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Reflection Moho observations across a continent: Near-vertical incidence and wide-angle reflection data from the Canadian LITHOPROBE project

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Background

The complex, variable nature of the continental Moho suggests that its structure is strongly influenced by compositional variation in the lower crust and upper mantle, which in turn is linked to the tectonic/magmatic history of the lithosphere. To illustrate this variability, we present a lithospheric cross-section that traverses the North American continent at $\sim$50^{o}N. The section is based on LITHOPROBE seismic reflection and refraction data combined with geological information. A large range of tectonic structures of different ages and evolution are sampled. From east to west, the transect crosses the Atlantic passive margin and Grand Banks continental shelf, the $\sim$0.4 Ga Newfoundland Appalachians, the $\sim$1.0 Ga Grenville orogen, the $\sim$2.7 Ga Superior Province, the $\sim$1.8 Ga Trans-Hudson and Alberta orogens, the $\sim$0.1 Ga southern Cordillera, and the Recent Cascadia subduction zone and Juan de Fuca plate. We also present a partial traverse of the continent at $\sim$60^{o}N, which begins in the $\sim$2.7 Ga Slave Province near Yellowknife and proceeds westward across the $\sim$1.9 Ga Wopmay orogen and the $\sim$0.1 Ga northern Cordillera.

The transect compilation includes LITHOPROBE data collected between 1984 and 2000. These are supplemented by data collected by: the Frontier Geoscience Program of the Geological Survey of Canada (1985, 1986, 1989), the ACCRETE transect (1994), and the Scotian Margin Transect (2001). This range of vintages highlights improvements in data acquisition technology and processing techniques during this time interval. Modern near-vertical incidence (NVI) reflection data have better signal-to-noise ratios, and display clearer geometric relationships between the surface, crustal reflection patterns, the reflection Moho, and mantle reflections. The refraction and wide-angle reflection (R/WAR) data yield velocity models from which structural, compositional, and thermal constraints can be inferred. Furthermore, the wide-angle (WA) data also sample the Moho at longer wavelengths and larger incident angles than the NVI data, thereby providing complementary information.

Results

Quantitative analyses are ongoing. However, a number of qualitative observations can be made from the profiles and preceding studies.

1. The Moho (i.e., the crust-mantle boundary as defined by refraction data) depth agrees within error with the NVI reflection Moho in virtually all LITHOPROBE transect regions. This means that the variable, but often distinct, changes in NVI reflectivity of the Moho correspond with a compositional change, responsible for refractions and WA reflections, that occurs over $\sim$1.5 – 4 km (the resolution of Moho depth in most R/WAR velocity models). Therefore, we will use the term seismic Moho unless the discussion requires distinguishing the source of the data.

2. NVI and WA reflections from the Moho exhibit considerable variability in lateral continuity and character. NVI reflections, in particular, range from: a) a narrow, well-defined band of reflections, to b) a drop in reflection amplitudes from a reflective lower crust into a poorly reflective upper mantle, to c) a gradual, poorly defined transition between reflective crust to non-reflective mantle (e.g., *Hammer and Clowes, 1997; Cook, 2002*). The LITHOPROBE data show that a seismic Moho is observed beneath virtually the entire continent. In addition, the full spectrum of reflective patterns are preserved beneath crust stable since the Archean, suggesting that age is poorly correlated with Moho reflectivity. Indeed, NVI and WA Moho reflectivity varies significantly within any given study area. A qualitative comparison between reflection data yields no simple correlations between Moho reflective patterns and specific tectonic processes. However, the LITHOPROBE dataset indicates that well-defined, sharp Moho reflections are linked with major deformational episodes including compression, transpression and extension. Therefore, this suggests that detachment along the Moho transition zone has an important role in enhancing reflective character. Conversely, seismic Moho definition is extremely poor in regions influenced by a magmatic arc.

3. With a few notable exceptions, the Moho is remarkably flat across the continent,

irrespective of the age of the crustal rocks or the time when the last major deformation occurred. Changes often occur beneath major tectonic boundaries, but even this is not always the case. For example, the SNORCLE/ACCRETE transect in northwestern Canada starts in the oceanic lithosphere, traverses across the Phanerozoic Canadian Cordillera and extends across Proterozoic orogens to the Archean Slave craton which includes the oldest rocks yet dated. The seismic Moho's depth is $\sim$27 km beneath the most recently accreted crust, thickens beneath the plutonic suture zone from 30 to 36 km depth, and then, for the remaining 1500 km, remains almost entirely within the depth range of 33-36 km (*Clowes et al., 2005).* In this transect and others, the significant changes in Moho depth occur at relict subduction zones and rifted margins (active and preserved). Only two well-preserved crustal roots are imaged within Canada – beneath the $\sim$1.8 Ga western Trans-Hudson orogen and the $\sim$1.9 Ga Torngat orogen in Labrador. Perhaps crustal roots are only preserved within unextended continent-continent collision zones. This interpretation is consistent with observations elsewhere (e.g., crustal roots beneath Pyrenees, Alps, and Urals).

4. Interestingly, the character of the NVI reflection Moho and the WA reflection Moho are quite different for the same location. Sometimes both datasets yield a very well-defined, sharp reflector, sometimes one is well-defined and the other extremely poor. This variable response provides clues as to the characteristic scales and impedance structure of the crust-mantle transition. The variability must correspond to differences in wavelengths and of the angle of incidence. Other factors that may play a role are the different paths the energy takes through the overlying "crustal filter" and complexity within those paths (e.g., whispering gallery effects).

5. Perhaps the most fascinating aspect of the seismic Moho observations is the preservation of structures that clearly were formed billions of years ago. Classic examples of relict subduction zones beneath the Superior province (2.7 Ga; Abitibi-Grenville Transect, Quebec; *Calvert et al., 1995)* and the Wopmay Orogen (1.9 Ga; SNORCLE transect, Northwest Territories; *Cook et al., 1999*) are astonishingly well preserved. In other areas it appears clear that the Moho has been thermally reset. For example, in the Canadian Cordillera, the NVI reflection data indicate that the Moho acts as a thermally controlled detachment surface (e.g., *Cook et al, 1995*).

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