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Data Resolution and Visualization

Y. J. Gu, A. M. Dziewonski, W.-J. Su, and G. Ekström, Harvard University

Sensitivity of individual data sets to the 14 radial B-spline functions used in a 3-D inversion of shear velocities in the mantle. B-spline functions are labeled in an increasing order from the CMB to the Earth surface. Normalized sensitivity of the data set in resolving the 14 B-spline functions are shown: large sensitivities are shown in intense red, and small, dark blue. It is evident that the surface wave dispersion measurements are highly sensitive to the near-surface splines. The mantle wave waveforms are sensitive to the upper mantle structure, while body wave waveform and travel time measurements have the largest contributions to depths below 500 km. WF 1 represents a waveform data set with recordings from 1977-1990; WF 2 represents a more recently compiled waveform data set.

To achieve good resolution in full range of depths it is often important to combine data sets such as body- and mantle-wave waveforms, travel times, surface waves phase velocities, etc., for the three-dimensional (3-D) inversion of shear velocities in the mantle. The diversity of data warrants a closer examination on the sensitivity of each data set to a given model parameter. We hereby describe a simple method to visualize the contribution of individual data sets to an inversion that is radially parameterized in 14 localized B-spline functions (Gu et al, 2000). Because the data sensitivity to the spline function centered at each radial knot is directly related to the corresponding diagonal elements of the matrix, we can define a simple normalized diagonal average for each data set: for the k-th data set and the i-th spline, a diagonal element of the averaged (A^T A)^(k) matrix contributions of all data sets of this study to the individual spline functions (normalized to the peak amplitude within each data set) and a color-coded representation is shown. It clearly illustrates the varying contributions of different subsets of data to the maximum resolution at various depths. For example, the inclusion of surface wave dispersion measurements allows us to resolve the structure in the top 200 km; various sets of mantle-wave waveforms provide adequate sampling in the upper mantle and transition zone, and body wave waveforms, in mid-mantle depths. The absolute travel time measurements help to constrain structure immediately below the 670-km discontinuity to mid-mantle, whereas the differential travel times of S-SKS, ScS-S and SKKS-SKS are particularly sensitive to the structure in the lowermost mantle. All of these data sets have been obtained from analysis of digitally recorded seismograms from the GSN, retrieved from the DMC over the years.

For further reading:
Global 3-D Models and Event Location

Michael Antolik, Göran Ekström, and Adam Dziewonski, Harvard University

Experiments performed using 3-D models of various resolution show that the event location with respect to the ground truth is not a simple function of the number of parameters in a model. To this effect we have compared the results obtained using a ‘high-resolution’ model described by 250,000 parameters, a ‘medium-resolution’ model described by 25,000 parameters, and a ‘low-resolution’ model described by 2,500 parameters. The result was that the corrections predicted by the ‘low-resolution’ model led to the most precise locations, while the ‘high-resolution’ model gave corrections that led to the best variance reduction.

Our previous experiments with the quality of the location used data from ISC Bulletins, which may not be representative of the IDC (International Data Centre, Vienna) data set. To investigate the effect of the smaller number of the reporting stations, we have artificially reduced the number of observations. The results reveal that 3-D corrections are even more important when the station coverage is sparser. The figure shows mislocation resulting from location trials using a group of 86 explosions and well-located earthquakes (Kennett and Engdahl, 1991) for four 3-D mantle models of increasing complexity from top to bottom, as well as the spherically symmetric model PREM (Dziewonski and Anderson, 1981). Models SP12 and MK12 (Su and Dziewonski, 1997) use spherical harmonic functions up to degree 12, model BDP98 (Boschi and Dziewonski, 1999) uses constant-velocity blocks of dimension 5° x 5° at the equator, and model VWE97 of van der Hilst et al. (1997) uses blocks with a dimension of 2°. We relocated each test event multiple times using different random selections of either 30 or 8 teleseismic P phases recorded by the GSN. As the figure shows, the more detailed 3-D models do not produce better results. The average mislocation resulting from the location trials is smallest for model SP12.

