The Upper Mantle Seismic Structure Beneath Northeastern North America

Author: Justin Tyler Hertzog

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THE UPPER MANTLE SEISMIC STRUCTURE BENEATH NORTHEASTERN NORTH AMERICA

A thesis

By

JUSTIN T. HERTZOG

Submitted in partial fulfillment of the requirements

For the degree of

Master of Science

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Abstract

THE UPPER MANTLE SEISMIC STRUCTURE BENEATH NORTHEASTERN NORTH AMERICA

By Justin Hertzog

Advisor: Dr. John E. Ebel and Dr. J. Christopher Hepburn

Using the seismic refraction technique with a least squares inversion methodology, arrival time data from 1985 to the present are analyzed to delineate, with improved spatial resolution, the upper mantle P-velocity structure throughout northeastern North America (NENA). A total of one hundred and sixty-eight earthquakes are analyzed utilizing over one hundred seismic stations throughout NENA. Seismic data analyzed between 200 - 400 km, 400 - 600 km, and 600+ km throughout NENA are used to study the increase in velocity with depth in the upper mantle. A jackknife analysis was carried out to put constraints on the uncertainties of the velocity measurements. The P-wave velocity of the upper mantle through the New England Appalachians is found to be uniformly 7.94 – 8.07 km/s at depths down to 75 km. Upper mantle Pn velocities throughout the southeastern Grenville Province show velocities ranging from 8.15 km/s to 8.54 km/s as epicentral distances increase. Uncertainties of P velocities range from 0.01– 0.12 km/s. Based on laboratory measurements of simulated upper mantle conditions and the orogenic history of the Grenville Province and northern Appalachians, upper mantle mineral compositions of eclogite (Grenville Province) and pyroxenite (northern Appalachians) are proposed to be the factor controlling seismic velocity variation in the upper mantle. Variations in upper mantle temperatures between the Grenville Province and northern Appalachians are ruled out as affecting the difference in upper mantle velocities between southeastern Canada and New England.
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1. INTRODUCTION

1.1 Overview

Northeastern North America (NENA) has been a focus of geophysical techniques to explain the complex geology of the northern Appalachians and the Grenville Province. To better understand the geologic history and regional geology of NENA, geophysical studies using methods such as electromagnetics, gravity, and seismology have been conducted by a number of different investigators (e.g., Radcliff and Balanis, 1981; Hayes and Lewis, 1984). The primary purpose of these geophysical studies was to identify geologic terranes throughout NENA and to determine the structural relationships that connect the terranes at their contiguous boundaries.

The purpose of this study is to determine the lateral seismic P-wave velocity variation of the uppermost mantle throughout southeastern Quebec and the northern Appalachians by using the seismic refraction technique with a least squares analysis. Earthquake seismogram data from magnitude 3.0 and higher events were gathered from databases of seismic station arrival times maintained by the New England Seismic Network (NESN), by the Natural Resources Canada (NRC), by the United States Geological Survey (USGS) and by the Lamont-Doherty Cooperative Seismographic Network (LCSN) (Figure 1). Figure 1 defines the extent of the study area.

Earthquake arrival-time data were compiled along with a written computer code that was used to perform a least squares and jackknife statistical analysis. This computer program
solves for the seismic P-wave velocity of an upper-mantle refractor beneath the surface of each seismic station and calculates the uncertainty of that P-wave determination. The depth of the refractor beneath the surface was determined from earthquake epicentral distances to the seismic stations for the Pn arrival (the wave refracted off the upper mantle). The end result of this analysis is the P-wave velocity of the Moho or sub-Moho refractor depth beneath a subset of seismic stations.

1.2 Geologic Setting

The western edge of the study area lies within the Grenville Province, which is composed of the remains of Early Proterozoic orogens. To the east are the Paleozoic Appalachians in New England that overthrust the Grenvillian Basement (Seeber et al., 2002). A simplified geologic map illustrates tectonic features from southeastern Quebec through the northern Appalachians (Figure 2).

