FIRST GRAVITY TRAVERSE ON THE MARTIAN SURFACE FROM THE CURIOSITY ROVER.

K. W. Lewis[1], S. F. Peters[2], K. A. Gonter[2] and the MSL science team. [1]Johns Hopkins University, Dept. of Earth and Planetary Sciences, Baltimore, MD. [2]Jet Propulsion Laboratory, Pasadena CA. (klewis@jhu.edu)

Introduction: Gravimetry surveys have long been a standard technique for probing the interior of the Earth and planetary bodies at a range of depth scales. Since nearly the dawn of the space age, orbiting spacecraft have been used to make increasingly precise measurements of many objects in the solar system, culminating most recently with the GRAIL mission to map the lunar gravitational field [1]. Due to the rapid loss in spatial resolution with altitude, ground, airborne, and ocean altimetry-based gravity surveys are typically employed on the Earth to investigate shallow-subsurface structure [2]. Aside from the Earth, the lunar Traverse Gravimeter Experiment (TGE), carried by the Apollo 17 astronauts, represents the only surface-based gravity traverse measurements on another planetary body to date [3]. Here, we report on the first gravity traverse measurements from the surface of Mars, from the Curiosity rover mission along a 10 kilometer traverse within Gale crater.

Method: Curiosity is equipped with dual redundant Rover Inertial Measurement Units (RIMUs) which are used for obtaining rover attitude and position information, particularly during drives. Each includes a set of three-axis micro-electromechanical (MEMS) accelerometers and fiber-optic gyros. In addition to its use during drives, data is routinely collected from the RIMU sensors over several minutes while stationary for fine attitude determination. Since landing, Curiosity has performed nearly 600 IMU data collection activities at over 250 separate locations within Gale crater.

RIMU accelerometer data is intended primarily for use in determining rover roll and pitch from the relative magnitudes of the three axes under the static acceleration *g* of the Martian gravitational field. However, the relative magnitude of *g* will change with both position (resulting from subsurface density variations) and elevation, which could be detectable with sufficient precision. Although the raw accelerometer data from the rover is insufficiently sensitive, we have developed a series of calibration procedures to account primarily for 1) temperature sensitivity effects and 2) slight biases among the three accelerometers when the rover is non-horizontal. Similar correction procedures have been successfully demonstrated for navigation-grade IMU data in terrestrial airborne gravimetry experiments [4].

Figure 1 shows the variance reduction associated with the three largest corrections to the RIMU data set. An additional correction is applied to remove a sinusoidal seasonal trend likely resulting from longer-term temperature hysteresis. After applying these corrections, we are able to achieve a relative precision of roughly 10 mGal (10^{-4} m/s^2). Although coarse by modern terrestrial gravimetric standards, this is roughly equivalent sensitivity to that reported for the Apollo 17 traverse gravimeter.

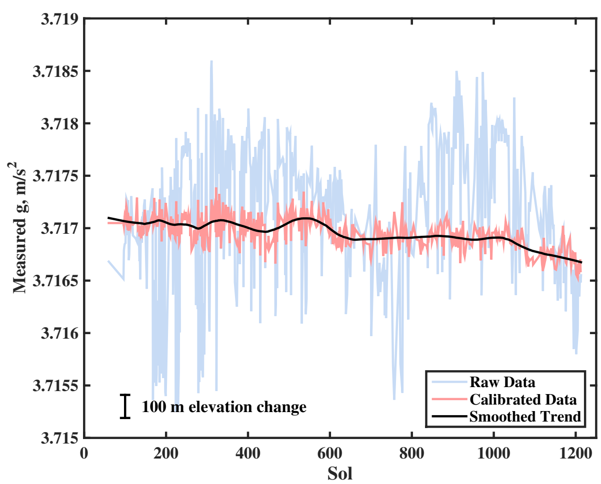

Figure 1 – First Martian gravimetric traverse data. Raw rover accelerometer data (blue), and calibrated data (red) after accounting for temperature, rover tilt, and seasonal trends. Final precision in the relative determination of Martian surface gravity is approximately 10 mGal. The residual downward trend is primarily a result of increasing altitude as Curiosity ascends Mount Sharp. The expected Δg for 100m of elevation gain is indicated.

Interpretations: The Curiosity rover, tasked with ascending the lower flanks of the 5km-tall Mt. Sharp, provides an ideal backdrop for a gravimetric survey. Given the Martian surface gravity gradient of 0.2 mGal/m in altitude, a 10 mGal signal might be attained in as little as 50 meters of elevation gain, compared to the >100 meters of elevation gained thus far by the rover since landing. The elevation change of the rover over its 10 km traverse represents the largest geophysical signal expected from the calibrated data set. Indeed, as shown in Figure 1, the measured gravitational acceleration has gradually decreased over the course of the mission.

