**EFFECTS OF PLANETARY RADIUS ON LITHOSPHERIC STRESSES AND MAGMA ASCENT ON THE TERRESTRIAL PLANETS.** M. M. Litherland[1] and P. J. McGovern[2], [1]Department of Earth Science, Rice University, Houston, TX 77005 (mairi@rice.edu), [2]Lunar and Planetary Institute, Houston, TX 77058 (mcgovern@lpi.usra.edu).

**Introduction:** Volcanic processes occur on all the terrestrial planets and the moon. However, while Mars is home to a few very large volcanoes, on the Moon and Mercury volcanism is manifested mostly through broad and flat volcanic plains. Venus and Earth have relatively large numbers of intermediate-sized structures. These variations suggest that the size of a planet may have an effect on the construction of volcanic edifices on its surface.

A load placed on the lithosphere causes deformation, which produces a field of stresses in the lithosphere. If the load is a volcano, this stress can impede or assist continued magma flow to the surface, and consequently it plays a role in what size and shape of volcano is likely to form [1]. Most studies of this effect have used models that assume a flat lithosphere, with no curvature. When flexure occurs on a spherical object such as a planet, there is an additional membrane stress due to the curvature in the lithosphere. This curvature is inversely proportional to planetary radius *R*. We examine how this might lead to variations in volcano formation depending on *R*.

**Flexure Models:** We modeled the flexure of the lithosphere under a conical volcano by systematically varying planetary radius *R*, gravity *g*, volcano height *h* and radius *r*, and lithospheric elastic thickness *Te*. The depression created by the flexing of the lithosphere (density of 3300 kg/m$^3$) was filled with material of the same density as the edifice, 2800 kg/m$^3$. We used Comer's thick plate analytic flexure solution [2] to model volcanoes on a flat plate, and Brotchie's spherical solution [3] for planets with high lithospheric curvature (small *R*).

Volcanoes are modeled as a positive load on the lithosphere, but it is also possible to use a negative load value to form a basin carved out of the lithosphere. This allows examination of the type of volcanism commonly found in the mare basins on the Moon. To study such basins, we used the profile of a young lunar crater, Copernicus, and scaled it using the depth-diameter relation given by Williams and Zuber [4]. Modeling flexure for impact basins is more complex than for volcanoes because the initial compensation state is unknown. The basin may be slightly undercompensated (the load will experience uplift) or significantly overcompensated (the load will subside) [5].

**Magma Ascent:** The stress state of the lithosphere affects magma ascent by regulating the propagation and direction of dikes. Both the magnitude and gradient of the stress affect the ease of magma ascent in a particular location. Extensional stress is necessary to allow fractures to open for dike formation, and a positive stress gradient (where the stress becomes more extensional closer to the surface) facilitates upward movement of magma from its source [6]. Few locations meet these conditions all through the lithosphere, but magma buoyancy and pressure from the magma source allows magma to ascend even if the stress conditions are slightly unfavorable. We set thresholds of $-1.0 \times 10^7$ Pa for the stress and $-1.0 \times 10^4$ Pa/m for the stress gradient as allowable for magma ascent, although the exact level is unknown and depends on the unique conditions of the area. The favored direction of dike formation is found by considering the relative magnitude of radial and tangential stresses.

**Results:** For a positive load, including the effects of *R* in flexure calculations caused the radial stresses to become more compressive throughout the lithosphere beneath the load. The tangential stress was slightly more compressive at the center of the edifice, but significantly more extensional on the flanks (Fig. 1). Both effects were most pronounced for smaller planetary radii. When planetary radius was the only factor varied, the results suggested that strong compressive stress is likely to inhibit magma ascent in the center of volcanoes on smaller planets. However, gravity is also lower on small planets. This causes two opposing effects: inhibiting compressive stresses have a smaller magnitude, but the magma has less buoyancy on a small planet than on a large one under the same conditions.

On a flat plate, the stress at the top of the lithosphere is always equal and opposite to the stress at the bottom of the lithosphere, so there is never a location where the stress is extensional all the way through the lithosphere. However, the spherical model introduces extensional tangential membrane stresses throughout the lithosphere around the volcano (Fig. 1b). This creates a favorable region for radial dike formation, especially when combined with a positive stress gradient (Fig. 2).

