VOLCANISM ON MERCURY: THE IMPORTANCE OF CRUST/MANTLE DENSITY CONTRASTS AND THE EVOLUTION OF COMPRESSIVE STRESS. L. Wilson[1,2] and J.W. Head III[2]. [1]Environmental Science Department, Lancaster University, Lancaster LA1 4YQ, UK (L.Wilson@Lancaster.ac.uk), [2]Department of Geological Sciences, Brown University, Providence, RI 02912, USA.

Background: There is great uncertainty about the internal structure of Mercury [e.g., 1]. The high mean density of the body suggests that it may have lost parts of its crust and mantle in a giant impact at some stage after most of its initial accretion was sufficiently complete that at least partial separation of a core had occurred. It is the uncertainty about the timing of the giant impact, and hence the physico-chemical state of proto-Mercury at the time that it occurred, that leads to difficulties in predicting the interior structure. However, it seems reasonable to assume that the Mercury we see today has some combination of a relatively low-density crust and a relatively high-density mantle [2]. The second uncertainty is the nature of the surface plains units, specifically, are these lava flows erupted from the interior, or impact-reworked earlier crust [3-5] (Figs. 1-2). Whatever the surface composition, the presence of planet-wide systems of wrinkle ridges and thrust faults implies that a compressive crustal stress regime became dominant at some stage in the planet's history [3, 6]. If the plains units are indeed lava flows, then the fact that the products of the compressive regime deform many plains units suggests that the development of the compressive stresses may have played a vital role in determining when and if surface eruptions of mantle-derived magmas could occur. This would be analogous to the way in which the change with time from extensional to compressive global stresses in the lithosphere of the Moon influenced the viability of erupting magmas from deep mantle sources [7-9].

Analysis: To investigate the relationship between lithospheric stresses and magma eruption conditions [e.g., 9-11] we have assumed a series of permutations of crustal density, crustal thickness, mantle density, magma density, source depth in mantle of melt generation, and crustal compressive stress, and investigated which permutations will allow the tranfer of magma from source to surface. With so many variables it is easiest to illustrate the results by choosing one set of densities and varying the depths and stresses.

We begin with crustal density of 2700 kg m^{-3}, a mantle density of 3400 kg m^{-3} and a melt density of 3000 kg m^{-3}. Table 1 then shows, as a function of the thickness of the crust (H_c), the minimum depth below the surface (H_m) from which mantle melts must be derived if their positive buoyancy in the mantle is to just compensate for their negative buoyancy in the crust and so enable them to reach the surface and erupt. For the values of H_m in Table 1 to be valid, the stress conditions in the crust must be such that a dike can remain open at all depths. However, this may not be possible in the presence of a horizontal compressive stress. The third and fourth columns of the table show the maximum horizontal compressive stress allowed if a dike is to remain open when the compressive stress is either uniform, i.e. the same at all depths in the crust (S_u), or variable, specifically decreasing from the value given (S_v) at the surface to zero at the base of the crust.

We now increase the crustal density slightly to 2800 kg m^{-3} but keep the mantle and melt densities the same. The results in Table 2 show, as expected, that the reduced amount of negative buoyancy of magma in the crust means that mantle melt sources need not be quite as deep as before. However, if a pathway is to remain open at all depths, significantly smaller compressive stresses are needed than in the previous case.

Implications: This comparison demonstrates the major trend that we find: as the crust becomes denser it is easier, in terms of magma buoyancy alone, to erupt magma from a given depth in the mantle. Given that all intrusions and eruptions emplace magma at some level into the crust, and therefore increase its density with time, this at first sight implies that surface eruptions of magma coming directly from the mantle could have become commoner with time on Mercury. However, the fact that the thermal history of the planet is likely to dictate that crustal compressive stresses increased with time, together with our finding that such an increase progressively suppresses the possibility of maintaining continuously open pathways between the mantle and the surface, suggests that conditions were much more finely balanced. By analogy with the Moon's thermal history [12, 13], compressive stresses at least a factor of two greater than those found here to suppress stable dikes must have been reached about half way through Mercury's lifetime, with even greater compressive stresses being needed to cause the observed thrust faults. Thus deep-seated eruptive activity must eventually have ceased on Mercury, with the timing of its cessation being very finely tuned by the planet's density and stress structure. As our knowledge of the surface composition and internal structure of Mercury improves with future exploration by MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) [14] and BepiColombo [15, 16], it will become possible to greatly refine the models presented here.