To accommodate future regional 3-D models, we have begun construction of a reference global model, using local function representation (3-D cubic splines) roughly equivalent to degree 18 in spherical harmonics. The model will be constructed using waveforms, surface wave dispersion measurements, and travel times in order to achieve better resolution in the upper mantle than contained in most existing block models. An arbitrary part of this model can be replaced by a regional model, and travel time corrections can be computed at regional distances using the regional model. At teleseismic distances, the corrections would be evaluated for a combination of regional and global structure.

For further reading:
Su, W., and Dziewonski, A.M., Simultaneous inversion for 3D variations for shear and bulk sound velocity in the mantle, PEPI, 100, 135-156, 1997.
Global Mantle Tomography: The Resolving Power of Low-Degree Spherical Harmonic Parameterization

Lapo Boschi and Adam M. Dziewonski, Harvard University

One important application of the data collected by IRIS, in the GSN and PASSCAL programs, is the derivation of the three-dimensional structure of Earth’s interior. In the last two decades, as the discipline of seismic tomography was developing, the reliability of different computational techniques has been debated. In fact, the determination of global 3-D velocity models, by a least-squares fit of seismic travel-time data, requires very intense computational procedures, both in terms of time and computer memory. In the early years of global tomography, it was therefore unavoidable to parameterize such seismic models of the Earth in terms of a limited number of basis functions; quite frequently, the lateral variations of P or S velocity within the Earth were described as a linear combination of spherical harmonic functions (up to a relatively low degree), multiplied by Chebyshev polynomials (which accounted for the radial dependence of the anomalies). More recently, it has been suggested (Pulliam and Stark, 1993; Megnin et al., 1997) that tomographic inversions based on low-degree parameterizations tend to generate artifacts and overestimate the spectral power at low degrees.

We believe that the validity of those early, long wavelength models, can be demonstrated by means of an ad-hoc synthetic test. We use the high-resolution model BDP98 (Boschi and Dziewonski, 1999) to compute theoretical delay times resulting from 3-D P-velocity anomalies. We then carry out a tomographic inversion of those “synthetic” data to determine a degree 12 spherical harmonics/degree 13 Chebyshev polynomials image of the Earth’s mantle. The similarity of the “input” and “output” models is a measure of the resolving power of this low-degree parameterization.

For further reading:


In the last few years, a large number of Rayleigh and Love wave phase anomaly measurements, based on seismic records from the GSN, have been collected by the Harvard seismology group, making use of the technique described by Ekström, Tromp and Larson (1997). Through tomographic inversion, these data have provided new images of the lateral variations of phase velocity at different periods, as well as three-dimensional (3-D) models of the shear and compressional velocity structure of Earth’s upper mantle, including significant anisotropic features (e.g., Ekström and Dziewonski, 1998; Ekström, 2000).

Recent developments in this research, made possible by the good quality of our measurements, include: (1) determination of 3-D images of the upper mantle based upon a 3-D starting model, accounting for the effect of the crust and the associated lateral variation in the sensitivity of our data to the underlying structure and (2) use of a locally varying parameterization, finer within a certain, well-sampled, region of interest.

For further reading:


Eight 1-degree by 1-degree phase velocity maps of the Mediterranean region, corresponding, as indicated, to surface waves of different periods and types. Each of these images is part of a global model, parameterized everywhere outside the region of interest in terms of 3-degree by 3-degree blocks. This variable resolution approach has two important advantages. First, it allows us to refine our model exclusively in one region, without dealing with the inconveniences of an exceedingly large number of free parameters. Second, it accounts explicitly for the sensitivity of global data to lateral velocity variations outside the region of interest; global data can thus be used to map regional structure.
Seismic Travel Times at Finite Frequency: The Next Step in Seismic Tomography

Guust Nolet, Tony Dahlen and Shu-Huei Hung, Princeton University

Although it is well known that anomalies in wavefronts heal as the wave propagates, the effects of this are generally ignored in global tomography. As shown in Dahlen et al (2000) and Huang et al (2000), the complexities of the raypath in realistic Earth models create a complicated, often counter-intuitive, relationship between the travel time of a broadband P or S pulse and the velocity structure inside the Earth. As a consequence, modeling errors are likely to affect interpretation of all but the shortest period travel time anomalies. For larger velocity contrasts, nonlinear effects may appear that are even more baffling to a classical seismologist whose intuition is sharpened by ray theory, but not necessarily by the realities of wave propagation inside the Earth.

