Seismic Tomographic Modeling Of The Coast Mountains Batholith, British Columbia, Canada

Sarah M. Quinonez

University of Texas at El Paso

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SEISMIC TOMOGRAPHIC MODELING OF THE COAST MOUNTAINS
BATHOLITH, BRITISH COLUMBIA, CANADA

SARAH MICHELLE QUINONEZ
Master's Program in Geophysics

APPROVED:

_________________________________________________________________
Aaron Velasco, Ph.D., Chair

_________________________________________________________________
Diane Doser, Ph.D.

_________________________________________________________________
Rodrigo Romero, Ph.D.

_________________________________________________________________
Stephen Crites, Ph.D.
Dean of the Graduate School
Dedication

I dedicate this thesis to my boys! Keith, Julian & Joaquin. As well as my grandparents, Noemi and Julian Padilla influenced the woman I am today, and I would not have been anywhere without their support in all aspects of my life. I am forever grateful for the assistance and support of my wonderful in-laws, Socorro and Pancho; I am truly blessed!
3D SEISMIC TOMOGRAPHIC MODELING OF THE COAST MOUNTAINS BATHOLITH, BRITISH COLUMBIA, CANADA

by

SARAH MICHELLE QUINONEZ, B.S.

THESIS

Presented to the Faculty of the Graduate School of
The University of Texas at El Paso
in Partial Fulfillment
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for the Degree of

MASTER OF SCIENCE

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Abstract

The Coast Mountains Batholith on the west coast of British Columbia, Canada, comprises a series of granitic to tonalitic plutons. The felsic continental crust is generated from mafic oceanic crust subduction by partial melting and fractionation, leaving ultra-mafic roots. In July of 2009, a sizeable controlled-source experiment was conducted along a 400km east-west transect from Bella Bella into central British Columbia. Student volunteers from multiple universities deployed 1,800 one-component and 200 three-component geophones connected to Texan data recorders with 200-m spacing intervals and shot spacing at 30-km. The 18-point sources ranged from 160 to 1,000 kg of high yield explosives. To analyze this data set, I implemented an enhanced 3-D finite-difference tomography approach for P-wave delays times (Hole, 1992) with a graphical user interface and visualization framework developed by colleagues at UTEP's Cyber-SHARE (Center of Excellence for Sharing Resources for the Advancement of Research and Education through Cyberinfrastructure) facility. In particular, to account for model sensitivity to picked P-wave arrival times, I used a model fusion approach (Olaya et al., 2011) to generate a final model with the lowest RMS residual that combines a set of Monte Carlo sample models. I used visualizations of model perturbation at each iteration to troubleshoot when a model was not converging by highlighting where the RMS residual values were the highest and pinpointing where changes were needed to achieve model convergence. In my final model of the upper mantle using 3-D P-wave tomography, I could not resolve depths below 30km and therefore could not image the ultra-mafic roots of the Coast Mountains Batholith.
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Chapter 1: Introduction

The Coast Mountains of western British Columbia, Canada, lie alongside the modern Pacific-North American-Juan de Fuca plate boundary system (Figure 1.1) but formed as a continental arc 160 to 57 Ma. In continental magmatic arcs, an oceanic plate subducts beneath a continental plate of intermediate to felsic composition. At depth, volatiles from the subducting oceanic plate flux the overlying mantle wedge producing mafic melts that rise up to hybridize and assimilate with higher-level crustal rocks (Monroe and Wicander, 1997.; Winter, 2010) (Figure 1.1). Given this mafic source, one would expect the plutons to be predominately iron and magnesium-rich; however, due to partial melting, the felsic material fractionated and rose up, leaving an ultramafic residue. The plutons in the Coast Mountains are granodiorites, mostly felsic to intermediate in composition. The Coast Mountains Batholith (CMB) is a natural laboratory to

Figure 1.1 Block diagram illustrating subduction of Juan de Fuca plate beneath North American plate and proximity to BATHOLITHS seismic survey. Modified from Geological Survey of Canada, Geoscape Series, Open file report 3309 December 2010
study continental crust formation from oceanic crust. In creating a 3D tomographic model, I explore the subsurface in an effort to determine if the batholith has ultramafic roots.

