Tau-p depropagation of five regional earthquakes recorded by Earthscope USArray to constrain the 410-km discontinuity velocity gradient

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1. Motivation

Seismic recordings by the Earthscope USArray from three Queen Charlotte region earthquakes and two southern Baja Mexico earthquakes are transformed to the tau-p domain and the post-critical P-wave branches are picked. Five one-dimensional velocity models are formed via depropagation of the picked tau-p curves. These five velocity models show the nature of the 410-km discontinuity velocity gradient.

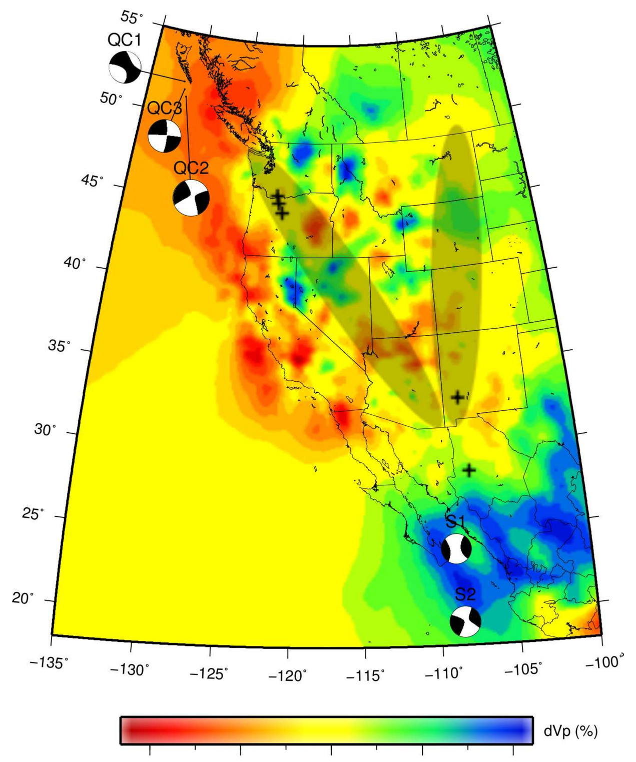

Figure 1. P-wave tomogram at 400 km depth (Burdick et al., 2009) The five earthquakes used in this study shown by the moment tensor and label (QC1-3, S1,2). The plus symbols (+) show center point of 410-km discontinuity bounce points for P410P. The TA stations sampling the earthauakes are approximated by the shaded ellipse regions.

2. Wavefield continuation method to determine earth structure

- Triplicate phases (i.e. pre-critical, critical, and post-critical reflections/refractions) are generated when a wavefield bottoms near a seismic discontinuity (Figure 2 and 3a.)
- The depth and impedance contrast of the discontinuity affects the amplitude, slowness and arrival time of the triplicate phases.
- Several different techniques have been developed to deduce earth structure from triplicate arrivals. In this study, we apply a wavefield continuation method. This method entails transforming composite record sections from the distance-time domain ($\Delta - T$; Figure 3a) to the slowness-tau domain ($p - \tau$; Figure 3b) and finally to the velocity-depth domain ($v - z$; Figure 3c).

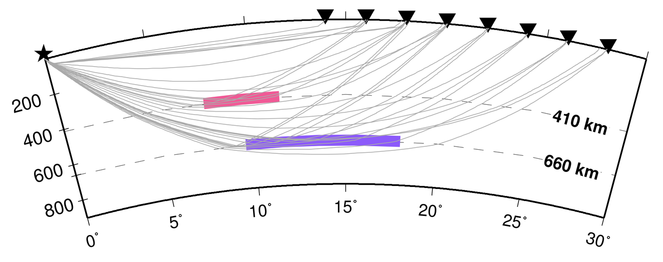

Figure 2: Upper mantle raypaths for far-regional events (10°-28°), highlighting the bottoming rays at the 410 km and 660 km discontinuity. Paths are for the IASPEI91 reference model.