In a recent analytical study of the phenomena in Nolet and Dahlen (2000), we concluded that the effects of wavefront healing for surface waves traveling in 2D are less severe than those for body waves in 3D; that the healing of delays is likely to contribute significantly to the scatter of observed travel-time anomalies; that tomographic inversions of long-period body waves face perceptible limitations in theoretical resolving power; and that positive travel-time anomalies evolve differently from negative ones. The figure shows the theoretical limits of resolution inside the Earth (assuming otherwise perfect ray coverage). For heterogeneities smaller than the ones in this figure, finite frequency effects are serious. Many of the current global models are based on travel times, or differential travel times, measured from the GSN at periods of 20 seconds or more. Such data effects of wavefront healing must certainly be taken into account in the interpretation.

For further reading:

To obtain a reliable snapshot of shear velocities in the mantle, particularly near the transition zone, we use a diversified data set consisting of body- and mantle-wave waveforms, travel times and surface wave phase velocities. Nearly all of these data have been obtained using seismograms recorded by the GSN. We conduct inversions using a local B-spline support for the lateral and radial dimensions. By parameterizing the radial variations of velocity using one or more sets of B-splines, we allow the velocities to vary smoothly (former), or discontinuously (latter) across depths at which the mantle is split. Our experiments suggest a significant change in the long-wavelength anomalies of the transition zone from those below. The attached figure shows a best-fit model for the Earth with two imposed discontinuities (400 km and 670 km). They are well established as global discontinuities in seismic velocities. The amplitudes of the heterogeneities at both discontinuities are comparable. Our experiment is intended to explore how the pattern of lateral heterogeneity changes across these boundaries. Near 400 km, only minor changes in the large-scale features are observed (panels a and b). The power spectra (panel c) shows a moderate decrease in degree 1 and 5 in the transition zone, which implies a decrease of the continent-ocean signature that characterizes the lithosphere. The overall change at 400 km, however, is too gradual to signify a flow boundary. In contrast, the amplitudes of fast velocities related to subducted slabs in the western Pacific and South America decrease notably in the transition zone, is strongly attenuated at the top of the lower mantle. Resolution tests show that these results are robust which suggest a possible reorganization of the flow between the upper and lower mantle.
A normal mode, or free oscillation, of the Earth is a standing wave resulting from the constructive and destructive interference of traveling waves. The resonance peak of a normal mode is split as a result of rotation, hydrostatic ellipticity and lateral heterogeneity. The effects of Earth’s rotation and hydrostatic ellipticity can be predicted, and the remaining splitting, represented as splitting function coefficients, can be used to constrain lateral variations in the mantle.

Recently, a large number of splitting function coefficients has become available through analysis of seismograms recorded after large earthquakes in 1994-1996. With the new data set, obtained using seismograms from worldwide stations including GSN, Geoscope and IDA, we have been able to invert not only for perturbations in shear velocity, but also for perturbations in compressional velocity and density. Inversion for density heterogeneity is a unique advantage gained by using long-period normal-mode data. Body-wave data, normally used in the construction of mantle models, are not sensitive to lateral variations in density.

An additional constraint on the density structure of the mantle is provided by the Earth’s gravity anomaly. This signal depends on density variations within the mantle and topography on internal discontinuities and the surface. We include the gravity data in our inversion by taking advantage of models of boundary topography determined previously through seismic and geodynamic studies.

