FAST MELT PRODUCTION AND EASY MELT MIGRATION IN DIFFERENTIATED ASTEROIDS IMPLIES GIANT SILLS, NOT MAGMA OCEANS. Lionel Wilson[1,2] and Klaus Keil[2], [1]Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, U.K. (l.wilson@lancaster.ac.uk), [2]HIGP/SOEST, University of Hawai'i, Honolulu, HI 96822, U.S.A. (keil@hawaii.edu).

Interior melting: Melting in differentiated asteroids was caused almost entirely by mantle-wide heat accumulation from the decay of the short half-life isotope ^{27}Al [1], not by localized pressure release during mantle convection as in planets like Earth and Mars. Thus melting started over a very wide range of depths at nearly the same time [2-6]. By analogy with melt transfer in zones of partial melting within the Earth [7-16], complex networks of veins and dikes evolved within the mantles of differentiated asteroids to move silicate melts efficiently once the degree of partial melting exceeded a few % [5]. The transfer time of any given batch of melt was as short as weeks to months [5] and only a few % of the mantle consisted of melt at any one time. Thus magma oceans, in the sense of largely molten mantles, should not have existed [17].

Melt intrusion: Upward transfer of melt directly to the surface would have been rare to impossible on asteroids with radii less than ~190-250 km due to both stress and cooling constraints [17], and accumulation of magma at depths of 6-8 km (the base of the conductively-controlled thermal and rheological lithospheric boundary layer [17, 18]) should have been common. Intrusions formed multiple isolated magma chambers or even a globally-extensive sill [5, 17]. Mafic mantle melts preferentially brought the major ^{27}Al heat source with them, and so all but the smallest intrusions would initially have become hotter, not cooler, with time, even though they were losing heat to surrounding rocks. Extensive metamorphism of the lower lithosphere is likely to have occurred [17] before residual magma bodies eventually cooled.

Eruption styles: Magma would have erupted episodically to the surface from the steadily replenished reservoirs, so eruption rates could have been hundreds to ~1000 m^3/s, comparable to historic basaltic eruption rates on Earth and very much greater than the average (tens to ~100 m^3/s) mantle melting rate [17]. The absence of asteroid atmospheres made explosive eruptions likely even if magmas were volatile-poor. On asteroids with radii less than ~100 km, gases and sub-mm pyroclastic melt droplets would have had speeds exceeding the escape speed assuming a few hundred ppm volatiles, and only cm sized or larger clasts would have been retained [19-21]. On larger bodies almost all pyroclasts returned to the surface. At low eruption rates and high volatile contents many clasts cooled to form spatter or cinder deposits, but at high eruption rates and low volatile contents most clasts landed hot and coalesced into lava ponds feeding lava flows [22]. Low gravity on asteroids caused these flows to be relatively thick, reducing cooling and letting flows reach lengths of tens of km. On most asteroids larger than 100 km radius experiencing more than ~30% mantle melting, erupted volcanic deposits buried the original chondritic surface layers of the asteroid to such great depths that they were melted, or at least very heavily thermally metamorphosed, leaving no present-day meteoritical evidence of their prior existence [17].

Relevance to 4 Vesta: The shape and impact crater density on 4 Vesta imply that several km of the original surface has been removed or at least extensively redistributed. The complex spatial pattern of eucrite and diogenite compositions detected by Dawn's spectrometers is consistent with the mixture of major shallow intrusions and surface eruptives predicted above.

References: [1] McCoy T. J. et al. (2006) *Meteorites and the Early Solar System II*, 733–745. [2] Ghosh A. and McSween H. Y. (1998) *Icarus*, *134*, 187–206. [3] Hevey P. J. and Sanders I. S. (2006) *Meteorit. Planet. Sci.*, *41*, 95–106. [4] Sahijpal S. et al. (2007) *Meteorit. Planet. Sci.*, *42*, 1529–1548. [5] Wilson L. et al. (2008) *Geochim. Cosmochim. Acta*, *72*, 6154–6176. [6] Moskovitz N. and Gaidos E. (2011) *Meteorit. Planet. Sci.*, *46*, 903–918. [7] Nicolas A. and Jackson M. (1982) *J. Petrol.*, *23*, 568–582. [8] Nicolas A. (1986) *J. Petrol.*, *27*, 999–1022. [9] Spence D. A. et al. (1987) *J. Fluid Mech.*, *184*, 135–153. [10] Sleep N. H. (1988) *J. Geophys. Res., 93*, 10255–10272. [11] Hart S. R. (1993) *Proc. Nat. Acad. Sci. U. S.* , *90*, 11914–11918. [12] Kelemen P. B. et al. (1997) P*hil. Trans. Roy. Soc. Ser. A*, *355*, 1–35. [13] Petford N. and Koenders M. A. (1998) *J. Struct. Geol*., *20*, 1425–1434. [14] Maaloe S. (2003) *J. Petrol*., *44*, 1193–1210. [15] Brown M. (2004) *Trans. Roy. Soc. Edinburgh, Earth Sci*., *95*, 35–48. [16]Valentini L. et al. (2007) *J. Volcanol. Geotherm. Res., 159*, 355–365. [17] Wilson L. and Keil K. (2012) *Chemie der Erde*, *72*, 289–322, [18] Warren P. H. (2011) *Meteorit. Planet. Sci*., *46*, 53–78. [19] Wilson L. and Keil K. (1991) *Earth Planet. Sci. Lett.*, *104*, 505–512. [20] Wilson L. et al. (2010) *Meteorit. Planet. Sci*., *45*, 1284–1301. [21] Keil K. et al. (2011) *Meteorit. Planet. Sci*., *46*, 1719–1741. [22] Wilson L. and Keil K. (1997) *Meteorit. Planet. Sci*., *32*, 813–823.