This thesis aims to develop a 3D seismic tomographic model based on $P$-wave arrival times to image the subsurface of the CMB. Using seismic data collected in the summer of 2009 from a 400-km long east-west transect from Bella Bella, British Columbia, into central British Columbia, we attempted to determine where the ultramafic material involved in the subduction of oceanic crust went. During this experiment, 1,800 one-component and 200 three-component geophones connected to 2,400 Texan data recorders were deployed at a 200-m spacing (Figure 1.2). Eighteen explosion sources (termed shots), ranging from 160 to 1,000 kg of high yield explosive, were detonated at 30-km intervals across the survey. The data were processed using the ProMAX® Seismic Processing Software by LandMark to pick $P$-wave arrival times and a specialized Apple/MacOS-platform program, MacR1D released by the Uninvited States Geological Survey (USGS), to generate a 1D velocity model. The data were then used in a 3D tomography code.

Figure 1.2 GMT image showing location of BATHOLITHS seismometer locations as black dots and shot point locations as blue dots with green center, and reference cities as red and red stars.
(Hole, 1992), termed *Hole’s code* throughout this document, enhanced by the Cyber-ShARE (Center of Excellence for Sharing resources for the Advancement of Research and Education through Cyberinfrastructure) Geosciences team at UTEP. The Cyber-ShARE Geosciences team has developed scripts and a graphical user interface to make Hole's software more user-friendly. They have provided 3D visualization techniques that will be discussed further. This thesis intends to examine the benefits of having the shell scripts and 3D visualizations provided by the Cyber-ShARE Geosciences team and compare my results with those obtained by other students at other universities using the same dataset. The purpose of the BATHOLITHS survey is to investigate the processes that generate continental crust through the use of seismic travel time tomography that produces seismic velocity models that define large-scale tectonic features associated with crustal structure (Spence 2007, Averil 2003.)

The work for this thesis began in 2009, which explains why the sources seem dated. While revisiting this thesis for completion, I tried to take a fresh look at more recent research in the survey area. I found that other researchers analyzing the same data set rendered models similar to mine. As technology has developed over time, seismic modeling has seen improved resolution and advancements in equipment. (Witherly 2019)
Chapter 2: Background Geology and Geophysics

The Coast Plutonic Complex of batholiths lies between two tectonostratigraphic superterrains, the Intermontane Superterrane to the east and the Insular Superterrane to the west (Monger, 1982.) (Figure 2.1). The present-day geologic setting results from multiple orogenic events, crustal shortening, and high-grade metamorphism (Monger, 1982.) In the late Proterozoic era (~1 billion to 542.0 million years ago), the North American continent, Laurentia, broke off from the Precambrian supercontinent Rodinia. This rift event led to the development of the World Ocean, Panthalassa. (Johnston and Borel. 2007) Arc magmatism began in the Devonian –

Figure 2.1 Geologic map of the study area, modified from the BATHOLITHS grant proposal to the Natural Sciences and Engineering Research Council of Canada. Spence, (2007)
Mississippian periods when the Farallon Plate began to subduct beneath the North American plate, creating volcanic island belts, including the Intermontane Superterrane (Gehrels et al. 2009.) The North American continent began to move westward about 195 to 115 Ma during the Omineca Episode. It collided with this volcanic island chain, folding sedimentary and igneous rocks and welding them to the coastline to create the Omineca Terrane (Nelson & Colpron 2007) (Figure 2.2). The CMB, a continental arc composed of granitic to tonalitic plutons in four northwest striking belts, formed between 160 Ma and 57 Ma (Hammer et al., 2000) when a pulse of magmatism occurred after the Insular Superterrane, a chain of volcanic islands, collided with the North American Continent in the mid-Cretaceous period (Gehrels et al. 2009, Johnston and Borel.