Shear and compressional velocity models obtained from normal-mode inversion are consistent with those obtained using travel-time or waveform data. Comparison of shear (β) and compressional (α) velocity models shows reasonable correlation throughout the mantle, consistent with a thermal origin of lateral variations. However, comparison of shear velocity and bulk sound velocity (ϕ) shows a decrease in correlation from the top to the bottom of the mantle. Near the core-mantle boundary, shear and bulk sound velocity are strongly anti-correlated (correlation coefficient of -0.63), which suggests the importance of variations from a non-thermal origin. This is further supported by the comparison of density and shear velocity models which shows regional anti-correlation near the core-mantle boundary.

For further reading:
Most global tomographic models to date are derived using a combination of surface wave (or normal mode) data and body wave travel time data. The former provide resolution in the upper mantle, and the latter, in the lower mantle. However, the travel time approach restricts the number of phases available for inversion by requiring them to be isolated on the seismogram. This may ultimately result in limiting the resolution of 3-D structure, at least in some depth ranges in the mantle. In previous work, we successfully derived a degree 12 whole mantle SH velocity tomographic model (SAW12D; Li and Romanowicz, 1996), expanded laterally in spherical harmonics up to degree 12 and radially in Legendre polynomials, using exclusively waveform data. In this inversion, a normal mode formalism suitable for body waveforms, the nonlinear asymptotic coupling theory (NACT; Li and Romanowicz, 1995), was combined with a body-wave windowing scheme, which assigns individual weights to different body-wave energy packets, and thus can enhance lower energy signals such as that of S diffracted waves. This can be contrasted with a more standard technique in which a single time window is considered from the first body wave arrival to the fundamental mode surface waves. Under NACT, the broadband body wave kernels correctly reproduce the sensitivity to structure along and around the theoretical ray-path, in contrast to the standard “path-average” (PAV) approximation, suitable for surface waves, in which the effect of 3-D structure is averaged horizontally between the source and the receiver. We have shown that the NACT approach is particularly important at mid-mantle depths (sampled by phases such as S and SS), whereas the windowing scheme improves resolution near-the core mantle boundary (Megnin and Romanowicz, 1999).

We now have applied the NACT approach to a larger dataset of SH waveforms, and have derived a higher resolution model, SAW24B16 (Megnin and Romanowicz, 2000), expanded laterally up to degree 24 and radially in cubic b-splines. The adoption of local basis functions in the radial parametrization allows to accommodate the varying ray sampling of mantle structure with depth, which is precluded by the use of global basis functions. The present model was derived from the inversion of 31,000 body waves, 9300 fundamental and 1400 overtone surface waves. The data were extracted from the IRIS DMC and the Geoscope data center, and correspond to events of magnitude larger than 5.5 for the period 1977-1994. To illustrate our model, we give an example of vertical cross-section across the African “plume” (figure), distinctly showing a strong and wide low velocity anomaly at the base of the mantle, narrowing as it rises high into the lower mantle, and shifting to the northeast with increasing radius. This anomaly appears to continue into the upper mantle and is deflected horizontally as it encounters the cold African continental root.

For further reading:


An Analysis of Large Scale Variations in Small-Scale Mantle Heterogeneity: Using IRIS GSN Recordings of Precursors to PKP

Michael A.H. Hedlin and Peter M. Shearer, University of California, San Diego

High-frequency precursors to the core phase PKP are caused by scattering off heterogeneities in the lowermost mantle and D" regions and provide a unique window into the small-scale structure of the deep Earth. We study lower mantle scattering by analyzing 412 high-quality PKP precursor records at ranges between 120° and 137.5° as obtained from the IRIS GSN during the last ten years. To examine regional variations in scattering strength, we compare individual records with the globally averaged PKP precursor stack of Hedlin et al. (1997). We identify strong differences in apparent scattering strength among specific source-receiver paths. Inversion of these data for scattering source regions is complicated by ambiguity between source- and receiver-side scattering and the sparse and uneven data coverage. Synthetic tests, however, suggest that inversions with applied smoothness constraints can resolve large-scale differences in scattering strength over significant parts of the lower mantle. We use a conjugate gradient method based on an approximation to Rayleigh-Born scattering theory to image differences in the average strength of scattering within the lowermost 1000 km of the mantle. Our results, shown in the figure above, indicate particularly strong scattering beneath central Africa, parts of North America, and just north of India, whereas weaker scattering is seen beneath South and Central America, eastern Europe and Indonesia. Some regions of strong scattering correlate roughly with large-scale anomalies revealed by seismic tomography including the African plume and the Tethys trench. These correlations are tentative rather than definitive because bootstrap resampling tests show that many details in our model are not reliably resolved and the network data alone do not permit complete resolution of the source-receiver ambiguity in all areas. Further progress in this area will require integration of available network recordings with data collected by regional networks and arrays, and consideration of the phase velocity of the precursors as well as their temporal variations.