1.2.1 Grenville Province

The Precambrian Grenville Province (~1.3 – 1.0 Ga) is exposed in southeastern Canada and northern New York. The Grenville orogeny produced metamorphic and igneous rocks attributed to the collision of Laurentia (eastern North America), with Amazonia (western South America), and ensuing formation of the supercontinent Rodinia (Levin, 2006). Grenvillian rocks consist of an intricate assemblage of high-grade metamorphic granulites (McLelland et al., 2010) and are distinguished by high seismic velocities
within the uppermost mantle (Hughes and Luetgert, 1991). The high seismic velocities are attributed to episodic fractionation and intrusion of felsic magmas from mantle-derived basaltic underplates (Figure 3) (Hughes and Luetgert, 1991).

Eclogitized metagabbros are found in the Adirondacks and throughout Quebec, and likely represent areas of deepest burial and most intense collision during the Grenville orogeny (Indares and Rivers, 1995). In the Adirondacks, high-grade granulites exist, which have evolved from the lower crust. These high-grade granulites at the surface are a result of deep seated metamorphic and igneous rocks of the lower crust gradually becoming exposed as overlying rocks were lost to erosion.

While the details of the assembly of the Grenville terrane are uncertain because of time gaps between the lithologic units, it is believed that the terrane was created by three main tectono-magmatic events known as the Elzevirian orogeny, the magmatic emplacement of the anorthosite-mangerite-charnockite-granite (AMCG) suite, and the Ottawan orogeny (McLelland et al., 1996; McLelland et al. 2010).

1.2.2 Appalachian Province

The Appalachian province is characterized by the eroded core of a Paleozoic mountain chain extending from southeastern United States to Newfoundland. The province is a result of at least three major Paleozoic orogenies (Taconic, Acadian, and Alleghenian) (Hatcher, 2010). The three orogenies have a complex history in the North Atlantic region.
Figure 1: Study area (in Lat./Long.) showing seismic stations used as triangles, along with their station IDs as referenced in Appendix A.
Figure 2: Generalized geologic terrane map. Small solid lines represent the Connecticut Valley-Gaspe synclinorium, Bronson Hill anticlinorium, Central Maine synclinorium, and the Nashoba-Avalon terrane boundary. Small dashed line represents the Norumbega Fault zone. The bold solid line represents the Superior Province to the northwest. The bold dashed lines represents the Grenville Province (after Williams, 1978; Taylor and Toksoz, 1979; Rivers et al., 1987; Hughes and Luetgert, 1991; Rast and Skehan, 1993; Hatcher, 2010).
Figure 3: Interpretation of the tectonic structure of the southeastern Grenville province. The crust was over-thickened by the development of large scale northwestward verging nappes coupled with magmatic underplating of the crust during the Grenvillian orogeny (Figure 3a). Isostatic and thermal adjustments were initiated by the eclogization and delamination of a denser underplated crustal root. This delaminated magmatic underplate created a lens of eclogite in the upper mantle, (Figure 3b). (Figure from Hughes and Luetgert, 1992).
involving the opening (650 Ma), closing (470 Ma – 290 Ma), and reopening (248 Ma) of an ocean basin (Hatcher, 2010). Accretion of two island arc terranes to the cratonic continent (Taconic and Acadian orogenies) led to a progressive eastwards migration of the onset of collision-related deformation, metamorphism, and magmatism creating terranes such as the Connecticut Valley Gaspe synclinorium, Bronson Hill anticlinorium, Merrimack trough, Nashoba, and Avalon belts (Figure 2) (Cees van Staal et al., 2009).

1.2.3 New England Appalachians

In the New England Appalachians there is a north- to northeast-trending belt of serpentinites along the Vermont to Quebec border that are located on strike with Newfoundland ophiolites (Stewart et al., 1991). Rocks of the New England Appalachians are deformed into a number of broad structural warps containing Paleozoic continental-rise or back-arc-basin metasediments in the synclinoria (Champlain Valley) and island-arc metavolcanics (Bronson Hill anticlinorium), ultramafics (Vermont ultramafic belt), and high-grade metamorphic rocks (Central Maine synclinorium) (Figure 2) (Rast and Skehan, 1993; McLelland, 2001; Hatcher, 2010).

