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LOWER MANTLE INHOMOGENEITIES INFERRED FROM PcP PRECURSORS

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Abstract. A search of phases arriving between P and PcP, the reflection from the core-mantle boundary (CMB), was performed in the Bulletins of the International Seismological Center (BISC). The distribution of the turning/reflection points of anomalous waves in the lowermost mantle indicates the areas which are possibly anomalous regions. The regions exhibiting these anomalies cover only a small fraction of the lowermost mantle sampled. The areas which can be associated with anomalous arrivals are the lowermost mantle under the North Pole region, northern Siberia, central Siberia, western Mongolia, Afghanistan northeastern China/Korea and the North Atlantic Ridge. These are the regions which should be studied in more detail by analyzing the seismograms, i.e. the amplitude and waveform information, at the corresponding stations in addition to the travel time information reported to the ISC.

Introduction

The structure of the lowermost 200 km of the mantle, also called D'', is of crucial importance for many geophysical disciplines since such diverse fields as mineral physics, seismology, geothermometry, geodesy, geodynamics, geochemistry and geomagnetism are affected by processes at the CMB (see e.g. Lay, 1989 for a review). Long-period S-wave observations (Lay & Helmberger, 1983; Young & Lay, 1987) indicate a discontinuity in D'' in the S-wave velocity, whereas Schlittenhardt et al. (1985) present evidence against such a discontinuity in P and S velocities as a global feature. The study of P-waves by Ruff & Lettvin (1984), Wright et al. (1985), Schlittenhardt (1986), Doornbos et al. (1986) and Baumgardt (1989) establishes that the P velocity of the lowermost mantle varies laterally. The global tomographic inversions of P travel times (Dziewonski, 1984; Inoue et al., 1990) and the stochastic analysis of the P travel times (Gudmundsson et al., 1990) also show relatively large perturbations in D''.
Davis & Weber (1990) and Weber & Davis (1990) observe a prominent anomalous phase arriving between P and PcP at the GRF array from events in the southern Kurile Island subduction zone. They show that this phase (PdP) is a reflection from a small scale P velocity anomaly of a few hundred kilometers lateral extension below northern Siberia. The best fitting model gives a P velocity jump of 3% approximately 290 km above the CMB. The fact that for these events other central European stations also report similar arrivals suggests the possibility of using the BISC to detect such anomalies and employing the information given in the bulletin to search for other regions where such anomalies might occur. Knowledge of the northern Siberia anomaly can then be exploited to test such an analysis of the ISC database.

Data

The ISC compiles arrival times of seismic phases and other parameters that are contributed by over 1,500 globally distributed stations. These individual reports are associated with seismic events and are published in the BISC. We use this data set for the years from 1964 to 1987. Our approach is somewhat different from that in tomography (e.g. Dziewonski, 1984). We use later phases and their travel time *difference* with respect to P instead of the travel times of P to determine the lateral inhomogeneity of the lower mantle.
We choose only events with focal depth deeper than 100 km to be sure that surface reflections (i.e. the pP-phase) arrive after PcP. The body-wave magnitude ranges from 5.0 to 6.0 since smaller events will usually not be reliably detected and larger earthquakes often have a more complicated source wavelet. To guarantee that only well-located events are used in this analysis a final requirement for the source selection was that the number of stations reporting P arrivals is larger than 40 and that the standard deviation of the P residual be smaller than 2 s. For the 4380 events meeting these requirements we use stations in the distance range from 70^o to 80^o. Only in this distance interval can a lower mantle velocity contrast of a few percent produce a sizable reflection and the separation of P and PcP is still several seconds. For details see Weber & Davis (1990).
To indicate the time segment between P and PcP in which anomalous phases can be identified, Figure 1a gives the travel time for these two phases for a Jeffreys-Bullen velocity model and a source depth of 100 km. The time segment containing the anomalous phases is the shaded area after P and before PcP, where a safety margin of 2.5 s in front of PcP was chosen. *All* arrivals falling in this anomaly wedge are considered anomalous phases since standard earth models do not predict phases there. The anomaly wedge is different for different source depths. The choice of the earth model is not crucial since the anomaly wedge is defined by the travel time *difference* of PcP and P and not by the absolute travel times. Histograms for all arrivals reported after P are shown in Figure 1b. The data are segmented into five distance bins of 2^o width. The distance range from 68^o to 70^o is also given. The theoretical PcP-P travel time difference is subtracted from the observed travel time difference between the additional phase