For further reading:
This figure shows the S velocity anomalies beneath the Western Pacific and South East Asia as derived from a waveform inversion of 4038 regional seismograms from the Global Seismographic Network. The high-velocity root beneath the western Yangtze Craton is the fastest anomaly in the whole region in the 120-300 km depth range. Sites of abundant Cenozoic intraplate volcanism are located in the northeastern corner of the East China Foldbelt, South China including the Hainan Island, and eastern Indochina. Prominent low-velocity anomalies underly these locations at 150 km and deeper. A significant slow anomaly is located beneath the Hainan Island region and seems to be continuous in the 100-660 km depth range. A major high-velocity anomaly occupies the transition zone beneath the eastern Sino-Korean Craton.

For further reading:
To improve the tomographic resolution of upper-mantle structure beneath the western Pacific basin, we collected extensive sets of frequency-dependent travel times from circum-Pacific earthquakes recorded by broadband seismometers in this region. A variety of seismic phases were analyzed in the band 10-50 MHz, including direct and multiple S waves, Love and Rayleigh surface waves, and ScS reverberations. We primarily employed sources from the seismic zones from Tonga to Japan distributed at distances of 40-75 degrees around the Hawaiian Islands, and particular emphasis was placed on event sets spanning the full range of focal depths. In our initial experiments, we inverted the data from individual source arrays in the New Hebrides, Solomon, Mariana, Izu Bonin-Ryukyu, and Japan island arcs for two-dimensional vertical tomograms of mantle structure using the technique described by Katzman, Zhao, and Jordan (1998) in their initial study of the Tonga-Hawaii corridor. The 2-D tomograms for these corridors were generally consistent with previous tomographic results, although they show upper-mantle features that are smaller in scale and larger amplitude than published global models. Resolution tests confirmed the ability of the data sets to resolve upper-mantle shear-velocity structures along individual corridors with scale lengths less than 1000 km horizontally and 200 km vertically, although this resolving power diminishes rapidly below the 660 discontinuity. We then inverted the entire data set from all corridors for a 3-D model of the western-Pacific upper mantle. At low wavenumbers, this regional model is consistent with large-scale features found from global tomography. For example, the uppermost mantle (< 200 km depth) shows fast anomalies in the interior of the Pacific plate and slow anomalies in the marginal basins along the Pacific rim, while this pattern is reversed in the transition zone (400-700 km). However, our model displays greater lateral heterogeneity in both isotropic and anisotropic structure than the global models, especially in the 200-400 km depth range, which can be attributed to the better resolution of small-scale features by our data set. Fast and slow anomalies in isotropic shear speed, some extended subparallel to the Pacific plate motion, are observed in the upper mantle. In particular, the Hawaiian Swell is underlain by a fast anomaly in the uppermost mantle and a slow anomaly in the transition zone. Near Hawaii, the amount of radial anisotropy is smaller than its surrounding regions, which is inconsistent with a recent study of global anisotropy by Ekström and Dziewonski (1998). Our tomographic results for the southwestern Pacific indicate that the upper mantle in this region is chemically heterogeneous and dynamically active.

**For further reading:**


Survey of Precursors to P’P’: Constraints on Mantle Discontinuities

Fei Xu, Paul S. Earle, and John Vidale, University of California, Los Angeles

Abrupt jumps in velocity and density near 410- and 660-km depths have been postulated to mark phase changes, however, because the reported details of these discontinuities vary in different studies, it has been difficult to say whether the phase-change explanation has difficulties.

