

# Sp images of sub-moho structure beneath the RISTRA, Laramie, Billings, and Lodore seismic arrays in the western U.S.

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**Introduction.** Currently the taxonomy of sub-moho negative Sp arrivals has two species : 1) a LAB arrival thought to manifest the juxtaposition of melt/hydration gradients against the base of the thermal lithosphere; 2) a MLD (mid-lithosphere discontinuity) arrival thought to manifest a sharp relict chemical contrast: e.g., a hydrated shallow mantle lithosphere overlying a dry thermally accreted lithosphere. Herein, an image of a double Sp negative velocity contrast at 90 and 140 km depth is presented in SE New Mexico very similar to an independent finding northern New Mexico (Dueker et al. meeting abstract). Because the shallow Sp negative at 90 km depth is best interpreted as an LAB-type arrival, then by definition the deeper Sp negative cannot be a MLD-type arrival. Hence, we nominate a new Sp negative species: a sub-LAB arrival we term a deep negative arrival (DNA).

**Data.** Ps and Sp images of moho features and sub-moho negative velocity contrast arrivals are constructed using dense (2-25 km station spacing) PASSCAL arrays that recorded for 1-2 years (Fig. 1): the 71 station RISTRA 1.0/1.5 line array across the Utah and New Mexico, the 30 station Lodore array in NW Colorado, the 30 station Billings array around Billings, Montana, and the 29 station Laramie array in SE Wyoming.

**Deconvolution and Stacking.** Receiver functions are estimated via a multi-channel spectral deconvolution method that assumes pure mode (P-to-P or S-to-S) scattering is both minimum phase and non-zero so that three component (P, SV, SH) receiver functions are calculated. The method has three fundamental steps. First, the P-component spectra from all stations recording each earthquake source are stacked and fit with a smooth spline to form an initial estimate of the source spectra. Second, the smooth estimates of the source spectra are used as constraint equations in a log-spectral least squares inversion to separate the amplitude spectra of the source and receiver functions. To exploit redundant sampling of similar source-receiver geometries, the sources recorded by each station are binned by ray parameter (0.0035 s/km) and back-azimuth ( $10^\circ$ ) so that a single estimate of the three-component receiver function is obtained for each bin. In the third step, the Kolmogorov spectral factorization is used to construct a set of sequential all-pass filters that recover the phase spectra of the receiver functions.

After deconvolution culling, the total number of receiver functions is: RISTRA (737 Ps and 893 Sp), Lodore (277 Ps and 337 Sp), Billings (557 Ps and 424 Sp) and Laramie (422 Ps and 222 Sp). For the RISTRA line array, offline stations and receiver functions at  $180^\circ$  -  $270^\circ$  back azimuths were deleted so the image is not contaminated by out-of-plane structure.

Common conversion point stacks of Ps and Sp receiver functions produce images of the subsurface shear velocity contrasts. The P and S velocity models used in the 1-D Ps/Sp moveout equation are extracted along the incident and scattered raypaths through a 3-D velocity model. This approximation does not perturb the raypaths calculated through our 1-D velocity models nor the associated incident ray-parameter. For the shallow (<200 km) images, a 3-D surface wave velocity model is used (Shen and Ritzwoller, pers. com) and a  $V_p/V_s$  of 1.76 in the crust and 1.81 in the mantle is assumed. For the deep (200-800 km)

images, the migration velocity profiles are extracted from a 3-D velocity tomograms (Schmandt and Humphreys, 2010). The bin widths for the arrays are: RISTRA (98 km), Lodore (35 km), Laramie (35 km), Billings (70 km). The filter bands for the images are: RISTRA Sp (5-30s), RISTRA Ps (3-30s), Lodore (2-30s), Laramie (2-30s), Billings (3-30s). Average hit-count in the center 2/3 of the sampled volumes are: RISTRA Sp (60), RISTRA Ps (55), Laramie (70), Lodore N-S (65), Lodore E-W (60), Billings N-S (105), Billings E-W (115).