1.3 Previous Geophysical Studies

The crustal and upper mantle structure of NENA has been an area of focused study by geophysicists and geologists for an extensive period of time. Numerous types of geophysical surveys have been completed which provide information about the
Figure 4: Areas of previous seismic refraction and tomographic studies by various researchers. The MSRP is labeled as stars through Maine and O-NYNEX is labeled as triangles through Ontario, New York, and New England from Luetgert and Mann (1990) and Hughes and Luetgert (1991), respectively. A tomographic study by Taylor and Toksoz (1979) is labeled by boxes (T & T) through central New Hampshire. A study by Zhu and Ebel (1994) is labeled by boxes (Z & E) throughout New England. A study by Chiburis and Ahner (1980) is labeled by boxes (C & A) throughout Connecticut.
crustal and upper mantle structure throughout NENA (Figure 4). Within the past few decades, seismic reflection and refraction surveys throughout New England and southeastern Quebec have helped resolve deep continental seismic structures and provided a means of extrapolating relationships between surficial geology and the underlying geologic structures.

Taylor and Toksoz (1979) developed a crustal velocity model for central New Hampshire by computing inversions of teleseismic P-wave travel times to yield an average lateral velocity variation pattern of the crust; however, their study did not give a detailed crustal velocity structure (Taylor and Toksoz, 1979; Kamiya et al., 1989). Taylor and Toksoz (1979) used a slowness perturbation method that was developed by Aki et al. (1977) to calculate crustal velocities for central New Hampshire. Taylor and Toksoz (1979) show an average P-wave velocity of about 6.4 km/s in the crust and an upper mantle velocity of 8.13 km/s. Chiburis and Ahner (1980) collected seismic data, using seismic stations as the receivers and earthquakes as the source, throughout New England to create a velocity crustal model for the southern New England region, which aided in locating earthquakes throughout New England. The data that were used in the Chiburis and Ahner (1980) velocity model came from seismic stations operated by the Consolidated Edison Company of New York as well as by Weston Geophysical Research, Inc. and by Weston Observatory of Boston College. The Chiburis and Ahner (1980) crustal model of P velocities shows an average crustal P-wave velocity of about 6 to 6.6 km/s down to 30 km, where there is a jump to 8.1 km/s defining the Moho. No P-wave velocity increase below 30 km was reported by Chiburis and Ahner (1980) for southern New England.
The U.S. Geological Survey and the Canadian Department of Energy, Mines, and Resources conducted a seismic-refraction experiment in Quebec and Maine in the fall of 1984, known as the Maine Refraction Seismic Profile (MSRP). The purpose of this survey was to understand the structure and tectonic evolution of the northern Appalachian orogen. Several important papers have been published on the data set that was collected during this survey; most notable are papers by Stewart et al. (1986), Spencer et al. (1987), Luetgert et al. (1987), Kafka and Ebel (1988), Spencer et al. (1989), and Zhu and Ebel (1994). These studies focused on the seismic illumination of tectonic features throughout the crust, but more importantly for the purposes of this study, provided data on the upper mantle P-wave velocity throughout Maine and southeastern Quebec. Results from these studies show an upper mantle starting at approximately 36 km depth and an upper mantle P-wave velocity that does not exceed 8.1 km/s down to 50 km for this area.

In 1988, the U.S. Geological Survey, the Geological Survey of Canada and the U.S. Air Force Geophysics Laboratory conducted a large scale seismic survey that crossed the northern Appalachians and the Grenville Province (Figure 4) aimed at distinguishing the crustal seismic structure throughout the area. This survey was known as the Ontario-New York-New England Seismic Refraction Profile (O-NYNEX). The data collected in this large-scale refraction/wide-angle reflection survey supplied seismic data for several studies. Hughes and Luetgert (1991) used a two-dimensional inversion technique to determine a seismic velocity model that extended from the surface down to the upper mantle for the Grenville Province and northern Appalachians. The crustal P-wave
velocities at approximately 15 to 30 km in depth in their model show an east-to-west change from approximately 6.3 km/s in the eastern portion of the survey, increasing stepwise to 6.6 – 7.0 km/s starting between the Connecticut synclinorium and the Green Mountains, and further increasing towards the west to approximately 6.6 – 7.1 km/s near the central granulite terrane (Adirondack Massif). Luetgert and Mann (1987) also show a gradational P-velocity interface for the Moho at 30 km to 50 km increasing from eastern Maine (~8.0 km/s) to southeastern Canada (~8.6 km/s).

