IS THE INTRINSIC DENSITY OF VENUS GREATER THAN THE INTRINSIC DENSITY OF EARTH? Kenneth A. Goettel, Department of Earth and Planetary Sciences, Washington University, St. Louis, Missouri 63130

Background
For many decades, virtually all models for Venus have been based on the assertion that the intrinsic density of Venus is slightly less than the intrinsic density of Earth. Most of the ~5% difference between the mean density of Venus, 5.245 g/cm³, and the mean density of Earth, 5.515 g/cm³, is attributable to the greater mass of Earth. Ringwood and Anderson (1) used pressure-density relationships from terrestrial seismic data to estimate that an Earth-like Venus (a model planet with the mass of Venus, but identical to Earth in composition and structure with temperatures equal to those in Earth at corresponding pressures, except near the hot surface) would have a mean density of 5.33 ±0.01 g/cm³; this estimate implies that the intrinsic density of Venus (i.e., the density of the materials constituting Venus at standard temperature and pressure) is about 1.6 ±0.2% less than the intrinsic density of Earth. Making similar assumptions, Goettel et al. (2) estimated that the intrinsic density of Venus is only 1.0 ±0.4% less than the intrinsic density of Earth; this lower estimate of the density difference resulted from assuming that temperatures in Venus are equal to those in Earth at corresponding depths (rather than corresponding pressures), and from including a modest density effect arising from suppression of the basalt/eclogite transition on Venus, as suggested by Anderson (3).

Discussion
However, the classical assertion that the intrinsic density of Venus is slightly less than the intrinsic density of Earth may be incorrect because: a) internal temperatures in Venus may be markedly higher than in Earth (2), and b) Venus may have a thick crustal layer of basalt and partial melt (3). As discussed by Goettel et al. (2), higher internal temperatures in Venus may result from differences in composition and tectonics between Venus and Earth. The composition of a planet affects internal temperatures via relationships between composition, melting temperature, viscosity and temperature in a convectively regulated planetary interior. In the end member case of the equilibrium condensation model (4), slightly higher heat source densities and the virtual absence of FeO and H₂O in the mantle of Venus could produce temperatures 200 to 400 °C higher than in Earth and lower the density of Venus by about 0.4 to 0.8% (assuming a mean thermal expansion coefficient of 2 x 10⁻⁵). In addition, the probable absence of subduction of surface plates on Venus results in less efficient heat transfer from the interior and may raise internal temperatures in Venus by 250 to 300 °C (5) and thus lower the density by an additional 0.5 to 0.6%. Therefore, higher mean internal temperatures in Venus could lower the density by as much as 0.9 to 1.4%. The high surface and upper mantle temperatures of Venus will also suppress the basalt/eclogite transition; Anderson (3) estimated that the existence of a 100 to 170 kilometer thick layer of basalt and partial melt would lower the density of Venus by about 0.8 to 1.5%. Thus, differences in near surface and internal temperatures between Venus and Earth could lower the density of Venus by as much as 1.7 to 2.9%.

The possibility that internal temperatures in Venus are substantially higher than in Earth and the possibility of a thick basaltic crust on Venus markedly affect the estimate of the difference in intrinsic density between Venus and Earth. Rather than Venus being ~1.0 ±0.4% less dense than Earth,
NEW MODEL FOR VENUS

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The revised estimate of the difference in intrinsic density between Venus and Earth may make it possible to explain most aspects of the compositions of the terrestrial planets with the following postulates:

1) The compositions of the terrestrial planets were governed in large part by condensation in the solar nebula and the variation in the composition of condensed material with heliocentric distance as suggested by Lewis (4).

2) Aerodynamic fractionation (6) resulted in a marked increase in the Fe/Si ratio of Mercury and a slight increase in Fe/Si for Venus; Earth and Mars have essentially solar Fe/Si ratios.

3) The simple, end member compositions of each planet were somewhat modified by accretion of material having a range of condensation temperatures and by mixing of materials from different heliocentric distances during late stages of the accretion process.

These postulates suggest the following composition for Venus (relative to Earth): a slightly higher Fe/Si ratio, substantially lower FeO in mantle silicates (perhaps 1-4 wt.%), much less total S, and much less total H2O. Thus, Venus may have a large Fe-Ni core with small amounts of S and a mantle with much lower amounts of FeO and H2O than the terrestrial mantle. These compositional differences along with the greenhouse-derived, hot surface environment may result in profound differences in the thermal and tectonic state of Venus relative to Earth. Better constraints on the composition of Venus require not only additional data from Venus but also better understanding of compositional and tectonic effects on internal temperatures in convectively regulated planetary interiors.

References