TESSERAE BULK DENSITY ESTIMATION USING A MODIFIED NETTLETON METHOD R. H. Dame[1] and P. B. James[1], [1]Baylor University, 1301 S University Parks Dr, Waco, TX 76706 (rudger_dame1@baylor.edu)

Introduction: The tesserae is a deformed terrain that is characterized by high radar backscatter (indicating roughness from centimeter to meter scale) and an elevated terrain. The tesserae cover $\sim$ 8% of the surface of Venus and are stratographically the oldest material on the planet [Ivanov and Head 1996a]. If we wish to understand Venus' early geological history the tesserae may be our best source of rocks from that time. By discovering the composition of the tesserae, we can constrain early geological processes that shaped the surface of Venus and the role of water in the planet's history.

One promising way to identify the composition of the surface is through calculating bulk density. *Higher bulk densities could imply a more mafic surface while a lower bulk density could imply a more felsic surface.* If the tesserae were shown to be more felsic in composition than the plains because of a lower density, this might hint at an ancient hydrosphere and plate recycling mechanism [2]. *Bulk density of localized regions could be calculated using a modified Nettleton Method.*

Venus geophysical data: The degree and order 180 MGNP180U data product was based on Magellan data and augmented with observations from Pioneer Venus Orbiter [3]. The gravity degree strength l_s is the spherical harmonic degree at which the power of the gravity uncertainty surpasses the signal power (this can be thought of as the maximum data resolution). The power spectrum of the error in the MGNP180U gravity surpasses the power of the coefficients above degree 70 (spatial block size 270 km), so this is the nominal degree strength of the data set. The actual degree strength varies considerably depending on geographic location, with a resolution as high as degree 100 near the equator and as low as degree 40 elsewhere on the planet (Fig. 1).

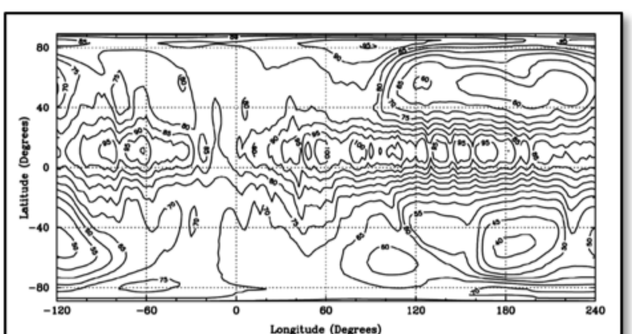

Figure 1: Map of the "degree strength" ls of Venus's gravity field [3]. The degree strength indicates the spherical harmonic degree at which the power of data noise surpasses that of the signal.

Nettleton's method: For 80 years we've known that the bulk density of a terrain may be estimated using gravity measurements [4]. While the initial implementation of Nettleton's method was flawed in the presence of large terrain variations, recent advancements in mathematical techniques allow us to precisely estimate the gravitational attraction of finite-amplitude terrains on other planets [5]. As a result, we are able to estimate the bulk density of Venus' crust in various locations (as long as there is a varying amount of topography) through a simple least-squares regression between the observed gravity and the gravity expected from topography (Fig. 2).

The gravity from Venus's topography can be estimated for a density of 1 kg/m^3 using the calculation described in [5]. The crust–mantle boundary also contributes to the observed gravity field, and this contribution may be estimated either by using an existing crustal thickness model (e.g., [6]) or by assuming a state of Airy isostasy. The bulk density may be estimated with and without relief on the crust–mantle boundary, and the difference between those two densities provides a plausible estimate of the uncertainty. These gravity from topography estimates incorporate a moho depth of 15 km in a state of Airy isostasy.

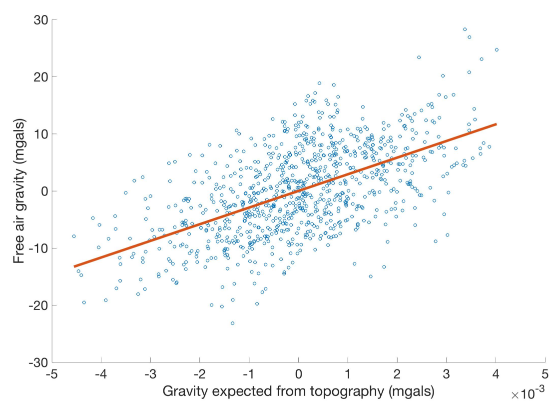

Figure 2: Least-squares regression between the observed gravity and the expected gravity of Haastse-baad tessera (assuming a ρ = 1 kg/m^3) with the slope being equal to a bulk density of 2930 kg/m^3.