Lateral velocity variations through the NENA region were also recognized by Zhu and Ebel (1994) in a study using refraction ray tracing theory as applied to the 1984 MSRP and 1988 O-NYNEX data sets, as well as to seismic data recorded by the NESN. Zhu and Ebel (1994) created several velocity profiles with respect to depth for their New England study region. Their profiles show lateral velocity variations in the upper 15 km of the crust that are correlated to regional and geologic structures. They also modeled the Moho discontinuity beneath northern New England, predicting a depth of about 33 km under southeastern Maine and 38.6 km under the northern Appalachians near the Chain Lakes Massif (Maine-Quebec border). The upper mantle velocity models that Zhu and Ebel (1994) compiled show that the first 40 km of upper mantle under the Avalon terrane (Figure 2) has a P-wave velocity of approximately 8.1 km/s with no observable P-wave velocity gradient with respect to depth. Under the Grenville Province in southeastern Canada they observed a velocity increase to 8.61 km/s at a depth of 60 km. Lastly they found a velocity of 8.74 km/s at a depth of 78 km.
1.4 Objective

The objective of this thesis is to determine the upper mantle P-wave velocity variation laterally throughout NENA and to fill in the gaps where there are few or inadequate results from previous seismic studies. This research expands onto those areas in NENA that were not covered by the previous seismic studies. The data from the previous studies throughout New England and southeastern Canada were divided into sections of P-wave velocity with respect to depth. For the top 40 km, the velocities are determined and contoured at 10 km intervals down to 60 km. Below 40 km, the intervals are in 5 km increments down to 60 km. The P-wave velocity data are based on the previously published seismic profiles of Figure 4 and are compiled in Table 1. The P-wave velocity information is limited to points directly beneath the receivers for each profile. From 10 km to 30 km (Figures 5, 6 and 7) crustal P-wave velocities are derived from the authors who have correlated the local geology to the seismic velocities (Taylor and Toksoz, 1979; Stewart et al., 1986; Luetgert et al., 1987; Kafka and Ebel, 1988; Hughes and Luetgert, 1991). At 40 km depth there is a strong lateral velocity variation as previous studies have shown that the Moho increases in depth from approximately 30-33 km in New England to over 40 km in southeastern Quebec (Figure 8) (Taylor and Toksoz, 1979; Stewart et al., 1986; Luetgert et al., 1987; Kafka and Ebel, 1988; Hughes and Luetgert, 1991; Zhu and Ebel, 1994). At 50 km depth and below, the seismic velocity data set is limited, but one can recognize the P velocity continues to increase laterally from New York and into Ontario from 8.1 km/s to 8.3 km/s (Figure 10). At 55 km depth (Figure 11) the velocity increases westward from approximately 8.1 km/s to 8.5 km/s across northern New York.
and into Ontario. Lastly, at 60 km depth (Figure 12), the velocity continues to increase westward across northern New York and into Ontario from about 8.2 km/s to 8.6 km/s.
Table 1: Compilation of previous studies throughout northeastern North America

