequency dictated by science priorities, traversability, rover safety and other operational requirements. Yet, their study is producing important insights into the formation processes of particles and soils and their evolution.

At present, over 5,500 microscopic images have been acquired by Spirit at Gusev and released into the Planetary Data System (PDS) Geoscience node since landing in January 2004. This number includes soils disturbed by the Mössbauer (MB) contact plate, scuffed and brushed soils, undisturbed soil and rock surveys, MI images supporting Instrument Deployment Device (IDD) and remote sensing (RS) experiments, monitoring of dust collection on the rover’s magnets over time, and engineering activity. The total number of MI images also takes into account multiple frames of the same targets at different depths of field, out of focus images, and overlapping fields in MI mosaics and anaglyphs. Overall, 140 individual soil targets were analyzed between the CMS and Penina at Troy (Sol 2024), including bedforms, composite, and unstructured soils [1-3] at, or above, MI resolution (31 \( \mu \)m/pix) and six trenches including natural vertical exposures and those dug by Spirit. Ten outcrops were also analyzed as plausible source-areas for spherules hypothesized to be lapilli [e.g., 5] and for other particles observed around Home Plate [3].

**Methods.** Methods for this analysis are consistent with standard sedimentologic techniques applied to the study of thin sections and digital images on terrestrial soils [1-4, 6-11]. Those have known constraints and biases [e.g., 12-16] and are well adapted to the limitations of documenting three-dimensional particles on Mars through the two-dimensional field-of-view of the MI. Biases and errors are linked to instrument resolution and particle size. Measurement accuracy and particle dimension are directly related, such as \( \text{Accuracy} = 1 - \text{Error/dimension} \) [e.g., 17]. Cabrol et al. [2] showed that, on average, results obtained with MI have 85% accuracy with particles of 400 \( \mu \)m and 99% at 8 mm. Accuracy falls to ~50% for particles 125 \( \mu \)m in size and 38% at 100 \( \mu \)m. Precision improves with increasing size and is unlikely to be consistent in the study of composite soil samples (mixings of small and large grains). All measurements are made using Image/NIH Image. This application has an image threshold definition capability allowing the software to identify particle boundaries and automate a series of measurements normally performed manually (e.g., particle long, short axis, shape classifiers). This capability reaches its best performance with highly contrasted images where particles stand out from the background. However, the background of the MI images is often composed of small particles of mixed albedo, which makes the definition of threshold values, thus the contouring of particles, imprecise. As a result, we opted for a semi-automated use of the software by manually delineating the perimeter of the particles using the freehand tool of the application and then let the software calculate particle axes, perimeter, area, and shape (roundness, circularity, aspect ratio). Before analysis, the image scale is calibrated and set to pixels/mm in the application. Only well-exposed particles (all edges visible) are selected.

Another methodological aim of this analysis is to address how to obtain a statistically sound and accurate representation of individual particles and soil mixings without having to analyze entire MI images. The objectives are to (a) understand the role of particle-size and resolution in selecting statistically significant study areas for microscopic images; (b) identify the smallest significant study area that provides accurate information consistent with the final distribution (complete image study); and (c) quantify the variations, if any, between the results from the various increments. Representative subsets of images are commonly selected using the “geologist’s eye” and the subset’s size depends on soil type and particle-size. Here, we run a series of analysis on MI images of various soil types at Gusev and Meridiani to test the hypothesis that the subset sizes for various types of particles and mixings can be quantified and that the experiment can be repeated with similar results both on...
the analyzed image and on other images containing individual particles and soil mixings of similar nature (Fig. 1). Identifying these typical subsets has the potential to contribute to the onboard automation of particles and soil mixings analysis in future missions using science-on-the-fly exploration strategies [18], hence significantly increasing mission productivity and helping in target selection. For these tests, the surface area of each MI image is analyzed in 10% increments. While the test is ongoing, current results provide high confidence that results are repeatable; discrepancies are more common in smaller size particles but they do not lead to misinterpretation (i.e., changes in particle class).

Figure 1 – Variations in the results of particle-size distributions for Cliffhanger (Sol 607) as a function of the percentage (10-100%) of MI image analyzed.

Soil Database: Inventory of Individual Particles & Mixings. Results from the analysis of soils at Gusev are being currently organized into a sedimentologic database. When posted on the PDS, this database will include descriptive (individual MI soil captions) and quantitative information on all MI soil images analyzed and will be updated following PDS schedule of release for the MER mission. Ultimately, the database will regroup all sedimentologic data for soils analyzed at Gusev and Meridiani. Quantitative data will be accessible both as Excel and ASCII spreadsheets or as histograms, charts, ternary diagrams, and others. At present, the particles and soil mixings quantitative database has information on over 7,600 particles at Gusev from 35 of the 140 MI targets, mostly bedforms and composite soils. Other soils below MI resolution require other quantification means and their analysis is in progress. All MI images of Gusev soils since landing have been captioned.

Quantitative data includes a series of 12 classifiers that allow the individual or combined analysis of various characteristics (size, morphology, texture, shape, orientation) of particles and soil mixings. The rationale for creating this database is multifold:

(a) Data will be made available to the planetary science community – An archive of individual particle measurements represents a vast repository of data that are critical clues in the understanding of soil and bedform formation and evolution. Such data are also central to the modeling of sediment transport and particles mobilization by wind on Mars, their transport in suspension, and surface movement through saltation [e.g., 6-8, 11];

(b) This archive will support current and future landing site selection activities i.e. Mars Science Laboratory (MSL). For instance, Fergason et al., [19] compared thermal inertia values derived from Mini-TES onboard the rovers in the first 90 sols of the mission to orbital data (THEMIS and TES) and MI images to understand the soil properties at the MSL candidate-landing sites. Our dataset will stimulate this type of efforts by providing direct access to a large and diverse statistical sample of martian soils with their quantitative analysis, helping reach greater precision in modeling and predictions, thus overall helping increase future missions’ safety;

(c) It will allow the comparison of data collected with microscopic imagers of similar or better resolution than the MI (e.g., Phoenix Optical Microscope, 16 µm/pixel, see 20) and future mission datasets (e.g., the Mars Hand Lens Imager, MAHLI on MSL, 15µm/pixel). Future comparative studies will allow to quantitatively address the impact of resolution on the ability to draw conclusions about processes associated with martian soil formation and evolution.