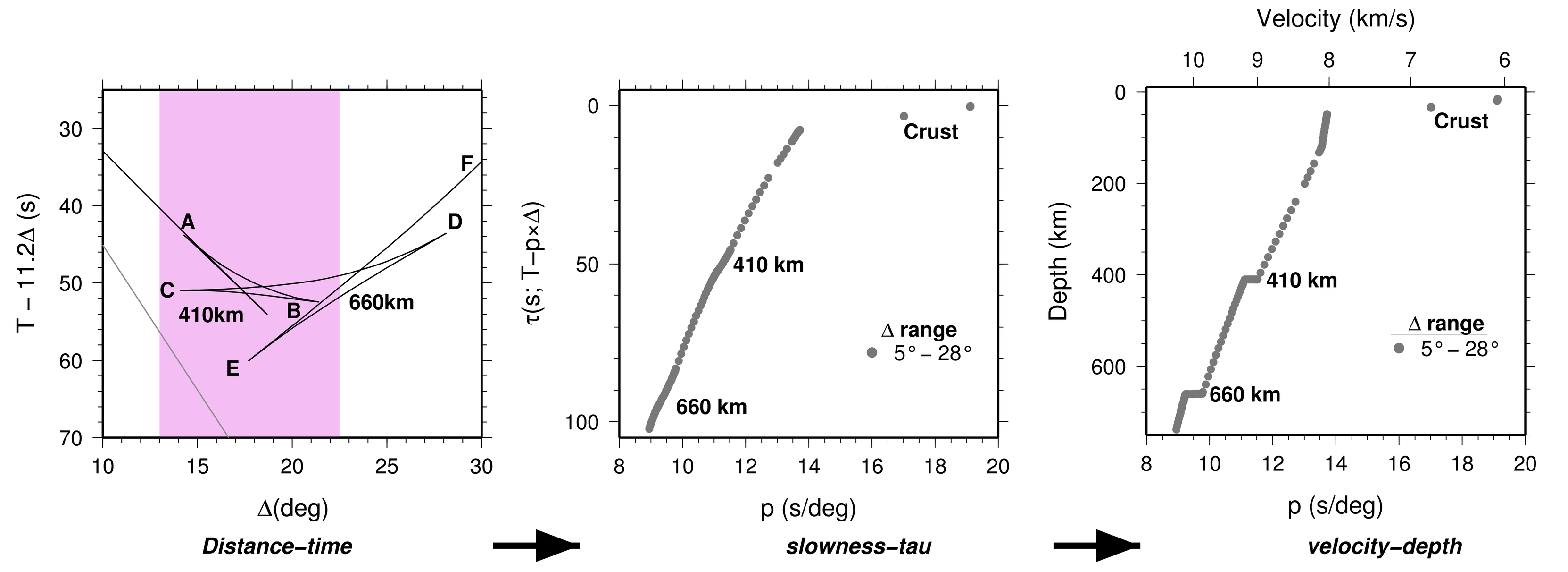

Figure 3: (a) Reduced-travel-time curves for a distance range of 10°−30° (IASPEI91 reference model). The region of 410 km triplications are highlighted. (b) The corresponding $p-\tau$ curve, where τ is the intercept-time. (c) The velocity-depth profile that results from migrating the $p-\tau$ curve.

- Processing Methods
  - Azimuth swath record sections are created using a 2-D Gaussian operator similar to *Neal and Pavlis* (1999).
  - No static corrections are applied.
  - Seismograms are bandpass filtered at 0.01-1.5Hz.
  - Wavefield record sections are then transformed into slowness and intercept time using a slant stack operator over a 8 s/deg to 15 s/deg slowness range.
  - The slant-stack wavefield ($\tau - p$ image) is then downward continued (depth migrated) to a velocity depth profile. This is an iterative process seeking convergence between the input model and migrated wavefield.

