An Alternative Model for the Origin of Non-Hotspot Intraplate Volcanism in the Pacific

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The formation of intraplate volcanic ridges on the south Pacific seafloor do not appear to be governed by conventional models of tectonic plate motion over a stationary hotspot. Although these volcanic seamount chains are oriented perpendicular to the plate spreading axis and parallel to the Pacific plate motion direction, geochemical evidence suggests that volcanism along the Pukapuka ridge propagates from west to east at a rate of 300 mm/yr, approximately 3 times faster than the plate velocity (Sandwell et al., 1995). Pronounced isotopic anomalies are found along the East Pacific Rise (EPR) (Mahoney et al., 1994) where the Pukapuka ridge is projected to have intersected the spreading center; anomalies with the same mixing trend that is found in Pukapuka (Janney et al., 2000), suggesting that there is material transport of anomalous mantle associated with volcanic ridge formation. We present seismic and petrologic results from the MELT and GLIMPSE marine geophysical expeditions indicating that enriched, and/or hotter mantle may underlie Pukapuka-type seamount chains. We are developing a new, alternative model in which intraplate volcanism is the surface expression of return flow to the EPR concentrated in low-viscosity channels or fingers in the asthenosphere, controlled by anomalous composition or temperature. Laboratory fluid experiments demonstrate that viscous fingering develops when a lower viscosity fluid is introduced into a higher viscosity fluid, consistent with classical Saffman-Taylor instabilities but for fluids where inertial forces are unimportant and viscous forces dominate.

Bathymetry, gravity, seismic, and magnetotelluric measurements from the MELT experiment demonstrate a pronounced asymmetry between the eastern and western sides of the EPR. Subsidence of the Nazca plate with increasing age is much more rapid than for the Pacific plate and seamounts are more abundant on the Pacific plate (Cochran, 1986, Scheirer et al., 1998). Body wave and Rayleigh wave tomography indicate lower seismic velocities beneath the Pacific plate (Toomey et al., 1998; Forsyth et al., 1998;). Surface wave and shear wave splitting studies indicate greater anisotropy on the Pacific side (Forsyth et al., 1998; Wolfe and Solomon, 1998). While ridge migration has been suggested as a mechanism for the observed asymmetry, geodynamic numerical models of mantle flow beneath a spreading ridge find that ridge migration alone has little effect on melt production or mantle temperature structure (Toomey et al., 2002; Conder et al., 2002). Anomalous temperatures or composition must be invoked in addition to the ridge migration.

P and S wave delays from the GLIMPSE experiment (Figure 1) show anomalous mantle directly beneath the volcanic ridges, and preclude the suggestion that volcanism is formed by lithospheric cracks that passively tap widely distributed, preexisting melt (Winterer, 2003). Further, the young Hotu Matua volcanic complex shows no indication that cracks or structural lineations precede volcanic activity. Normal faulting, which might support the lithospheric boudinage hypothesis (Winterer and Sandwell, 1987), is also not observed. Lastly, much attention has been given to convective rolls that are thought to originate as instabilities from cooling of the lower lithosphere in the presence of plate motion (e.g. Richter, 1973; Richter and Parsons, 1975). This hypothesis, however, must be reconciled with the observation of linear, low, free-air gravity anomalies (Haxby and Weissel, 1986) that flank the volcanic ridges and the rapid propagation of the volcanism from west to east towards the EPR opposite plate motion direction. Evidence of age progressions within the south Pacific volcanic ridges, continuity of isotopic signatures between intraplate volcanism and the spreading axis, enriched, water-rich magmas, and asymmetric seafloor subsidence, volcanism, and seismic wave propagation surrounding the EPR point to transport of anomalous asthenospheric material from the west to east beneath the Pacific plate.

