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Understanding the Effects of Slab Holes on Mantle Flow and Surface Dynamics

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Recent tomographic studies have imaged an increasing number of discontinuities, gaps, or holes in subducting slabs, which can range in size from one to several hundreds of kilometers and commonly occur in proximity to alkaline volcanism. Studies of slab detachment suggest vertical advection of subslab asthenosphere can occur through slab gaps or holes, transporting material into the mantle wedge and leaving a geologic footprint in terms of dynamic surface uplift and volcanism with intraplate signatures. However, it is not clear whether all slab gaps leave a surface expression. Thus, the physical parameters required for slab gaps to have an effect on the mantle flow field, and consequently on the surface, are not well understood.

Here we analyze the effect of slab hole-size and -depth on mantle and surface dynamics through analytical and analog modeling. The analytic models are used to constrain order of magnitude pressure gradients and mantle velocities for varying hole size and mantle viscosity. The analytic models suggest that a hole size greater than 150 km wide is capable of producing a dynamic effect detectable above background mantle flow. The analog models are simplified to a two-layer Newtonian viscous flow model, carried out in an 80x80x11 cm Plexiglas tank. A low-viscosity, high-density glucose syrup is used as the analog of the upper mantle. The lithosphere is modeled with silicone putty that is 200 times more viscous and 75 kg/m3 denser than the glucose syrup. In the analog models, the slab hole is represented by a pre-cut rectangular hole in the silicone putty plate. A series of hole sizes were tested. The analog models indicate that both the size and depth of the hole are important parameters controlling whether there is an observable surface response. Models with a slab hole that spans 30% of the lithospheric plate width result in significant alteration of the slab, trench morphology, as well as the mantle flow pattern. However, our observations show only a weak dynamic topography response of the altered mantle flow and solely when the vertical extension of the gap in the middle of the slab is at least 70% of the slab length. On the other hand, significant horizontal surface flow alteration is observed when the hole is near the trench and a diminishing surface expression occurs as the hole is dragged deeper into the mantle. The sensitivity of vertical mantle flow on slab hole size and depth may provide a better context for interpreting how slab discontinuities influence time-dependent surface tectonics and topography. The geodynamic modeling results provide a key for understanding regions like East Java, Central Turkey, Argentina or the Central-Apennines. In these locations, seismic tomography models showed the presence of slab holes but the surface expression varies between each place.