

# Fractional Crystallization of Martian Magma Oceans and Formation of a Thermochemical Boundary Layer at the Base of the Mantle

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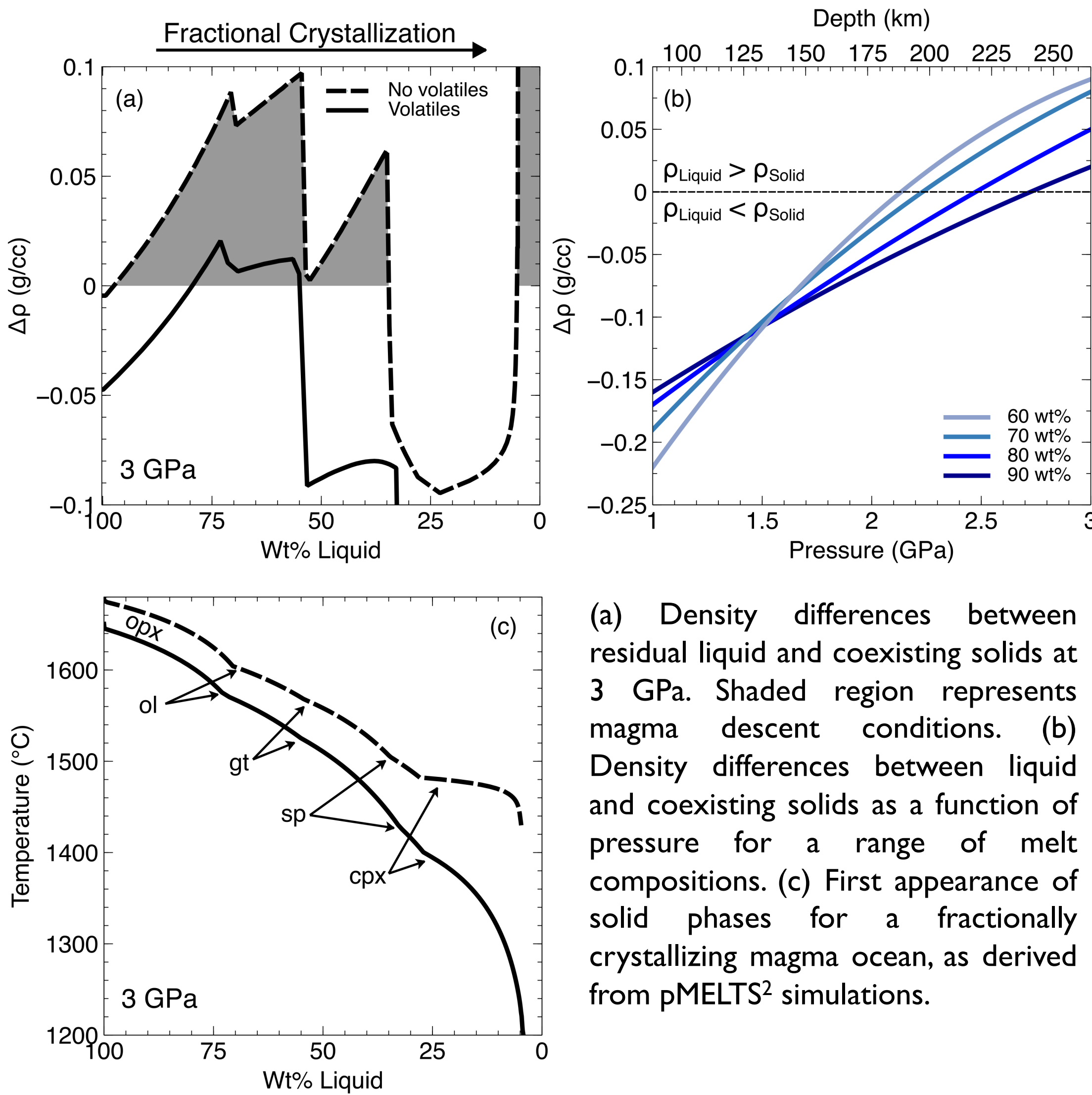


## Key Points

1. Large impacts in the early history of Mars induce mid-mantle melting.
2. As magma oceans crystallize, residual melts can become dense enough to descend to the core-mantle boundary and form a thermochemical boundary layer around the core.
3. Such a chemically distinct boundary layer could play a role in the present lack of a Martian dynamo and, as a dense basal layer, potentially contribute to the fixity of mantle plumes on Mars.

