LATE AMAZONIAN SUBSUMMIT MAGMA RESERVOIR VOLUME CONSTRAINTS AT OLYMPUS MONS FROM RING FAULTING AND DISCORDANT LAVA FLOWS. E. B. Grosfils¹, H. Peterson¹, P. J. McGovern², and J. Chadwick². ¹Geology Department, Pomona College, Claremont, CA 91711 (egrosfils@pomona.edu), ²LPI/USRA (McGovern@lpi.usra.edu), ³Dept. of Geology & Environmental Geosciences, College of Charleston (chadwickj@cofc.edu).

Introduction: Many Late Amazonian lava flows in the plains surrounding Olympus Mons are discordant, i.e. their plan view azimuth is no longer aligned with the downhill direction in current topography. This observed discordance was found to be a consequence of loading-induced flexural deformation with 1.3x10⁵-1.4x10⁶ km³ of volcanic material (ρ = 3150 kg/m³), or 1-10% of the volcano’s volume, added to the edifice since these flows were emplaced [1], though the distribution of this material within the edifice is not well understood. The presence of a prominent caldera complex with inward-trailing floors [2], however, along with younger discordant lava flows recently identified near the calderas [3], provides clear evidence that some portion of this bulk volume stalled to form one or more magma reservoirs beneath the summit. Reservoir models that reproduce formation of the ring faults observed [4] and the observed summit-proximal lava flow discordance provide a way to test this hypothesis. Integrating them, we are seeking to constrain how much of the volcanic load added to Olympus Mons in the Late Amazonian was associated with formation of the caldera complex and the subsequent evolution of the summit region.

Methods and Results: Mapping lava flows and channels in the summit region and then integrating our data with previous results [5] shows that (a) discordance decreases with distance from the calderas and (b) independent of their discordance most features are radial to a location near the center of Zeus Patera, the largest and oldest caldera in the summit complex (Fig. 1). The first observation confirms that the discordance observed derives from a source localized to the region containing the nested caldera sequence, consistent with other arguments [2] that magma reservoir activity is the most plausible driver. The second suggests that summit lavas erupted onto a simple, shield-like pre-caldera paleotopography, but this presents a challenge: pressure changes within a magma reservoir beneath Zeus Patera can change (even reverse) the slope of radially aligned lava flows but cannot cause azimuthal discordance. This implies that magma reservoirs centered at more than one location have been active at the summit, but where else besides beneath Zeus might they have been?

To begin addressing this question we used a Mogi-style model to examine inflation and deflation events centered at 781 locations across the summit region (Fig. 2), focusing on the array of features SE of the caldera complex where the greatest discordance occurs [6]. By integrating geometric limits upon the creation of discordance—introduced by how volcanic features are aligned relative to any given reservoir’s assumed position—with how well the analytical deformation predicted matches what is observed, we identify four plausible locations for discordance-producing magma reservoir activity. Two of these, at the margin of Zeus Patera and 50 km to the east, require a deflating magma reservoir, while the others are close to the area of discordance and imply a reservoir undergoing inflation.

Figure 1: Map of lava flows and channels (left) and their discordance in degrees (right) near the summit caldera complex on Olympus Mons.

Figure 2: Mogi-style assessment of discordant volcanic features SE of the caldera (regions A-C) for 781 reservoir locations. The fractional percentage of features deformed into discordance (left; high values are better) and the net fit between the deformations predicted and the discordances observed (right; low values are better) are plotted at each. Integrating these data, four reservoir sites are identified.

Mechanical Analysis. Informed by these results we are moving beyond the limitations of an analytical approach by using 3D finite element models in COMSOL Multiphysics (https://www.comsol.com) to...
simulate magma reservoir activity. This allows us to assess different mechanical consequences of pressure changes beneath the summit region and the volume of new volcanic material implied. Our models to date, with HRSC/MOLA topography resampled to 400 m/pixel as the upper surface (these data were also used to quantify discordance), employ gravitationally loaded elastic conditions and assume a lithostatic stress state in the host rock as well as identical host rock and magma densities. While adopted for simplicity as we gain initial insight, these conditions are internally self-consistent and geologically sensible yet can closely approximate results obtained when different, more complex and computationally demanding rheologies are used [4,7].

Zeus Patera. Since it is the oldest and largest caldera, we first assess the inflation conditions needed to prime the host rock for ring fault initiation [4] at Zeus Patera using an oblate reservoir of the same general radius (~30 km); an oblate geometry is well suited for ring fault formation under a variety of conditions [cf. 8]. Since the caldera complex had yet to form, however, the current topography at the summit can’t be used in our models. To generate plausible paleotopography at the summit of Olympus Mons above an elevation of 19 km we employ a method used for edifice reconstructions in Hawaii [9] to create a splined surface derived from upward projection of the lower portions of the volcano. This yields a paleoedifice resembling the overarching shield-like shape of modern Pavonis Mons.

An illustrative model using a reservoir of half-height 5 km and radius 30 km, centered 20 km below the surface and subjected to an overpressure 0.5x the vertical stress at the crest (Fig. 3), will form outward dipping reverse ring faults that propagate upward as the pressure elevates, although their ability to form also depends upon reservoir depth and other factors. At the surface where doming occurs the host rock stress favors circumferential reverse faulting, and the area is primed to accommodate the approaching ring faults. Given the outward fault dip, throughgoing failure and subsidence of the cap rock is likely. Interestingly, if the volume of Zeus Patera (~3000 km³) is roughly equivalent to magma removal from the reservoir to accommodate foundering, then ~15% of the reservoir volume was removed as the caldera formed, consistent with the range seen for caldera-forming eruptions on Earth [7].

Discussion: The reservoir explored here to illustrate our process can form a caldera akin to Zeus Patera. By volume, it contains ~10% of the volcanic material added to Olympus Mons during the Late Amazonian [1]. Younger calderas in the complex may form above other discrete magma bodies, or could instead represent continued activity within isolated cupolas [10] above the Zeus-forming reservoir that then destabilized to form small calderas along the Zeus ring faults. Our Zeus-forming magma reservoir volume estimate may thus be conservative. In addition, as noted above, at least one magma reservoir must have been active—without forming a caldera—at a location offset from the caldera complex. Our work modeling reservoir candidates and comparing the lava flow discordance they produce with observations is currently under way, and we expect these results, and continued modeling of Zeus-forming conditions, will further refine our volume estimates.

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Figure 3: Top: model volume and surface; black circle is 120 km across. White box shows inset area with doming caused by inflation (colors) and reverse fault trends (blue symbols). Dashed white line shows cross section position. Bottom left: Mohr Coulomb failure (reverse = yellow, ss = pale blue) expands as overpressure (OP) elevates. Inset shows how normal faulting (dark blue) commences as OP rises. Bottom right: ring fault development sensitivity to depth.