3. Earthquake Record Sections and Tau-p depropagation

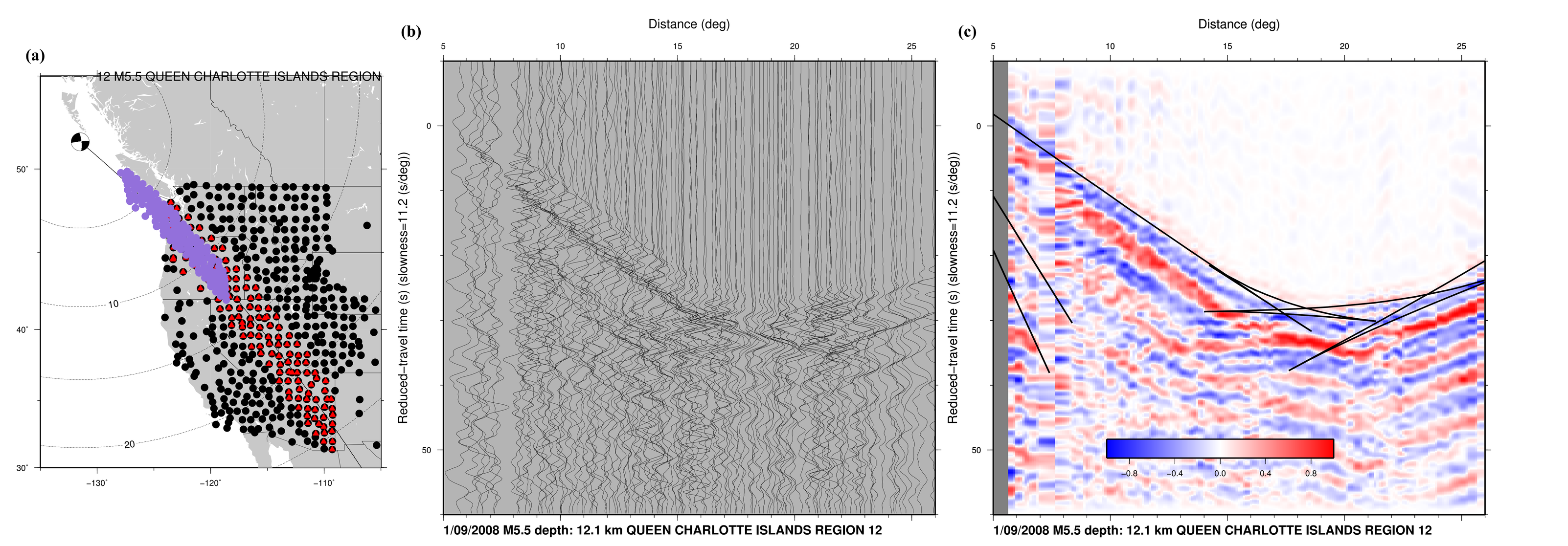

Figure. 4. Earthquake QC3 data. (a) Earthquake location, focal mechanism, and TA stations. Stations within 1.5 deg of projection line (red triangles) are processed together. The purple dots show approximate ray turning depths. Circular contours show distance from epicenter in degrees. (b) Time-reduced record section of raw waveforms. (c) Binned record section from (b) with amplitude rendered in color with up-motion (red) and down-motion (blue). Black lines are theoretical (ak135) P-wave arrival times. Note the B-C branch is observed to 12-13 deg.