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<td>7.20</td>
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Figure 5: Depth of 10 km P-wave velocity contour based on the data locations indicated in Figure 4 and velocity-depth information shown in Table 1 from Taylor and Toksoz (1979), Chiburis and Ahner (1980), Luetgert et al. (1987), Hughes and Luetgert (1991), and Zhu and Ebel (1994).
Figure 6: Depth of 20 km P-wave velocity contour based on the data locations indicated in Figure 4 and velocity-depth information shown in Table 1 from Taylor and Toksoz (1979), Chiburis and Ahner (1980), Luetgert et al. (1987), Hughes and Luetgert (1991), and Zhu and Ebel (1994).
Figure 7: Depth of 30 km P-wave velocity contour based on the data locations indicated in Figure 4 and velocity-depth information shown in Table 1 from Taylor and Toksoz (1979), Chiburis and Ahner (1980), Luetgert et al. (1987), Hughes and Luetgert (1991), and Zhu and Ebel (1994).
Figure 8: Depth of 40 km P-wave velocity contour based on the data locations indicated in Figure 4 and velocity-depth information shown in Table 1 from Taylor and Toksoz (1979), Chiburis and Ahner (1980), Luetgert et al. (1987), Hughes and Luetgert (1991), and Zhu and Ebel (1994).
Figure 9: Depth of 45 km P-wave velocity contour based on the data locations indicated in Figure 4 and velocity-depth information shown in Table 1 from Taylor and Toksoz (1979), Chiburis and Ahner (1980), Luetgert et al. (1987), Hughes and Luetgert (1991), and Zhu and Ebel (1994).
Figure 10: Depth of 50 km P-wave velocity contour based on the data locations indicated in Figure 4 and velocity-depth information shown in Table 1 from Hughes and Luetgert (1991).
Figure 11: Depth of 55 km P-wave velocity contour based on the data locations indicated in Figure 4 and velocity-depth information shown in Table 1 from Hughes and Luetgert (1991).
Figure 12: Depth of 60 km P-wave velocity contour based on the data locations indicated in Figure 4 and velocity-depth information shown in Table 1 from Hughes and Luetgert (1991).
2. THEORY

2.1 Seismic Refraction

The seismic refraction analysis of upper mantle velocities entails plotting first arrival times of compressional (or P) waves versus epicentral distance to each individual seismic station (Figure 13). Refraction seismology assumes that the layers in the Earth are laterally homogeneous and that seismic velocity increases only with depth. A limitation of the seismic refraction technique that is low velocity layers (LVL) in the earth, such as within the lithosphere and upper mantle, cannot be detected.

Snell’s law describes the relationship between the angles of incidence in refraction:

\[
\frac{\sin \theta_1}{\sin \theta_2} = \frac{V_1}{V_2} \sin \theta_1 / \sin \theta_2 = \frac{V_1}{V_2} \tag{1}
\]

where \(V_1\) is the speed of the incident wave and \(V_2\) is the speed of the refracted wave. In Equation 1, \(\theta_1\) is the incident angle for a wave that is refracted off of a velocity boundary, and \(\theta_2\) is the angle at which a wave is refracted in the second medium. A critically refracted wave is produced by an incident wave that intersects a boundary at the critical angle of incidence \(i_c\). When the seismic P wave refracts at an interface the critical refraction angle is 90° and therefore \(\sin(\theta_2) = \sin(90°) = 1\), then according to Snell’s law one can rewrite equation 1 as

\[
\sin(i_c) = \frac{V_1}{V_2} \tag{2}
\]

Equation 2 shows how the critical angle is dependent upon the wave speeds in the layer above and below the boundary.
Figure 13: Travel time curve and travel paths for seismic waves critically refracted in a structure consisting of horizontal layers (Robinson, 1988).
2.2 T-X Curve

If the source of energy is created at the surface, the first wave to arrive at a receiver will travel along the land surface and is known as the direct wave. This is the first wave to be plotted on a travel time curve, a plot of first arrival time versus distance (T-X), and it is labeled $V_1$ in Figure 13. After seismic energy has been critically refracted at a velocity interface below the surface, it will be detected by the next receiver at a distance $X$ away from the source (Figure 13). The waves that arrive after they have been critically refracted at some critical angle $i_c$, and received at some distance $X$, are known as the head waves. The ray paths in Figure 13 make it obvious that the refracted wave will always travel a longer distance than the direct wave. Since $V_2 > V_1$, at some distance $X$ the head wave will arrive before the direct wave. In Figure 13 this occurs at receiver 5 and beyond. The head waves are refracted waves in which each unique wave is responsible for an arrival at each distance $X$. The slope of the travel-time points gives the inverse of the velocity of the wave (Equation 3).

