

elastic thickness, demonstrating the agreement of the axisymmetric and two-dimensional models in the case of a large corona. For smaller coronae, we find that elastic lithosphere thicknesses between 10 km and 15 km provide the best fits to the flexural topography (Table 1).

TABLE 1.

| Corona Name | Location    | Diameter (km) | Elastic Thickness (km) |
|-------------|-------------|---------------|------------------------|
| Fatua       | 17°S, 17°E  | 310           | 15                     |
| Selu        | 43°S, 6°E   | 300           | 10                     |
| Aramaiti    | 26°S, 82°E  | 350           | 10                     |
| Boann       | 27°N, 136°E | 300           | 5                      |
| Latona      | 20°S, 171°E | 800           | 30                     |

The disk loading model can be used to deduce the gravity signature of a corona. We will report calculations of gravity using the disk loads inferred for the larger coronae and compare with recent gravity data, e.g., over Artemis [6].

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**RADAR-ANOMALOUS, HIGH-ALTITUDE FEATURES ON VENUS.** Duane O. Muhleman and Bryan J. Butler, Division of Geological and Planetary Science, California Institute of Technology, Pasadena CA 91125, USA.

Over nearly all of the surface of Venus the reflectivity and emissivity at centimeter wavelengths are about 0.15 and 0.85 respectively. These values are consistent with moderately dense soils and rock populations, but the mean reflectivity is about a factor of 2 greater than that for the Moon and other terrestrial planets (in the case of the Earth, regions free of moisture). Pettingill and Ford [1], using Pioneer Venus reflectivities and emissivities, found a number of anomalous features on Venus that showed much higher reflectivities and much lower emissivities with both values approaching 0.5. These include Maxwell Montes, a number of high regions in Aphrodite Terra and Beta Regio, and several isolated mountain peaks. Most of the features are at altitudes above the mean radius by 2 to 3 km or more. However, such features have been found in the Magellan data at low altitudes and the anomalies do not exist on all high structures, Maat Mons being the most outstanding example. A number of papers have been written that attempt to explain the phenomena in terms of the geochemistry balance of weathering effects on likely surface minerals; see reference [2] and papers cited therein. The geochemists have shown that the fundamentally basaltic surface would be stable at the temperatures and pressures of the mean radius in the form of magnetite, but would evolve to pyrite ( $\text{FeS}_2$ ) and/or pyrrhotite ( $\text{Fe}_{0.877}\text{S}$ ) in the presence of sulfur-bearing compounds such as  $\text{SO}_2$ . Pyrite will be stable at altitudes above 4 or 5 km on Venus. The details of the stability of these rather good electrical conductors depends on the availability of O in excess over that tied up in equilibrium with the parent constituent of the atmosphere,  $\text{CO}_2$ . This is clearly explained in [2]. However, the abundance of the sulfur compound  $\text{SO}_2$  is very

uncertain and arguments are made that it is actually varying with time on a scale of 10 yr.

Although the geochemical arguments are rather compelling, it is vitally important to rationally look at other explanations for the radar and radio emission measurements such as that presented by Tryka and Muhleman [3]. The radar reflectivity values are retrieved from the raw Magellan backscatter measurements by fitting the Hagfors' radar scattering model in which a surface roughness parameter and a normal incidence electrical reflectivity are estimated. The assumptions of the theory behind the model must be considered carefully before the results can be believed. These include that the surface roughness exists only at horizontal scales large compared to the wavelength, the vertical deviations are gaussianly distributed, there is no shadowing, and that the reflection occurs at the interface of two homogeneous dielectric half-spaces. Probably all these conditions are violated at the anomalous features under discussion! The most important of these is the homogeneity of the near surface of Venus, particularly in highlands. Under the assumptions of the theory, all of the radio energy is reflected by the impedance jump at the very boundary. However, in heterogeneous soil some fraction of the illuminating energy is propagated into the soil and then scattered back out by impedance discontinuities such as rocks, voids, and cracks. In light soils, the latter effect can overwhelm the scattering effects of the true surface and greatly enhance the backscatter power, suggesting a much higher value of an effective dielectric constant that would be estimated from Hagfors' model.