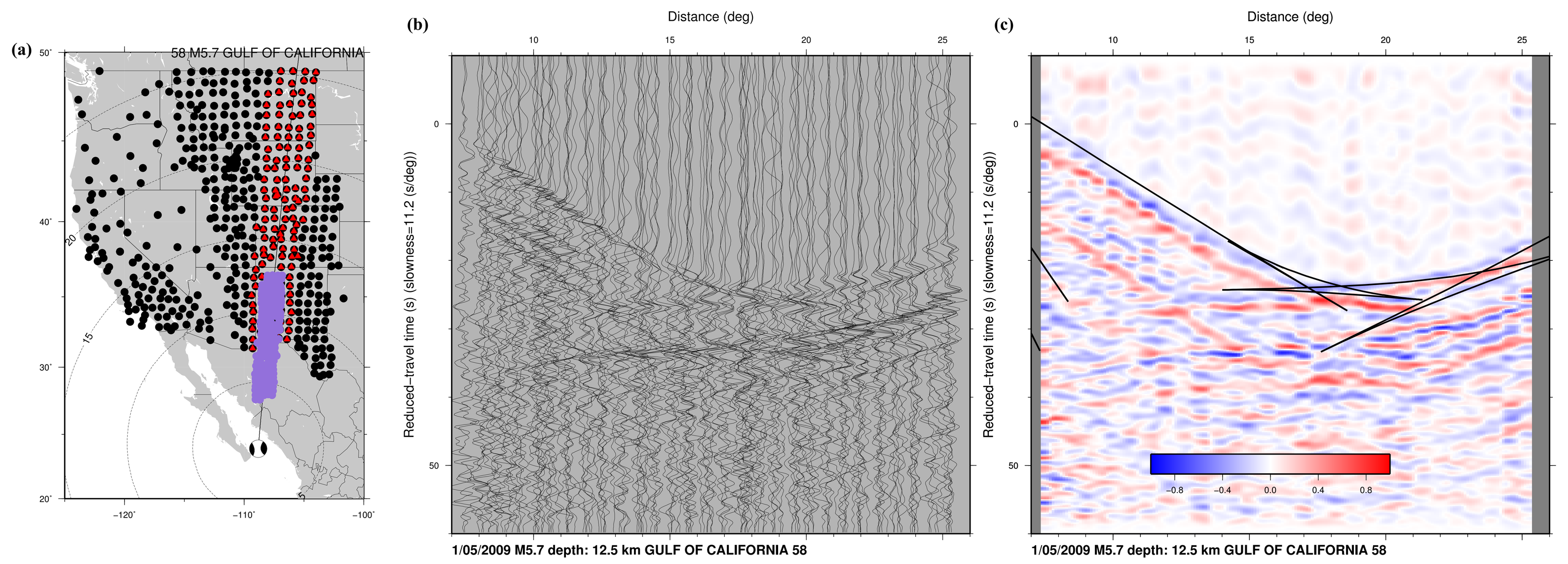

Figure 5. Earthquake S2 data.

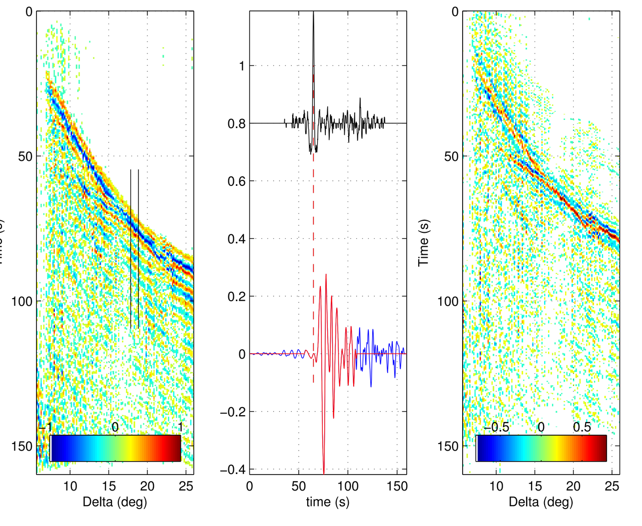

Figure 6. Earthquake QC1 deconvolved waveforms. (a) Raw binned waveforms. Two vertical lines denote the distance range from which the source wavelet is formed. (b) Bottom trace is windowed source wavelet stack shown in (a) and upper trace is the deconvolved wavelet. Vertical dashed line indicates the peak amplitude of deconvolved wavelet lined up with P-wave onset. (c) Deconvolved record section.

