DETERMINING THE 3D SUBSURFACE DENSITY STRUCTURE OF TAURUS LITTROW VALLEY USING APOLLO 17 GRAVITY DATA. N. Urbancic[1], R. Ghent[2,3], S. Stanley[3], C. L. Johnson[1,4], K. A. Carroll[5], D. Hatch[5], M. C. Williamson[6], W. B. Garry[7] and M. Talwani[8], [1]Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, Vancouver, BC, V6T 1Z4, Canada. [2]Department of Earth Sciences, University of Toronto, Toronto, ON, M5S 3B1, Canada. [3]Department of Physics, University of Toronto, Toronto, ON, M5S 1A7, Canada. [4]Planetary Science Institute, Tucson, AZ, 85712, USA. [5]Gedex Systems Inc., Mississauga, ON, L4Z 2H2, Canada. [6]NRCan-Geological Survey of Canada, Ottawa, ON, K1A 0E8, Canada. [7]NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA. [8]Department of Earth Science, Rice University, Houston, TX, 77005, USA.

Introduction: Surface gravity surveys can detect subsurface density variations that can reveal subsurface geologic features. In 1972, the Apollo 17 (A17) mission conducted the Traverse Gravimeter Experiment (TGE) [1] using a gravimeter that measured the local gravity field near Taurus Littrow Valley (TLV), located on the south-eastern rim of the Serenitatis basin. TLV is hypothesized to be a basalt-filled radial graben resulting from the impact that formed Mare Serenitatis. It is bounded by both the North and South Massifs (NM and SM) as well as other smaller mountains to the East that are thought to be mainly composed of brecciated highland material [2][3].

The TGE is the first and only successful gravity survey on the surface of the Moon. Other more recent satellite surveys, such as NASA's Gravity Recovery and Interior Laboratory (GRAIL) mission (2011-2012), have produced the best global gravity field to date (~13km resolution) [4]. However, these satellite surveys are not sensitive enough to detect fine-scale (<1km) lunar subsurface structures. This underscores the value of the data collected at the surface by A17.

In the original analysis of the data a 2D forward-modelling approach was used to derive a thickness of the subsurface basalt layer of 1.0 km by assuming a simple flat-faced rectangular geometry and using densities derived from Apollo lunar samples [1]. We are investigating whether modern 3D modelling techniques in combination with high-resolution topographical and image datasets can reveal additional fine-scale subsurface structure in TLV.

Data Analysis and Modeling Approaches:

Correcting Apollo 17 Data. First, the TGE dataset was georeferenced to determine measurement locations. We performed this step manually by aligning hand-drawn maps to previously georeferenced Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) images (resolution of ~0.5m/pixel) [5].

To correct the gravity measurements we used an approximately 40 x 25 km region, G1 (boundary of Fig. 1a), from the LROC Digital Terrain Model (DTM) [6], which has a resolution of ~2m, about 250 times higher than topography maps available at the time of A17. We applied a free-air correction to account for differences in the height of measurements. We then performed a terrain correction to isolate the contribution from subsurface structure. Due to substantial improvements in accuracy of elevation maps for TLV since [1], our analyses resulted in large changes in the free-air and terrain corrections, relative to those in [1].

Creating Density Models for TLV. Because of the low spatial density of stations in the region we used a 3D forward-modeling approach (instead of inversion) to estimate the subsurface structure of TLV. We produced a series of subsurface structural models for the region. Each model assumed an inverted frustum shape bounded by the edges of the valley, with a fixed depth, width and angle. The density contrast for the models was taken to be 0.65 ± 0.25 g cm^{-3}, reflecting the difference between basalt (3.2 g cm^{-3}) and the background brecciated highland rock material (2.3 – 2.8 g cm^{-3}) [1]. Each model covered a ~24 x 27 km region, G2 (Fig. 1a), enclosing the northern half of G1 and all of the A17 stations (Fig. 1a). We verified that, for each station, the gravity computed using the larger region, G1, was less than 1.5% different from the gravity computed using G2.

To make the models for the valley geologically realistic, we used available geophysical datasets of TLV to determine the range in possible valley dimensions. From analysis of the Apollo 17 seismic experiment data [7], the thickness of the subsurface basalt layer was determined to be 1.2 km. In combination with the result from [1], yielding a thickness of 1.0 km, we modelled valley depths of 0.8 km, 1.0 km and 1.2 km.

From the LROC DTM elevation profile (Fig. 1b) of the region along line T (Fig. 1a) we measured the angles of the massifs (NM = 26° and SM = 20°), and set the angle of the north and south walls of the valley equal to these values. For each depth we produced both a multi-angled wall model as well as a rectangular model (with identical widths and depths to each of the multi-angled wall models) to compare with [1]. For all of our models we used the "ModelVision" software package to compute the vertical gravity at each station location [8].

Results and Discussion: Figures 1b-d show the elevation, free-air ($g_{free\text{-}air}$) and terrain ($g_{terrain}$) corrections at computed at each station location and projected to line T, from [1] as well as our results using the LROC NAC DTM. The corrected gravity profile, $g_{corrected}$, is equal to the sum of the raw observed gravity values, g_{obs}, and the corrections, $g_{free\text{-}air}$ and $-g_{terrain}$.

Near the landing site (LM) the elevations used in [1] were similar to the LROC NAC DTM elevation values, but were underestimated to the west of the LM and overestimated to the east of the LM by up to ±75m. The elevation profile from [1] results in a free-air correction that is also similar at the LM, underestimated to the west of the LM and overestimated to the east of the LM by ±10 mgals.

We can see that by performing a terrain correction using the LROC NAC DTM our terrain correction is positive, and larger in amplitude across the profile by ~10 mgals at the LM to ~60 mgals at the edges of the profile near the north and south massifs. These preliminary results show promise for revealing 3D structure in the shallow lunar crust.

We plan on improving our 3D flat-faced right rectangular prism algorithm (used to calculate the terrain correction) to include angular-faced triangular prisms to better compensate for local topographic variations. This will improve the accuracy of the terrain correction in areas of steep gradients. After this, we will be able to compare our models to the measured data in 2D (along line T) to compare to results from [1], as well as in 3D. This will allow us to determine the best fitting subsurface model, which will provide insight into the angles of the walls of the graben forming TLV, as well as the depth of the basalt inflow into TLV.

References: [1] Talwani, M. et al. (1973) NASA: *Apollo 17 Preliminary Science Report*, 13. [2] Wolfe, E.W. et al. (1981) *USGS Professional Paper* 1080, 280. [3] Lunar and Planetary Institute (1992), *LPI Technical Report* No. 92-09, Part 1, 26-27. [4] Zuber, M. et al. (2012*) Science*, 339(6120), 668-671. [5] Robinson, et al. (2010) *Space Science Reviews*, 150(1), 81-124. [6] Oberst, J. et al. (2010) *LPS XXXXI*, Abstract #2051. [7] Kovach, R., Watkins, J. (1973) *NASA: Apollo 17 Preliminary Science Report*, 10. [8] ModelVision v14.0 (2014) *Tensor Research Pty Ltd.*

Figure 1: (a) LROC NAC DTM for TLV (region G1) and region G2 (black dashed box), showing the location of the stations (red circles) and the line "T" (solid black line) used for the 2D analysis in [1]. (b) LROC DTM elevations (solid black line) measured relative to the LM along line T, compared to the original elevation measurements used in [1] (dashed black line). (c) Free-air ($g_{free\text{-}air}$) and (d) terrain ($g_{terrain}$) corrections computed at each station and projected onto line T, for [1] (dashed black line) and our analysis using the LROC NAC DTM (solid black line).