The phenomenon of emission is similar but has several important different characteristics. In the case of thermal emission from a smooth, homogeneous dielectric into vacuum, some of the radiation generated in the effective black body passes through the interface to the observer and a fraction is reflected back downward into the material where it is reabsorbed. In the simple case of an isothermal layer (such as the near surface of Venus), radiating from a homogeneous layer, the emissivity is determined by the Fresnel reflection coefficients at the observing angle to the normal. However, if the layer contains multiple scatterers in a light soil, radiation generated even at small depths cannot reach the surface since the tendency is to scatter the energy backward, similar to the strong backscattering reflection from above such a surface. Thus, the emissivity can be greatly depressed and the observed brightness temperature will be low. This phenomenon for Venus was discussed in 1979 [4] as an explanation for the decrease in the average disk temperature of Venus at wavelengths longward of 10-20 cm.

The most outstanding and relevant example of the importance of multiple scattering or volume scattering in radar and microwave emission are the icy satellites of Jupiter [5]. The radar reflectivity of the full disk of Europa at 13-cm wavelength is 0.65 and the emissivity is about 0.42! Certainly, the surface of Europa is almost pure water ice that, if it existed in the form of dense ice, would have a reflectivity of 0.07 and an emissivity of 0.93. If the Europa ice was in the form of a homogeneous layer, under dense frost the reflectivity would be even lower. It is obvious that the reflection and emission phenomena on Europa are independent of the Fresnel surface reflection coefficients and dependent entirely on the physical structure of the near surface, i.e., the existence of lumps, voids, cracks, etc. It is also very important that ice as cold as 130 K is highly transparent at centimeter wavelengths and very little of the energy is ohmically absorbed in the near surface. If that were not the case, the surface would be a good emitter and a rather poor reflector.

The radiative transfer calculations for the emission and reflection from a layer with volume scattering are very complex, with the

results strongly dependent on the details of the individual scattering elements and the electrical parameters of the matrix of material in which the scatterers are "suspended." The most fundamental example for which an analytical solution is known is the case of isotropic scattering in a semi-infinite, plane parallel half space [6]. The assumptions of this theory are important, of course. It assumes that radiation incident on a scatterer is uniformly scattered in all directions. For this to be strictly true, electromagnetic theory requires that the scatterers be ellipsoidal with random orientations and be separated by distances long compared to the wavelength in the medium. Chandrasaker's solution intrinsically assumes that the scatterers are suspended in a transparent medium. The ideas were adopted in [3] with the argument that rocks in light venusian soils may behave this way to first order on average, even though the scatterers are probably far from spherical and may be piled on top of each other. The fact that the matrix supporting the scatterers is not completely transparent is not serious as long as it is sufficiently transparent to allow the radiation to scatter a "few" times before absorption or before the energy is backscattered out of the layer.

If we visualize the scatterers as rocks and fragments we may consider a suite of likely models that would display the microwave observables seen in the PV and Magellan data. Such rocks would exist at all sizes from dust to the rare boulders of many meters. It is reasonable to assume that the particle sizes could be represented by a power law distribution and a good guess at the slope parameter of the distribution would be about -3, consistent with that found from tumbling rocks in a fracturing process. The index is not of great importance. We assume that the soil matrix has a real dielectric constant of 2, consistent with the flat regions on Venus that exhibit the lowest reflectivity. Such soils would have densities under 1 gm/cm<sup>3</sup> and power absorption lengths of order 2-3 m. The rocks would have dielectric constants in the range of 5-8, primarily dependent on the metal content, and corresponding absorption lengths of about 0.6-0.1 m. Silicate rocks have low complex dielectric constants and mafic rocks such as basalts high in Fe have large values. We have applied the theory from [3] to a typical granite and a typical basalt and the resulting 13-cm reflectivities and emissivities at normal incidence are shown in Table 1. An important unknown parameter is the largest size cutoff of the power law size distribution. Obviously, if the "particles" could be as large as kilometers, the results would degenerate to the parameters of the largest sphere and scattering would not be important. The results are presented in the table as a function of the cutoff radius of the size distribution.

