Head and Wilson (1991)

The problem: Most lunar basaltic volcanism is in the form of large, isolated eruptions. Large shield volcanoes and calderas are conspicuously absent. (There are some small shield volcanoes and small calderas.)

The proposed solution: Shallow magma reservoirs are key to the formation of both large shield volcanoes and calderas. Shield volcanoes form from repeated low-volume eruptions that gradually build up a cone, and calderas form from collapse of the shallow magma reservoir itself. Because basaltic partial melts of the lunar mantle are denser than the anorthositic crust, the vast majority of lunar magmas can't form shallow reservoirs at neutral buoyancy zones in the upper crust. Basaltic lunar magmas can only rise through the crust if there is a massive overburdened pressure in the deep reservoir—a pressure strong enough to propel a dike all the way to the surface. Due to the large amount of pressure needed, it is likely that a large amount of magma will extrude rapidly, as opposed to the slow, repeated eruptions that arise from shallow reservoirs.

Material	Density (g/cm^3)
Lunar mantle	3.4
Anorthositic crust	2.8
Basaltic partial melt	3.2
Noritic lower crust	3.1*

Features of the Head and Wilson (1991) model

- Negatively buoyant basaltic dikes in the anorthositic crust must be propelled by pressure from a magma body that is in the mantle, where it's positively buoyant.
- As a result, dikes can't be disconnected from the magma body.
- Two primary factors limit the ability of a dike to propagate to the surface: the weight of the magma in the dike and the stress required to keep the dike open. Of these, the stress required to keep the dike open is the limiting factor.
- Because of the geometries of the dikes, the melt volumes erupted typically exceed the volume of the dike, resulting in very large eruptions on the scale of 200-600 km^3.

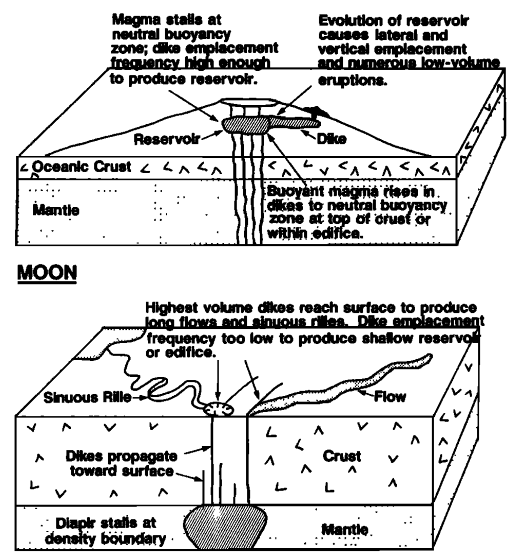

Fig. 2. Structure of a Hawaiian-type shield volcano on the Earth, compared to the characteristics of crustal structure and magma ascent on the Moon.

Discussion questions

- Could this model apply to LIP formation on Earth?
- How would a noritic lower crust play into this model?
- To what extent does this model apply to large impact basins like Imbrium, Crisium, Nectaris, and Serenitatis where the anorthositic upper crust may be thinned or entirely removed, possibly leaving only a noritic crust (Wieczorek and Phillips, 1999)?

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* Wieczorek, M., and Phillips, R., 1999, "Lunar Multiring Basins and the Cratering Process," *Icarus*, 139, 246-259.