$$slope = \frac{\Delta t}{\Delta x} = \frac{1}{V_n} \quad (3)$$

$x = $ distance from seismic event

$t = $ travel time of seismic wave

$V_n = $ velocity of seismic wave

The travel time curve in Figure 13 shows the distance at which two straight lines for different seismic phases intersect, which is known as the crossover distance $X_c$. This crossover distance is the distance at which a geophone would receive both the direct
wave and the refracted wave at exactly the same time. For distances beyond $X_c$, the
refracted wave is the first arrival and the direct wave is a later arrival. If a straight line is
drawn through the arrival time points on a time versus distance graph, as seen in Figure
13, one can determine the intercept time by extrapolating the lines to the vertical axis at
the time value of $T_1$. The intercept time $T_1$ of the refracted wave can then be used to
determine depth to the top of that refractor. To determine depth to the top of a refractor,
one can utilize either the crossover distance or the intercept time. If a source $X$ and a
receiver $R$ are separated by a distance $x$, as seen in Figure 14, then the travel time for the
direct wave will be

$$t_D = \frac{x}{V_1} \quad (4)$$

The travel time for a refracted wave along its travel path is

$$t_R = \frac{SA}{V_1} + \frac{AB}{V_2} + \frac{BR}{V_1} \quad (5)$$

The right angles created by $SCA$ and $BER$ show that

$$SA = BR = \frac{h_1}{\cos(i_c)} \quad (6)$$
$$CA = BE = h_1 + \tan(i_c) \quad (7)$$

Where $i_c$ is the critical angle of incidence at which a wave refracts at the top of the faster
layer below the interface. One must then subtract distances $CA$ and $BE$ to obtain $AB$

$$AB = x - CA - BE \quad (8)$$

If Equations 6, 7, and 8 are substituted into Equation 3 this gives

$$t_R = \frac{2h_1}{V_1} \cos(i_c) + \frac{x - 2h_1 \tan(i_c)}{V_2} \quad (9)$$

One can use the identity $\tan(i_c) = \frac{\sin(i_c)}{\cos(i_c)}$ to obtain

$$t_R = \frac{x}{V_2} + 2h_1 \frac{V_1}{V_2} \cos(i_c) * (1 - \frac{V_1}{V_2} * \sin(i_c)) \quad (10)$$
Figure 14: Geometry of the wavefront travel path critically refracted along a horizontal medium. The source (S) creates a wavefront that later arrives at the receiver (R). Here SA and BR are the paths of the critically refracted ray in the first layer. In this figure, CD and EF are geometric constructs that are used to calculate CA and BE (after Robinson, 1988).
Substituting in Equation 1 one can rewrite Equation 10 as

\[ 1 - \left( \frac{V_1}{V_2} \right) \sin(i_c) = 1 - \sin^2(i_c) = \cos^2(i_c) \]  

(11)

yielding the equation

\[ t_R = \frac{x}{V_2} + \frac{2h_1}{V_1} \cos(i_c) \]  

(12)

For a critical refraction, one can use Equation 1 with well-known trigonometric identities to show that

\[ \cos(i_c) = \left(1 - \sin^2(i_c)\right)^{1/2} = \left(1 - \left(\frac{V_1}{V_2}\right)^2\right)^{1/2} = \left(\frac{V_2^2 - V_2^1}{V_2^2}\right)^{1/2} \]  

(13)

Equation (13) can be substituted for \( \cos(i_c) \) into Equation (12) giving

\[ 2h_1/V_1 \left(\frac{(V_2^2 - V_2^1)/V_2^2}\right)^{1/2} \]  

(14)

Rearranging Equation (14), solving for \( h_1 \) and simplifying, one gets the depth to the refractor

\[ h_1 = \frac{X_c}{2} \left(\frac{(V_2 - V_1)/(V_2 - V_1)}\right)^{1/2} \]  

(15)

From Equation 12, if one makes \( 2h_1/V_1 \cos(i_c) \) a constant \( k \), one can then write the equation as

\[ t_R = \frac{x}{V_2} + k \]  

(16)

Equation 16 is the equation for a straight line on a graph of time versus distance that has a slope \( 1/V_2 \) and an intercept \( k \). Equation 16 is therefore an expression for the straight line in Figure 13 that represents the refracted wave. The constant \( k \) here is the intercept time, so one can solve for \( k \) yielding

\[ k = T_1 = \left(2h_1/V_1\right) \cos(i_c) \]  

(17)

Then solving for the layer thickness one can get

\[ h_1 = \left(T_1/2\right) \left(V_1/\cos(i_c)\right) \]  

(18)
Lastly substituting in Equation 13 for cos(ic) gives the equation

\[ h_1 = \left( \frac{T_1 V_1 V_2}{2(V_2^2 - V_1^2)^{1/2}} \right) \]  \hspace{1cm} (19)

Here the intercept time \( T_1 \) can be observed from the intersection of the line representing the refracted wave on the vertical axis of the graph.

