COULD PANTHEON FOSSAE BE THE RESULT OF THE APOLLODORUS CRATER-FORMING IMPACT WITHIN THE CALORIS BASIN, MERCURY? Andrew M. Freed[1], Sean C. Solomon[2], Thomas R. Watters[3], Roger J. Phillips[4], and Maria T. Zuber[5], [1]Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907, USA, freed@purdue.edu; [2]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA; [3]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560, USA; [4]Planetary Science Directorate, Southwest Research Institute, Boulder, CO 80302, USA; [5]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA.

Introduction: One of the most remarkable surface features imaged by the MESSENGER spacecraft during its first Mercury flyby [1] was Pantheon Fossae (Fig. 1), a complex of more than 200 troughs radiating from a location near the center of the Caloris impact basin [2]. The troughs are interpreted as simple graben formed in response to near-surface extensional stresses in the basin interior. The radially-oriented graben appear to be part of a larger pattern of extensional features within the basin floor; beyond about 300-km radial distance from the basin center the graben are more typically circumferential to the basin rather than radial, although radial trends are also observed and the distal graben in places form a polygonal pattern [3]. Pantheon Fossae is also noteworthy because within a few kilometers of the projected center of the radiating pattern of troughs is the ~40-km-diameter Apollodorus crater. The near-coincidence of the center of symmetry for Pantheon Fossae and Apollodorus crater raises the question as to whether the two features are causally related. Although explanations for Pantheon Fossae unrelated to Apollodorus crater have been suggested [2,4], we examine in this paper the hypothesis that the two features are physically linked. Specifically, we explore whether the Apollodorus crater-forming impact modified the state of stress within the central Caloris basin floor in a manner that led to the formation of many, if not all, of the graben of Pantheon Fossae.

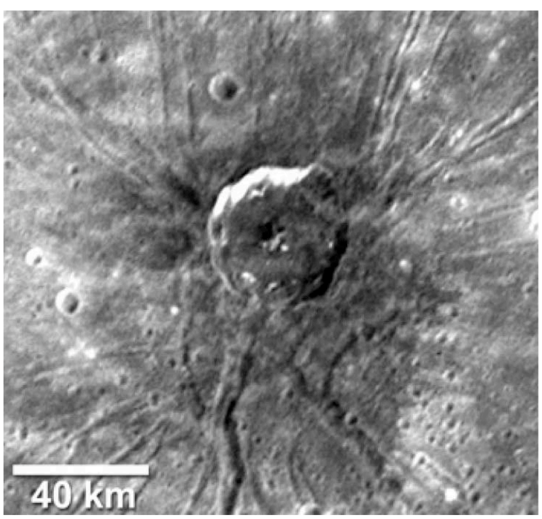

Figure 1. Radial graben of the Pantheon Fossae complex extending outward from the Apollodorus crater near the center of the larger Caloris basin (adapted from [2]).

Approach: Here we use a series of three-dimensional (3-D) viscoelastic finite element models to describe quantitatively a scenario whereby the Apollodorus impact induced a change to a pre-existing stress state, generating Pantheon Fossae. Under this idea, a pre-existing stress state resulting from early basin subsidence followed by later uplift left the surface of the Caloris basin in a state of net extension (Fig. 2). Evidence for this extensional state is the existence of circumferentially-oriented graben throughout the outer regions of the basin. As horizontal radial and circumferential stresses near the center of the Caloris basin are calculated to be nearly equal in magnitude, there was no preferred orientation for extensional features near the basin center prior to the Apollodorus impact.

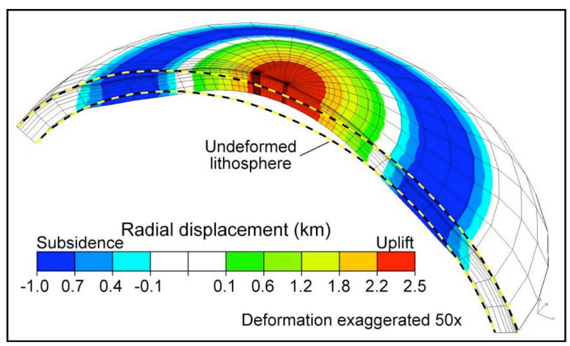

Fig. 2. 3-D spherical finite element model covering a cap extending radially to 80° of arc and to a depth of 400 km. Calculated deformation of Mercury's lithosphere due to loading associated with the external smooth plains assumed to completely surround the Caloris basin between radial distances of 850 and 1850 km from the basin center. Subsidence of the smooth plains is shown in cool colors, while the resulting uplift of the 1500-km-diameter Caloris basin is shown with warm colors.

In addition to the ~40-km-diameter crater, the Apollodorus impact would also have generated a potentially much larger damage zone. The introduction of this damage zone would have reduced the ability of the volcanic fill to support the pre-existing extensional stress state. Modeled by introducing a sudden reduction in the elastic strength of the impact and damage zone, this change in state causes central floor material to move radially outward. This movement causes a decrease in radial stress and an increase in circumferential stress conducive to the formation of the radial graben.

