Stress-driven Melt Migration in Partially Molten Rocks: The Connection between Field Observations, Laboratory Experiments, Theoretical Analyses, and Numerical Models

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Field observations, laboratory experiments, and theoretical analyses all demonstrate a strong coupling between melt transport and rock deformation. Chemical disequilibirum between erupted basalt and the bulk rock through which it traveled necessitates melt flow through high-permeability channels. Field observations in ophiolites indicate that dunite shear zones act as such channels for rapid extraction of melt from a lherzolitic mantle. Laboratory experiments reveal both a significant reduction in viscosity with increasing melt fraction and an associated stress-driven segregation of melt into melt-enriched, anastomosing sheeted structures. Theoretical analyses establish that the dependence of rock viscosity on melt content causes melt to flow into regions slightly enriched in melt since they are weaker and consequently at lower mean pressure than those with lower melt content. This positive feedback leads to melt segregation and channel growth. Stress-driven melt segregation, therefore, produces melt-enriched, high-permeability channels that isolate the melt phase from the solid residuum allowing chemical disequilibrium to exist between the ascending magma and the host rock. To match the orientation of melt-enrich band structure formed in laboratory shear experiments, theoretical analysis indicates that viscosity must be anisotropic. Such viscous anisotropy arises from grain scale alignment of melt and from a strong crystallographic fabric, both of which are produced in laboratory deformation experiments. Finally, numerical models provide the link needed to apply stress-driven melt segregation phenomena to the longer temporal and spatial scales appropriate to earth processes.