Geophysical Research Abstracts, Vol. 7, 05903, 2005
SRef-ID: 1607-7962/gra/EGU05-A-05903

Upper mantle heterogeneities beneath Archean, Proterozoic and Mesozoic crust of western Canada: Results from LITHOPROBE controlled-source seismic experiments

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BACKGROUND

Observations of upper mantle reflectivity from wide-angle seismic data at numerous locations around the world have been linked to the presence of a heterogeneous distribution of rock types within a broad zone or layer in the upper mantle. This phenomenon is observed in wide-angle reflection data from LITHOPROBE's Alberta Basement Transect [SAREX and Deep Probe experiments of 1995], Trans-Hudson Orogen Transect [THoRE experiment of 1993] and SNORCLE Transect [SNoRE experiment of 1997]. SAREX and Deep Probe image the Archean lithosphere of the Hearne and Wyoming Provinces; THoRE images the Archean and Proterozoic lithosphere of the Trans-Hudson Orogen and neighbouring regions; and SNoRE images the much thinner Mesozoic lithosphere of the northwestern Canadian Cordillera. In all three experiments, the heterogeneities are manifest on the data sections as a coherent coda that develops after the Pn phase beyond offset distances of 300 – 400 km. This coda typically consists of intermittently coherent arrivals with apparent velocities between 8.5 and 8.0 km/s (decreasing with increasing offset) that are continuous over tens of kilometers.

Two-dimensional finite-difference modeling schemes are applied to constrain the position and physical properties of the reflective zones within the subcrustal lithosphere. SAREX / Deep Probe and SNoRE modeling use a 2-D visco-elastic finite-difference routine; THoRE modeling uses a pseudospectral algorithm. In both methods, the upper mantle is parameterised in terms of two media. One medium is the background matrix; the other is statistically distributed within the first as a series of elliptical bodies. Such a scheme is suitable for modeling: (1) variations in lithology ($e.g.$, a peridotite matrix with eclogite lenses) or (2) variations in rheology ($e.g.$, lenses of increased strain within a less strained background.)

RESULTS

Results indicate that the thickness and nature of the heterogeneous upper mantle zone within the subcrustal lithosphere of the two Precambrian regions vary only slightly. Beneath the Trans-Hudson Orogen in Saskatchewan, the layer is best modeled to lie at depths between 80 and 150 km. Based on observations from perpendicular profiles, anisotropy of the heterogeneities is inferred. Beneath the Precambrian domains of Alberta, 400 km to the west, upper-mantle heterogeneities are modeled to occur between depths of 100 and 140 km. In both cases the heterogeneous elliptical bodies within the model have cross-sectional lengths of tens of kilometers, vertical thicknesses less than 1 km, and velocity contrasts from the background of –0.3 to –0.4 km/s.

In contrast, wide-angle reflections from the upper mantle beneath the Mesozoic Cordillera of NW British Columbia can be explained by a heterogeneous zone that occupies the full extent of the thin ($\sim$20-30 km in depth extent) sub-crustal lithosphere below a shallow Moho at 35 km depth. The Pn coda was matched by a fabric of dipping elliptical bodies, 5-20 km long and 1-2 km thick with a small velocity contrast of about +/-0.1 km/s. However, the Pn coda could also be generated by reflections from the top of the asthenosphere or scattering in the lower crust. In this region, coincident near-vertical incidence reflection data do not image these sub-Moho heterogeneities.

We do not have an explanation for the cause of the heterogeneities although we speculate that the layer in the Precambrian regions may have formed by lateral movement of the upper mantle during the tectonic evolution of these regions. Such movement relative to the overlying crust also could have occurred in the Cordillera. Alternatively, or in addition, pods of eclogite could form the heterogeneities, particularly in the Cordillera which has a lengthy history (180 Ma) of subduction from west to east as well as north-south lateral movement.

Deep lithospheric studies such as those described in this contribution provide the potential for overlap between earthquake-source teleseismic methods and controlled-source techniques (refraction, wide-angle reflection and near-vertical-incidence reflection).