The stress produced in the lithosphere by an undercompensated basin is the opposite of what is produced by a positive load (Fig. 3). Due to the membrane stress, the radial stress is more extensional and tangential stress is less so. Extensional radial stress beneath

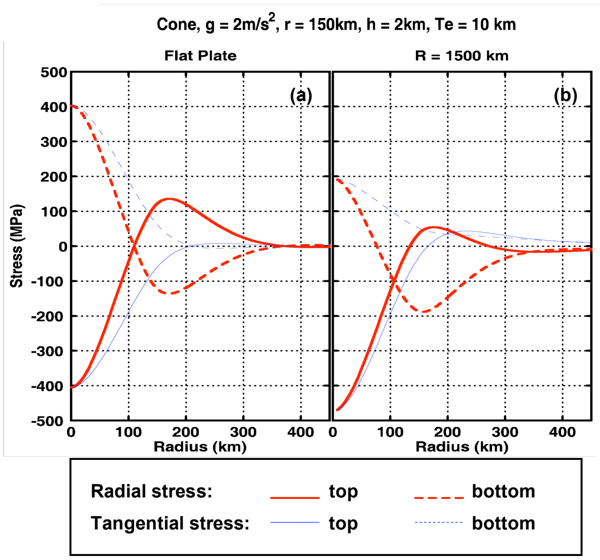


**Fig. 1** The stress in the lithosphere underneath a conical volcano on (a) a flat plate and (b) a spherical body of radius 1500 km. For the flat plate, the top and bottom stresses mirror each other, but for the spherical model they are offset from the center.

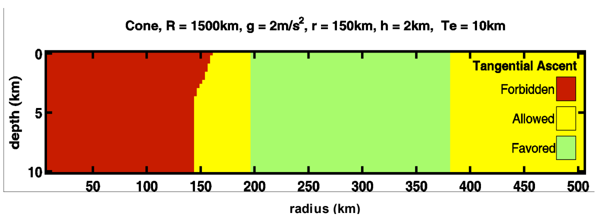


**Fig. 2** Ascent conditions for radial dikes through the lithosphere. In the favored region, stress and gradient are positive throughout the lithosphere.

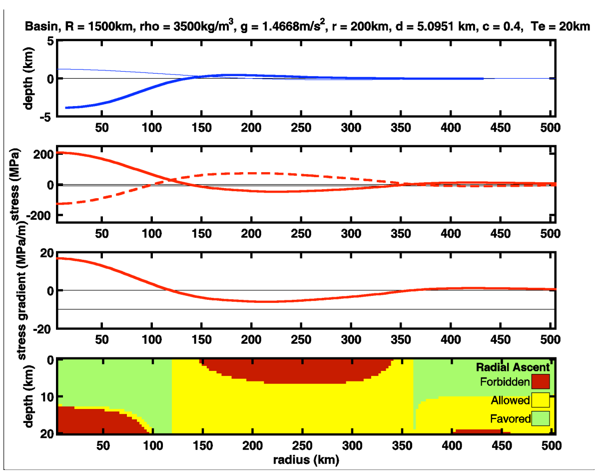


**Fig. 3** For an undercompensated basin: (a) topography of the basin (the top line shows the flexure), (b) radial stress, (c) stress gradient, and (d) magma ascent conditions. This situation favors magma ascent into the basin.

the basin produces a region favorable to magma ascent. The stress orientation in this region makes it particularly likely to produce circumferential dikes. A basin with superisostatic compensation produces a positive load, and the stress underneath the lithosphere was similar to the other volcanoes, with an unfavorable region for ascent underneath the basin.

**Discussion:** Planetary radius directly affects the stress under positive loads due to the competing effects of the membrane stress and gravity. However, there are also more indirect effects produced by including planetary radius in flexure models. The zones of extensional tangential stress produced around positive loads on spherical bodies strongly favor the production of radial dikes, which could explain why radial features are found around many volcanoes, particularly on Venus [7]. Such regions may also have contributed to the formation of the "wings" of magma found on the Tharsis Montes on Mars. These three volcanoes lie in a straight line, and each has excess magma buildup on its flanks along this line. The extensional tangential force surrounding each volcano would be reinforced along the line, leading to the extra magma.

The models show that initially undercompensated basins are likely to fill with magma, while initially overcompensated basins are not. This suggests that the initial superisostatic uplift inferred [5] for several lunar basins is inconsistent with the voluminous mare deposits within them. Instead, the densification of crust by the feeder dikes [8] may account for the anomalous gravity signal.

Several factors other than the stress state influence magma ascent. The long period of time involved in volcano formation and alterations in the rock caused by magma ascent allow magma to ascend in some conditions that would be prohibited by our models [9,10]. However, models of magma ascent for planets with different radii show important variations that could explain some of the features observed in nature. Our calculations show that planetary curvature strongly influences the stress state of the lithosphere under a volcano, particularly on small bodies, and it should be taken into account when examining magma ascent.

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