![Figure 2.2 Tectonic Assemblages and Cordilleran Terranes. Images from Geologic Survey of Canada 2005, modified from Wheeler and McFeely 1991.](image)

2007). Transpressional tectonism occurred 85 to 65 Ma, thickening the crust to about 55 km along with crustal shortening events and vertical accretion of mantle-derived melts (Hollister and Andronicos, 2006). The Coast Shear Zone is the source for much of the metamorphism in the Coast Mountains and the Canadian Cordillera (Klepeis et al. 1998). At this time, the tectonic
regime switched to transtensional deformation, removing approximately 15 km of crust and exhuming the core of the CMB (Hollister and Andronicos, 2006). The 1994 ACCRETE seismic survey, conducted about 300 km northwest of the 2009 BATHOLITHS seismic survey (Figure 1.3), concluded that the thickness of the crust at the northern end of the CMB is relatively thin (~32 km,) most likely due to extension (Morozov et al., 2001; Hammer et al., 2004). The crust further south, near Bella Coola (Figure 2.1), is much thicker (40-45 km), making this an excellent location to examine the crust's original structure, and it is unaffected by extension to the north (Calkins et al., 2010). LITHOPROBE was a comprehensive seismic study of Canadian Geology, with multiple transects covering much of Canada's surface area. The 1984-85 LITHOPROBE, Southern Cordillera transect, was conducted about 300+ km south of where the BATHOLITHS survey was deployed (Figure 2.3). The LITHOPROBE surveys intended to map the subsurface of

![Figure 2.3](www.lithoprobe.ca/transects/sc/summary.asp)
the Canadian mountain belts to determine their origin and evolution in relationship to each other (Varsek et al., 1993). LITHOPROBE has given earth scientists a wealth of knowledge of many geologic processes and historical questions about plate tectonics and geologic history (Clowes, 2011).
Chapter 3: Discussion of Methodological Considerations

3.1 Overview of Seismic Travel Time Tomography

The BATHOLITHS project is a seismic refraction and tomography survey (Figure 3.1). Seismic waves or rays bend at the interface of a velocity change (Stein and Wysession, 2009), and can be used to probe the subsurface for Earth structure. Specifically, using a source (explosion/earthquake) from a specific location, the travel times (generally P-waves) can be measured at a receiver (seismic station) and used to infer the earth's velocity profile through which they propagated, yielding a simple, 1-D velocity model. Travel time tomography uses each ray path from each source to every receiver to calculate the perturbations in the velocity both laterally and vertically across the survey line (Figure 3.1). 3-D seismic tomography can give the highest resolution images from the dataset due to its ability to sense and highlight velocity perturbations horizontally and vertically (Hole, 1992). The purpose of the BATHOLITHS survey is to investigate the processes that generate continental crust, and we use seismic travel time
tomography to produce seismic velocity models that define large-scale tectonic features associated with crustal structure (Spence 2007; Averill 2003).

3.2 Tomography Algorithm (A.K.A. Hole's Code)

I used the tomography algorithm written by John Hole (Hole, 1992), termed Hole’s Code. It is a popular approach due to its ability to produce a tomographic model with suitable resolution in a reasonable time frame. First, $P$-wave arrival times are calculated by solving the Eikonal equation using the finite difference method of Vidale (1988). The travel time residuals from each change in the velocity model are then inverted. It is necessary to input a 1-D starting velocity model, and the code expands the 1-D model to cover the 3-D model space. The inversion reduces the travel time residuals at each iteration after the travel times are calculated from the updated forward velocity model. The model space consists of one km$^3$ cubes, and the rays from the explosions (termed shots) travel through these cubes. All cubes have a different number of rays traveling through them. For each discrete cube in the model space, the average velocity of all rays is calculated. Then, a moving average filter smoothes over the model and assigns velocity values to all cubes based on neighboring cubes. This can cause artificial structures to appear in areas where ray coverage is zero, so the program also keeps track of what areas of the model have coverage so that only those areas are interpreted. I ran sixteen iterations of Hole's Code to receive an acceptable RMS of the travel time residual value of 0.096 km/s.
3.3 BATHOLITHS data set

BATHOLITHS onland deployed instruments and detonated shots in western British Columbia, Canada, in July 2009. We deployed 2,400 geophones attached to Texans recorders during the survey to record these shots, such as the example shown in Figure 3.2. A geophone is an instrument coupled to the ground to record motion, such as the vibration caused by propagating seismic waves. It uses a magnet with a metal coil of wire around it. When the ground vibrates, the magnet, having more inertial mass, moves less efficiently than the coil of wire. The greater motion of the coil of the wire relative to the magnet induces a current in the coils recorded as a voltage proportional to the extent of ground displacement. This voltage is recorded by a Texan, a battery-powered "miniature seismic recorder" (www.reftek.com), as shown in (Figure 3.2).

