Identifying partial melt in seismic images of the upper mantle

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Seismic tomography allows us to map the 3D wave-speed structure of the Earth's deep interior with ever-increasing precision. In particular, techniques that exploit the full seismic waveform have recently become computationally feasible, and can resolve shorter-wavelength and larger amplitude structures than those obtained by classical methods. However, interpretation of seismic images in terms of dynamically relevant parameters such as temperature, chemical composition and melting, is inherently non-unique, and distinguishing between different models can be challenging.

In this study we focus on interpreting the S-wave speed structure in the upper mantle beneath Europe, as obtained from from full-waveform tomography. Especially low wave speeds (3.76-4.0 km/s) are seen beneath Iceland and other parts of the mid-Atlantic ridge, as well as beneath Iberia, reaching a minimum wave-speed between 120-130 km. Such low wave-speeds have also been observed in parts of the Pacific, and their origin is debated.

We compared the seismic properties of 4 million synthetic thermochemical models with wave-speed distributions of the tomography model. The synthetic models sample the full range of realistic mantle compositions, and their wave-speeds are corrected for mineral intrinsic anelasticity.

Even when considering a wide range of plausible chemical compositions, taking into account mineral intrinsic anelasticity, and allowing for presence of water, it is very difficult to create sufficiently low velocities to fit the slowest regions of the tomography model, using simple variations in temperature or composition. Doing so requires either extremely high temperatures or unrealistically high attenuation. However, the slowest velocities can readily be modelled by including c. 1-2% melt. The depths and geographic locations at which partial melt is likely are in good agreement with those predicted by geodynamic models of the region.