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Mantle wedge character associated with slow-spread lithosphere subduction beneath the Lesser Antilles arc from P- and S-wave seismic attenuation tomography

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Subduction zones are key regions where water is exchanged between the solid Earth, oceans, and atmosphere. Yet, water transport within subduction zones is only partially understood. Most studies have focussed on the subduction of fast-spread lithosphere in circum-Pacific margins; however, the subduction of oceanic lithosphere formed at slow-spreading ridges may result in a greater fluid fraction entering the deep Earth (e.g. via serpentinised fracture zones). A natural laboratory to test this hypothesis is the Lesser Antilles subduction zone, which is currently being investigated by the VoiLA project (Volatile Cycling in the Lesser Antilles). In order to image pathways of volatiles through the subduction zone, we image the 3-D variation of seismic P- and S-wave attenuation beneath the Lesser Antilles from local earthquakes. The earthquakes were recorded by 34 broadband ocean bottom seismometers deployed for 14 months.

We inverted the amplitude spectra of P- and S-waves from 378 well-located local earthquakes for the path-averaged attenuation operator (t*). We obtained ∼2,600 and ∼1,500 t* measurements for P- and S-waves, respectively. Using intermediate-depth earthquakes, we grid-searched for the best-fitting frequency-dependence exponent ([U+1D6FC]), broadly indicating weak frequency dependence ([U+1D6FC]∼ 0.3) in the mantle wedge, consistent with laboratory results at seismic frequencies. We inverted the t* measurements for a 3-D tomographic Qp and Qs model. We computed ray-paths in a 3-D seismic velocity model being developed using local earthquake tomography as part of the VoiLA project.

Our images highlight the main domains of the subduction zone. The subducting plate is imaged as a weakly attenuating structure (Qp > 250; Qs > 200), consistent with hypocentres of intermediate-depth earthquakes. We also find a low attenuation anomaly (Qp∼500; Qs ∼300) extending to ∼80 km depth above the subducting slab beneath the forearc and arc. We interpret this low attenuation anomaly as the cold-corner of the mantle wedge. Finally, a very high attenuation anomaly (Qp ∼80; Qs ∼25) lying above the slab in the back-arc at 80-130 km depth is consistent with the mantle wedge asthenosphere, the core of which is laterally offset west of the arc by 50-70 km. This mantle wedge anomaly is most prominent (largest and most strongly attenuating) in the back-arc behind Martinique and Dominica.

The location of the attenuating mantle wedge beneath the back-arc is consistent with local velocity tomography images from local earthquakes and teleseismic surface, and shear-wave splitting observations. Based on kinematic thermal-mechanical modelling of the Lesser Antilles margin, which verifies a relatively cold subduction zone, significant fluids and/or melt are needed to explain the observed high attenuation values in the mantle wedge. The location of the most strongly attenuating mantle wedge beneath Dominica is consistent with high observed B/Nb ratio, indicating high water content in magmas. Finally, the large depth extent of the cold mantle wedge corner requires a greater than normally assumed decoupling depth, which may be a common feature of slow subduction zones. We use the forward numerical models to formally explore the resolving capability of the tomographic images.