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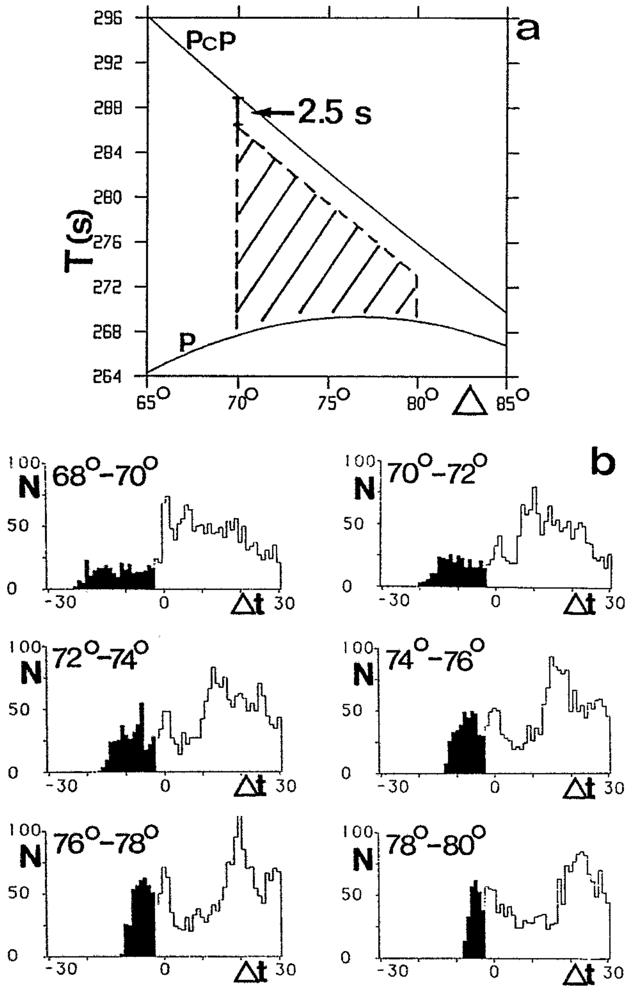

Fig. 1. (a) Travel time of the P- and PcP-phase with the *anomaly wedge* (shaded area) which contains the anomalous phases. (b) Histogram sections for phases reported after P, plotted with respect to the theoretical PcP-P travel time difference for six different distance ranges. The darkened bins represent phases in the *anomaly wedge.*

and P. Thus the time axis is a residual in travel time difference. PcP-phases are close to $\Delta t = 0$, and the dark parts correspond to the anomaly wedge.

For $\Delta t < 0$ the first histogram (68°-70°) gives an indication of the noise level in the BISC. The phases arriving after PcP are mostly pP-phases. For distances greater than 72°, the distribution over $\pm$ 10 seconds becomes bimodal indicating a population of anomalous phases which arrive before PcP. This indicates that our data set can contain energy which is reflected at considerable distance above the CMB, since the safety margin of 2.5 s corresponds to an elevation of about 150 km, whereas typical values of CMB topography are on the order of some kilometers (Morelli & Dziewonski, 1987). The reason that the number of the anomalous phases is of the same order or even larger than the number of PcP is that the amplitude of PcP *decreases* with increasing distance whereas the amplitude of PdP, i.e. a reflection from the top of D'', *increases* with increasing distance. For a velocity contrast of 2% to 3% and distances larger than 71° PdP has larger amplitudes than PcP. For details see Schlittenhardt (1986, Figure 13) and Weber & Davis (1990, Figure 10, Figure 4b,c).