In order to model mantle flow within the asthenosphere, we perform laboratory fluid experiments that consider viscous fingering between two fluids in a thin horizontal layer. Displacement of a high viscosity fluid by a low viscosity fluid is found to proceed in the form of fingers or instabilities that develop due to a differential pressure gradient between the two fluids (Hill, 1951; Saffman and Taylor, 1958). The Reynolds number (Re), which describes the ratio of inertial forces to viscous forces, is much less than unity both in the oceanic upper mantle and in our laboratory experiments, assuring that inertial forces are negligible and viscous forces dominate. Preliminary results suggest that for viscosity ratio greater than about 10, the low viscosity fluid will propagate within a fluid-filled horizontal layer as fingering instabilities that grow radially from the point of introduction (Figure 2). We suggest viscous fingering of mantle material as a possible transport mechanism to explain the geophysical and geochemical observations described above and provide agreement with satellite gravity lineations presented in previous studies (Haxby and Weissel, 1986). Volatile rich or hot mantle material introduced into the colder, more depleted ambient asthenosphere in the superswell region of the southern Pacific plate (Phipps Morgan, et al., 1995; Gaboret, et al., 2003) may flow eastward towards the EPR more rapidly in low viscosity channels that develop due to Saffman-Taylor instabilities.

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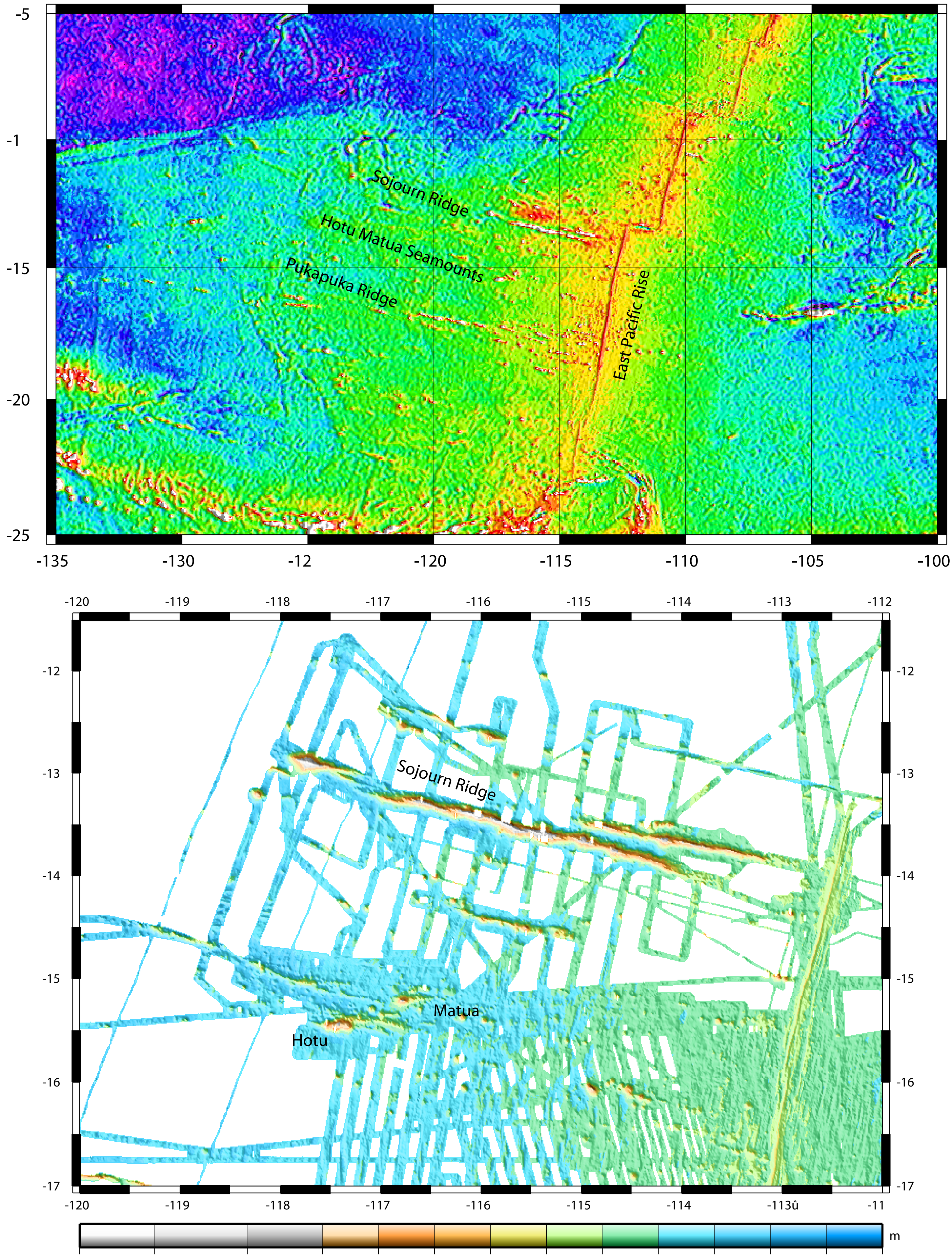

