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Radial, Viscous, Saffman-Taylor Fingering of Hot Asthenosphere associated with the Icelandic plume beneath the North Atlantic Ocean

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The Icelandic plume has had a significant influence upon the geologic and oceanographic evolution of the North Atlantic Ocean throughout Cenozoic times. Published full-waveform earthquake tomographic imaging of this region shows that the planform of this plume has a complex irregular shape with significant shear wave velocity anomalies lying beneath the lithospheric plate at depths of between 100 and 200 km. The planform of these anomalies suggests that five or more horizontal fingers extend radially beneath the fringing continental margins. The best-resolved of these fingers lie beneath the British Isles and beneath western Norway where significant crustal isostatic departures have been measured. Here, we propose that these radial fingers are generated by a well-known fluid dynamical phenomenon known as the Saffman-Taylor instability. Experimental and theoretical analyses show that radial, miscible viscous fingering occurs when a less viscous fluid is injected into a more viscous fluid. The wavelength and number of fingers are controlled by the mobility (i.e. the ratio of viscosities), by the Peclet number (i.e. the ratio of advective and diffusive processes), and by the thickness of the horizontal layer into which fluid is injected. We have combined shear wave velocity estimates with residual depth measurements around the Atlantic margins to calculate the planform distribution of temperature and viscosity within an asthenospheric layer beneath the lithospheric plates. Our calculations suggest that the mobility is 20-50, that the Peclet number is O(10000), and that the asthenospheric channel is 150 +/- 50 km thick. The existence and form of viscous fingering is consistent with experimental observations and with linear stability analysis. A useful rule of thumb is that the wavelength of viscous fingering is 5 +/- 1 times the thickness of the horizontal layer. Our proposal support the notion that dynamic topography of the Earth's surface can be generated and maintained by rapid horizontal flow within spatially evolving asthenospheric fingers.