References: [1] M. T. Zuber et al. (2007) *SSR*, 131. 105-132. [2] W. V. Boynton et al. (2007) *SSR*, 131, 85-104. [3] J. W. Head et al. (2007) *SSR*, 131, 41-84. [4] S. Milkovich et al., (2002) *MAPS*, 37, 1209-1222. [5] J. W. Head et al. (2008) *LPSC 38*, this volume. [6] R. G. Strom et al. (1975) *JGR*, 80, 2478-2507. [7] S. C. Solomon and J. W. Head (1979) *JGR*, 84, 1667-1682. [8] S. C. Solomon and J. W. Head (1989) *RGSP*, 18, 107-141. [9] J. W. Head and L. Wilson (1992) *G&CA*, 55, 2155-2175. [10] J. W. Head and L. Wilson (2001) *Workshop on Mercury: Space Environment, Surface and Interior* (LPI), 44-45. [11] L. Wilson and J. W. Head (2008) *LPSC 39*, #1104. [12] M.A. Wieczorek et al. (2007) *New Views of the Moon, MSA-RMG 60*, 221-364. [13] C. K. Shearer et al. (2007) *New Views of the Moon, MSA-RMG 60*, 365-518. [14] S. C. Solomon et al. (2007) *SSR*, 131, 3-39. [15] R. Grard et al. (2000) ESA Bull., 103, 11-19. [16] A. Anselmi and G. Scoon (2001) *PSS*, 49, 1409-1420.

Table 1. Minimum depths of melt sources, H_m, allowing surface eruptions, as a function of crustal thickness, H_c. Also given are the maximum horizontal compressive stresses allowed if a dike is to remain open at all depths, S_u when the stress is uniform with depth in the crust and S_v when the stress decreases with depth. These values assume crustal density = 2700 kg m^{-3}, mantle density = 3400 kg m^{-3} and melt density = 3000 kg m^{-3}.

H_c/km	H_m/km	S_u/MPa	S_v/MPa
20	35	8	17
30	52	13	23
40	70	23	33
50	88	32	43
60	105	40	49
70	122	46	57

Table 2. Minimum depths of melt sources, H_m, allowing surface eruptions, as a function of crustal thickness, H_c. Also given are the maximum horizontal compressive stresses allowed if a dike is to remain open at all depths, S_u when the stress is uniform with depth in the crust and S_v when the stress decreases with depth. These values assume crustal density = 2800 kg m^{-3}, mantle density = 3400 kg m^{-3} and melt density = 3000 kg m^{-3}.

H_c/km	H_m/km	S_u/MPa	S_v/MPa
20	30	2.5	10
30	45	4	19
40	60	5.5	22
50	74	6	28
60	90	8	35
70	105	9.5	39

Fig. 1. Regional plains with wrinkle ridges on Mercury (a: 385 km wide), the Moon (b: 70 km wide) and Mars (c) [4].

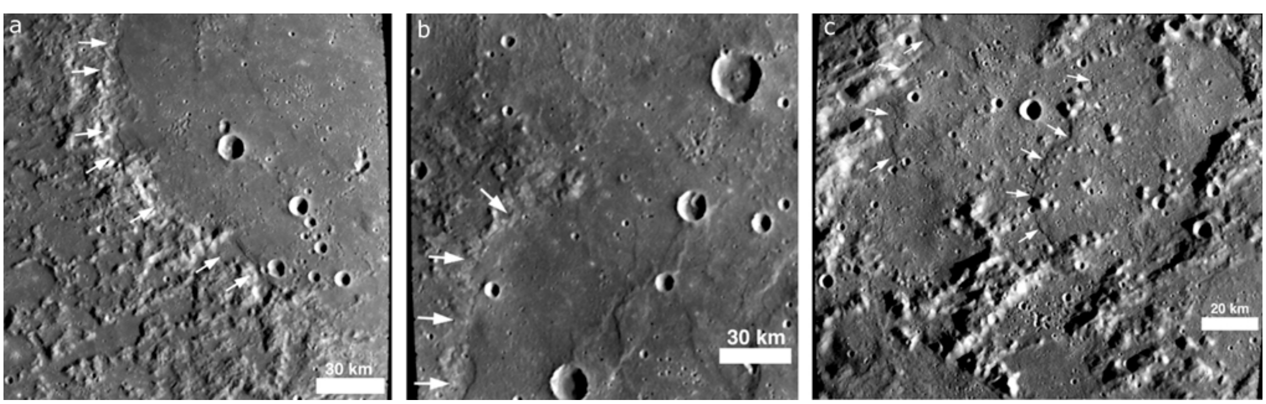

Fig. 2. Smooth plains on Mercury; arrows show lobes: a) embaying the margin of Van Eyck; b) within the Odin Formation; c) within the Nervo Formation [3, 4].