Interpretation

Energy in the P coda may also attributed to source and receiver effects which are difficult to distinguish from the effect of structure in the lowermost mantle. A first step at reducing these effects is to use a binning concept that stacks the information of many source-receiver pairs that have a common mid-point and thus suppresses the influence of singular source and receiver effects. This binning concept also helps to handle the large amount of data involved. We choose the size of the cells (bins) as 3.6° by 3.6° which results in 2600 cells of equal area. This size corresponds to the effective Fresnel zone, i.e. the zone contributing coherently energy to a reflection, at a frequency of 1Hz.

The location of the bins which contain the turning points of the P-waves in the lower mantle is given in Figure 2a. About 80,000 source-receiver combinations meet the requirements defined in the preceeding section and cover about 44% of the bins, i.e 44% of the lower mantle. Figure 2b shows the bins which have anomalous phases after the P-wave, i.e. the phases in the anomaly wedge illustrated in Figure 1a. Only 25% of the cells covered can be associated with anomalous arrivals. The regions well covered but almost free of anomalous bins are large parts of the Pacific, North America, the Caribbean, southern and eastern Asia. Because of the noise in the ISC data, anomalous phases that do not correspond to earth structure are also present. These arrivals occur by chance and may accumulate in well-sampled bins. This effect is accounted for by displaying the percentage of anomalous versus total hits for each bin in Figures 2c and 2d. This ratio is not well constrained for sparsely sampled bins. This is why we show in Figs. 2c and 2d only the cells which have more than 10 P hits and 60 P hits, respectively, and more than 3 anomalous hits. These bins therefore represent the areas with good source-receiver coverage and a relatively high number of anomalous hits. They cover 7% and 3% of the bins sampled respectively.

Discussion

The regions which are eliminated or strongly reduced in their significance as anomalous bins by this weighting are the areas under the Aleutians/Alaska, southeast of Hawaii, Central America, the region west of the Azores Islands, the Arabian Sea, the West Pacific Rim, the region south of Australia and several areas in Siberia. This shows that the binning and weighting procedure is able to isolate the more significant regions.

The areas left are the North Atlantic Ridge, the North Pole region, central Siberia, western Mongolia, Afghanistan and northeastern China/Korea. The region west of the Azores and the Arabian Sea are possibly also regions with lower mantle anomalies.

The anomalous region beneath northern Siberia was located and analysed before by using array techniques. This feature is confirmed in this study and it is possibly the