Results: This scenario was explored by considering a variety of assumptions regarding the extent of the damage zone [e.g., 5] induced by the Apollodorus impact, the thickness of Mercury's lithosphere, the relative elastic strength of basin fill and Mercury's surrounding crustal material, and the magnitude of basin uplift prior to the Apollodorus impact. In order to explain the generation of radial graben that extend as much as ~230 km (the radial distance of graben clearly associated with Pantheon Fossae) from the Caloris basin center, a large Apollodorus-related damage zone is required, extending to perhaps three crater radii (~60 km) or more from the crater center. The calculated stress state following the Apollodorus crater formation is shown in Fig. 3.

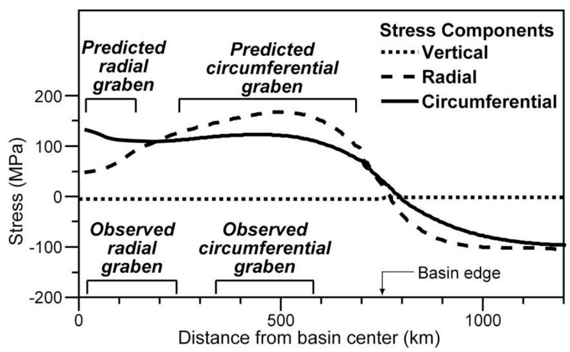

Figure 3. Calculated principal stress components near the surface as functions of distance from the center of Caloris basin resulting from basin subsidence due to interior fill, subsequent uplift caused by the emplacement of exterior smooth plains, and finally the Apollodorus impact. Regions of predicted radial and circumferential graben are shown where the horizontal circumferential and radial stress components are the least compressive principal stresses, respectfully. Also shown are the locations of observed radial (Pantheon Fossae) and circumferential graben.

The calculations also suggest that, under this scenario, the Caloris basin fill had greater strength than the surrounding crust and that the basin uplift and extensional stress field prior to the Apollodorus impact were close to azimuthally symmetric.

Discussion: As the stress changes associated with Apollodorus-impact-related damage would have traveled at seismic wave speeds and the faulting could have progressed at rupture propagation speeds (both measured in kilometers per second), ejecta from the Apollodorus impact transported ballistically outward from the crater could still have been deposited after the graben had largely formed, as is observed [2].

Whether this scenario could provide significant stress changes out to ~230 km or more from the basin center is not known, inasmuch as the magnitude of differential stress required to form graben 100 to 200 m deep [6] is poorly constrained. Broader stress changes associated with the Apollodorus impact are generated with a greater initial extensional stress state (i.e., a greater pre-Apollodorus uplift), a broader damage zone, a stronger basin fill relative to surrounding crust, and a thicker lithosphere. Once initiated, self-propagating faulting may have also increased the radial extent of Pantheon Fossae beyond where models predict significant impact-induced changes to stress.

Our models suggest that the location of the Apollodorus crater, and therefore Pantheon Fossae, very near the center of the Caloris basin, is, remarkably, coincidental. A similar complex of radial graben could have been generated from a similar-sized impact anywhere within about 300 km of the Caloris basin center. The fact that no other similar sized impacts induced such a complex implies either that no significant extensional pre-stress was present at the times of those impacts, or our scenario linking Apollodorus and Pantheon Fossae is not correct. We also find that the symmetry of both the Pantheon Fossae complex and the circumferential graben in the outer reaches of the Caloris basin interior requires fairly symmetric external loading. If external loading is found to be asymmetric, then another source of pre-Apollodorus uplift (e.g., lower crustal flow) must be postulated in order for the scenario outlined here to explain the formation of Pantheon Fossae.

Future observations by MESSENGER of topography and gravity across the Caloris basin region should help to constrain further the models used to calculate the pre-Apollodorus stress state. Additional high-resolution imaging and spectroscopy should improve knowledge of the distribution, thickness, and relative age of smooth plains deposits interior and exterior to Caloris, as well as of the geometry of Pantheon Fossae, whether the complex is superposed on older faults, and the tectonic history of the Caloris basin more generally.

References: [1] Solomon, S. C., et al. (2008), *Science, 132*, 59-62. [2] Murchie, S. L., et al. (2008), *Science, 231,* 73-76. [3] Watters, T. R., Nimmo, F., and Robinson, M. S. (2005), *Geology*, *33*, 669-672. [4] Head, J. W., et al. (2008), *Science, 321*, 69-72. [5] Senft, L. E., and Stewart, S. T. (2007), *J. Geophys. Res., 112*, E11002. [6] Watters, T. R., et al. (2008), *Earth Planet. Sci. Lett*., submitted.