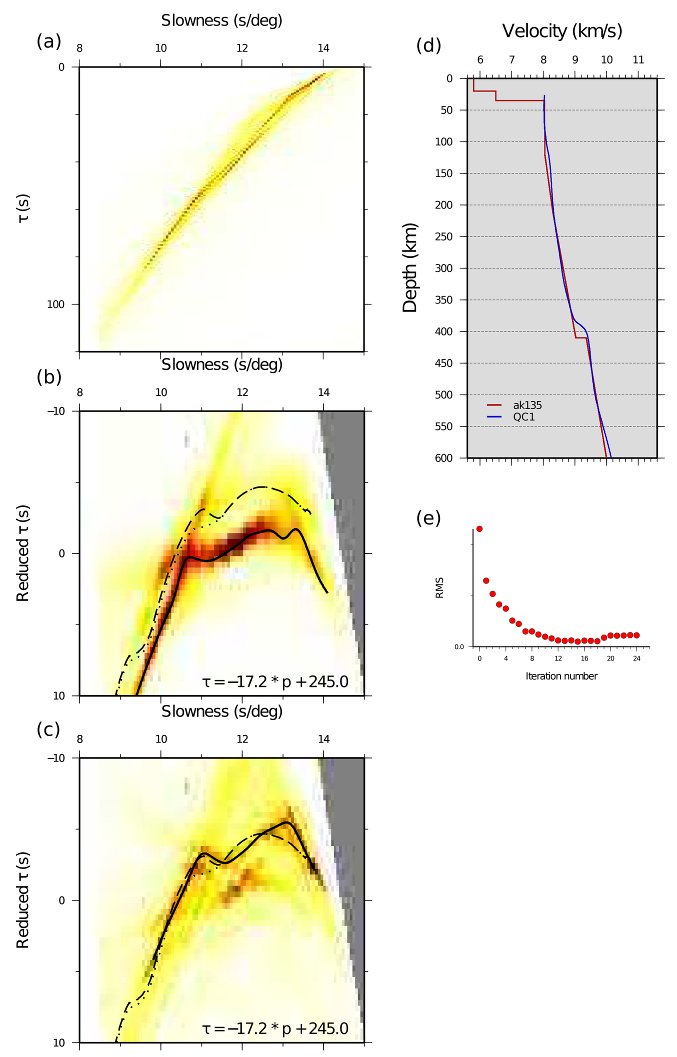

Figure 7. Earthquake QC1 slant-stack of squared deconvolved binned record section image and downward continuation results. (a) Slant-stack (tau-p) image. (b) Reduced tau-p image (0.05-0.2 Hz). ak135 predicted tau-p curves shown for a first-order 410-km discontinuity (dashed curve) and a linear 40 km 410-km discontinuity gradient (dotted curve). The picked post-critical curve is the solid curve. (c) Reduced tau-p band-pass filtered at 0.07-0.6 Hz. (d) Tau-p depropagated P-wave velocity model (blue graph) and ak135 P-wave velocity model (red). (e) RMS difference between the input velocity and migrated velocity models with respect to iteration number. The solution converges after 15 iterations, after which the migrated velocity model changes by <0.01 km/s.

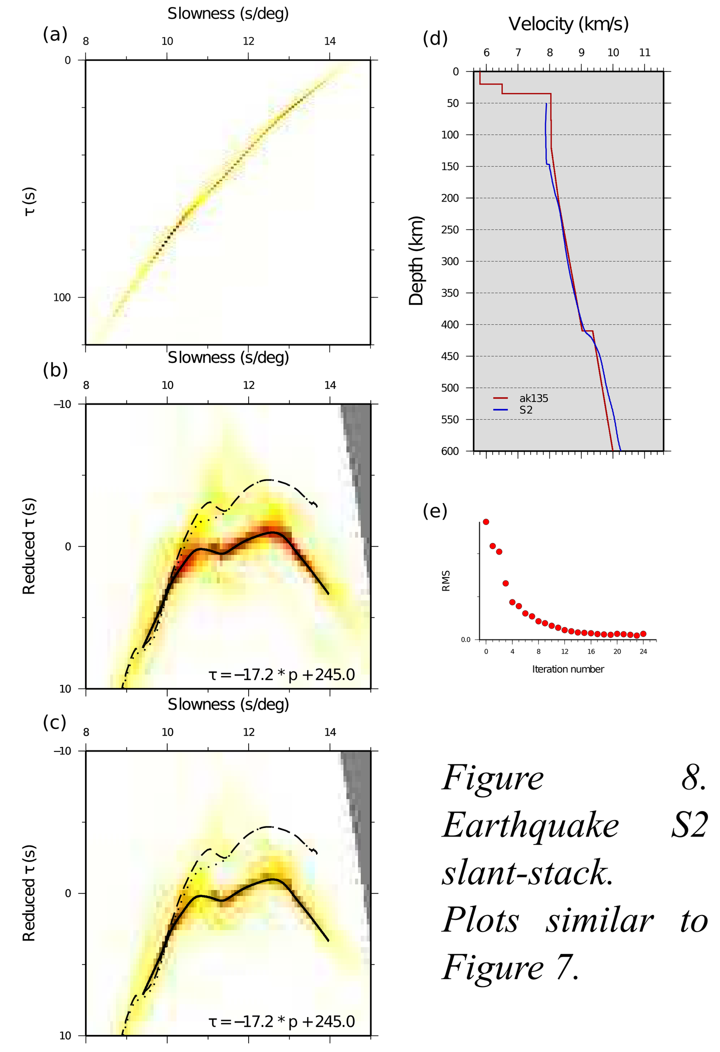

Figure 8. Earthquake S2 slant-stack. Plots similar to Figure 7.