For multiple layers the travel time at the top of the \( n^{th} \) layer is represented by a line with slope \( 1/V_n \), that can be extrapolated to its intercept on the \( t \) axis, \( \tau_n \), and written as

\[ T_h(x) = x/V_n + \tau_n \]  \hspace{1cm} (20)

By analogy to Equation 19, the layer over the half-space case for multiple layers

\[ \tau_n = 2 \sum_{k=0}^{n-1} h_k (1/V_{k+1}^2 - 1/V_k^2)^{1/2} \]  \hspace{1cm} (21)

2.3 Least Squares Inversion

The seismic data analyzed comes from earthquakes with epicentral distances from 200 km to 900 km in NENA. Upper mantle velocities can be observed as first arrivals on travel-time plots at epicentral distances starting at approximately 185 to 200 km depending on the depth to the Moho. For any single earthquake, arrival times were sorted into epicentral distances bins of 200 – 400 km, 400 – 600 km and 600 – 900 km. These distance bins are based on previous studies that determined the bottoming depths for different epicentral distances (Hill, 1972; Taylor and Toksöz, 1979; Hughes and Luetgert, 1992; Zhu and Ebel, 1994; Ruppert et al., 1998, Engdahl et al., 1998). The average bottoming depths to each bin of epicentral distances corresponds to
approximately 40 km, 60 km and 75 km based on these previous studies in NENA. The method to determine upper mantle velocity assumes that for each earthquake all of the data points from each event within a given distance bin come from the same refractor and, therefore, have the same apparent velocity beneath the seismic station. However, the intercept point for the refraction for each event on a travel-time plot is different due to the focal depth of the earthquake and the uncertainty in the event origin time. Thus, both the intercept time for each event and the apparent velocity that is common to the entire event data within a distance bin are unknown and must be determined.

2.4 Inversion Technique

To solve for the refractor velocity, the arrival time data at a common set of seismic stations within one of the distance bins from many different earthquakes are combined into a single inversion problem. In the inversion, the data consists of the arrival times for each earthquake at each seismic station, and the unknowns are the single slope of the lines that fit through the data; one line for the data from each earthquake. All of the lines are assumed to have the same slope. These unknowns are solved for using the least squares methodology. Travel time is defined as $T_{ij}$ and epicentral distance is defined as $X_{ij}$ where $i$ is the index of the $i^{th}$ seismic station and $j$ is the index of the $j^{th}$ seismic event. The equation for travel time $T_{ij}$ as a function of epicentral distance $X_{ij}$ is:

$$T_{ij} = \frac{X_{ij}}{v}b_j + b_j$$  \hspace{1cm} (22)

where $b_j$ is the unique intercept time for each seismic event and $v$ is the common refractor velocity for all of the events. Equation (23) is the least-squares inversion technique. Here
$m$ is the total number of seismic events and $n$ is the total number of travel-time observations with $n_j$ observations for the $j^{th}$ earthquake, where $n_1 + n_2 + \ldots + n_i = n$.

