Digitization, Georeferencing, and Modelling of Regan and Hinze's Barringer Crater Study. C. D. Mitchell[1] and P. B. James[1], [1]Baylor University, One Bear Place #97354, Waco, TX 76798-7354

Introduction: Gravity has long remained one of the most effective tools for determining variations in the subsurface, such as changes in density and porosity. Regan and Hinze, in a study of Barringer Crater, AZ [1] (colloquially known as Meteor Crater) completed an extensive gravity and magnetic survey along the crater's rim and interior. The existing data, and the possibility of accessing the crater to conduct a similar modernized gravity survey led to our interest in Barringer Crater. Unfortunately the raw data from this project has been lost, and there has not been a similar body of work that has been completed at the crater. By using the available figures and work from Regan and Hinze's paper, we have recreated and digitized the raw data sets and performed terrain corrections using modern computational techniques.

Methodology: The Regan and Hinze figures of interest were those relating to gravity surveys: figures 3, 4, 6, and 7 [1], pertaining to the Bouguer anomaly, the terrain correction, the regional gravity anomaly field, and the residual gravity anomaly respectively. The data in these figures is based around a cartesian coordinate system, with a center located 111°01'19" West and 35°01'40" North, with dots representing the observation points where data was collected. The crater rim is drawn along each figure, and the majority of stations are notably absent along the crater wall. There are some exceptions however; 6 observation point coordinates fall near the interior of the crater rim and are ostensibly measured along the crater wall. We recreated the data set by initially determining which stations were viewable across all figures, 293 stations in total. We recorded the station locations in a cartesian coordinate system, then interpolated and digitized the values. We interpolated the data set and recreated the figures in MATLAB. We then compared the resulting figures to the originals for correction. Next, we completed a simulated gravity survey in the region. Using a digital elevation model (DEM) [2] we stacked the Regan and Hinze's figures over the modern DEM to align the coordinate grids with one another, which indicated that the center of the crater was at a different longitude and latitude. To realign, we used MATLAB to extract the raster from the DEM file and overlaid the coordinate system to establish another plausible center of the crater lying southwest. We then used imaging software to overlay an image of the crater to scale with figures. This further reinforced the possible misalignment of the crater, which was also accounted for in the following terrain correction model. We also created a map of residual values from our own calculations and those from Regan and Hinze, and determined an uncertainty of ±10m of the cartesian center.
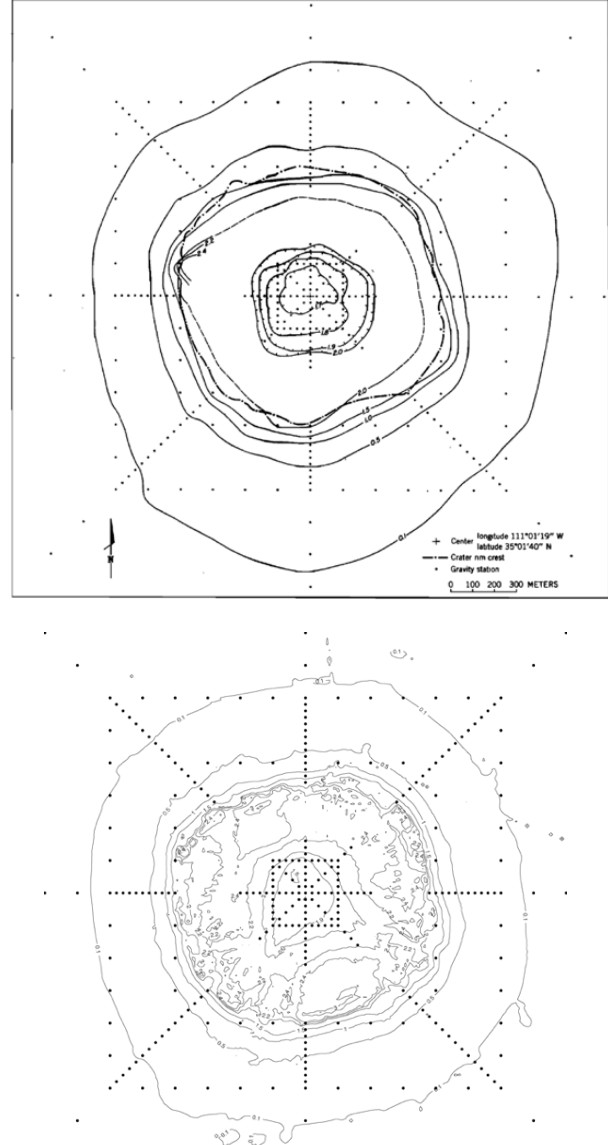

Fig. 1. Comparison between the terrain correction of Regan and Hinze [1] vs. recreation using DEM data, multi-level discretization and gravity from prism calculations. The origin of the x-y axis (b) is 111.02274° West and 35.02772° North. The center indicated in the in (b) is located Southwest of Regan and Hinze's coordinate system roughly 73m West, 6m South. Both figures assume an average density of 2.3 g/cm³.