5. Final observations and velocity models

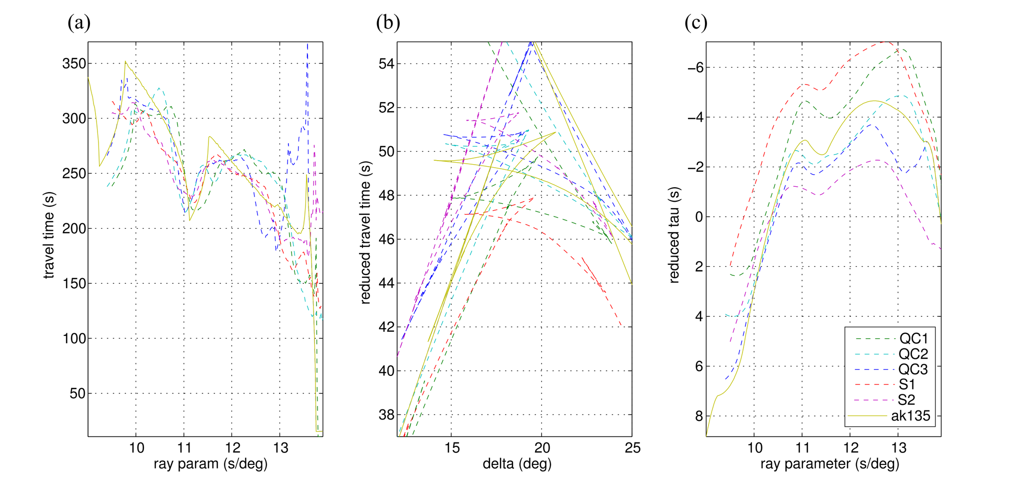

Figure 9. Summary of observations for five earthquakes. (a) Ray parameter vs P-wave travel time. (b) Epicentral distance vs travel time reduced by 11.2 s/deg. (c) Ray parameter (p) vs time-intercept (tau) reduced by Tau = -17.2 p + 245 (s).

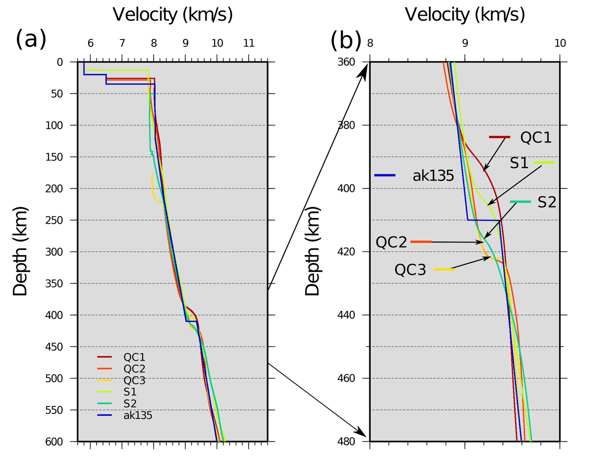

Figure 10. Tau-p migrated velocity results for five earthquakes. (a) Velocity to 600 km depth. (b) Close-up of 410-km discontinuity velocity profiles.

