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Inefficient melt extraction out of large, partially molten layers

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This presentation reviews the mechanisms associated with efficiency of gravitational settling or rising of partial melts in the Earth's deep interior. Two specific regions of interest are the low velocity layer (LVL), atop the transition zone, and the ultralow velocity zones (ULVZ), atop the core mantle boundary. The LVL is characterized by a relatively large thickness, about 70 km [1] and globally varying on the order of 30-90 km [2]. It is inferred that the LVL is characterized by a modest amount of melting, 1 or less. The ULVZ, in contrast, is much thinner, with an average thickness of 10 km. It is also characterized by a density between 8% to 10% higher than the surrounding mantle, and contains an estimated melt volume percent of 10%. Three factors, reduced melt mobility, capillary tension, and stirring can lead to long term melt retention in these partially molten regions. While the first two factors are more relevant to the LVL, the third, and possibly the second factor are applicable to the ULVZ.

The mobility of a dense or buoyant melt, at a given melt viscosity, depends strongly on the melt volume fraction. For dihedral angles less than 60°, the frictional resistance is inversely proportional to the melt fraction squared [3]. Consequently, the drainage efficiency of both buoyant and dense melts are reduced at lower melt fractions. Maximum fluid velocity in a compacting 1D melt column [4] is plotted as a function of the melt volume percent in the column in Figure 1(a). The calculated melt velocity for 1% melt volume fraction, with a 5% density contrast between the melt and the matrix, is less than 1 mm/yr. Assuming a characteristic mantle upwelling velocity of 1 cm/yr, such sluggish rate of melt extraction will likely lead to long term retention of melt in the LVL. The frictional resistance offered by the matrix is also plotted as a function of the melt volume percent in Figure 1(b). The sharp, two orders of magnitude increase in the frictional resistance with a 1% decrease in the melt fraction indicates that melt drainage out of the partially molten zone will be rather sluggish.

Secondly, at small melt fractions, surface tension arising from grain boundaries reduce the efficiency of gravitational drainage. Strong tension on intergranular contacts reduces the dihedral angle at the melt-grain triple junctions, establishing a well-connected network. Despite the presence of this well connected pathway, a larger force is required to counter the strong capillary tension and segregate melt from the matrix, especially at small melt fractions [5]. Numerical models indicate that surface tension, coupled with compaction-decompaction, can influence buoyancy-driven melt drainage over length scales several times larger than the matrix compaction length [5]. Thus, if the melt in the low velocity layer has a density contrast with the matrix, for the inferred 1% melt volume fraction for the LVL, drainage of such melt out of the low velocity layer can be inefficient. Finally, gravitational drainage of partial melt is also an issue in the ULVZ [6]. Besides surface tension effects [5], compaction within the ULVZ stirred by convective motions in the overlying mantle can also preclude substantial drainage of melt and retain the melt over geologically relevant timescale [7].

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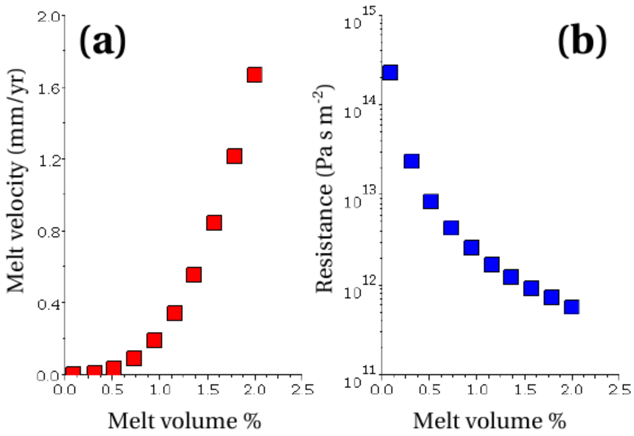

Figure 1: Results of melt drainage in a one dimensional melting column as a function of melt volume percent. (a) Melt velocity in a compacting, partially molten column is displayed as a function of the melt volume percent. (b) Frictional resistance of melt to percolation.