Standard error of the slope: The calculated bulk density, using the Nettleton's Method, is the slope of the least-squares regression (Fig. 2). The standard error of the slope would then be the bulk density uncertainty. The standard error of the slope for the least-square regression was calculated by solving for s:

$$s = \frac{s_{y/x}}{\sqrt{\sum (x_i - \bar{x})^2}} \quad (1)$$

$$s_{y/x} = \sqrt{\frac{\sum (y_i - \hat{y}_i)^2}{n-2}} \quad (2)$$

where $\bar{x}$ is average expected gravity from topography. $y_i - \hat{y}_i$ is representative of the distance in the y direction between the true y-value and the least-square regression slope y-value. n is amount of spherical harmonics that are included after the filter normalized to the fraction of global topography being studied.

Uncertainty due to degree strength: Unlike spatio-spectral estimates of Venus' crustal density [7], our new method is capable of inferring density on relatively short scales. A weakness of Nettleton's method is that it is influenced by gravity anomalies at all wavelengths. The gravity data at low spherical harmonic degrees are sensitive to the presence of crustal roots and the deeper mantle, which can sometimes artificially decrease the interpreted density. Therefore, we apply a filter to the observed and predicted gravity data: we suppress the lowest spherical harmonic degrees and also suppress the spherical harmonic degrees higher than the local degree strength (Fig. 1).

In the case of Venus, where the degree strength is still too low to avoid the influence of crustal roots and mantle on the gravity field, incorporating a synthetic gravity field from the moho with the gravity from topography (assuming a ρ = 1 kg/m^3) will help avoid receiving an artificially lower density estimate. However, an inaccurate estimated of the gravity field from the moho will create a certain amount of uncertainty in the density estimate that would go beyond the uncertainty in the slope. This uncertainty should decrease as we include only higher degrees of spherical harmonics.

To calculate the uncertainty in the density estimate due to the degree strength in the gravity field, a series of varying synthetic gravity fields all with crustal density of 2900 kg/m^3 were used to test the Nettleton's method using different degrees of spherical harmonics. The synthetic models were made using Venus topography and varying possible values for the elastic thickness, crustal thickness and moho density contrast on Venus. Different combinations of values for the elastic thickness, crustal thickness and moho density contrast were used, which led to varying density estimates for the crust (the true crustal density value being 2900 kg/m^3). Values used for these lithosphere characteristics were assigned a weight and using a weighted standard deviation calculation we can calculate the uncertainty due to the degree strength of the field.

Gravity enhancement: In preliminary uses of Nettleton's method, density calculations were found to be lower than physically plausible. This bias toward lower apparent density is due to the suppression of noise during the calculation of the gravity field models. [8] proposed an technique called "enhancement", the purpose of which is to reduce the bias in the observed gravity field. The enhanced gravity is ultimately the original gravity field with an added presence of noise. The enhanced gravity is calculated by dividing the observed gravity by n_l:

$$g_{lm}^{enhanced} = g_{lm}^{obs}/n_l \quad (3)$$

$$n_l = [1 + (\frac{l_s}{l})^{-2}(\frac{r_0}{a})^{2(l-l_s)}]^{-\frac{1}{2}} \quad (4)$$

Results: The Nettleton's method was used to calculate the bulk density of two tesserae: Tellus and Haastse-baad. Tellus tessera was analyzed using spherical harmonics 60-90 and looking at topography above the planetary radius of 6051.5 km. The bulk density estimate for this tessera was 2630 ± 450 kg/m^3. Haastse-baad tessera was analyzed using spherical harmonics 65-95 and looking at topography above the planetary radius of 6051.5 km. The bulk density estimate for this tessera was 2930 ± 400 kg/m^3. These uncertainties were calculated based on the slope of the least squares regression. Using the synthetic Venus gravity models and spherical harmonic degrees 60-90, preliminary work shows a calculated uncertainty of $\sim$400kg/m^3 in density calculation based on the.

Discussion: While the two uncertainty calculations tell us two separate things about our density calculation, it seems that $\sim$400kg/m^3 can be a trusted uncertainty. In spite of the size of the uncertainties, these density calculations seem somewhat reasonable. Based on our density estimates, we can still safely assume that the tesserae could possibly be basaltic in nature like much of the surface. Even though the density estimates come with large uncertainties, we might still be able to use these estimates to compare to each other and decide whether areas on Venus are more mafic or felsic than other areas.

References: [1]Ivanov, M. A. and Head, J. W. (1996) JGR, 101, 14861-14908 [2] Gilmore, M. S. et. al. (2015) Icarus, 254, 350-361. [3] Konopliv, A. S. et al. (1999) Icarus, 139, 3-18. [4] Nettleton L. L. (1939) Geophysics, 90, 1151–1154. [5] Wieczorek M. A. and Phillilps R. J. (1998) JGR, 103, 1715-1724. [6] James, P. B. et al. (2013) JGR-Planets, 118, 859–875. [7] Dahlen, F. A. and F. J. Simons (2008). [8] James, P. B. (2017) LPSC XLVIII, Abst #2199 [9] Bills, B. G. and Ermakov, A .I. (2019) Planetary and Space Science, 104744.