6. Raypaths for final velocity models

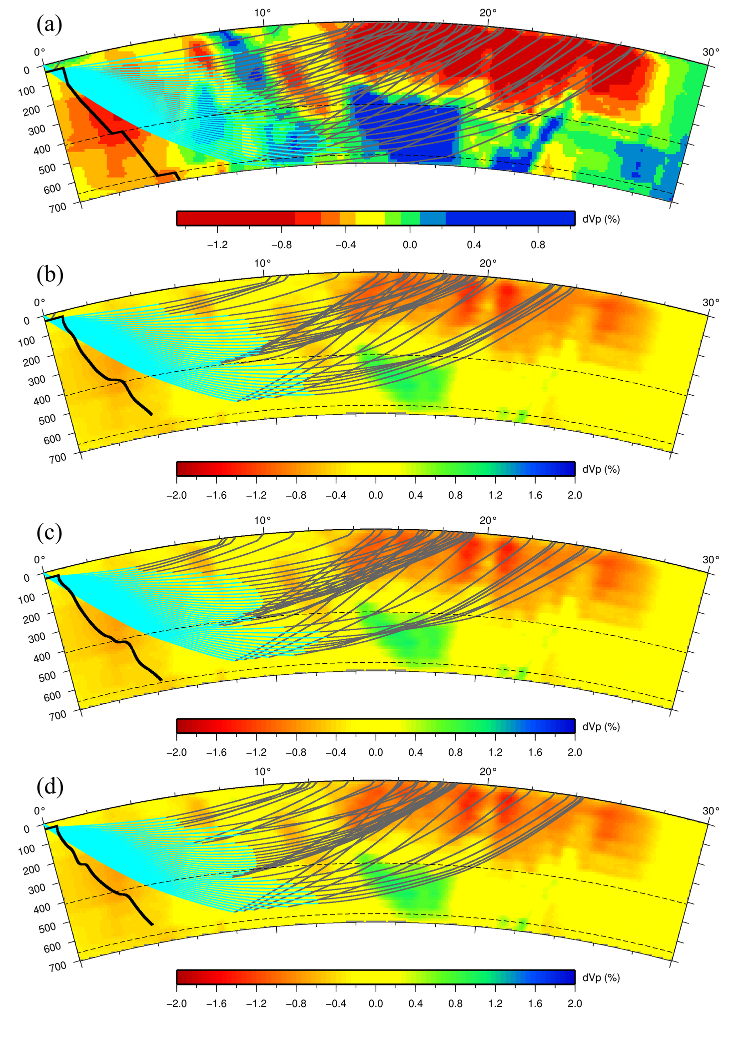

Figure 11. Raypaths for three Queen Charlotte velocity models. The velocity model is shown at the left hand side of each plot. Downgoing rays are blue and upgoing rays are dark gray. The color palette renders the P-wave tomogram of Burdick et al. (2009) along cross section line for QC earthquakes. (a) Raypaths for ak135. Note velocity scale is clipped at -0.8% to +0.4%. (b) Raypaths for QC1. Note color scale is not clipped. (c) Raypaths for QC2. (d) Raypaths for QC3.

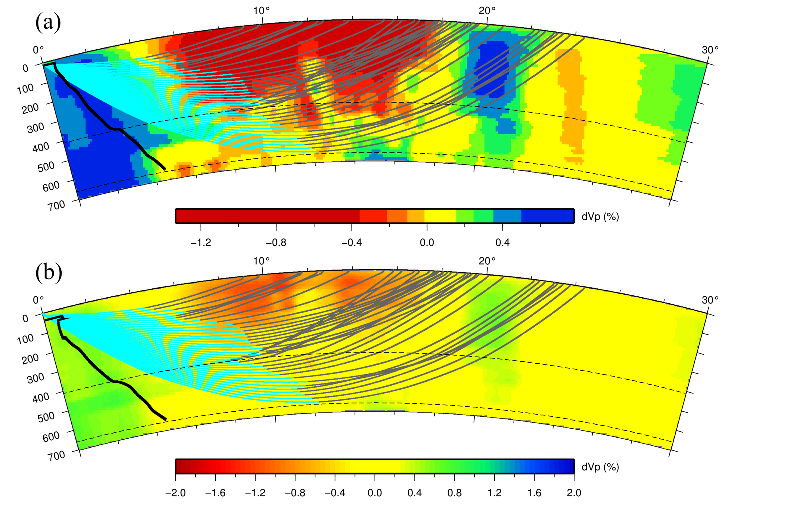

Figure 12. Raypaths for two Mexican earthquake velocity models, similar to Figure 11. (a) Raypaths for S1 velocity model. (b) Raypaths for S2 velocity model.

7. Summary and Conclusions

From depropagation of tau-p curves from three Queen Charlotte earthquakes and two Mexican earthquakes, all five models are in good agreement with the ak135 reference model velocity gradients both above and below the 410-km discontinuity and the observed 410 P-wave velocity step is within 10% of ak135. The 410 velocity gradients for three of the models are sharp (<5 km) and for two of the models are gradational (25-30 km). The maximum 410 velocity gradient is found at depths of 392-443 km. From this small sample set, no correlation between the 410 widths and depths is observed. All five models have 2-4% higher velocities in the 50-100 km depth interval above the 660-km discontinuity, which may manifest stagnated slabs. The two models with a large 410 gradient can be explained by up to 500 ppm mass hydration levels.