LARGE VOLCANIC EDIFICES AND RISES ON VENUS: THE BENEFITS OF IMPROVED TOPOGRAPHY AND GRAVITY DATA. P. J. McGovern, Lunar and Planetary Institute, Universities Space Research Association, 3600 Bay Area Blvd. Houston TX 77058: mcgovern@lpi.usra.edu.

Introduction: The surface of Venus is covered by hundreds of volcanic edifices with diameters in excess of 50 km [e.g., 1-2]. Many of them are superposed on broad topographic rises of volcano-tectonic construction. These are targets of interest because they contain clues to the volcanic, geologic, and thermal evolution of Venus, and because they constitute a "natural volcanological laboratory" where hundreds of millions of years of volcano-tectonic history is exposed and preserved, free of the obscuring effects of erosion or oceans. Here I explore the beneficial effects of increasing the resolution of topography and gravity datasets for Venus.

Target: Sif Mons (22˚ N 351.5˚ E) and the Western Eistla Rise it is emplaced upon are typical of the type of volcanic features targeted here, but there are hundreds of potential targets.

Science Goals: Investigation of the geophysical and geological settings of large volcanoes and rises addresses the following VEXAG Goals, Objectives, and Investigations [3]: II.A.1, II.A.3, and II.B.3, concerning Venus surface and interior history and crustal and lithospheric structure and processes.

Topography: The Magellan radar altimeter collected measurements of topography with along-track resolution elements of width 8-15 km and across-track resolution depending on orbital coverage but usually > 10 km [4]. The gridded topography dataset had a 10-20 km horizontal resolution, and vertical resolution was 50-100 m [4]. While a late phase ("Cycle 3") of Synthetic Aperture Radar (SAR) right-looking imaging data collection allowed generation of higher-resoltuion topography via stereo processing [e.g., 5, 6], such data only covers about 20% of the planet, missing many volcano-rich areas. However, two large volcanoes (Kunapipi and Anala Montes) with rifted summits fell in these areas, and the order-of-magnitude improvement of horizontal resolution (to about 1-2 km) of the stereo-derived dataset of [5] allowed fault throws to be determined along the rifts [6]. The fault throws were converted to strain, and the observed strain distributions were compared to predictions from models of inflating oblate magma chambers, allowing estimation of chamber depths and widths [6].

Further improvements in resolution and coverage would greatly facilitate studies of large volcano structure and evolution. Consider the characteristic "inverted soup bowl" topographic profile [7] of Isla Fernandina in the Galapagos Islands, as revealed by the TOPSAR radar imaging/topography system [8], with horizontal resolution of approximately 10 m (Fig. 1, top). This profile is associated with distributions of short (near the summit) and long (on the lower flanks) lava flows and circumferential (summit) and radial (lower flank) fissures [9]. Clearly, the topographic profile needs to be fully resolved in order to evaluate the roles of these features in the evolution of the volcano. If the TOPSAR topography is degraded to Magellan resolution of order 10 km (Fig. 1, bottom), however, the "soup bowl" disappears, replaced by a shallower shield shape. Interpretation at this resolution would fundamentally alter any conclusions reached about the volcano-tectonic evolution of the edifice, rendering the results suspect. I conclude that improvements in available topographic resolution for Venus could greatly improve our interpretations of volcanic edifice evolution.

Gravity: The Magellan mission collected gravity data via Doppler tracking. The tracking data were used to assemble spherical harmonic expansions of geoid and gravity fields [10]. Variations in the quality of the collected data resulted in spatial variations in the resolving power of the gravity expansions: these are reflected in the "degree strength" maps of [10], specifying the maximum harmonic degree l at which the field has robust content as a function of position. A global reckoning of gravity/topography (g/t) coherence for Venus vs. l shows a near-constant decline with increasing l [11]. The extent to which this decline is an authentic feature of the g/t relationships on Venus, as opposed to an artifact due to spacecraft elevation or incomplete removal of non-conservative forces exerted on the Magellan spacecraft is unclear. [11] proposed that the low g/t correlation at high l at Venus could be in part explained by volcanic resurfacing at short and intermediate wavelengths, and spatio-spectral localizations of gravity and topography for large volcanoes on Venus [12] show generally declining (but often oscillating) g/t correlations with increasing l. Mars, however, has comparable volcanoes and volcanic units and yet lacks such a strong (global) decline [11].

Lessons from missions to the Moon may be illustrative: g/t coherence determined from the Lunar Prospector (LP) at first increase, then decrease with increasing l [11]. The improved resolution and farside coverage (using sub-satellites) of the Kaguya mission resulted in an increased peak coherence and a slight increase the value of l corresponding to the peak, but the shape of the curve was essentially the same as for LP [11]. The several orders-of-magnitude improvement in sensitivity offered by the GRAIL mission revealed the true nature of the g/t coherence of the Moon: asymptotically approaching unity with values > .95 for l greater than about 50 [11]. Thus, the short-wavelength decline obtained previously was the result of limitations of the gravity measuring techniques. Further, [11] argued that the short-wavelength asymptotic increase of coherence with increasing l at the Moon reflected the increasing ability of the lithosphere to support loads without compensating masses at depth and increasing attenuation of signals from deep sources. This logic applies to Venus as well, suggesting that the observed sharp decline of coherence with l is the result of incompletely resolving the Venus gravity field, even at degrees held to be "resolved" in the latest field [10].

