A Novel Approach to Bulk Density Estimation with Gravity Gradients at Meteor Crater, Arizona. C. D. Mitchell[1], P. B. James[1], and D. A. Kring[2]. [1]Baylor University, One Bear Place #97354, Waco, TX 76798; [2]Lunar and Planetary Institute.

Overview: Completion of a 2019 gravity survey of the 1.2 km diameter Barringer Crater (colloquially known as "Meteor Crater") generated a new gravity dataset with which geophysical methods can be tested. Previously at LPSC 51 [1], we outlined the process by which we combined new gravity data with a legacy dataset [2]. Concurrent with the new survey, we also collected measurements at variable heights using a precisely machined three-level tripod at 25 of our survey stations—ideal for measuring the vertical gradient in the free-air gravity anomaly. In this abstract, we focus on a new technique to extract average density from those gravity gradient measurements. Gravity gradients are more sensitive to the shallow density structure of a terrain than the normal gravity anomalies, and it is typically sensitive to depths less than tens of meters. As such, this technique is complementary to traditional gravity anomaly data.

Our methodology is as follows: using a LiDAR Digital Elevation Model (DEM) [3], we calculated the expected gravity from the terrain assuming a unitary reference density, i.e., 1 kg/m^3. Once we calculate the expected gravity at the top and bottom of our tripod (with a vertical separation of one meter), we compare this to the observed difference in free-air gravity at these two elevations. The ratio of the observed gravity difference over the expected gravity difference is equivalent to the bulk density of the nearby terrain.

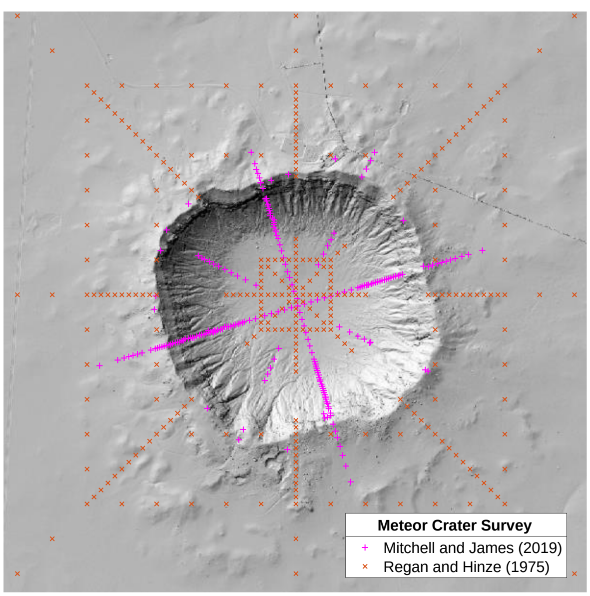

Fig. 1. Measured gravity stations on a shaded relief digital elevation model of Meteor Crater.

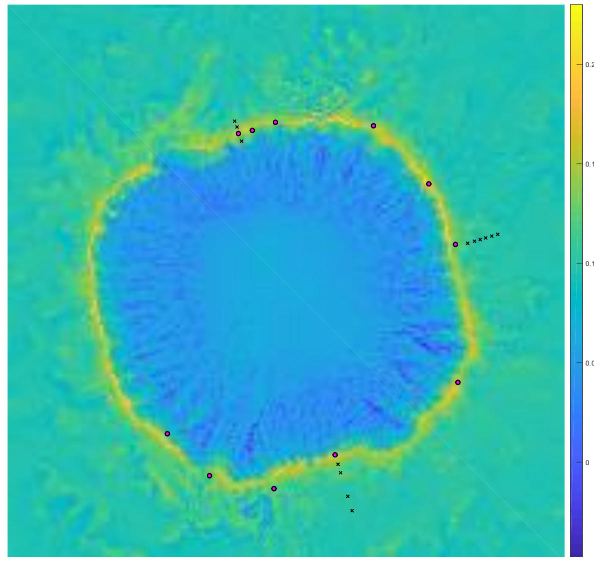

Fig. 2. Synthetic first derivative of the free-air gravity anomaly at 10m intervals. Larger values indicate greater sensitivity to this analysis.

Predicted Gravity from the Terrain: To perform terrain corrections for Meteor Crater, we first discretize Meteor Crater into prisms of increasing width and length via ratio of average elevation and distance from the station. Each prism is bound by the average elevation of the topography and elevation of the gravimeter. From these prisms, we use a gravity-from-prism equation [4] to calculate the contribution to gravity for each of these prisms to the measuring station, the corners of which are bound by the discretized area. This operation is performed over the extent of a DEM [3] with each discretized prism added to the total "Terrain Correction" (TC) for the station, which is defined to be the difference between a flat Bouguer slab and the total gravity from the terrain. This operation is performed with station elevations 0.2 and 1.2m above topography to generate synthetic datasets like Fig. 2., and the exact heights of the gravimeter stand when performing terrain corrections with collected observed gravity data.