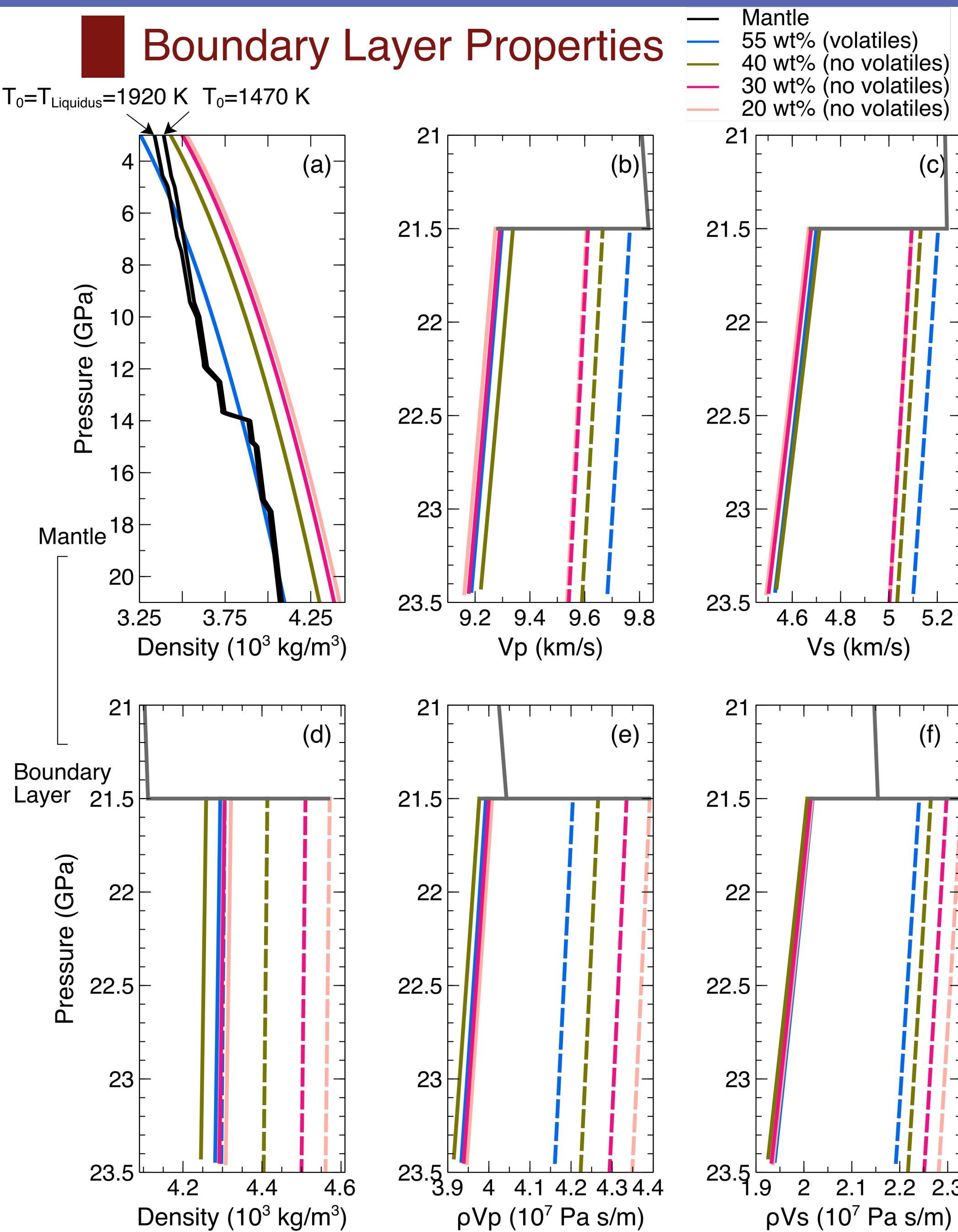
For a more detailed treatment, see Zeff & Williams (2019)<sup>1</sup>.

