

**A COMPARISON OF THEORETICAL MINERAL EQUILIBRIA AND PIONEER VENUS RADAR DATA**

J. B. Garvin, R. A. Fogel, R. A. F. Grieve, and J. W. Head, Dept. Geol. Sci., Brown Univ., Providence RI 02912

The nature of the chemical interaction between the surface and atmosphere of Venus is imperfectly known. Models involving mineral equilibria and measured atmospheric constituents have been explored previously (1-6). These models have focused on carbonation and other reactions (1-3) over the range of surface P,T conditions on Venus: approx. 40 bars, 650K in the highest mountains, over 100 bars, 750K in the lowlands. In this study we attempt to correlate theoretical venusian carbonation reactions with the Pioneer Venus (PV) radar altimetry and reflectivity for the Beta-Phoebe region in an effort to understand the geological ramifications of proposed chemical weathering reactions (1-4). The PV radar instrument mapped approximately 93% of the surface at spatial resolutions from 30-110 km (7). Thus large-scale changes in the nature of the surface of the planet such as those caused by chemical weathering could potentially be observed in the data. The technique used is to correlate elevation intervals at which certain phases would be stable with radar reflectivity intervals corresponding to different surface material properties.

Several equilibria were considered, including carbonation reactions, tremolite decomposition and pyrite ( $\text{FeS}_2$ ) production. The stability of the reactions was expressed in  $\log f_i$  versus T format, where  $f_i$  is the fugacity or fugacity ratio of the gases involved in the reaction. Equilibria for carbonation reactions takes the form:  $\log P = (A - \log(.97)) + B/T$ , where A and B are constants. For other volatiles, the  $f_i$  are less well known. For example,  $f\text{O}_2$  has an uncertainty of  $10^5$  (4-6) and equilibria involving oxygen are therefore poorly constrained. The PV descent probes collected data on the P,T conditions of the atmosphere down to the surface (8), and from these data the following relationships between elevation Z, P, and T can be derived:

$$\log P = 0.0032(T) - 0.832 \quad (1)$$

$$Z = -0.1315(T) + 97.279 \quad (2)$$

$$T = -7.6(Z) + 739.57 \quad (3)$$

The wollastonite reaction (solid phase activity = 1) is  $\text{CaSiO}_3 + \text{CO}_2 = \text{CaCO}_3 + \text{SiO}_2$ , and  $\log f\text{CO}_2 = 8.036 - 4435.2/T$ . This relationship and eqs. (1) and (2) above, indicate that  $\text{CaCO}_3$  would be produced by this reaction at elevations  $Z > 1.68$  km (where Z is relative to 6051 km). Similarly, the reaction  $\text{Mg}_2\text{SiO}_4 + \text{CO}_2 = \text{MgSiO}_3 + \text{MgCO}_3$  produces  $\text{MgCO}_3$  at  $Z > 5.7$  km. Fugacities of  $\text{H}_2\text{O}$  on Venus above the tremolite equilibrium value inhibit reaction, whereas lower  $f\text{H}_2\text{O}$  induce breakdown. The breakdown of ilmenite to produce highly dielectric rutile ( $\text{TiO}_2$ ) occurs at  $Z < 2.2$  km. From the present uncertainty in available data on  $f\text{O}_2$ , it is unclear whether pyrite  $\text{FeS}_2$  would be stable everywhere on the surface of Venus or whether it would be unstable everywhere, on the basis of the suggested reaction involving anhydrite (2,3,9). A similar situation occurs for chloride reactions. From the stability ranges for the above carbonate and ilmenite reactions, we have considered 4 elevation intervals corresponding to various assemblages:

- I.)  $Z < 1.7$  km (Wo, Fo,  $\text{TiO}_2$ )
- II.)  $1.7 < Z < 2.2$  km (Fo,  $\text{TiO}_2$ ,  $\text{CaCO}_3$ )
- III.)  $2.2 < Z < 5.7$  km (Fo,  $\text{CaCO}_3$ , Ilm)
- IV.)  $Z > 5.7$  km ( $\text{CaCO}_3$ , Ilm,  $\text{MgCO}_3$ )