We have systematically collected high-quality recordings of the seismic phase P’P’ and its precursors. The phase P’P’ reflects from the surface once 145° from the earthquake, then arrives at the station 290° away (70° the other way round). The data come from the GSN FARM database, regional networks in California and the LASA array in Montana.

First, we searched the FARM database for P’P’ precursors. In order to collect precursors with the highest signal-to-noise ratio, we collected more than 1200 vertical-component, broadband records of events larger than Mw 6.3 recorded in the distance range 67° to 73°. The broadband traces were filtered to retain mainly 1-s-period motions and the records with low signal-to-noise ratios or protracted P’P’ coda were discarded. This reduced the dataset to 91 seismograms.

An increase in the envelope is visible at the expected time for P’660P’. The amplitude of the P’660P’ arrival, 4% of P’P’ after correction for attenuation, matched that observed at long period. The distribution of bounce points for the 91 P’P’ arrivals is mostly beneath the middle Americas and Asia, but spans several styles of surface tectonics. We expect this sampling of the upper mantle discontinuities to be relatively unbiased.

Next, we examine network data, which has greater sensitivity due to a larger numbers of stations. As we did with the GSN data, we filter, select good traces, and stack. P’P’ has two more transits through the shallow mantle than its precursors, which will cause more attenuation than experienced by the precursors.

The stack of the network records is shown in the figure. It is clear that “660” is generally more reflective than the “410” for 1-s period P waves. Further, the amplitude of the precursors from the “660” are consistent with most of the velocity contrast occurring with just a few km, and the “410” being more diffuse.

These new data are consistent with the details predicted for the “410” by Stixrude (1997), rendering additional complications such as compositional variation, nonequilibrium transformation, or the influence of water unnecessary across the region that we sampled.

For further reading:


Topography on the 410-km Discontinuity Near Slabs

Megan P. Flanagan, Lawrence Livermore National Laboratory
Peter M. Shearer, University of California, San Diego

Mercator projection of the South America and Tonga subduction zones together with the bounce point locations of s410S (red circles), s410P (green triangles), and p410P (yellow squares) as they sample 400 km depth. Contours of the subducted lithosphere are shown at the surface trench (long-dashed line) and at 400 km depth (solid line) as taken from Gudmundsson and Sambridge (1998), and from an earlier study of Billington (1980) in Tonga (short-dashed line). Clusters of bounce points for which we obtain estimates of the 410 discontinuity are circled with labels corresponding to the 410 depths we measure from the subgroups in the actual data stacks.

Topography on the 410-km discontinuity in several subduction zones is measured from examining sS, sP, and pP precursors as observed from stacking long-period records from deep earthquakes. Rather than focusing on a single subduction zone or phase geometry, we adopt a comprehensive approach which incorporates all data currently available from the global digital archives maintained at the IRIS DMC in order to identify consistent features in the data and map lateral variations in the 410 wherever possible. We stack the teleseismic depth phases sS, sP, and pP produced by deep focus earthquakes to image precursory arrivals that result from near-source, underside reflections off the 410-km discontinuity and use differential time measurements between these phases and their precursors to compute discontinuity depths near seven subduction zones around the Pacific Ocean margin. We find approximately 30 km peak-to-peak topography on the 410 near some slabs which is consistent with the expected thermodynamic response of the olivine phase changes at 410-km depth to the colder temperatures of subducted lithosphere. Near most slabs the results indicate little change in the average depth to the 410-km discontinuity in the local areas sampled by the precursor bounce points compared to broad regional depths inferred from SS precursor results (Flanagan and Shearer, 1998). This implies that any large variations in depth to the 410-km discontinuity near subduction zones are limited to a narrow zone within the slab itself where they may be difficult to resolve with long-period data. Coverage for the Tonga and Peru-Chile subduction zones is sufficiently dense that we can observe lateral variations in 410 depths. The discontinuity depth appears to vary from the northern to the southern part of the slab beneath South America with the 410 being uplifted by about 10 to 18 km in the northern region. In Tonga the results suggest depth variations perpendicular to the slab of up to 33 km, after correcting for probable lateral heterogeneity in velocity above 400 km depth, and variations parallel to the slab orientation as large as 13 km. The cross-slab variation is consistent with the elevation of olivine phase transformations in cold regions; the variation along strike suggests a more complex thermal heterogeneity that may be related to the subduction history of the Tonga-Fiji region.