Figure 1a.) Compiled bathymetry for south Pacific and b.) local Hotu Matua area (after GLIMPSE experiment)

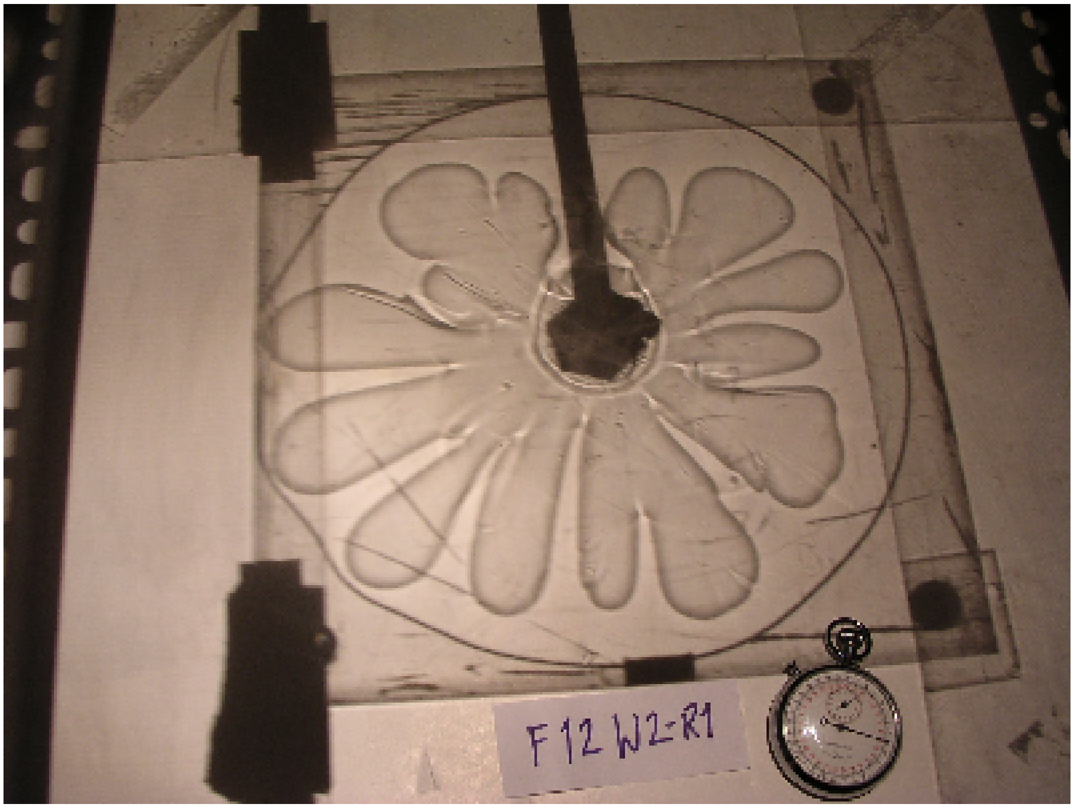

Figure 2. Viscous fingering in laboratory fluid experiments.