CANALI-FORMING MAGMAS: GENERATION OF CARBONATE-SULFATE MELTS ON VENUS.
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Venus' canali, very long meandering channels, are inferred to be products of carbonate-sulfate magmas, comparable in some ways to carbonatite magmas on Earth. In 1994, [1] inferred that alkali-rich carbonate sulfate magmas were common and abundant just beneath Venus' surface. Current understanding of Venus suggests a cooler geotherm, so that carbonate-sulfate melt can be abundant only at pressure > 1 kilobar or so (depth > ~3.5 km). Carbonate and sulfate minerals may form by chemical weathering of basalts at the Venus surface, and can be brought to that pressure by burial under more basalts or by tectonic processes. Carbonate-sulfate melts can form much closer to the surface if temperatures are above the average geotherm, i.e., above a plume, near an igneous body, or at a meteoroid/comet impact site.

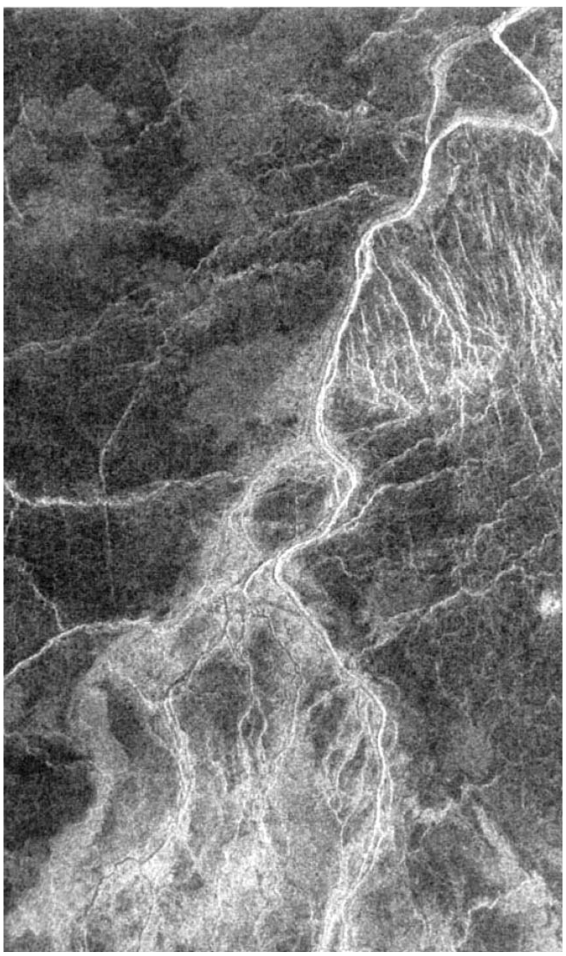

Figure 1. Portion of a canale in Sedna Planitia, from Magellan FMIDR 45N019; N is up, image ~ 70x55 km. Note meanders, cut-offs, point bar, and distributary channels at S.

Introduction: Venus' canali are meandering channels of great length (>500km) and relatively constant widths (3-5 km), with features like cutoff meanders, cut banks, overbank deposits and levees, crevasse splays, and distributory braided channels – Figure 1 [1-7]. All these features are familiar on river-cut channels on Earth, and imply that canali-forming fluids had rheological properties like those of liquid water.

The most likely canali-forming fluids, with water-like rheology and consistent with Venus' present climate, are ionic melts rich in alkali- and alkaline earth carbonates and sulfates, i.e., natrocarbonatite magma [1,8-11]. Water itself is not stable now at Venus' surface (T=740K, P=96 bars), but could have been present in earlier climates [12]. Mafic silicate lavas [6] would probably cool too quickly to form canali [11,13] (but see [14]), except perhaps in an earlier hotter climate [15] or underground [16]; subsurface flows seem unlikely to yield the observed channel landforms. Liquid sulfur has water-like rheology [17] but a melting T less than that of Venus' surface [13], and so would not likely form levees or other constructions and would likely evaporate [18]. Fluid-absent granular suspensions have been suggested [19], but seem unlikely (to me) because most source areas lack a source of such material – i.e., a pyroclastic volcano or large cliff.

Venus Geotherms and Carbonate-Sulfate Melting: If canali were likely formed by carbonate-sulfate melts, it is worth revisiting how those melts could form on Venus [1,10]. In 1994, [1] inferred that carbonate-sulfate melts would be stable just below Venus' surface in a global 'magmafer'. Since then, estimates of Venus' 'normal' geothermal gradient have declined, and there is new data on carbonate-sulfate melts.

In 1994, [1] used the best available estimates of Venus' 'normal' crustal geothermal gradient, 25-50 K/km. Since then, estimates of the 'normal' geothermal gradient are smaller i.e., ~10-25 K/km [20]. Geotherms in Figure 2 span this latter range.

