VENUS MESOSPHERIC WINDS AND THE CARBON MONOXIDE BULGE. Mark A. Gurwell[1], Duane O. Muhleman[1], and Kathryn Pierce Shah[2], [1]California Institute of Technology, Mail Stop 170-25, Pasadena CA 91125, USA, [2]Goddard Institute for Space Studies, New York NY, USA.

One of the most striking features of Venus is the superrotation of the atmosphere with a period of about 4 days, compared to the solid-body rotation period of 243 days. The winds were discovered by B. A. Smith [1] in 1967 from changes of the ultraviolet markings. The mid- and lower-latitudinal zonal winds have been directly measured by radio tracking of the Pioneer entry probes from about 65 km altitude down to the surface and by radio tracking of the Vega balloon, which floated at about 55 km. The measured winds reach a maximum speed of about 100 m/s at 65 km [2] and values above that, until recently, have been basically theoretical. In 1985, Clancy and Muhleman [3] interpreted their microwave spectral line observations of CO in the Venus mesosphere (roughly 70 to 110 km in altitude) as evidence for the continuation of the zonal winds to at least 100 km, the altitude of their experimental weighting functions. They showed, using planet-averaged measurements of the CO absorption line, that the abundance had a maximum (or "bulge") a few hours after local midnight. Pioneer Venus *in situ* mass spectrometer measurements [4] made at about 160 km had found a similar postmidnight bulge in helium but the abundances of the other species (including O, N_2, CO, and CO_2) appeared to be symmetrically distributed around the antisolar point in the thermosphere.

Recently, our group [5] mapped the CO absorption lines on the disk of Venus in 1988 using the synthetic aperture array at the Owens Valley Radio Observatory. Observations were made in the (0-1) rotational transition of CO at 115 GHz, or a wavelength of 2.6 mm. Systematic variations in the doppler shifts of the lines (particularly near the limbs) enable the group to directly map the wind field at 100 ± 10 km, the peak altitude for the experimental weighting functions used. These measurements show that the winds are indeed of order 100 m/s at this altitude. Previously, many had assumed that the vertical wind profile would quickly fall to zero above the cloud tops, due to cyclostrophic breakdown. This work is reviewed in this talk.

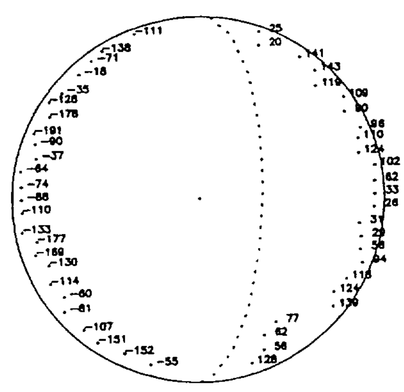

Fig. 1. Wind speeds (in m/s) near the limb of Venus in 1988 at 100 ± 10 km found from doppler shifts in CO line cores, corrected for incidence angle. Positive speeds represent winds approaching sub-Earth longitude and negative speeds winds receding. Dotted line represents the evening terminator.

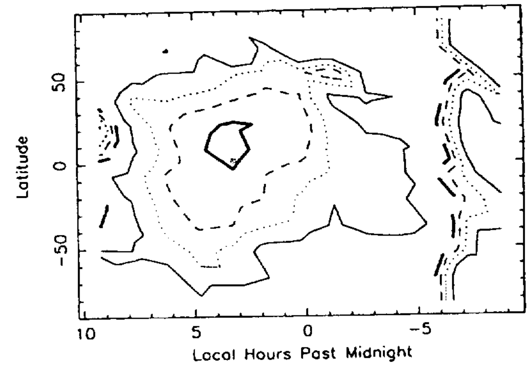

Fig. 2. The mixing ratio of CO at 96.5 km found from inversion of (0-1) rotational spectra. The map is a synthesis of data from 1986 (morning terminator) and 1988 (evening terminator) observations. The thick solid contour stands for a mixing ratio of 10^{-3} and the thick dashed contour stands for 10^{-4}. Intermediate contours for the night (-6 to 8.5 local hours) are 7×10^{-4} (thin dashed), 5×10^{-4} (dotted), and 3×10^{-4} (thin solid). For the afternoon (-6 to -9 local hours) the same contour styles represent 7×10^{-5}, 5×10^{-5}, and 3×10^{-5} respectively.

