Upper crustal structure of Newberry Volcano from P-wave tomography and finite difference waveform modeling

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We show that seismic tomography combined with waveform modeling can constrain the dimensions and melt content of a magma body in the upper crust at Newberry Volcano, Oregon, USA. We obtain a P-wave tomographic image by combining travel-time data collected in 2008 on a line of densely spaced seismometers with active-source data collected in the 1980s. The tomographic analysis resolves a high-velocity intrusive ring complex surrounding a low-velocity caldera-fill zone at depths above 3 km and a broader high-velocity intrusive complex surrounding a central low-velocity anomaly at greater depths (3-6 km). This second, upper-crustal low-velocity anomaly is poorly resolved and resolution tests indicate that an unrealistically large, low-velocity body representing ~60 km^3 of melt could be consistent with the available travel times. This uncertainty in magma volume is largely due to wavefront healing of the first arriving seismic phase.

Here we show that we can more accurately constrain the magmatic system when, in addition to using arrival times of the primary phase, we also include amplitude information as well as the timing and amplitude of secondary phases that have interacted with the magmatic system. The densely spaced 2008 Newberry seismic data exhibit low amplitude first arrivals and an anomalous secondary P wave phase originating beneath the caldera. Two-dimensional finite difference waveform modeling through the tomographically obtained velocity model does not reproduce these observations. To reproduce these phases, we predict waveforms for models that include synthetic low-velocity bodies and test possible magma chamber geometries and properties. Three classes of models produce a transmitted P-phase consistent with the travel time and amplitude of the observed secondary phase and also match the observed lower amplitude first arrivals. These models represent a graded mush region, a crystal-suspension region, and a melt sill above a thin mush region. The three possible magma chamber models comprise a much narrower range of melt volumes (1.6-8.0 km^3) than could be constrained by travel-time tomography alone.