TABLE 1.

|         | Maximum Radius (cm) | Reflectivity | Emissivity |
|---------|---------------------|--------------|------------|
| Granite | 5                   | 0.617        | 0.355      |
|         | 10                  | 0.496        | 0.486      |
|         | 30                  | 0.383        | 0.599      |
|         | 50                  | 0.341        | 0.637      |
|         | 100                 | 0.291        | 0.679      |
| Basalt  | 5                   | 0.486        | 0.509      |
|         | 10                  | 0.386        | 0.581      |
|         | 30                  | 0.304        | 0.664      |
|         | 50                  | 0.273        | 0.690      |
|         | 100                 | 0.245        | 0.728      |

It is clear that this explanation is sufficient for the Venus anomalous features. Furthermore, the parameters approach the average values of the Venus surface when the value of the maximum particle size is increased moderately. There are ambiguities in these calculations, but the ambiguities are intrinsic to the Magellan measurements themselves in rough, heterogeneous areas on Venus where the Hagfors' assumptions are severely bent. New scattering theories involving Monte Carlo techniques will be presented.

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**THE GABBRO-ECLOGITE PHASE TRANSITION AND THE ELEVATION OF MOUNTAIN BELTS ON VENUS.** Noriyuki Namiki and Sean C. Solomon, Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge MA 02139, USA.

**Introduction:** The linear mountain belts of Ishtar Terra on Venus are notable for their topographic relief and slope and for the intensity of surface deformation [1,2]. The mountains surround the highland plain Lakshmi Planum. Volcanism is rare to absent in Maxwell, Freyja, and Akna Montes, but a number of magmatic features are evident in Danu Montes [2,3], the mountain range least elevated above Lakshmi Planum. Whether western Ishtar Terra is a site of mantle upwelling and consequent hot spot volcanism [4-6] or of mantle downwelling and consequent convergence of lithospheric blocks [7,8] is currently a matter of debate. However, the mountains are generally regarded as products of large-scale compression of the crust and lithosphere [2,9].

Among the four mountain belts surrounding Lakshmi Planum, Maxwell Montes is the highest and stands up to 11 km above the mean planetary radius and 7 km above Lakshmi Planum. The bulk composition and radioactive heat production of the crust on Venus, where measured, are similar to those of terrestrial tholeiitic basalt [10]. Because the thickness of the low-density crust may be limited by the gabbro-garnet granulite-eclogite phase transitions (Fig. 1), the 7-11-km maximum elevation of Maxwell Montes is difficult to understand except in the unlikely situation that the crust contains a large volume of magma [11]. A possible explanation is that the base of the crust is not in phase equilibrium. It has been suggested that under completely dry conditions, the gabbro-eclogite phase transition takes place by solid-state diffusion and may require a geologically significant time to run to completion [12]. Solid-state diffusion is a strongly temperature-dependent process. In this paper we solve the thermal evolution of the mountain belt to attempt to constrain the depth of the gabbro-eclogite transition and thus to assess this hypothesis quantitatively.

**Thermal Model:** The one-dimensional heat equation is solved numerically by a finite difference approximation. The deformation of the horizontally shortening crustal and mantle portions of the thermal boundary layer is assumed to occur by pure shear, and therefore the vertical velocity is given by the product of the horizontal strain rate  $\dot{\gamma}$  and depth  $z$ . The thermal diffusivity is assumed to be  $1.0 \times 10^{-6} \text{ m}^2 \text{ s}^{-1}$  in both crust and mantle. Crustal heat production is assumed to equal  $1.4 \times 10^{-13} \text{ K s}^{-1}$ . The initial temperature profile is determined by the assumption of steady-state conditions with zero velocity. Temperature at the surface and the