The combination of the 1988 measurements, made when the evening terminator was visible from Earth, and 1986 measurements of the disk [6], which observed the morning terminator, has allowed us to map the CO abundance over most of the planet in the altitude range from 80 to 105 km. The abundance map is shown in latitude and local time coordinates in Fig. 2 for an altitude cut at 96.5 ± 1.25 km. The CO bulge is clearly visible centered at 3:30 a.m. and near the equator. Carbon monoxide is produced in the photodissociation of the major atmospheric constituent CO_2 and is cycled back in catalytic reactions involving Cl or possibly OH radicals on the dayside of the planet.

Apparently, the CO molecules are created on the dayside, mostly in the region between 65 and 90 km in altitude, and are then "blown" to the nightside. The abundances of species capable of destroying CO falls off rapidly from the dayside to the nightside, allowing CO to pile up at high altitudes without being destroyed. It was suggested in [3] that this process may be controlled by solar to antisolar winds in the thermosphere ($z \geq 110$ km), an idea that has been developed further by Bougher [7] and his colleagues based on the Dickenson-Ridley thermospheric models. Their three-dimensional model was used to investigate the effects of zonal circulation in the thermosphere, and found that light species (H and He) had maxima displaced 3 to 5 hr LT toward the morning, but that heavier species (CO, O, and CO_2) would be mostly unaffected, leading to symmetric distributions around local midnight at 160 km. Their model assumed that zonal wind speeds near 100 km were essentially zero.

We will present new evidence for superrotating winds in the Venus mesosphere, including the first high-resolution maps of the CO distribution at several altitudes. We argue that the displacement from local midnight toward the morning terminator of the nighttime CO bulge is due to mesospheric zonal winds, complementing the CO doppler shift analysis of Shah et al. The sensitivity of our measurements extends to over 100 km, and it seems possible that the winds continue up through at least 160 km, as in the models of Bougher et al. In this case, at some altitude above 110 km but below 155 km the zonal superrotation would somehow cease to affect the CO distribution, and above that CO becomes symmetric around local midnight.

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TECTONICS AND VOLCANISM OF EASTERN APHRODITE TERRA: NO SUBDUCTION, NO SPREADING.

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Introduction: Eastern Aphrodite Terra is approximately equal in size to the western North American Cordillera, from Mexico to Alaska. Its size and unique landforms make it an important area for understanding the tectonics of Venus, yet models for its formation are diametrically opposed. This region is part of the Equatorial Highlands, which was proposed as a region of lithospheric thinning, isostatic uplift, and attendant volcanism [1,2]. Head and Crumpler [3] suggested, on the basis of topographic symmetry and proposed cross-strike lineaments interpreted from Pioneer Venus data, that this area represents a zone of crustal divergence, analogous to terrestrial midocean ridges. Using Magellan SAR data, Suppe and Connors [4] proposed that Eastern Aphrodite Terra forms part of a circumglobal rift zone separating two major venusian plates. In contrast, McKenzie et al. [5] interpreted Eastern Aphrodite Terra as a region dominated by crustal shortening and subduction of venusian crust. They argued that structures resembling trenches display the same curvature and topographic asymmetry as terrestrial subduction zones. Sandwell and Schubert [6] modeled the trench and outer rise topography of the rim of Artemis and Latona coronae as a thin elastic plate subjected to a line load with a bending moment beneath the coronae. They calculated elastic thicknesses and bending moments, and used these values together with a yield strength model to estimate lithospheric temperature gradients. They concluded that the amplitudes of the trench and outer rise are too large to be explained by thermal subsidence alone, and they propose a lithospheric subduction model wherein the lithosphere outboard of the corona perimeter subducts as the corona diameter increases [7]. Thus, Eastern Aphrodite Terra has been interpreted as a region analogous to both a terrestrial midocean ridge extensional plate boundary and a terrestrial subduction plate boundary.