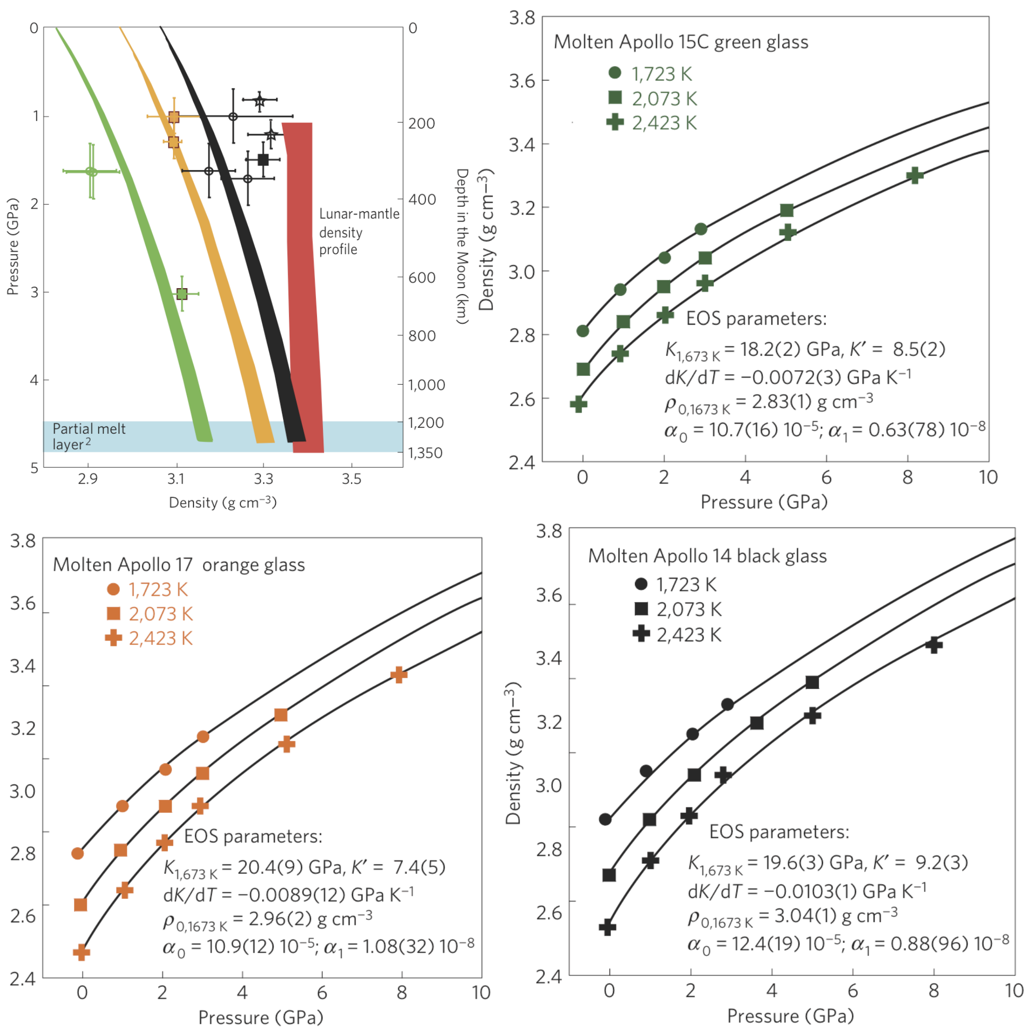
Parker et al. (2012)

Summary: Due to the absence of moonquakes deeper than ~1100 km, the existence of a large partially molten region has been hypothesized, with melt volumes up to 30% between 1200 km and 1350 km. Parker et al. (2012) find that only melts with ~16 wt% TiO_2 are neutrally buoyant at these depths. Because the source rocks for these very high TiO_2 melts are thought to form near the surface during crystallization of the magma ocean, Parker et al. (2012) propose a major overturn of the mantle after magma ocean crystallization.

Apollo 15 green glass	Apollo 17 orange glass	Apollo 14 black glass
0.23 wt% TiO_2	9.1 wt% TiO_2†	16.4 wt% TiO_2

Sources of density data

- X-ray absorption density measurements (circles)
- Sink-float density measurements (squares)
- Classical molecular dynamics simulations producing Birch Murnaghan equations of state.



† Parker, M., Agee, C., Duncan, M., van Westrenen, W., 2010, "Compressibility of molten Apollo 17 orange glass and implications for density crossovers in the lunar mantle," *Geochimica and Cosmochimica Acta*, 75, 1161-1172.