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Volcanism on Jupiter's moon Io and its relation to interior processes

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Jupiter's moon Io is the most volcanically active body in the Solar System and offers insight into processes of tidal heating, melt generation, and magma ascent. Investigating these processes contributes to a better understanding of Io's geologic history, internal structure, and tidal dissipation mechanisms, as well as to understanding similar processes operating on other tidally-heated worlds (e.g., Europa, Enceladus, and some exoplanets). Four recent developments provide new observational constraints that prompt re-examination of the relationships between Io's surficial geology and interior structure. These developments include: (1) completion of the first 1:15,000,000 scale geologic map of Io based on a synthesis of Voyager and Galileo data; (2) re-interpretation of Galileo magnetometer data, which suggests that Io has a globally continuous subsurface magma ocean; (3) new global surveys of the power output from volcanic centers on Io; and (4) identification of an offset between volcano concentrations and surface heat flux maxima predicted by solid body tidal heating models. In this study, the spatial distributions of volcanic hotspots and paterae on Io are characterized using distance-based clustering techniques and nearest neighbor statistics. Distance-based clustering results support a dominant role for asthenospheric heating within Io, but show a 30–60° eastward offset in volcano concentrations relative to locations of predicted surface heat flux maxima. The observed asymmetry in volcano concentrations, with respect to the tidal axis, cannot be explained by existing solid body tidal heating models. However, identification of a global magma ocean within Io raises the intriguing possibility that a fluid tidal response—analogous to the heating of icy satellites by fluid tidal dissipation in their liquid oceans—may modify Io's thermal budget and locations of enhanced volcanism. The population density of volcanoes is greatest near the equator, which also agrees with predictions from asthensopheric-dominated tidal heating models, but the nearest neighbor analysis of hotspots (i.e. sites of active volcanism) and paterae (i.e. caldera-like volcano-tectonic depressions) reveals a random to uniform spatial organization. This suggests that Io may have an extensive subsurface magma reservoir with vigorous mantle convection, and/or a deep-mantle heating component, which reduces the amplitude of surface heat flux variations that would otherwise favor clustering. The tendency toward uniformity among volcanic systems may reflect their interaction through a process of magmatic lensing that focuses rising magma and inhibits volcanism in the surrounding capture zone. In summary, the distribution of volcanism on Io generally supports the presence of a globally extensive asthenosphere with local interactions occurring between volcanic systems, but a 30–60° eastward offset in the location of enhanced volcanism relative to predicted surface heat flux maxima cannot be explained by existing solid body tidal heating models. This may imply faster than synchronous rotation, state of stress controls on the locations of magma ascent, and/or a missing component in models of Io's interior, such as fluid tides generated within a globally extensive layer of interconnected partial melt.