Most of the geophones in the deployment were 1-component sensors that recorded only vertical ground displacement. A small number of 3-component geophones were also deployed that recorded vertical and horizontal displacement in the east-west and north-south directions.
Each set of geophones in the seismic deployment was connected to a Texan data recorder; the three-component geophones had a Texan recorder for each component. These instruments were spaced 200 m apart, and every tenth deployment included a 3-component (x, y, & z) geophone. UTEP and the IRIS-PASSCAL instrument pool provided the geophones and Texans.

The BATHOLITHS experiment included eighteen shots detonated at a 30-km spacing along the survey line. There was a shot at either end of the line, and the other shots were nearly equally spaced throughout the seismic line. GPS was used to collect latitude, longitude, and elevation data at each station during deployment. This information was essential to run Hole's tomography code and interpret subsequent models (Hole, 1992). The waveform data collected by the Texans was processed into the SEG-Y format by Michelle Kuhn with the assistance of Dr. Steven Harder and Galen Kaip in August of 2009. The SEG-Y format is a standard file format created by the Society of Exploration Geophysicists to store seismic line data (Barry et al. 1975; Norris and Faichney 2001).

For the BATHOLITHS experiment, there were a total of 18 SEG-Y files, one for each shot and each containing data from all 2000 stations in the deployment. In this thesis, sixteen of the shots and 1689 of the receiver stations were used, excluding the two northern seismic lines 101

![Figure 3.3 Texan data recorder stations represented by blue diamonds and shot points represented by red squares. Top plot shows station and shot profile before rotation. Bottom plot shows line rotation of 9° to the south](image)
and 102. (Figure 1.2). I rotated the station and shot profile by 9° south to avoid non-straight line errors (Snelson et al. 2005; Averill, 2007) (Figure 3.3).

Once I obtained the seismic data as SEG-Y files, I used ProMAX®, a part of Halliburton's large Landmark geophysical suite software package, to read the data and pick the first breaks (P-wave arrival times) for each station for every shot point on the survey line. I first uploaded the SEG-Y files into a folder in the Unix computer where ProMAX® would search for these files. Once the data were imported to ProMAX®, I created an area for the BATHOLITHS project. This area housed the lines and flows for further data processing. I processed all of the shots as a singular line; multiple flows were executing different jobs, processing the data with different geophysical methods in this line. (Figure 3.4) Some of the flows told ProMAX® how to organize and store the data; others directed reformatting of the data to create ASCII files used as input for MacR1D and Hole's Code. Several geophysical tools and filters were applied to the seismic data to clean it up.
and make it easier to interpret. A Butterworth filter was used to filter out local noise, such as vehicles traveling along the road and other anthropogenic noise. The frequency limits for the Butterworth filter were 8 – 4 Hz and 40 – 25 Hz, based on examining the range of the frequencies in the data. An Automatic Gain Control (AGC) was set to 2000 – 5000 ms to emphasize strong signals, such as first breaks. The AGC could also emphasize other arrivals or reflections, so one must be careful to pick from the data and not artifacts from the filters. A Linear Moveout Correction (LMO) was implemented based on the assumption that the velocity at which the waves are traveling through the upper mantle is approximately eight km/s. The LMO will "flatten" the first breaks at eight km/s those that are traveling from the mantle, making it easier to see, at a glance, which seismic arrivals are coming from the mantle and which are coming from the crust.

Once I had created ASCII files in the ProMAX® database that contained the station offset, shot point location, and travel time information, I used MacR1D to generate the 1D velocity model that I used as the initial velocity model for Hole's Code. In MacR1D, there are three windows to manipulate and create the 1D model interactively. One window contains the text file of the 1D velocity model.

![Figure 3.5 Screen shots of MacR1D ray tracer. The left side shows the velocity vs depth profile and the right shows how the travel times predicted for the model match the observed travel times.](image-url)
velocity model. The V-D (velocity -depth) window is a graphical representation of the 1D velocity model with velocity on the x-axis and depth on the y-axis (see the left side of Fig. 3.5). This is the window where manipulation and creation of the 1D model take place. In the Travel Time window, uploaded pick times are plotted with reduced (LMO) time on the y-axis and map distance on the x-axis (see right side of Figure 3.5). Whenever a node is moved in the V-D window, the Travel Time window is updated; the objective is to create a 1D model in the V-D window that best fits the pick times in the Travel Time window.

