AN INVESTIGATION OF THE MANTLE-CRUST TRANSITION BENEATH NORTH AMERICA & POISSON'S RATIO OF THE NORTH AMERICAN CRUST

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1 INTRODUCTION

The mapping of Earth's interior is among the most successful achievements in the geosciences. For much of the last century geoscientists and in particular, seismologists, have refined ideas and improved maps of the internal structure of our planet. From elementary observations of Earth's shape, mass, and inertial properties, it is widely accepted that the planet is highly differentiated (Poirier, 1991) with a light, thin crust, lying on a thick mantle, which in turn rests on a dense core. From work based primarily on seismic observations, this differentiated structure can be closely approximated by homogeneous shells of uniform or slowly varying properties of depth (*e.g.* Dziewonski and Anderson, 1981). Material properties change with depth as a result of composition changes, or pressure and temperature increases. Major changes in Earth structure generally represent chemical and/or thermal boundaries, while other global transitions signal the onset and the end of pressure induced changes in mineralogy (*e.g.* Brown and Mussett, 1993).

Earth's outermost "shell" is the crust, which accounts for only a fraction of a percent of Earth's mass and volume (Turcotte and Schubert, 1982). However, the crust is an important geochemical reservoir, enriched with more than 30% of Earth's potassium, uranium, and thorium (Taylor and McLennan, 1995). About 79% of the volume of Earth's crust is continent, 21% is ocean, and the remaining 1% is transitional between the two (Condie, 1993). The crust is about 40 km deep beneath the continents and is composed principally of SiO_2-rich igneous and metamorphic rocks overlain by sedimentary material (*e.g.* Meissner, 1986; Condie, 1993). The continents range in age from the earliest parts of Earth's history to the present; the oldest crustal rocks are about 4 Ga (*e.g.* MacDougall, 1996). The long history of the continents is reflected in their complexity; continental crust can be strongly heterogeneous, even its thickness ranges from about 15 to 70 km. Like the continents, the oceanic crust is a volcanic extract from the mantle but it is structurally and chemically different from the continents. For example, oceanic crust is much thinner, on the order of 7 km (ranges from 5 to 15 km), much younger (< 200 Ma), and chemically more uniform than its continental counterpart.

Beneath the crust is the mantle, the largest component of Earth by volume. The mantle is almost 3000 km thick and composed mainly of ultramafic silicates rich in olivine, pyroxene, garnet, or higher P equivalents (*e.g.* Condie, 1993). The mantle accounts for approximately 83% of Earth's volume, and just under 68% of its mass (Turcotte and Schubert, 1982). At the greatest depths is Earth's mostly iron core, composed of a liquid outer shell (the source of the geomagnetic field) and a solid inner (perhaps anisotropic) sphere. The core accounts for 16% of Earth's volume and 32% of its mass (Turcotte and Schubert, 1982).

1.1 Important Questions

Many questions regarding the details of Earth's structure remain unanswered, and are the focus of ongoing research. In this dissertation I focus on the nature of the continental crust underlying North America. Specifically, I explore the variations in bulk crustal chemistry by estimating Poisson's Ratio, a parameter sensitive to the amount of silica in rocks. The relationship between Poisson's ratio and composition is not unique, but generally provides more information on composition that either P or S velocity alone. I also map variations in the Mantle-to-Crust Transition (MCT) thickness beneath the continent. The MCT may hold clues to the answers to important questions regarding crustal evolution. Is the MCT frozen at the time of creation of the crust? Is it modified only during large-scale plate interactions (subduction, collision) or does it evolve as material is added to the base of the crust during underplating during rifting, plume or other volcanic processes? Can the character of the MCT be related to the recent or ancient geologic history of the region? The work described here does not provide answers to all these questions, but represents a step towards those answers.

1.2 Why North America?

Central to any scientific study are the observations. North America is an ideal field area for this work since it is a composite of tectonic provinces that vary in age and history, and it is the home of many seismic stations that provide a substantial data set for this survey (Figure 1.1). The western cordillera of North America includes the volcanic provinces in Mexico and the U.S. Pacific Northwest, a major strike-slip boundary along the coast of California, the elevated, wide continental rift in the Basin and Range, and the Rocky Mountains. The large, stable eastern portion of the continent hosts the Appalachian Mountains, as well as the shields and platforms that comprise the eastern conterminous U. S. and Canada. Figure 1.1 is a map of the