Crater Rim and Slope Density Determination: Together with the standard gravimeter stand measurements, there are also areas where we collected gravity measurements using a precisely spaced three-level tripod. Using the map attached in Fig. 2, we identified areas that were the most sensitive to changes in the free-air gravity gradient, and collected measurements at 2 levels on the tripod. These areas are referred to as rim stations, stations that are adjacent or along the crater rim, and slope stations, which are immediately adjacent to the exterior of the crater rim and composed of the continuous ejecta blanket. Because the free-air gravity is a linear equation, we can calculate the observed free-air gravity gradient (first derivative) by the following equation, where g_{obs} are the recorded gravities at the top and bottom of the tripod separated by 1 meter:

$$\Delta \mathrm{FA} = g_{obs}^{top} - g_{obs}^{bottom}$$

Similarly, you can also measure the change in Terrain Correction as a gradient, ΔTC, shown here with a change in elevation of 1m:

$$\Delta \mathrm{TC} = \mathrm{TC}_{top} - \mathrm{TC}_{bot}$$

Under the assumption that the subsurface densities do not vary laterally, the vertical derivative of the Complete Bouguer Anomaly will be zero, allowing us to calculate the density of areas near large contrasts of topographic relief by the following equation. Derived from the Complete Bouguer Anomaly, ρ is the calculated average density of the immediate surrounding terrain, ΔTC is the differential terrain correction calculated using prisms [4] and discretization at the station, and *G* is the universal gravitational constant (for a distance of 1 meter between the two measurement heights):

$$\rho = \frac{(\Delta \mathrm{FA}) + 0.3076}{2\pi G - (\Delta \mathrm{TC})} = \frac{Form.1}{Form.2}$$

In practice, we can generate a scatter plot with the numerator of this equation plotting as the y-coordinate and the denominator plotting as the x-coordinate (Fig. 3). The best-fit regression of this scatter cloud yields average calculated densities for the slope and rim stations of 2.2297 g/cc and 2.8969 g/cc respectively. When compared to Meteor Crater samples, the range of bulk densities of materials collected around Meteor Crater range from 1.98-2.49 g/cc for sediments along Meteor Crater's slopes and 2.19-2.68 g/cc for samples collected along the crater rim [5].

Discussion: The uncertainties of data points in Fig. 3 are dominated by *Form.* 2, suggesting this technique is sensitive to the resolution of the DEM model and the geodetic positioning of our stations relative to the DEM. As expected, our analysis suggests that the crater rim is more dense than the slopes. The measured bulk density of the rim is higher than expected; while this result could be explained by data uncertainty, it could also indicate that the crater rim has relatively low porosity despite its violent formation.

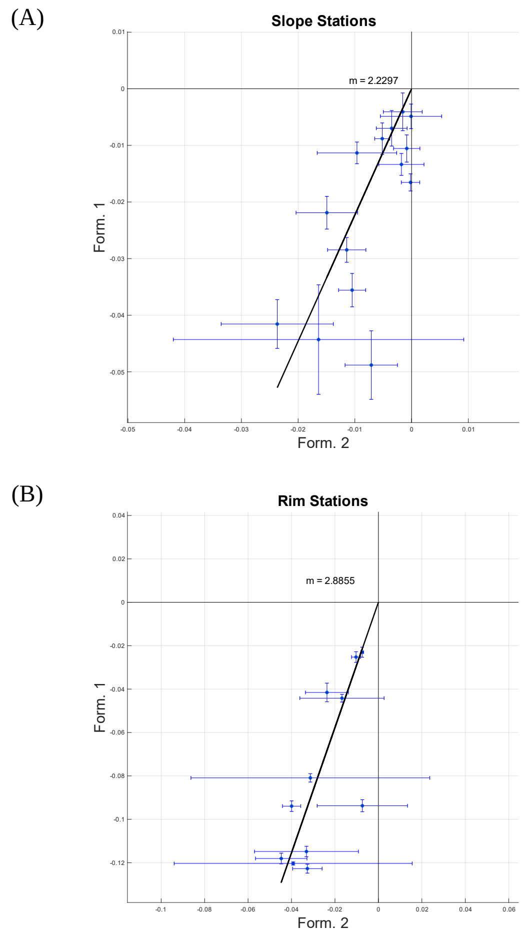

Fig. 3. Calculated average densities via 3-level tripod measurements. (A) Measurements taken outside the crater rim along the ejecta slope. (B) Measurements taken around the crater rim.

Future Work: This work is one part of a broader geophysical analysis of Meteor Crater utilizing gravimetric data. The project encompasses a broad analysis of Meteor Crater's bulk density variations, and more results will be released in the future as work progresses.

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References: [1] Mitchell C. D. and James P. B. (2020) *LPS L*, Abstract #2868. [2] Regan R. D. and Hinze W. J. (1975) *JGR*, *80*, 776–778. [3] Palucis M. and McEnulty T. (2010) *NCALM Mapping Project Report: Meteor Crater, Az*. [4] Banerjee B. and Das Gupta S. P. (1977) *Geophysics*, *42*, 1053–1055. [5] Watkins J. S. and Walters L. A. (1966) *USGS Open-File Report* 67-272, 259–267. [6] Kring D. A. (2007) *LPI Contrib.* No. 1355, Houston.