For further reading:
We analyze whole broadband seismograms containing triplicated S, SS, SSS and ScS which sample the sub-East Pacific Rise mantle to assess Transition Zone topography. We simultaneously model all body waves traversing depths from the lithosphere to the core-mantle boundary, thereby eliminating depth-velocity ambiguities. Data consist of western North American broadband recordings of EPR-affiliate transform events that form a continuous record section from 26° to 82° and sample nearly the entire East Pacific Rise. We find no discernible variation in apparent depths of the 405 and 660 Km discontinuities over ridge-orthogonal distances on the order of 1000 Km (or 20 MA crust). High frequency waveform comparisons indicate we can resolve discontinuity depths to 5 Km, providing an upper limit to Transition Zone topography. These depth estimates exclude the possibility of short-wavelength Transition Zone topography which could escape previous SS precursor analyses, and show that nowhere along the sub-EPR Transition Zone is markedly different from the global average. The striking homogeneity of the sub-EPR upper mantle requires that spreading ridge can not be actively supplied from the local lower mantle, and that tomographically imaged lateral variation beneath the ridge likely reflects lateral smearing of outlying velocity gradients. Dynamically, the Transition Zone therefore appears vertically decoupled from overlying East Pacific Rise.

Modeled S, SS, SSS, and triplicated ScS. Regional Transition Zone thickness variation would be manifested as systematic misfit in sub-phases of the SSS triplication, which is not observed. These data are fit with three different lithospheric Lid thicknesses (V, 4.55 Km/S). At 57° to 61° (sampling oceanic plate with age ~12 Ma), the synthetics are computed with a Lid of 73 Km, which grows to 76 Km for data between 62° and 66° (~13Ma). At ranges of 68° to 78°, the modeled Lid thickness is 58 Km thick, reflecting the first surface bounce near the East Pacific Rise ridge crest. The largest mis-fit in the record section is the ScS phase on stations ARC, WDC, MIN, and ORV, may reflect heterogeneity in D'.
The upper mantle seismic discontinuities provide important constraints on models of mantle composition and dynamics. New observations of reflected and converted phases from the discontinuities have made possible more detailed measurements of discontinuity structure than are provided by traditional analyses of refracted waveforms. This figure shows stacks of long-period data from the global seismic networks obtained from the IRIS DMC, including over 13,000 transverse component and 25,000 vertical component records between 1976 and 1997. To enhance the visibility of the discontinuity reflections, we align the seismograms on the maximum amplitudes of SS and PP and stack the data in bins of constant source-receiver range. The underside discontinuity reflected phases $S_{410}S$ and $S_{660}S$ are visible in the transverse component stack, arriving 2 to 4 minutes before the direct SS phase, while the underside $P$ reflection off the 410-km discontinuity, $P_{410}P$, is seen in the vertical component stack. By analyzing the timing differences between these discontinuity reflections and the main phases, it is possible to map large-scale variations in discontinuity topography (e.g., Flanagan and Shearer, 1998, 1999). These maps indicate the following: (1) The amplitude of the large-scale 660 topography is significantly greater than the 410 topography, (2) The topographies of the 410 and 660 discontinuities are largely uncorrelated, (3) The power in the observed topography at long wavelengths is dominated by low spherical harmonic degree, and (4) Depressions in the 660 km discontinuity are correlated with subduction zones, consistent with the response of the 660 phase change to cooler temperatures. A depression in the 660-km discontinuity near the subduction zones in the northwest Pacific is particularly well-resolved due to the dense data coverage in this region.