## Magma Ocean Fractional Crystallization (3 GPa)



(a) Density differences between residual liquid and coexisting solids at 3 GPa. Shaded region represents magma descent conditions. (b) Density differences between liquid and coexisting solids as a function of pressure for a range of melt compositions. (c) First appearance of solid phases for a fractionally crystallizing magma ocean, as derived from pMELTS<sup>2</sup> simulations.

## Boundary Layer Properties



(a) Density profiles of Mars' mantle and fractionally crystallized magma ocean liquids. Mantle density profiles were calculated in BurnMan<sup>3</sup> assuming an adiabatic temperature gradient, starting at different initial temperatures. In (b)–(f), solid lines represent Assemblage 1 (ringwoodite-dominated), and broken lines represent Assemblage 2 (garnet-dominated); gray lines between 21 and 21.5 GPa represent the bulk lower mantle assemblage (gt + rwd). (b)–(c) Calculated P and S wave velocities of lower mantle and thermochemical boundary layer (TCBL) assemblages. (d) Density profile of lower mantle and TCBL assemblages. (e)–(f) P and S wave impedances of the lower mantle and TCBL assemblages.

## Solid Mantle and Melt Compositions

	Solid Mantle <sup>4</sup>	HM55	AM40	AM30	AM20
SiO <sub>2</sub>	43.90	36.89	35.67	35.20	35.43
Al <sub>2</sub> O <sub>3</sub>	3.15	5.03	4.57	3.76	2.50
Fe <sub>2</sub> O <sub>3</sub>	—	2.33	2.65	2.93	3.07
FeO	18.80	25.06	30.26	33.87	35.56
MgO	31.66	25.76	22.14	18.52	17.42
CaO	2.50	3.84	4.71	5.71	6.01
H <sub>2</sub> O	—	0.90	0.00	0.00	0.00
CO <sub>2</sub>	—	0.18	0.00	0.00	0.00
Density	—	3.26	3.43	3.50	3.53

Total iron in the solid mantle is reported as FeO. The first two letters in the name of each melt composition indicate an initially anhydrous (AM) or hydrous mantle (HM). The number indicates wt% melt. Melt compositions were generated in pMELTS. Density reported in g/cc.

## Boundary Layer Mineralogy

	Solid Phase	Composition	HM55	AM40	AM30	AM20
Assemblage 1	Ca-perovskite	CaSiO <sub>3</sub>	8	9	10	10
	Garnet	(Mg <sub>0.8</sub> Fe <sub>0.2</sub> ) <sub>3</sub> Al <sub>2</sub> Si <sub>3</sub> O <sub>12</sub>	6	5	4	2
	Ringwoodite	(Mg <sub>0.75</sub> Fe <sub>0.25</sub> ) <sub>2</sub> SiO <sub>4</sub>	60	47	37	35
	Wüstite	FeO	20	30	36	37
	Stishovite	SiO <sub>2</sub>	6	9	13	15
Assemblage 2	Ca-perovskite	CaSiO <sub>3</sub>	7	9	10	10
	Garnet	(Mg <sub>0.8</sub> Fe <sub>0.2</sub> ) <sub>3</sub> Al <sub>2</sub> Si <sub>3</sub> O <sub>12</sub>	5	5	3	2
	Majorite	(Mg <sub>0.6</sub> Fe <sub>0.4</sub> )SiO <sub>3</sub>	42	54	49	47
	Ferropericlae	(Mg <sub>0.85</sub> Fe <sub>0.15</sub> )O	20	13	8	10
	Wüstite	FeO	26	20	29	31

Mineralogy in mol %.

## References

1. Zeff, G., & Williams, Q. (2019). *Geophys. Res. Lett.* **2**. Ghiorso, M.S., et al. (2002). *Geochem. Geophys. Geosyst.* **3**. Cottar, S., et al. (2014). *Geochem. Geophys. Geosyst.* **4**. Elkins-Tanton, L.T., et al. (2003). *Meteorit. Planet. Sci.*