Observations: Structural mapping and kinematic interpretation of Magellan SAR imagery of Eastern Aphrodite Terra provide new evidence for the formation of this region. Eastern Aphrodite Terra comprises a band of predominantly circular structures and east-trending fractures that extends from Artemis corona to Atla Regio. The belt is approximately 1500 km wide and greater than 8000 km long. The circular structures vary in diameter from 100 to 2500 km and they fit the description of coronae as described by many workers and summarized by Stofan et al. [8]. The largest circular structure is Artemis corona, although Artemis does not exhibit many of the features discussed here. The curvature of these features generally varies between 180° and 270°, although 360° is preserved locally, particularly in structures of small diameter. The circular structures commonly display both radial and concentric fractures. A single circular structure may have as many as four nested sets of concentric fractures, each separated by a region marked by little or no deformation. Fractures from one structure commonly overlap with those of adjacent structures. The circular structures are the sites of extensive volcanism. Flows emanate from both the center of the structures and the concentric fractures. Artemis corona is different from adjacent circular features; it is almost three times the size of the next largest feature and it does not show nested concentric fractures, although it has associated volcanism.

Detailed examination of one of these circular features with center at 14°S, 164°E, herein referred to as 14S/164, reveals that the structure is approximately 600 km in diameter, with at least three sets of concentric fractures stepping outward from the center (e.g., 11.5°S, 164°E). Locally, radial fractures <100 km in length form normal to concentric fractures (e.g., 12.5°S, 166.5°E). Lava flows emanate from the center of the circular structures into channels formed by radial fractures. Extensive lava flows also emanate from each set of concentric fractures and flow outward. The central radial flows are radar-dark whereas the youngest flows from the concentric fractures are radar-bright. Radar-dark flows are interpreted as generally less viscous than radar-bright flows because radar-dark regions appear to flood into preexisting fractures and are influenced by local topography, whereas radar-bright flows form lobate structures and define their own boundaries (e.g., 14.5°S, 168°E). The spatial and temporal relations between radar-bright and radar-dark flows may provide evidence for magma differentiation at depth. Examination of the outermost concentric fracture set reveals that radar-dark flows fill a moat outside this concentric fracture set as evidenced by the sharp truncation of earlier cross fractures. Radar-bright flows, ~30 km wide and greater than 100 km long, flow outward from the concentric fracture set. Flows from each of the concentric fracture sets are cross-cut by the next outward concentric fracture set. Therefore, the concentric fracture sets are interpreted to become younger outward, with the youngest fractures farthest from the center of the circular feature.

Radial fractures within the circular features are readily identifiable where flooded by volcanic material from the center of the structure (e.g., 16.5°S, 162.5°E). The radar look direction, as well as structure orientation, must be considered while mapping individual sets of structures and in interpreting the timing relations between structures. For example, north-trending lineaments, oriented perpendicular to the radar look direction, commonly appear dominant, and therefore they may be interpreted as cross-cutting less visible east-trending lineaments (e.g., 17.5°S, 163°E). In this particular circular structure, central radial fractures cut concentric fractures where the radial set is north trending, and lava flows following east-trending radial fractures are not apparently truncated by circular north-trending concentric fractures. We therefore interpret these lava-filled radial fractures as younger than the inner concentric fractures. The presence of lava flows makes these east-trending troughs visible; without the lava fill the east-trending troughs are difficult to see. The temporal relations, radial fractures younger than adjacent concentric fractures, imply that these radial fractures are relatively deep in order to act as lava conduits. It is possible that the central radial fractures and their attendant volcanic flows completely disguise early formed, inner-concentric fracture sets. The presence of volcanic flows in both the center and associated with the outermost concentric fractures indicates that volcanism played an important role in the formation of 14S/164.

East- to east-northeast-trending fractures overprint 14S/164. These fractures belong to a regional fracture set that trends northeast between Latona and Alta Regio, to the east west of Latona, and to the east-northeast west of Dali and Diana Chasmata. The relationship between 14S/164 and Diana and Dali Chasmata is not clear. The two outermost sets of concentric fractures of 14S/164 trend into parallelism with the trough of Diana Chasma, which is itself parallel to the set of regional east-trending fractures. Radar-bright volcanic