I modified the 1D model after the first tomography run gave residuals well above 0.1 sec. Hole's code (1992) cannot handle abrupt velocity changes due to the use of the Eikonal equation. I generated the final 1D starting model from pick times that ignored areas with a low signal-to-noise ratio and abrupt velocity gradients.

3.4 Seismic Picking in ProMAX

I used a Unix-based program to pick the P-wave arrivals, ProMAX®. It is a very comprehensive and robust in its capabilities for data processing, making it a challenging tool to use. There are numerous options for loading the data, fine-tuning how the data is read into the database(s), and for what attributes are collected. There are also many ways to export the data from the different databases.

The first few attempts I made to load the data and make the picks were unsuccessful. I had read in the seg-y files incorrectly, and I had not told ProMAX® how to handle the data I was giving it: therefore, ProMAX® went to the default settings, which were not suited for the needs of the BATHOLITHS dataset. This resulted in the multiple attempts at picking first breaks from 32,598 traces, where the picks I made were not saved. Once I learned how to save the picks, I could only get them printed to the screen, not a file. With 18 shot points and 1811 traces in each shot, this proved to be a big problem.
Even more frustrating than not being able to extract my data was my inability to properly communicate my problem to someone who understands the inner workings of ProMAX®. All available resources at UTEP had either not used these functions of ProMAX® in many years or had used ProMAX® for other purposes. Luckily, I had Dr. Kate Miller to help me, but even then, since she was not locally available, she could not understand what I was doing wrong. Finally, during one of her visits to UTEP, as we talked about how to access the databases in ProMAX®, I discovered that I had not set up the appropriate databases to handle the data. The software's default was to create one database, and for the purposes of this thesis, I needed three separate databases.

Unfortunately, I could not salvage the work from the previous three semesters; I had to start from scratch and chalk up all my prior picking attempts to "experience." Previously, I ran each shot in a unique flow, but I needed to enter them all in one flow. I also needed to explicitly tell ProMAX® how to organize the data by performing functions such as trace header math and using the correct input function and output function. To make the data processing products in ProMAX® extractable as ASCII files, I created internal files for input into Hole's Code and the Mac R1D Ray Tracer. A total of seven flows were necessary to process the data adequately.

Figure 3.6 Screen shot of flows in ProMAX. Segy_read is used to read the seg-y files. Look is used to verify the files were read in properly. Geom_prep is used to adjust the geometry for ProMAX so it knows what its looking at. Statno is used to make sure the traces are numbered by their field station number in addition to a sequential number. Statno2header is used to transfer the station number to the header file. More2header is used to transfer additional data to the header from the seg-y files. Cp_picking is the flow where the picking
Figure 3.8 Screen shot showing picking of first breaks in ProMAX, before any filters or corrections have been applied to the data
3.5 Seismic tomography algorithm and implementation via CYBER-SHARE

The seismic travel time tomography code (Hole, 1992) requires two ASCII files as input: 1) a shot point file that gives the location of all the shot points and 2) a pick file that provides the $P$-wave arrival times for each shot point. Dr. Romero of Cyber-ShARE has developed a user-friendly shell interface for the Hole (1992) code (Figure 3.7). The inversion portion of the tomography code iteratively inverted travel time residuals (observed minus predicted travel times) and updated a 3-D velocity model during each iteration. Smoothers were applied to stabilize the inversion scheme since it is an underdetermined system (Hole 1992, Averill 2003). My model ran for 48 iterations.

Handpicked $P$-wave arrival times were assumed to have an uncertainty of 75 ms, so I estimated my picking error to be $>0.1$ s. I considered my model complete when the RMS value was $<0.1$ s. The model dimensions were 400x40x60 km ($x,y,z$) with a 10 km buffer zone surrounding the entire model. I used Model Fusion (Olaya, 2011) to generate a model with low RMS residuals by combining a set of Monte Carlo sample models. The Monte Carlo sample models are computer generated using different sets of experimental pick times and fusing the models to generate a combined velocity model out of the different samples (Olaya, 2011).
Chapter 4: 3D Velocity Model

4.1 Introduction

The starting model is a 1-D velocity model extended to a uniform 3D model covering the span of the survey area, with a 1km³ grid space. Each cubic kilometer is a pixel in our model.