Note that the LP and Magellan situations are similar in terms of strong variation of resolving power with position, in the former dominantly as a function of longitude (i.e., missing farside coverage), while in the latter a strong function of latitude (see Fig. 3 of [10]). In contrast, the near circular orbit of GRAIL has similar resolving power at all latitudes and longitudes, suggesting that a mission with more uniform gravity coverage may yield improved g/t coherences at Venus.

Perhaps the limitations inherent to Magellan acceleration data explain at least part of the correlation dropoff at Venus. If so, improved techniques for determination of the Venus gravity field could yield much improved assessments of g/t relationships, with benefits for analysis of large volcanic edifices and rises. For example, g/t admittance spectra at large volcanoes on Venus often show poor matches to predictions of lithospheric loading models over significant spectral bands with low or oscillating coherence [12], thereby complicating attempts to infer quantities of geophysical interest like elastic lithosphere thickness T_e and quantities than can be derived from it like heat flux q. If the current fidelity of the Venus gravity field is limited by technique and/or geographic coverage, improved gravity determinations by future missions could result in more reliable estimates of these quantities.

Prescriptions for a future mission to Venus: Topography: a dataset with horizontal resolutions of hundreds to tens of meters, and high vertical precision. Gravity: an investigation with near-circular orbits and globe-spanning latitudinal and longitudinal coverage.

References:

[1] Head J. W. et al. (1992) *JGR, 97*, 13,153-13,197. [2] McGovern P. J. and Solomon S. C. (1998) *JGR, 103*, 11,071-11,101. [3] VEXAG (2014) http://www.lpi.usra.edu/vexag. [4] Ford P. G. and Pettengill G. H. (1992) *JGR,* 97, 13,103–13,114. [5] Herrick R. R. et al. (2012) *EOS 93,* 125-126. [6] McGovern. P. J. et. al., *Geology, 42*, 59-62. [7] McBirney A. R. and Williams H. (1969) *GSA Mem. 118*. [8] Madsen S. N. et al. (1995) *IEEE Trans. Geosci. and Remote Sensing, 33*, 383–391. [9] Chadwick W. W. and Howard K. A. (1991) *Bull Volcanol. 53*, 259-275. [10] Konopliv A. S. et al. (1999) *Icarus 139*, 3–18. [11] Zuber M. T. et al. (2013) *Science, 339*, 668. [12] Herrick R. R. et al. (2005) *JGR, 110*, doi:10.1029/2004JE002283.

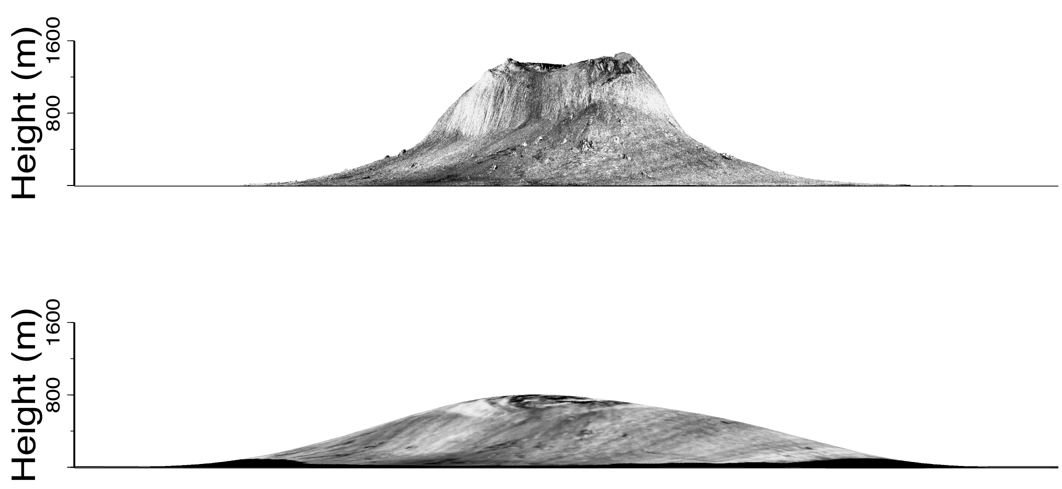

Figure 1. The subaerial part of Isla Fernandina, Galapagos, rendered using TOPSAR radar imaging overlain on TOPSAR topography [8]. Only the subaerial part of the edifice is shown, approximately 30 km wide. (a) Full-resolution TOPSAR topography and imaging (approximately 10m postings) are shown. (b) Topography is degraded to order 10 km resolution, and imaging to 100 m, typical of Magellan.