THERMAL MODELS OF SULFUR AND SILICATE MAGMA INTERACTION, IO

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This report summarizes the results of observations and modeling of several aspects of volcanism on Io. Thermal models demonstrate that the observed lifetimes, thermal output, latitudinal distribution and structure of plumes and calderas on Io are consistent with a simple model in which sill-like silicate magma bodies intrude at the boundary between a solid sulfur crust a few kilometers thick and a silicate lithosphere from one to two hundred kilometers thick.

Hemispheric density plots of the distribution of dark-floored calderas and plume deposits show a concentration of dark-floored calderas in equatorial regions and a concentration of big plumes within $\pm 60^{\circ}$ of the equator, as previously suggested by Strom, and others [1]. Also, in agreement with previous estimates [2], the average separation between calderas of all types is $233 \pm 104$ km; and the median diameter of dark-floored calderas is 50 km. If power for the observed surface volcanism is derived from the tidally heated interior, which is presumed to be silicates, this average separation distance suggests that the bottom of the convective active layer may be about 200 km. Therefore, the depth to silicate melting is of this order, and low conductive heat flow (10 ergs $cm^{-2}s^{-1}$) would be a consequence.

The bulk of the tidal dissipation in Io can be accounted for in the form of thermal radiation from hot spots, which in many cases are associated with dark-floored calderas. Few dark-floored calderas are uniformly dark, and detailed measurements show the average dark-floored caldera to consist of 10% black surfaces, 40% dark gray surfaces and 40% lighter gray surfaces. Assuming these surfaces correspond to the various allotropes of sulfur at model temperatures, the total radiative power output of all dark-floored calderas combined is between $10^{21}$ and $10^{22}$ ergs $cm^{-2}s^{-1}$. Similar estimates have been based on terrestrial observational data [3]. This figure exceeds current estimates of probable tidal dissipation within Io [4]. Thus, efficient convective heat transfer from the silicate melts to a sulfur crust may easily control the thickness of the silicate lithosphere.

Thermal models of molten sulfur lava lakes or calderas show that the bottomless calderas as prescribed by the sulfur ocean model [5] are unstable against solidification. Sulfur calderas of finite depth have lifetimes more consistent with implied time scales from Voyager 1 and 2; that is, a 10 m deep lake solidifies in 130 to 170 days, and a 100 m deep lake solidifies in 34 to 40 years. The range depends on whether convective mixing or pure conduction cools the lake.

Sulfur plumes would result from vaporization of sulfur at the contact with a silicate magma. The contact temperature between a sulfur crust and a silicate magma sill depends upon the temperature and the thichness of the sulfur crust, and on the temperature of the silicate magma. Using estimates of the probable range of these quantities, thermal models show that the contact quickly equilibrates to 600 to 700 K, approximately the boiling point of sulfur. The time which the contact remains at or above the sulfur vapor temperature is expected to be a few months to one year for a 10 m silicate sill, and 3 years to 70 years for a 100 m thick silicate sill, depending upon the mode of convective heat transfer. In this model, as vaporized sulfur and liquid sulfur are mobilized to the surface subsidence occurs to occupy the displaced volume of sulfur, and a caldera results.

As the contact temperature of the sulfur and silicate magma interface is sensitive to the prevailing temperature of the sulfur and to the silicate

magma temperature, the presence or absence of vaporized sulfur, and the volume of sulfur melt, would depend critically upon the thickness of the sulfur crust, the surface temperature of the planet, the conductive heat flow which the sulfur crust must carry, and upon the silicate magma temperature. Thermal models based on all realistic combinations of these variables imply that the dearth of plumes and plume deposits in high latitudes is merely a consequence of the colder surface temperatures combined with a low global conductive thermal gradient, and the thickness of the sulfur crust is on the order of one to two kilometers. Therefore, this model obviates the necessity of having high thermal outputs or large heat sources confined to equatorial regions, but at the same time offers an explanation for the apparent concentration of large plumes and calderas in low latitudes.

[1]Strom, R.G., R.J. Terrile, H. Masursky and C. Hansen, 1979, Nature, 280, 733-736.

[2] Masursky, H., G.G. Schaber, L.A. Soderblom, and R.G. Strom, 1979, Nature 280, 725-729.

[3] Matson, D.L., G.A. Ransford, and T.V. Johnson, 1981, Jour. Gephy. Res. 86, 1664-1672.

[4] Peale, S.J., P. Cassen, and R.T. Reynolds, 1979, Science 203, 892-894.