PULSES OF MAGMA MOVEMENT TRIGGERED BY THE SOUTH POLE-AITKEN BASIN IMPACT. P. J. McGovern[1,2], R. W. K. Potter[1,2], G. S. Collins[3], D. A. Kring[1,2], M. L. Grange[4], and A. A. Nemchin[4], [1]Center for Lunar Science and Exploration, USRA Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058, [2]NASA Solar System Exploration Research Virtual Institute, [3]Impacts and Astromaterials Research Centre, Dept. Earth Science and Engineering, Imperial College, London UK, [4]Department of Applied Geology, Western Australian School of Mines, Curtin University, Western Australia (mcgovern@lpi.usra.edu).

Introduction: Basin-scale impacts have profound consequences for the surface and interior evolution of their target bodies. The South Pole-Aitken (SPA) basin, the oldest, widest, and deepest impact basin on the Moon, set off immense global pressure waves, with enormous implications for the structural and magmatic evolution of the Moon. Elsewhere [1], we pose the question of whether a global-scale epoch of magmatism could have been triggered by the SPA impact event, in order to account for a striking peak in magmatic zircon ages at 4.30-4.36 Ga [e.g., 2-3]. Here, we explore in more detail the mechanical effects that such pressure waves would exert on potential magma pathways in the lunar crust and lithosphere, linking hydrocode model results to magma ascent theory.

Method: We examine the stress state in an axisymmetric model Moon struck by a 10 km/s, 170 km diameter impactor [4], as calculated by the iSALE hydrocode [5]. Reported in-plane stresses are rotated into a local horizontal-vertical coordinate system, and when combined with the out-of-plane normal stress (also effectively a horizontal stress) the propensity for opening of potential magma-transporting fractures in both vertical (dikes) and horizontal (sills) orientations can be assessed. For vertical pathways, we assess whether each horizontal stress is less compressive than both the vertical stress at that timestep and the initial vertical stress. For horizontal pathways, we assess whether the vertical stress is less compressive than both of the horizontal stresses at that timestep and the initial horizontal stress. If an assessment is true, the fracture opening criterion is satisfied. Further, variations in stress with depth in the lunar crust are input to a calculation of pressure balance on the walls of potential dikes [6-8], allowing magma ascent velocities to be estimated.

Results:

Intrusion orientations. Variations in stress vs. time for a location at about 20 km depth and about 15 degrees from the impact antipode (Fig. 1a) show quite large excursions from the pre-impact lithostatic (all stress components equal) state. At the earliest stages, the criteria for opening vertical and horizontal fractures are satisfied at apparently alternating times (Fig. 1b). At time t ~ 90 minutes, an extended period during which the horizontal stresses are significantly more extensional than the vertical stress commences, lasting for about 38 minutes, predicting opening of vertical fractures (potential magma pathways) during that time. This is immediately followed by a comparably long time interval when the horizontal stresses are strongly more compressional than the vertical, indicating opening of horizontal sill-like pathways for magma movement. Similar excursions in stress magnitudes and intervals of dominance for each potential intrusion orientation are seen at locations farther from the antipode (out to at least 45 degrees from the antipode).

Magma ascent velocities. Stress distributions vs. depth at the angular location (15 degrees from antipode) of the point in Fig. 1 during the 38 minute vertical fracture opening event predict strong, positive magma ascent velocities in the lower crust (Fig. 2a), with a similar result holding for a similar event in a column at 45 degrees from the antipode (Fig. 2b). Ascent velocities are negative in the upper crust for both locations/times, indicating that ascent is inhibited there during the time that vertical fractures are opening.

Discussion: The large, global-scale excursions of stress expected in the crust of the Moon immediately after the SPA impact have enormous implications for transport of magma. Long-duration (10s of minutes) vertical fracture-opening events (Fig. 1) favor magma ascent in dikes, at velocities that allow the entire lower crust to be traversed within the timeframe of the events (Fig. 2). Stress gradients adverse to magma ascent (horizontal stresses becoming more compressional with decreasing depth) result in arrest of the ascending magmas, producing an intrusive horizon in the mid-crust. Further, the lateral spread of magmas at this horizon is favored by subsequent periods of horizontal fracture opening, that are comparable in duration to the vertical fracture opening events. Thus, the mobilized magmas will be widespread and widely available for incorporation into materials that ultimately arrive in the sample record. This pulse of impact-generated magma ascent into the lower crust would produce a complementary pulse of magmatic crystallization ages over a longer, yet still short-duration period of order 10 Myr. In addition, the establishment of widespread intrusive systems introduces mechanical inhomogeneities in the crust that can facilitate magma mobility long after the initial pulse of magma has solidified. While it is not necessary for magmas to erupt to enter the sample record, local pre-existing perturbations in topography and tectonic structure can provide limited pathways to the surface.