Next, we considered modeling the crater's terrain correction using the DEM's data. The effect of gravity from a right rectangular prism [3] was used along with a discretization technique to calculate the terrain

correction; using prisms to calculate the terrain correction is computationally intensive when applied to the entirety of the DEM, but has a greater resolution than the Hammer technique used by Regan and Hinze [1]. We refer to our technique as multi-level discretization, which involves dividing the DEM into 'bins' – squares of equal width and averaged height (Fig. 2) – and calculating the effect of gravity from each bin. The division is determined by a combination of the distance from the station taking the measurement to the bin and change in elevation across the bin for more accurate crater rim calculations. The program discretizes on a condition of distance from station and elevation contrast at the crater rim, thus fully utilizing the DEM's data while keeping computation times low using the following ratios, where W is width of the bin, R is the distance from the bin to the station, and h is average elevation inside the bin:

$$\frac{W}{R} > \frac{1}{8} \qquad \frac{W^2 * h^2}{R^3} > \frac{1}{8}$$

Lastly, we computed the regional Bouguer gravity by using an 8th order polynomial fit to the interpreted data.
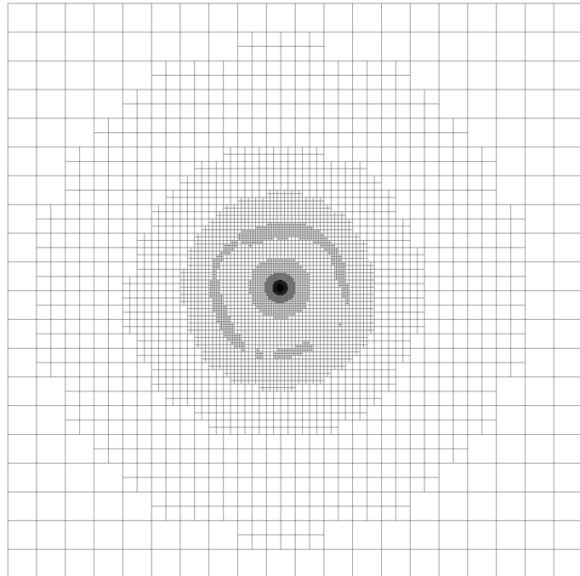

Fig. 2. Illustration of the multi-level discretization of a DEM[2] covering Barringer Crater, which is used when calculating the terrain correction for a station at the crater's center.

Results: We assembled 3 figures to further validate or refute the alignment of Regan and Hinze's coordinate system: a comparison of the paper's coordinate system to that of the topography, the crater rim in the paper to that of the DEM, and terrain corrections drawn from a modern DEM and that of the paper. Comparing the models shows that, although not perfect, the data drawn from Regan and Hinze's figures better align to a cartesian coordinate system centered 75m West and 33m

South from the DEM center, or 73m West and 6m South from Regan and Hinze's center, ±10m from the resulting cartesian coordinate system origin. This results in a new cartesian origin at 111.02274º West and 35.02772º North.
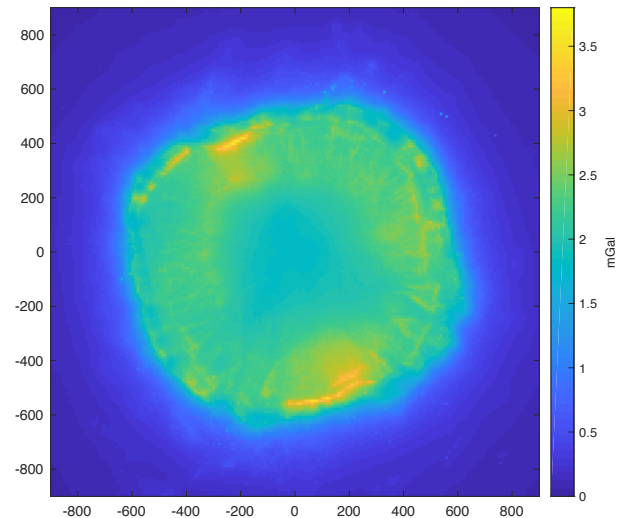

Fig. 3. Image of the terrain correction using DEM. Each pixel represents a hypothetical station where a gravimeter is deployed, with a pixel spacing of 10x10m.

The new techniques applied to calculate the terrain correction utilizing a DEM also generated larger values for the terrain correction than were previously calculated. We assume our corrections more accurately construct the terrain correction than Regan and Hinze's previous findings, in part due to the utilization of higher detail DEM data.

Conclusions: With the establishment of a new origin, the resulting terrain correction adequately reconstructs the previous terrain correction using a multi-level discretization and gravity from prism model. Also, the full utilization of a DEM using multi-level discretization yields more accurate terrain corrections than surveys performed many years prior. Our complete data set is stored on a spreadsheet, archived here: http://doi.org/10.5281/zenodo.2535780

Our analysis has implications for impact-induced porosity. With our more sophisticated terrain correction, we find that Regan & Hinze underestimated the Residual Bouguer Anomaly on the crater floor by roughly 0.15 mGals. This implies that porosity under the crater is slightly lower than previously assumed.

References: [1] Regan R. D. and Hinze W. J. (1975) *JGR, 80, No. 5.* [2] Palucis M. and McEnulty T. (2010) *NCALM Mapping Project Report: Meteor Crater, Az.* [3] Banerjee B. and Das Gupta S. P. (1977) *GEOPHYSICS, v. 42, p. 1053–1055.*