Introduction

The precursor wavefield to PP, a P-wave once reflected at the free surface between source and receiver, contains information about the structure of the upper mantle. Underside reflections of PP (and SS) beneath the mid reflection point off the upper mantle discontinuities have been extensively used to map topography on the discontinuities and to infer temperature and composition of the upper mantle.

However, additional precursor arrivals that are not related to reflections off the global discontinuities can be detected in short period recordings. These precursors can be easily detected in the 95 to 110 deg distance range due to the velocity structure of the upper mantle [King, Haddon and Husebye, 1975]. These arrivals show slowness strongly different from PP (several s/cg), therefore excluding symmetric underside reflections as their origin. It has been proposed earlier that this energy originates from asymmetric scattering of PP energy in the upper mantle [White and Matheiu, 1969; White, 1972; King, Haddon and Husebye, 1975].

Here, we study earthquakes from the SW Pacific and Indonesia recorded at the Canadian, short-period Yellowknife array (YKA), that show similar precursors as described in the earlier work. Using a frequency-wavenumber analysis we are able to measure the full slowness vector of the precursor energy. Using this information we can trace the energy back to the likely position of the scatterer or reflector by fitting slowness (s), backazimuth (θ) and differential traveltime (τ) with respect to PP.

We find that many of the precursors can be explained by scattering in or just below the oceanic lithosphere in the Pacific. Nonetheless, more than half of the scatterer positions are located at depths larger than 300 km and show strong correlation to detected fast features in seismic tomography. Our mineralophysical modeling predicts an impedance contrast for the harzburgite to basalt (and pyrolite to basalt) for these mid-mantle depths in agreement with our seismic data, so that we likely detect the remains of subducted slabs in the mid-mantle.

Method

We use the frequency-wavenumber analysis (k-analysis) [Capon 1973] to determine the full slowness vector (slowness and backazimuth) of the precursors. Short time windows (typical 4-6 s) are chosen for the k-analysis. We also measure the differential travel time between precursor and PP. Many of the precursors show rather impulsive onsets. We estimate the differential travel time uncertainty to be less than 1 s.

Using a backtracing algorithm it is possible to locate the likely origin of the precursors. We fit all three measurements (slowness, backazimuth and traveltime) and find the likely reflector (latitude, longitude and depth) by raytracing through a 1D Earth model (e.g., IASP91). We assume that the energy is scattered to P precursor energy at the PP reflection. Scattering combinations such as PP and P3PP were also tested, but it has been found that these combinations did not fit the measurements. Most of the precursors show backazimuths strongly off great circle path, with slownesses smaller than PP, which indicates an origin on the receiver side of the path.

Discussion and Interpretation

Results 1

We detect 116 precursors from the 21 events. 110 of these allowed a successful backtracing to its origin, while 6 precursor measurements were rejected and could not be traced back to a PP scattering location. More than half of the scatterers can be mapped to depths larger than 400 km. Scatterers in the upper mantle are likely related to scattering in the oceanic lithosphere or shallow upper mantle. Precursors show a high correlation to fast velocities from tomographic images. The reflectors form shearlike structures between two subduction zones.

The reflectors beneath the Tonga-Fiji and the Mariana subduction zone can be found to depths of 1000 km, thus indicating the penetration of these slabs into the lowermost mantle. Previous studies in the Mariana region show evidence for mid mantle structure at depths of 1100 to 1500 km to the north-east of our study area.

- PP precursors contain information about Earth structure besides what can be resolved from upper mantle discontinuity structure.
- Using array methods it is possible to extract this information of the precursor wavefield to resolve fine-scale Earth structure.
- This experiment using YKA data shows evidence for scattering from small-scale heterogeneities in the oceanic lithosphere.
- Additionally, many deep scatterers can be found mainly beneath the Mariana and Tonga-Fiji subduction zones.

Scatterers have a high correlation to the location of high seismic velocities from tomographic models.

- These scatterers form a shear-like structure that projects to the surface location of the subduction zones.

- Using PP we are able to confirm that subducted material can penetrate into the mantle to depths of at least 1000 km.

- Mineralophysical modeling shows that both the harzburgite-to-basalt and the basalt-to-pyrolite transitions at mid mantle depths can produce the PP precursors.

- Impedance contrast decrease rapidly around 1300 km depth, which might make a detection in the lowermost mantle difficult.