Figure 2 also shows melting curves for relevant compounds: pure alkali sulfates and carbonates, the Na-K carbonate eutectic, and a natural Na-K-Ca-rich carbonate magma. Ionic melt systems with mixed cations, like $(Na,K)_2CO_3$, typically have peritectic melting points at much lower T than those of the pure cation systems [21,22]. The minimum melting point of an alkali carbonate system changes little with addition of alkali sulfate [10,24], because the thermochemistry of mixing in the carbonate-sulfate melt is very similar to that in the carbonate-sulfate solid solution. Adding halogens lowers the melting T significantly [25]. The natural natrocarbonatite magma from Oldoinyo Lengai volcano (Fig. 2) is close to the eutectic (minimum T) melt composition in the system Na_2CO_3 – K_2CO_3 – $CaCO_3$ with added halogens and sulfate [26-28]. These lavas have eruption temperatures near 820K (545°C), and solidify completely near 760K (490°C) [26,28].

It is worth noting that Venus' carbonate magmas may not resemble terrestrial carbonate magmas in origin or trace element chemistry. Earth's carbonate magmas, carbonatites, represent small-volume partial melts from the mantle or extreme differentiatiates (perhaps with silicate-carbonate liquid immiscibility) of alkali- and volatile-rich magmas [29]. Venus' carbonate magmas, in this model, derive from low pressure melting of carbonated and sulfated basalt, comparable to the rare melted limestones on Earth [29,30].

Geologic Settings: Figure 2 shows further that carbonate-rich melts (like the Oldoinyo Lengai magma) should not form under 'normal' Venus geotherms [20] at pressures less than ~1 kbar, i.e., depths less than ~4 km. These cooler geotherms are not consistent with the earlier inference of a planet-wide shallow carbonate-sulfate 'magmafer' [1]. Hotter geotherms, such as might develop above plumes and shallow magma bodies or near impacts, would permit formation of abundant carbonate-sulfate melts (Fig. 2).

So, one could expect signs of carbonate-sulfate melts in areas of high geothermal gradients (present or past). Canali themselves are mostly found in the lowland plains, presumably of 'normal' geotherm, but source areas are poorly defined [2]. Many areas inferred to have had high geotherms (volcanos, coronae, and impact craters) also show evidence of low-viscosity fluids – several sorts of non-canali channels and valley networks [2,5].

Future Work: Much work remains to test the idea of carbonate-sulfate magmas on Venus. Experimental studies should examine: formation of solid sulfates and carbonates by basalt-atmosphere weathering, melting of altered basalt in Venus crustal conditions, and solution properties of ionic melts [10]. Geologic studies can continue to constrain the properties of canali-forming magmas [7]. Ionic melts in the subsurface (being electrically conductive) might be detectable with geophysical methods like GPR (from orbit or on the surface) or magnetotelluric sounding.

Acknowledgments: Thanks to W. Kiefer and S. Schwenzer for assistance, and E. Stofan and VEXAG for encouragment. Supported by the NASA CAN to the LPI.

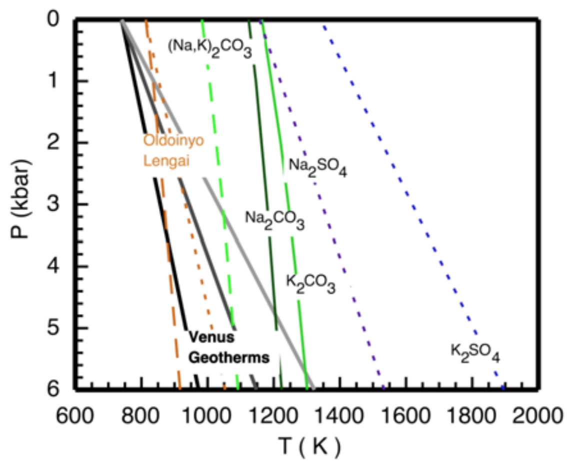

Fig. 2. Venus geotherms and carbonate-sulfate melting curves. Geotherms are for 10, 17.5, and 25 K/km (black, dark gray, light gray; surface T=740K, rock density = 2.9 g/cm^3, g = 8.87 m/sec^2). Melting curves for Na_2CO_3 and K_2CO_3 from [23]; dashed curve for $(Na,K)_2CO_3$ eutectic takes 1-bar T from [21] and dP/dT extrapolated from [23]. Dotted curves for Na_2SO_4 and K_2SO_4 use 1-bar melting T, and dP/dT=ΔS(melt)/ΔV(melt) from [21]. Oldoinyo Lengai is natural alkali-carbonatite magma, with 1-bar liquid T from [26,28]; dashed line uses dP/dT extrapolated from [23]; dotted line uses estimated dP/dT=ΔS(melt)/ΔV(melt) from [21].

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