First arrival times are calculated for each pixel in the model, using Vidale's finite difference method (Vidale, 1988). The difference between the observed travel times (picked times) and the calculated travel times is the travel time residual. 3D travel time seismic tomography is a trusted method for creating a reliable model of the earth's geologic structure beneath the surface. What makes Cyber-ShARE's implementation of Dr. John Hole's tomography algorithm exceptional are the visualizations and shell scripts added to the code to increase user interactivity and decrease the necessity for the user to generate their own scripts. Working on this dataset simultaneously with other universities allowed me to compare my results to their results.
4.2 Visualizations

I used several visualizations to achieve a convergent model. Dr. Romero generated most of these visualizations and rewrote some of the tomography code, telling it to output the variables necessary to generate these visualizations. The data used to generate these visualizations was always available but never manipulated for display in this manner. Having the ability to identify areas of non-convergence in such a large dataset was a valuable tool. When there were issues of convergence with the model, I examined cell relative RMS residuals (Figure 4.1) and highlighted all of the ray paths with an RMS value greater than 0.3 s (Figure 4.2). I was also able to look at the rays for each shot point and zoom in to see how the rays were behaving (Figure 4.1) to determine what steps I needed to take to get the model to converge. For example, receivers within a 6 km radius of each shot point would cause a lot of interference and non-convergence. Using the 3-D visualizations (Figure 4.3), I was able to identify receiver locations that had bad data and remove them from the model to achieve model convergence. After making appropriate changes

![Figure 4.3 Image of rays from shot 46. Viewed in the XY plane, showing some rays were going wild and influencing the perceived velocities of other rays](image-url)
to the pick times and the 1-D model based on the visualizations, I re-ran the tomography algorithm and saw the model converge numerically and visually (Figure 4.2).

**Figure 4.4** Image showing RMS residuals per cell in the model after, re-picking and removing a 6 km radius of receivers around each shot point.

### 4.3 Comparisons

Kai Wang, an MS student of Dr. John Hole at Virginia Tech, performed a tomographic analysis of the same data set I used. Kai and I worked independently of each other for over a
year until December 2011, when we exchanged models. We did not contact each other while picking or running the model through Hole's code or working towards model convergence. Yet, we achieved very similar models (Figures 4.5 and 4.6). The Virginia Tech model (Figure 4.5) was vertically exaggerated at a 4:1 ratio, while the UTEP model (Figure 4.6) remained at a 1:1 ratio.

Similarities in the models can be seen near shot point 31 (Figure 4.5), where Kai's model has a low-velocity zone at about 7 km depth. My model has a low-velocity zone in the same area (Figure 4.6). Due to the angle of the image, this feature occurs near the velocity markers six km/s and seven km/s. A thickening of the seven km/s velocity layer is also present in both models beneath the 36, 46, and 41 shot points at about 25 km depth (Figures 4.5 & 4.6). Closer to the surface, between shots 41 and 27, there is a thickening of the 5.5 km/s velocity zone.

Figure 4.6 3D tomographic image with Cordilleran Terranes outlined and tectonic structures labeled. Velocities (black) and shot points (red).
I also compared my model to other studies near the BATHOLITHS survey and saw similar features. Using data and images from the LITHOPROBE and ACCRETE geological surveys, I was able to correlate some tectonic structures and terranes in the area of the BATHOLITHS survey (Figure 4.6). I compared my tomography model with a Bouguer anomaly map (Figure 4.7) that shows a correlation between areas of faster sub-surface velocities and greater, positive gravitational anomalies signifying greater density of mass. Magnetic data from Thomas et al. (2011) correlates the location of the volcanic fields that are present as higher velocities in my seismic model, showing higher magnetic readings between +500nT and +1500nT. These anomalies are also visible in the Bouguer anomaly map (Figure 4.7).

Figure 4.7 Bouguer Anomaly map of survey area modified from Geological Survey of Canada (1993). Annotated and trimmed to show BATHOLITHS survey line (in green)
Chapter 5: Conclusions and Discussion

5.1 Results

The tomography model I created compares well to previous work, meaning that any changes and additions made to the Cyber-ShARE group's software did not negatively affect the algorithm. The support of Cyber-ShARE did have an enormous positive impact on the completion of this tomographic model. The ray coverage only reached depths of 30 km; therefore, we could not interpret velocities below that depth with any degree of confidence (Figure 5.1). Both models depict thicker crust towards the west with more sedimentary basin structure to the east, based on slower travel times in that region. The Bouguer Anomaly map (Figure 4.7) also leads me to this conclusion due to minor, positive gravity anomalies towards the east.

