ANALYSIS OF UPPER MANTLE P WAVE VELOCITY STRUCTURE BENEATH N. AMERICA AND EASTERN EUROPE USING P AND PP PHASES

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There is strong evidence for large lateral variations in both P and S wave upper mantle velocities beneath continental regions. Lateral variations in shear wave velocity persisting to depths of 400 km beneath North America have been demonstrated (Grand and Helmberger, 1984). The corresponding depth extent of variations in P wave velocities has not yet been established. The use of SS phases to extend the distance range sampling the upper mantle has been instrumental in the development of distinct shield and tectonic shear wave models. We have exploited PP phases in a similar manner to investigate the lateral variations in upper mantle P wave velocity structure beneath North America and eastern Europe.

Figure 1 highlights the regions of the upper mantle sampled by our data set and Figure 2 shows the corresponding velocity models derived for each region. Appropriate velocity models were determined by modeling the observed P and PP travel times and waveform characteristics using synthetic seismograms. The use of PP phases in the modeling procedure has several advantages over direct P observations, such as an increase in the distance range sampling the upper mantle, a doubling of the time and distance between triplication arrivals, and a reduction in source area anomalies due to local structure or event mislocation, through the use of PP-P differential arrival times. Synthetic seismograms were constructed using the WKB technique of Chapman (1978). For the southern shield (PS2) and tectonic regions (PT2) of North America and the Russian Platform (PS2), we used published upper mantle P wave velocity models as starting models which we adjusted to fit the observed data. We constrained all models to be identical below 280 km. Model PSN42, which samples the northern Canadian Shield, was only slightly altered from a model of Lefèvre and Helmberger (pers. comm., 1987) in order to match the other velocity models below a depth of 280 km.

Observed and synthetic data profiles for the four different regions are shown in Figure 3. The North American data consist of long-period Worldwide Standardized Seismic Network (WWSSN) and Canadian Seismograph Network (CSN) recordings of shallow earthquakes in the Arctic, Mexico and Alaska. Our data traversing eastern Europe consist of broadband recordings of a shallow earthquake in the U.S.S.R. on 19 March 1984, by the Network of Automatically Registering Seismographs (NARS) and the Digital Worldwide Standardized Seismic Network (DWSSN) which have been converted to the response of the WWSSN long-period instrument for direct comparison with the North American data. The resulting P wave models (Figure 2) reveal a continuous spectrum of lateral variations in velocity beneath North America. The fastest velocities were obtained beneath the northern shield, becoming progressively slower beneath the southern shield and tectonic regions, respectively. The upper mantle beneath the Russian Platform appears to be most similar to the southern shield region of North America; both areas were successfully modeled with the same velocity structure (PS2).
Lateral variations in the P wave velocity models have been successfully constrained to occur above 280 km; however, recent work on upper mantle shear wave velocities indicate that substantial differences must occur to depths of 400 km (e.g., Grand and Heimberger, 1984; Lerner-Lam and Jordan, 1987). The apparent difference in the required depth extent of lateral variations in the P and SH wave velocities has important implications for the thermal and chemical structure of the upper mantle. In order to further investigate possible differences in upper mantle P and SH velocity structures, we examined broadband NARS seismograms sampling the Russian Platform–Alpine tectonic boundary. Rial et al. (1984) report a sharp transition in shear wave velocity from a fast shield–like structure beneath western Eurasia to a slow tectonic–like velocity structure beneath western Europe that is coincident with the northern boundary of the Alpine belt. Figure 4a shows some of the WWSSN long-period SH data that Rial et al. modeled. Paths that are contained mostly within the Russian Platform (event 3 to COP) are well matched with the shield model SNA, while paths that are predominantly within the Alpine tectonic zone are better matched with the tectonic model TNA. Although the transition from a shield (PS2) to tectonic (FT2) structure is less obvious in P wave synthetics than for SH wave synthetics, the NARS broadband waveforms we examined, that sample the Russian Platform and Alpine tectonic province, do not indicate a sharp upper mantle velocity transition between them (Figure 4b). The NARS recordings of the event on 19 March 1984 are well modeled assuming a shield–like upper mantle structure. NARS recordings of an event to the south on 29 April 1987 are also well modeled with this structure, even for paths that have large portions in the Alpine tectonic province (Figure 4b). This provides further evidence for a difference in the nature of lateral variations of upper mantle P and SH velocities.

To test the accuracy of the velocity models derived from long-period data, we modeled broadband data sampling the Russian Platform and North America. The broadband data profile of the 19 March 1984 U.S.S.R. event is very well modeled with synthetics computed using velocity model PS2 (Figure 5). Broadband Regional Seismic Test Network (RSTN) recordings of a shallow event in Mexico on 9 May 1983, which sample the upper mantle beneath the central and eastern United States, are slower than predicted by model PS2, and are better fit by model SNA (Figure 6), a modification of the P wave model S8 of Burdick (1981).

A summary of our P wave velocity modeling is shown in Figure 7. The P wave data sampling several regions of North America and Europe, reveal a spectrum of upper mantle velocities that is dependent on the tectonic province traversed; all of the P wave models are able to match the observed data with the constraint that the velocity structure below a depth of 280 km be identical in each region. Shear wave velocity models derived for the upper mantle beneath North America (SNA and TNA) by Grand and Heimberger (1984), and successfully used to model data sampling the upper mantle beneath Europe and Eurasia (Rial et al. 1984), require lateral variations that persist to a depth of 400 km (Figure 7). The difference in lateral variations of upper mantle P and SH wave velocities suggests that thermally induced processes, rather than chemical differences, may be responsible for the variations at depths below 280 km. Further confirmation of the difference in the required depth extent of lateral variations in P and SH wave velocities is important to understanding the thermal and chemical structure of the upper mantle.
References


Figure 1. Equal area projections of North America and Europe showing the regions of the upper mantle sampled in this study.

Figure 2. P wave velocity models appropriate for the different regions indicated in Figure 1.
Figure 3. Observed and synthetic profiles showing the four different geographic regions. Travel time curves for the appropriate velocity model are superimposed, the data have been aligned on the expected P wave arrival time.
Figure 4. a) Figure from Rial et al. (1984) showing observed and synthetic SH wave seismograms computed for shield and tectonic models SNA and TNA respectively. The dot-dash line represents the boundary between the Russian Platform and Alpine belt. Paths that sample the Alpine tectonic region are best matched by model TNA, while the path predominantly sampling the Russian Platform is better matched with model SNA. b) Broadband P wave observations sampling this same region do not appear to require an abrupt transition in upper mantle velocities. Sheld model PS2 fits paths sampling the Russian Platform–Alpine tectonic boundary, two distinct models are not necessary to match the P wave data.
Figure 5. Observed and synthetic broadband profile of NARS and DWSSN recordings of the 19 March 1984 event. Shield model PS2 fits the data quite well.
Figure 6. Comparison of observed RSTN recordings and synthetics of a Mexican event on 9 May 1983. The synthetics computed for shield model PS2 are too fast, slower model SBA provides a better match to the observed data.
Figure 7. Summary of upper mantle $SH$ and $P$ wave velocity models. $SH$ models require differences that persist to 400 km, while $P$ waves require differences to only 280 km. The difference in the required depth extent of lateral variations in $P$ and $SH$ wave velocities has important implications for the chemical and thermal structure of the Earth.