**RISTRA interpretation.** The RISTRA array sampled from west Texas to central Utah, traversing the eastern Basin and Range, Colorado Plateau (CP), Rio Grande Rift (RGR), the Jemez volcanic lineament (JVL), the high mantle velocity Escalante Anomaly area in south-central Utah (EA) (Levander et al., 2011), and the Permian Delaware basin in Texas (Fig. 1 and 2). The primary sub-moho negative velocity contrast arrival is at 65-110 km depth and is deepest (115 km) beneath the CP and shallowest (65 km) beneath the Basin and Range and RGR/JVL area. A second deeper sub-moho Sp negative is imaged at 110-125 km depth beneath SE New Mexico at 32.8° to 35 latitude. This Sp doublet (DNA) arrival resides between the Rio Grande Rift and SE New Mexico and is very similar to a Sp doublet imaged beneath northern New Mexico (Dueker et al. meeting abstract)

A dim Ps moho amplitude and doublet is imaged over the high mantle velocity Escalante Anomaly (EA) beneath the central Colorado Plateau around the Glen Canyon area (Fig. 2). Levander et al. (2011) interpreted Transportable Array Ps/Sp images to define a east dipping positive velocity contrast interface and interpreted this structure to be relate to active delamination of a dense lower crustal section concomitant with thermal down-flow of a dense, but hydration weakened, lower lithosphere. This interpretation is challenged by our finding of a strong sub-moho Sp negative arrival that traverses the EA (Fig. 2). If the EA is a thermal downwelling, it seems implausible that an LAB-type arrival due to a partial melt gradient would exist within the volume of the EA fast mantle. Yet, resolution issues exist with regard to our 75 km bin size (near the width of the EA width transected by the RISTRA-line) and the 50 km scale vertical smearing of the body wave tomography tomograms.

**Lodore/Laramie/Billings array interpretation.** To extend characterization of Sp negative structure using high-fold arrays like the RISTRA array, the Lodore, Billings, and Laramie arrays were processed. A strong Sp negative is imaged at 80 - 100 km depths beneath the Laramie array and sporadic weak negative arrivals are found beneath the Lodore and Billings arrays. In the E-W Billings section, two weak negative bands at 80 km and 110 km depth are imaged. Given the Archean age of the Wyoming province lithosphere and low heat flow under Billings, Montana, this Sp doublet could be interpreted as a mid-lithospheric and LAB type arrival (Fig. 3).

**Conclusion.** The RISTRA and Laramie array images find a high amplitude Sp negative arrival that can reasonable be interpreted as manifesting a melt porosity gradient 30-80 km below the moho. Beneath the Rio Grande Rift, a deep negative arrival (DNA) at 120 km depth could imply a deep solidus crossing due to a upwelling hydrated mantle from dehydration of underlying slabs tomographically imaged about 800 km depth. To better constrain the origin of the Escalante Anomaly, we believe that a 2-D seismic sampling three times denser than the Transportable Array sampling is needed. The Billings array image finds a set of weak Sp negatives at 70-110 km depth that may manifest a LAB- and MLD-like set of arrivals.

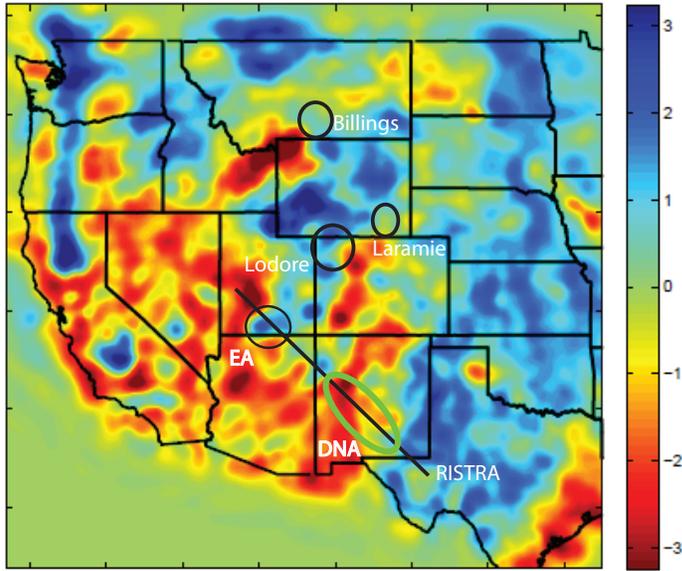


Figure 1. 1-D RISTRA array sampling and 2-D Lodore, Laramie and Billings array samplings. P-velocity tomogram at 120 km depth from Schmandt and Humphreys (2010). The high velocity Escalante Anomaly (EA) is the E-W trending high-velocity feature transected by the RISTRA array at 37°-37.7° latitude. The region where the RISTRA array images a double Sp negative arrival (DNA) is outlined by the green oval.