![Figure 5.1 Masked velocity of final tomographic model. Deepest rays only reached a depth of 30 km](image)

When modeling anything for scientific interpretation, one must consider what an acceptable error range would be. For the BATHOLITHS dataset, our acceptable picking error is 0.1 s. In our first run of Hole's Code (Hole, 1992), our error was huge; 0.5 s was as low it would go. So after analyzing the visualizations (Figures 4.2 – 4.4), I took a few steps back. I went back into ProMAX®, re-picked the first breaks, and changed my perspective of the data by zooming out and looking at 500 receivers at a time instead of the usual 100. I noticed that about 200 km away from the shot point, I was no longer picking the first breaks but some other arrival (Figure
Every shot was re-picked, only picking arrivals not surrounded by too much noise and not interpolating picks through regions of noisy data

### 5.2 Discussion

Considering the Virginia Tech model, it is interesting that, like the UTEP model, the color scheme is the opposite of the standard used by the geophysical community. This "mistake" that we both made, however, made comparing our two tomographic models much more straightforward.

I am confident that the smoothers, model fusion, and GUI shell scripts for Hole's (1992) code positively impacted generating a robust tomographic model of the BATHOLOTHS' data set. Comparing Kai Wang's model (Figure 4.5) and my model (Figure 4.6) and seeing the similarities in the velocity structure and unique artifacts show no degradation to the data occurred during the
processes executed in the CyberSHARE lab. Analogous tomography models created by other students from the BATHOLITHS deployment also show these same features (Stephenson et al., 2011).

5.3 SUMMARY

More seismic surveys are necessary to achieve the depth resolution necessary to model the Moho and upper asthenosphere in order to determine if the ultra-mafic roots of the batholiths are discernable. I know that we are on the right track with the modeling since our model agrees with other geophysical studies in the same general area. The CMB and the Canadian Cordillera are significant areas of study. The CMB is a continental arc fossil that can be used to study continental crust formation, and the Canadian Cordillera is a great place to study how the continental crust is deformed. Hopefully, with advancements in seismic data collection and analysis, new depths can be reached, and we can determine where the ultra-mafic material of the oceanic crust goes during continental crust formation.
References


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Vita

Sarah Michelle Quinonez, born Sarah Michelle Padilla to Janie Emilia Padilla and David Michael Seeber on March 6, 1984, in El Paso, Texas, at Providence Hospital. She is their eldest daughter, with two younger siblings Elizabeth Marie Seeber and Andrew Michael Seeber. She is wife to Keith Quinonez and mother to Julian Nikolai and Joaquin Ignacio Quinonez. She graduated from J. M. Hanks High School, El Paso, Texas, in the spring of 2002 and entered the University of Texas at El Paso that fall as a pre-science major. In the spring of 2006, she decided to change her major to Geophysics and graduated with a Bachelor of Science degree in the summer of 2009. While pursuing her bachelor's degree, she worked on an internship with Jacobs Engineering, a NASA contractor at Johnson Space Center, Houston, Texas, in the summer of 2008. While at Johnson Space Center, she worked with fellow UTEP students to edit the Apollo 15 surface video for geologic context. At the 2008 fall meeting of the Geological Society of America, she presented a poster with S. Marrufo titled Depositional Changes in an Active Rift Basin Reflected in Well Logs and Cuttings, Hueco Bolson, West Texas, and was awarded 2nd place in the Sigma Gamma Epsilon Undergraduate Research Session. Sarah wrote a Senior (undergraduate) Thesis; Well Log Analysis and Stratigraphy, Hueco Bolson, West Texas. In the summer of 2009, she volunteered with the NSF-funded BATHOLITHSonland seismic survey to deploy geophones for the survey in an East-West transect across the Coast Mountains Batholith, British Columbia, Canada. Participating in this deployment inspired her to pursue a master's degree in science in geophysics and study the data collected in the BATHOLITHSonland survey in the fall of 2009.