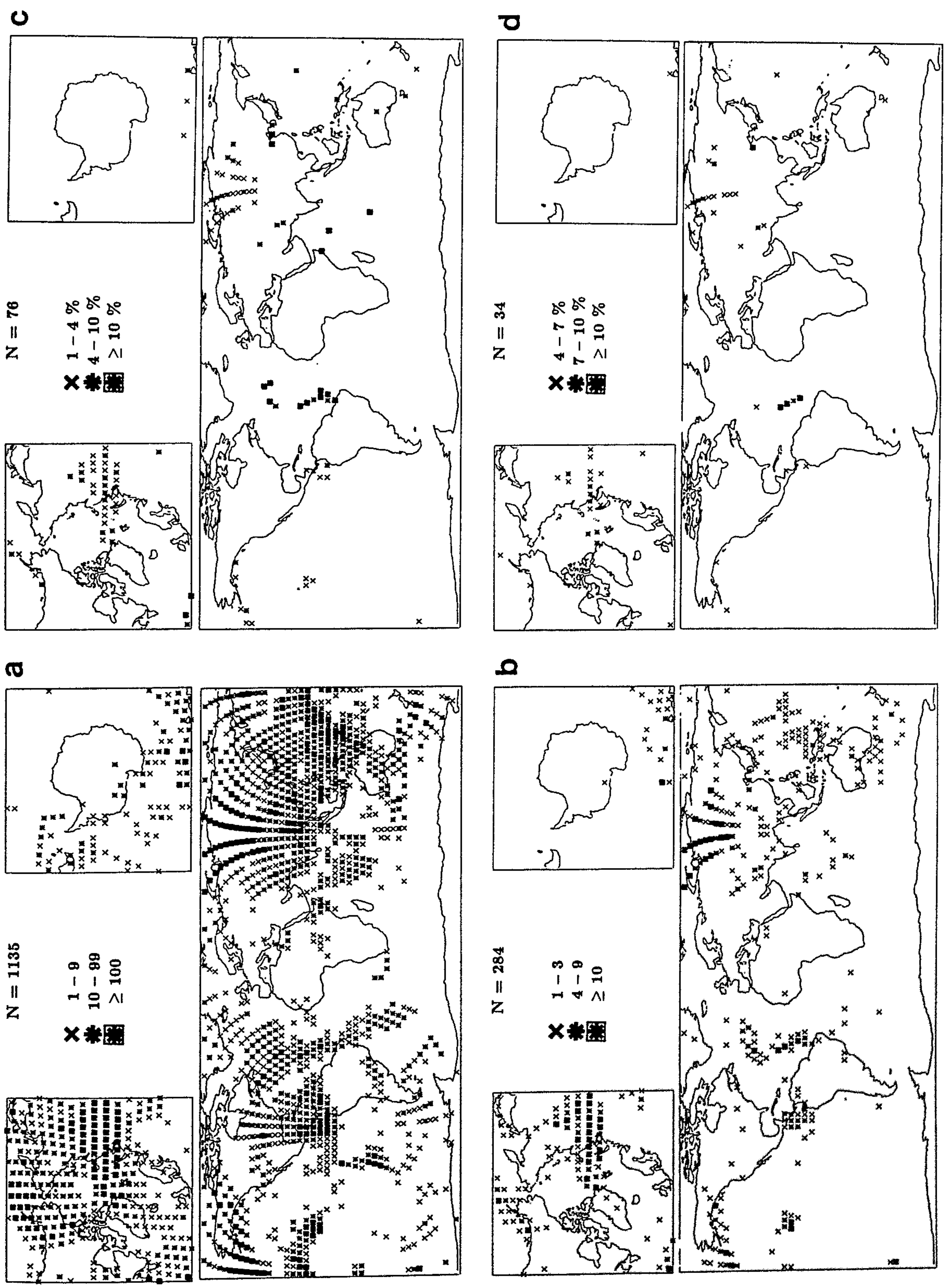

Fig. 2. (a) Distribution of 3.6°x3.6° cells containing the turning points of P *(P hits)* in the lower mantle for the event-receiver combinations used in this study. N is the number of cells hit by P-waves. The number of hits in each individual cell is indicated by the different symbols. (b) As a) but for the anomalous phases, i.e. distribution of *anomalous hits.* (c) Distribution of cells containing more than *3 anomalous hits* and more then *10 P hits.* The percentage of *anomalous hits* to *P hits* in each cell is indicated by the different symbols. (d) As c) but only cells containing more than *60 P hits* are shown.

most prominent anomaly in the lowermost mantle. The reproduction of this feature illustrates the usefullness and feasibility of our approach.

It is interesting to note that two of the anomalous regions in the lower mantle can be correlated with tectonic features, i.e. the North Atlantic Ridge area with the rifting in the Atlantic and northeastern China/Korea with the Japan subduction zone system, whereas the majority of the anomalous regions show no direct correlation to surface features. We would also like to mention that the Earth's magnetic field at the CMB exhibits a major anomaly beneath northern Siberia (Bloxham & Gubbins, 1989), i.e. in an area with a strong velocity anomaly.

Since the selection criteria and the distribution of sources and receivers permits us to investigate only about 40% of the lower mantle, additional lower mantle anomalies may exist in the remaining 60%.

Conclusion

By analyzing the travel time information of the BISC for additional phases between the P- and the PcP-phase we are able to specify regions, covering a few per cent of the lowermost mantle, that are prime candidates for small scale anomalies in P velocity. These areas which should be analyzed further using the *full* information of the seismograms are: the North Pole region, northern Siberia, central Siberia, western Mongolia, Afghanistan, northeastern China/Korea and the North Atlantic Ridge.

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