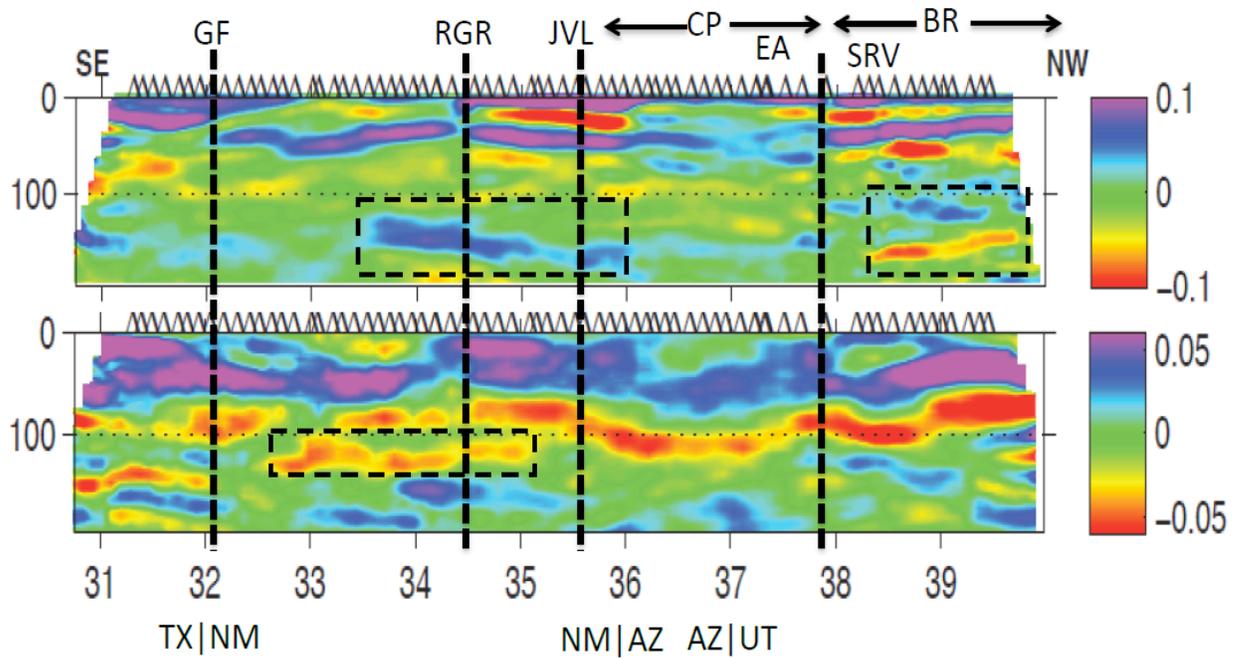


Figure 2. Ps (top) and Sp (bottom) image along the RISTRA line array. Labels are: Grenville Front (GF), Rio Grande Rift (RGR), Colorado Plateau (CP), Escalante high mantle velocity anomaly (EA), San Rafael propagating volcanic trend (SRV), Basin and Range (BR). The vertical lines denote volcanic/tectonic boundaries where correlated changes in Sp and Ps images are imaged. The sub-moho Sp negative is continuous from the BR to the RGR with 20-30 km offsets. The Sp negative deepens by 30 km beneath the CP. SE of the RGR the Sp negative becomes discontinuous with near absence in two regions. A deep secondary Sp negative arrival beneath SE New Mexico is outlined by a box; a similar arrival is found in northern New Mexico. The Ps image dotted boxes show arrivals under investigation. The occurrence of an Sp negative arrival traversing the high velocity Escalante mantle anomaly

(EA) between 37-37.7° is challenging to explain as an LAB type arrival (see text), if the EA is interpreted as a thermal downwelling (Levander et al., 2011).