The amplitudes of the 410 and 660 underside reflections are also examined to measure the velocity and density jumps across these discontinuities. This is done by modeling the observed range dependence of the $S_{410}S$, $S_{660}S$, $P_{410}P$, and $P_{660}P$ phases. The PREM is within our computed 95% confidence ellipse for the 410-km discontinuity but well outside the allowed jumps across the 660-km discontinuity. Current pyrolite mantle models appear consistent with our constraints for the 410-km discontinuity but overpredict amplitudes for the 660-km reflections. The density jump across the 660-km discontinuity is between 4% and 6%, substantially below the PREM value of 9.3% commonly used in mantle convection calculations.

The potential of upper-mantle discontinuity phases to resolve mantle structure has only begun to be tapped. Migration methods (e.g., Shearer et al., 1999) can be used to improve the resolution of the images and reduce diffraction artifacts. The amplitudes of the discontinuity phases provide direct constraints on the velocity and density jumps across the interfaces. Because individual discontinuity phases are very weak, large numbers of seismograms must be analyzed to obtain reliable results. The IRIS program has been a key factor in the success of these efforts, facilitating ready access to high-quality global datasets.

For further reading:
Looking at ULVZs With Data Available Through the IRIS DMC

John Castle, Massachusetts Institute of Technology

The details of the state of the bottom of Earth’s mantle are difficult to characterize. However, these “details” may have large effects on Earth processes such as hotspot genesis, heat transport across the core-mantle boundary (CMB), and magnetic field reversals.

Excitingly, distorted waveforms suggest that 5-40 km thick zones of distinct material with ultra-low \( V_p \) wavespeeds (ULVZs) exist just above the CMB (e.g., Garnero, 2000). Evidence for these zones is found most frequently within broader slow regions at the base of the mantle but also found within some broad fast regions, such as at the base of the mantle beneath the Gulf of Alaska. Additionally, evidence for ULVZs has come from \( V_p \) observations but not \( V_s \) observations.

Because of the archive and data request facilities available at the IRIS DMC, I was able to investigate ULVZs beneath the Gulf of Alaska and Central America regions (Castle and van der Hilst, 2000). The datasets available from IRIS included seismic waveforms from high-density seismic networks. By comparing waveform shapes and amplitudes, these seismograms showed that the waveforms of phases reflected at the CMB (PcP, ScP) beneath Central America can be well-modeled using the PREM model. Similar waveforms from the Gulf of Alaska cannot be modeled by the PREM or AK135 model. Furthermore, including an ULVZ with a \( V_s \) decrease makes the waveform fit worse. The best way to model the waveforms in this region is with very low shear wave attenuation (\( Q_s > 600 @ 1Hz \)) and high, not low, \( V_s \) wavespeeds. Either this area is an ULVZ for \( V_p \) and a high-velocity zone for \( V_s \) or the previous observation of an ULVZ in this region is in error.

Should the latter be true, it would reinforce a one-to-one correlation between broad slow regions at the base of the mantle and the presence of ULVZs. If ULVZs are found only in slow regions, regions that are likely to be warmer than the surrounding ambient mantle, and not found in cold regions, it becomes more plausible that ULVZs are accomplices in plume genesis.

As further data from dense seismic networks become easily available, such as through the IRIS DMC, we will be able to better describe the base of the mantle and understand its many influences.

For further reading:


Sample Publication List

Below is a partial list of publications that have appeared in the following 15 journals during the 1999 calendar year and that specifically acknowledge IRIS data or instruments.

Bulletin, Geological Society of America
Bulletin, Seismological Society of America
Earth and Planetary Science Letters
Geology
Geophysical Journal International
Geophysical Research Letters
Journal of Geophysical Research
Nature
Physics of the Earth and Planetary Interiors
Pure and Applied Geophysics
Reviews of Geophysics
Science
Seismological Research Letters
Tectonics
Tectonophysics


Nowack, R. L. and W.-P. Chen “Source-receiver reciproc-


Winslow, N. W. and L. J. Ruff “A hybrid method for calculating the radiated wave energy of deep earthquakes.” *Phys-