Radar reflectivity ( $p$ ) is sensitive to porosity and electrical properties of surface materials (9). Models (10,11) can be applied which relate  $p$  and  $\epsilon$  (dielectric) and  $\delta$  to surface density ( $\delta$ ). The Krotikov model (10) is valid for geologic materials with densities from approx. 1.5 to 3.5 g/cm<sup>3</sup> and relates  $\delta$  to  $p$  by:  $\delta = 4\sqrt{p} / (1-\sqrt{p})$ . We use this relationship to subdivide the  $p$  spectrum for Venus into 4 levels:

- (1)  $p < 0.1$  (soils,  $\delta < 1.9$  g/cm<sup>3</sup>)
- (2)  $0.1 < p < 0.15$  (soil and rocks,  $1.9 < \delta < 2.5$  g/cm<sup>3</sup>; avg. for Venus)
- (3)  $0.15 < p < 0.2$  (rock,  $2.5 < \delta < 3.3$  g/cm<sup>3</sup>)
- (4)  $p > 0.2$  (high  $\epsilon$  materials)

These intervals are gradational. It should also be noted that there is a degree of ambiguity in interpreting radar  $p$  values in terms of their absolute magnitude. For instance, increased cm-scale roughness can make  $p$  artificially low even for a rocky surface.

Maps were constructed for the Beta-Phoebe region (Fig. 1) using the unit definition technique described in (12) with a simple grey scale to represent groups of units (various silicates and carbonates and combinations of rock and soil), as follows:

- BLACK** : Wo, Fo,  $\text{TiO}_2$ ; soil and rocks
- MED. GREY** : Fo,  $\text{CaCO}_3$ ,  $\text{TiO}_2$  or Ilm; soil and rocks
- DARK GREY** :  $\text{CaCO}_3$ ,  $\text{MgCO}_3$ ,  $\text{TiO}_2$  or Ilm; rock
- WHITE** : high dielectric materials (all phases permissible)

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While some correlations of material properties with geochemically defined topographic regions can be observed (i.e. carbonates/rock cluster with high  $\rho$  regions), there are no simple overall patterns that demonstrate a control of the investigated reactions in determining the physical nature of the surface. For example, since carbonation reactions involve large increases in molar volume and thus provide a mechanism for rock breakdown, they might be expected to correlate with areas of soils and rocks ( $\rho < .15$ ). Areas with such correlations do exist (*MED. GREY*). On the other hand, large areas where primary silicates are stable relative to carbonates consist of soils and rock (*BLACK*). Some of this may be due to the limitations associated with considering only these idealized reactions (with unit activities) coupled with the ambiguities inherent in the geological interpretation of radar  $\rho$  data.

Notwithstanding these limitations and assuming these reactions occur, some features warrant discussion. There are large areas associated with Beta and Phoebe which correspond to carbonates and soils/rock. On the other hand, there are only limited areas where carbonates are stable and  $\rho$  suggests rock densities (*DARK GREY*, Fig. 1). The most elevated areas of Beta correspond to high dielectric materials and also carbonates. If carbonation reactions occur, then this requires that these surfaces be relatively unaltered and therefore young as suggested by high resolution Arecibo radar images (13). The other areas of high dielectrics (e.g. SW corner of Fig. 1) are in the silicate stability field and, in this interpretation, need not be geologically young. This analysis neither supports nor precludes the occurrence of pyrite to explain the high  $\rho$  materials through the reaction of anhydrite (2,9). A more rigorous test of this suggestion requires better constrained  $fO_2$  values and their variation with elevation.

It is apparent from the above discussion that simple carbonation reactions (1-4) are not entirely consistent with the modeled surface characteristics and that additional weathering mechanisms are likely to be operating on Venus. As an additional step, it would be appropriate to consider more complex and coupled reactions involving other volatile species. As noted, however, such equilibria are highly sensitive to accurate determinations of the relevant fugacities. Further analysis of map pattern relationships are in progress along with consideration of correlations with surface roughness.

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**Figure 1.** Mercator map of a section of Venus (240° to 350°, 40° to -40°) showing the Beta (top center) and Phoebe (middle center) highlands and surrounding plains. See text for units and details.