OCCURRENCES OF LOW-EMISSIVITY SURFACE MATERIAL AT LOW ALTITUDES ON VENUS: A WINDOW TO THE PAST; John A. Wood, Harvard-Smithsonian Center for Astrophysics, Cambridge MA 02138

A few craters at plains level on Venus have low-emissivity material in their floors and ejecta. At this altitude the stable weathering product has magnetite as its Fe mineral, and it should display high emissivity. Apparently the craters exhumed pyritic deep crustal material, which has not yet weathered to the stable assemblage. Deep, old crustal material that was weathered by a low-SO_2 atmosphere prior to the ~0.5 Gy resurfacing event would contain pyrite as its Fe mineral.

The radiothermal emissivity of surface material on Venus tends to be high (>0.7) at low altitudes, *i.e.*, over most of the planet, but low (<0.7) on mountain summits. The low-emissivity character of material at high altitudes has been attributed to a mineralogical composition, specifically the presence of the mineral pyrite (FeS_2), that gives it a high bulk dielectric constant [1]. Klose *et al.* [2] showed that, for a plausible atmospheric f_{O2}, the distribution of low- and high-emissivity surface material could result from the position of a phase boundary that controls the composition of the thermodynamically stable weathering product. At high altitudes (hence low temperatures) most Fe resides in the semiconductor mineral pyrite, which is abundant enough to give the bulk surface material (acting as a loaded dielectric) the required high dielectric constant. At low altitudes (high temperatures) the stable Fe mineral is magnetite (Fe_3O_4), which is also a semiconductor but not present in great enough abundance to impart a high dielectric constant to the bulk soil.

A puzzling exception to the above situation is the observation that the floors and ejecta blankets of some impact craters in the plains, such as Boleyn, Stanton, Stuart, and Mead, display anomalously low emissivities [3,4,5]. It appears that the craters excavated high-dielectric-constant crustal material from depth. This raises the question of the expected nature of Venus crustal material at depths of several km.

There is no reason to think the crust to the depths reached by these ≤280-km-diam. craters consists of other than a stacked sequence of old basaltic lava flows. However, primary basalt on Earth does not have an intrinsically high dielectric constant; most of the Fe in igneous basalts on Earth and probably also on Venus occurs in the $FeSiO_3$ components of pyroxenes, not as semiconducting Fe minerals. It is possible that the flows are no longer primary igneous basalts, but were deeply weathered before they were buried; However, as noted above, weathering of basalt by the present Venus atmosphere at plains altitude does not produce a mineral assemblage with a high dielectric constant either.

But it is unlikely that deeply buried basalt weathered under the same conditions that obtain at the Venus surface today. Since Venus has not been very active volcanically since the major epoch of volcanic resurfacing ~0.5 Gy ago [6], deeply buried basalts were erupted before (or during) that epoch. The 0.5-Gy epoch of volcanism must have injected a very large amount of SO_2 into the atmosphere. Only weathering, which probably operates very slowly on Venus, can remove SO_2 from the atmosphere, so it is likely that the present level of atmospheric SO_2 is still enhanced from the 0.5-Gy volcanism. Prior to 0.5 Gy ago there may have been much less SO_2 in the atmosphere than there is now.

It would seem that if deep crustal material weathered in a less sulfurous atmosphere than is present today, this would do nothing to change the character of the weathering product in the direction of a pyritic (hence high-dielectric and low-emissivity) mineral assemblage, but paradoxically this is not the case. Another variable, temperature, affects the stable mineral assemblage: since SO_2 is an important greenhouse gas, its removal from the atmosphere would result in lower surface temperatures [7], and under the circumstances contemplated this favors the stability of pyrite.

I have calculated the ranges of temperature and SO_2 concentration in which pyrite and magnetite are stable, using the energy-minimization program of [2]; the results are shown in Fig. 1, which shows that pyrite stability is affected by both SO_2 concentration and temperature. [7] estimate that removal of all SO_2 from the Venus atmosphere would lower the surface temperature by 52K. The dashed line in Fig. 1 reports this effect, assuming a linear relationship between SO_2 concentration and greenhouse warming. It can be seen that below the present atmospheric SO_2

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concentration there is a broad range of concentrations, ~8 to ~130 ppm, where the stable Fe mineral at plains altitudes is pyrite, not magnetite.

I suggest the occurrence of low-emissivity crater ejecta on Venus is telling us this: prior to the 0.5-Gy resurfacing event the SO_2 content of the Venus atmosphere was less than it is now, being in the range ~8 - ~130 ppm, and the surface temperature was commensurately cooler. Basaltic flows at all altitudes weathered to a pyritic mineral assemblage having a high bulk dielectric constant. The planetary surface would have displayed low emissivity and high SAR brightness everywhere to Magellan, if it had been there. The 0.5-Gy resurfacing epoch deeply covered this sequence of soil profiles, and injected large amounts of SO_2 into the atmosphere, raising the concentration of this species far above its present level. During subsequent weathering of 0.5-Gy and later flows, much of this SO_2 was removed (more by formation of anhydrite, $CaSO_4$, than pyrite), but the buried old soil profiles were protected from reaction. Large cratering events have exhumed this high-dielectric-constant material and left it scattered in and around the craters. The low-emissivity signature of this material persists until the debris has had time to weather to the depth sampled by the emissivity measurement (several m), after which it has the same magnetite-bearing, high-emissivity character as other surface material. Thus only the youngest large craters display low emissivities.

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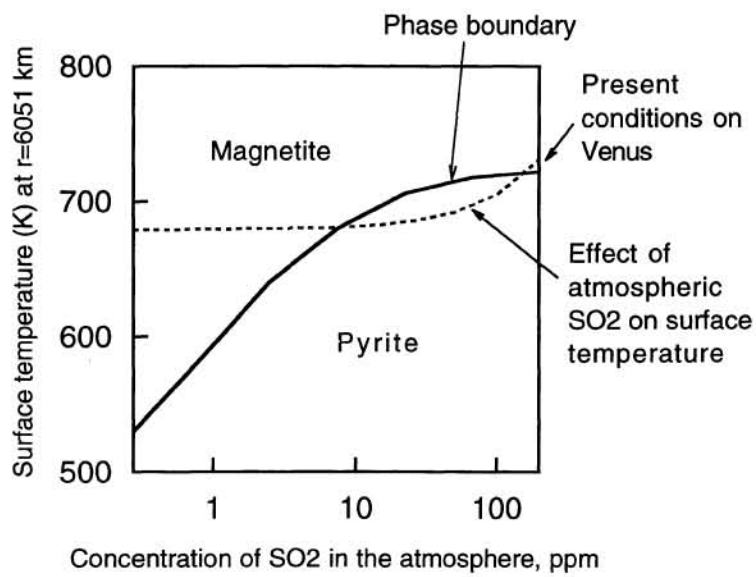

Figure 1. Effect of temperature and SO_2 abundance on the fields of stability of magnetite and pyrite as the major Fe minerals in weathered Venus surface material (computational assumptions: planetary radius, 6051 km; system pressure, 97.6 b; conc. of H_2O, 100 ppm; redox state, δ as defined by [2] = -2.6×10^{-5}). Dashed line shows the greenhouse effect of SO_2 in the atmosphere [7].

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