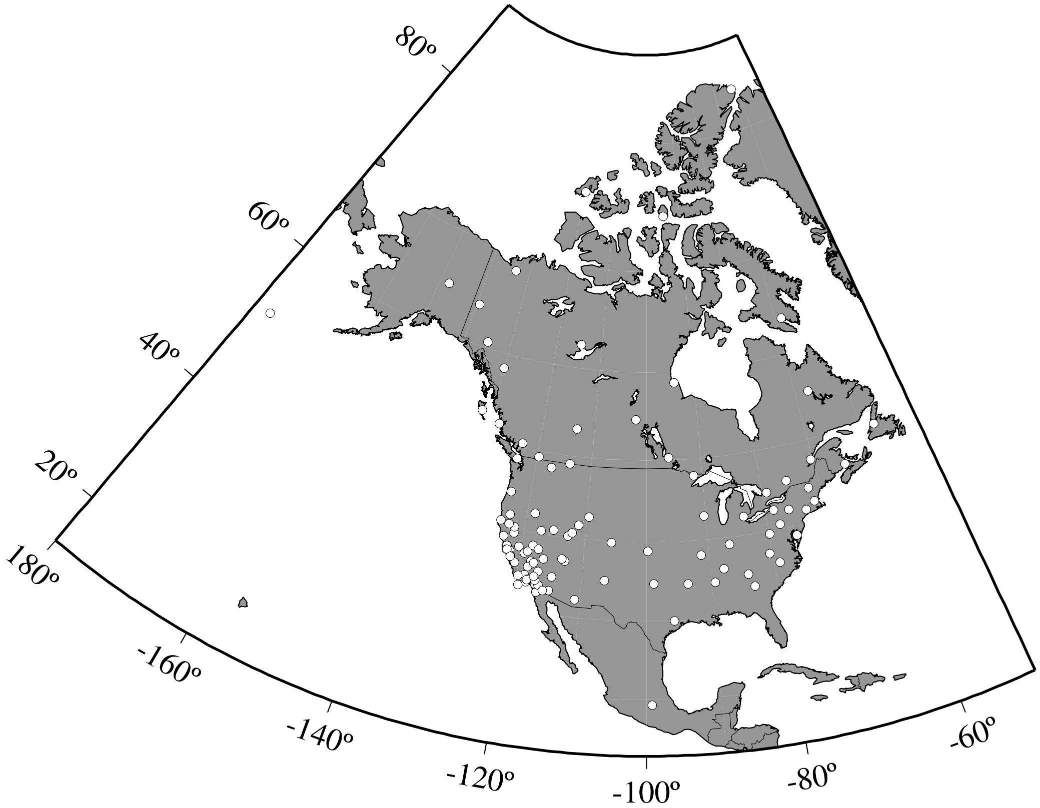

Figure 1.1 Broadband three-component seismic stations over the study area. Each symbol identifies the location of a station used in this work. Permanent and temporary stations are included. Regions of active earthquake activity are much better sampled than the more stable continental interior.

locations of the seismometers used in this study. The stations are concentrated in regions of active tectonics, particularly in the western conterminous United States. Coverage of Mexico is limited to a single station, but Canada has a nice distribution of stations sampling several geologic provinces. Although many of the “older” regions of the continent suffer from less coverage, the number of stations is sufficient to make a first -order investigation of crustal and MCT heterogeneity.

1.3 Methods and Techniques

To estimate Poisson's ratio I use receiver functions to examine the propagation times of P and S-waves traveling between Earth's surface and the MCT (Zandt and Ammon, 1995; Zandt *et al.*, 1995). I also use receiver functions to explore variations in the MCT thickness, but focus on the frequency-dependent amplitudes of waves converting from P-to-S waves at the MCT. The receiver function technique is ideal in regions of simple structure, but has some rather simple assumptions that often are inappropriate in regions of complex structure. Still, the method has proven to be a powerful tool, with relatively easy and inexpensive application, which provides a straightforward approach for imaging seismic velocity transitions in the lithosphere (*e.g.* Ammon *et al.*, 1990; Owens, 1984; Langston, 1979) and upper mantle transition zone (*e.g.* Gurrola *et al.* 1994). Further, recent advances in seismic data collection and storage provide an unprecedented opportunity to gather large amounts of high quality, broadband, data that comprise an ideal data set for this study.

1.4 An Outline

Before launching into the seismological aspects of these investigations, I begin with a review of properties of the MCT and ideas on the evolution of continental crust in Chapter 2. This literature search was written as much for myself as for the reader, but the material forms the background under which the seismological results described in later chapters must be viewed. Since receiver functions are the primary data used in both investigations of the North American crust, I provide an overview of receiver functions and receiver-function methods in Chapter 3. Again, much of this material is available in existing literature, but I also describe the method I developed and used to estimate the MCT thickness, which cannot be found elsewhere. In Chapter 4, an alternative method to calculate receiver functions is described and tested. This method, based on the iterative process introduced to seismology by Kikuchi and Kanamori (1982), results in simpler signals that ease interpretation. Much of Chapter 4 appeared in Ligorría and Ammon (1999). With the reviews complete, I describe the data used in Chapter 5, which includes maps and a tectonic classification used to interpret the results in later chapters. Finally, Chapter 6 is a description of the Poisson's ratio study, using the iterative deconvolution method outlined in Chapter 4. Chapter 7 is a report of the variations in MCT thickness beneath North America. Although some interpretation is included in Chapters 6 and 7, a summary of the results and implications of this work is provided in Chapter 8. Since the data set is large and the interpretation is focussed on medians, averages, and general trends in the observations, I provide many of the detailed numbers and measurements in appendices that follow the main body of the text.