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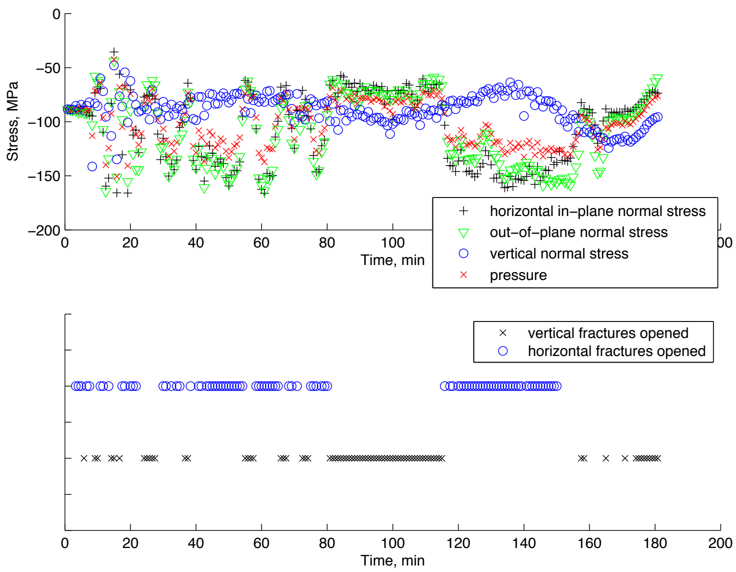

Figure 1. Stresses and fracture opening criteria for a location at ~ 20 km depth and 15 degrees from the SPA impact antipode. a, top) Stresses in MPa as functions of time in minutes. b, bottom) Criteria for opening of horizontal (blue circles) and vertical (black ‘x’s) as a function of time in minutes. Symbols are plotted at times when criteria are satisfied.

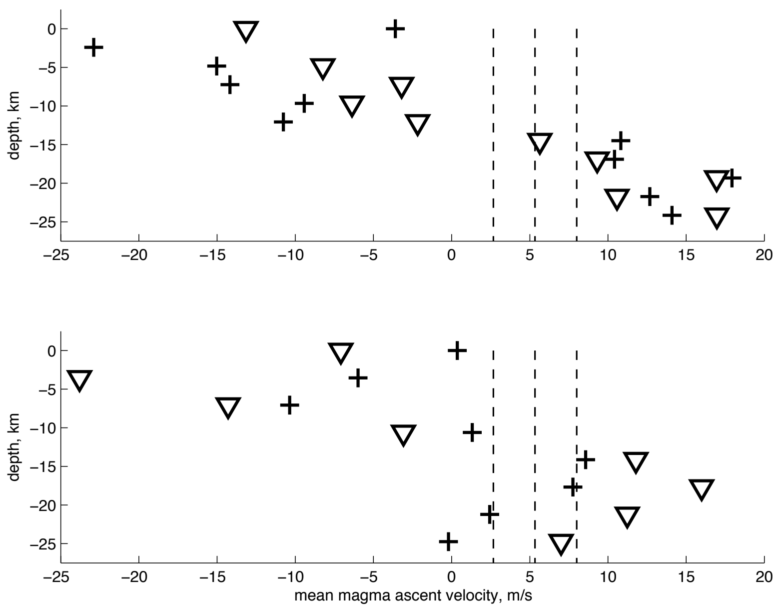

Figure 2. Magma ascent velocity and effective mechanical buoyancy as a function of depth in the lunar crust, for a horizontal opening event of duration 2300 seconds. Plus signs correspond to in-plane horizontal normal stress, triangles to out-of-plane (hoop) stress. Dashed lines delineate effective buoyancies of 200, 400, and 600 kg/m^3 from left to right. a, top) Location 15 degrees from SPA antipode. b, bottom) Location 45 degrees from SPA antipode.