After applying the (free air) correction for varying measurement elevation, remaining anomalies are primarily due to subsurface density variations, including the density of the topographic features along the rover traverse. By modeling the remaining free air anomaly along the rover traverse, we can constrain average subsurface rock density at depth.

In the simplest case, we assume a constant bulk density in the subsurface for the geologic units comprising the floor of Gale crater and lower Mount Sharp. To avoid potential contamination from seasonal temperature trends, we fit Curiosity's known elevation profile (Figure 2a) to the residual gravity anomaly over one full Martian year (Figure 2b). Applying an infinite mass sheet Bouguer correction via linear regression, we find a best-fit average density of 1600 ± 700 kg/m^3 within the upper ~100 meters of the crust to explain the residual signal. This density reliably explains the observed falloff in the magnitude of *g* since the beginning of the mission.

The subsurface density estimated from these data is surprisingly low, given the occurrence of lithified sedimentary rock found consistently along the Curiosity traverse. Based on chemical composition and normative mineralogy alone, expected densities for rocks analyzed by Curiosity might be as much as twice that implied by the gravity signal [5]. This may imply a combination of porosity at both large (e.g., fracturing resulting from impact cratering) and small scales (perhaps resulting from weak lithification and/or later dissolution). Although more complex models can be constructed to explain the data, their application is difficult to justify given the data acquired by Curiosity thus far.

Summary: We have demonstrated the successful recovery of relative changes in Martian surface gravity along the Curiosity rover traverse. As Curiosity continues to ascend Mount Sharp, further elevation gain will greatly increase the precision of our estimated average subsurface bulk density, and potentially reveal density variations between different geologic units encountered within the stratigraphy of Mount Sharp. The spectral identification of hematite has been reported within a future geologic target of interest for the mission [6]. If hematite is found in sufficient quantities to a sufficient depth, its substantially higher density could potentially provide a signal large enough to be detected by continued gravimetry measurements.

The successful application of even moderate precision IMU accelerometer data to infer subsurface geologic structure here demonstrates the scientific potential of gravimetric measurements for future landed planetary missions. For Mars, surface gravimetry has the potential to enhance scientific results from other subsurface investigations, including thermophysical, radar, neutron and gamma ray spectroscopic instruments.

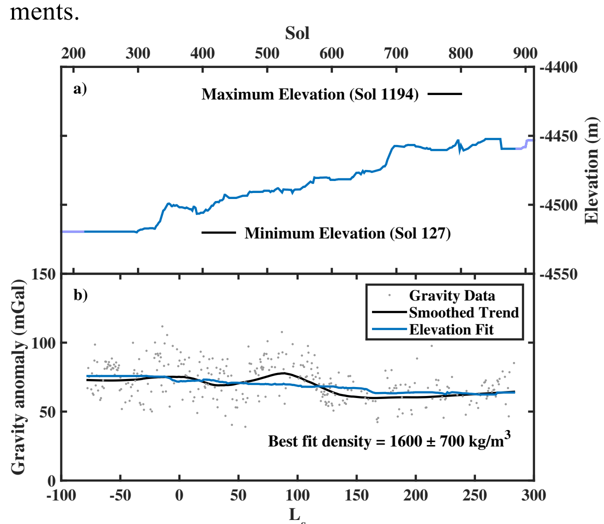

Figure 2 – Determination of the relationship between gravitational acceleration and elevation. a) Rover elevation data as a function of Sol. b) Calibrated gravity measurements as a function of solar longitude (L_s). Elevation data is fit over one Martian year to avoid seasonal trends. The falloff in *g* as Curiosity has climbed Mount Sharp can be explained most simply by a low subsurface density for Mount Sharp (best fit – 1600 kg/m^2).

References: [1] Zuber et al., 2013 *Science* 339 (6120): 668-671. [2] Pavlis, 2012 *JGR Solid Earth.* 117(B4) doi: 10.1029/2011JB008916 [3] Talwani et al., 1973, Apollo 17 Preliminary Science Report. [4] Becker et al. 2015 *J Geodesy,* 89:1133–1144. [5] Baratoux et al. 2014 *JGR Planets 119 (7) 1707-1727* [6] Fraeman et al., 2013 *Geology* 41(10), 1103-1106.