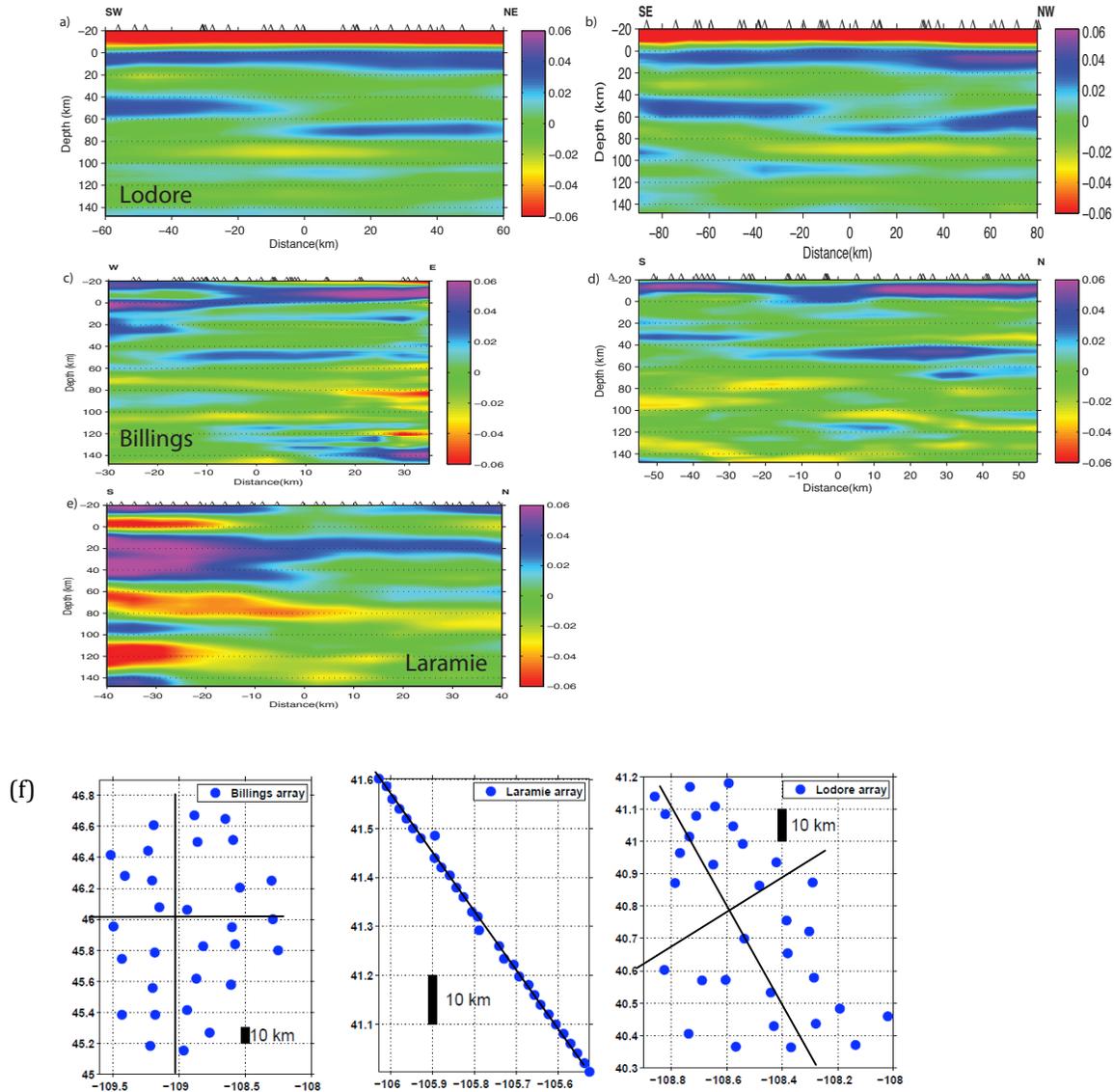


Figure 3. Sp images using 10-12 month recordings from three dense station spacing PASSCAL arrays. (a) Lodore array E-W section. (b) Lodore N-S section. (c) Billings array E-W section. (d) Billings N-S section. (e) Laramie array N10°W section. The blue arrival at 35-60 km is the moho image. The Laramie array image has a high amplitude Sp negative that dips to the north at 60-80 km depth and the Lodore array image shows a low amplitude Sp negative at 70-80 km depth over 60% of the sampled area. The Billings array image has Sp negatives at 90 km depth over 50% of the area along with some positive arrivals. (f) Cross sections and stations for the Billings (left), Laramie (center), and Lodore (right) arrays. See Fig. 1 for array locations.