\[
\begin{bmatrix}
T_{11} & x_{11} & 1 & 0 & 0 & 0 \ldots & 0 \\
T_{12} & x_{12} & 1 & 0 & 0 & 0 \ldots & 0 \\
T_{13} & x_{13} & 1 & 0 & 0 & 0 \ldots & 0 \\
T_{1n_i} & x_{1n_i} & 1 & 0 & 0 & 0 \ldots & 0 \\
T_{21} & x_{21} & 0 & 1 & 0 & 0 \ldots & 0 \\
T_{22} & x_{22} & 0 & 1 & 0 & 0 \ldots & 0 \\
T_{23} & x_{23} & 0 & 1 & 0 & 0 \ldots & 0 \\
T_{2n_i} & x_{2n_i} & 0 & 1 & 0 & 0 \ldots & 0 \\
T_{31} & x_{31} & 0 & 0 & 1 & 0 \ldots & 0 \\
T_{32} & x_{32} & 0 & 0 & 1 & 0 \ldots & 0 \\
T_{33} & x_{33} & 0 & 0 & 1 & 0 \ldots & 0 \\
T_{3n_i} & x_{3n_i} & 0 & 0 & 1 & 0 \ldots & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
T_{mn_j} & x_{mn_j} & 0 & 0 & 0 & 0 \ldots & 1 \\
\end{bmatrix} \begin{bmatrix}
1 \\
\frac{1}{V} \\
b_1 \\
b_2 \\
b_3 \\
\vdots \\
\vdots \\
b_m \\
\end{bmatrix} = * \tag{23}
\]

Or

\[
T = G \cdot M \tag{24}
\]

The $T$ matrix is $n \times 1$, the $G$ matrix is $n \times (m + 1)$, and the $M$ matrix is $(m + 1) \times 1$. Here the unknowns in the $M$ vector are the inverse of the velocity $(1/V)$ and the intercepts $(b_j)$. Equation (25) solves equation (24) for $M$, where $\text{inv}(G)$ is the least-squares inverse matrix of $G$.

\[
M = \text{inv}(G) \cdot T \tag{25}
\]
2.5 Jackknife Methodology

A statistical analysis known as the jackknife method was applied to the seismic data analyzed. This statistical methodology estimates the bias and variance of the parameters determined from the data set by resampling the data set (Bear and Palvis, 1997). The jackknife method was implemented using the Matlab code given in Appendices C to I. The jackknife code resamples the data set by removing each earthquake one at a time from the data set and then reprocesses the data for new estimates of M. This provides a set of estimates of M from which the variance of each element of M can be calculated. This analysis provides an estimate of the variance of the refractor velocity beneath the seismic stations and of the intercept time for each of the seismic events that are analyzed.
3. DATA ANALYSIS

3.1 Data Collection

Observed P-wave arrival times from the years 1985 to 2010 were collected from regional seismic stations throughout NENA (Figure 1). A total of 176 earthquakes were analyzed (Appendix A, Figure 15) that have assigned letters to reference each event. Within this study area there are 144 seismic stations where the P-wave first arrival times were recorded (Appendix B, Figure 1). The seismic stations are referenced using the numbering scheme given in Appendix B and shown in Figure 1.

Observed P-wave first arrival data from each earthquake was collected if there was a minimum of two stations to carry out the linear inversion needed to calculate the apparent velocity of the first arriving P phase. For a majority of the earthquakes that took place from 1985-2010 of magnitude 3.0 and less, it was most likely difficult for the analyst who processed the earthquake waveform data to recognize many of the observed P-wave arrival times at distances of 200 km and greater due to low signal-to-noise ratio. Knowing this, the data set in this study comes from earthquakes of magnitude 3.0 and larger. Observed first P-wave arrival times are reported using Coordinated Universal Time and estimated to the nearest hundredth of a second. The earthquakes were located using a search criterion that was a rectangular latitude and longitude area with coordinates 63° – 83° W and 39° – 50°.
Figure 15: Study area (in Lat./Long.) showing seismic events analyzed along with their event ID’s (Appendix A).
3.2 Databases

There are three databases that were utilized to collect the observed P-wave arrival times. The first source used was the online bulletins and reports of earthquake locations and arrival time readings by Weston Observatory from the New England Seismic Network (NESN) \(^1\). This database consists of the Northeastern U.S. Seismic Network (NEUSSN) Quarterly Reports as well as the NESN Quarterly reports, and it lists earthquakes that occurred throughout New England and contiguous regions during each calendar quarter.

The second database of earthquake locations and arrival time readings that were used in this analysis was the United States Geological Survey (USGS) database\(^2\) from the years 1985 - 2010. The seismic stations included in this database are confined to seismic stations throughout the United States, specifically, for the area that included seismic stations within the New England region (Appendix B). The search parameters mentioned above were entered into the online search engine for this database, which then gives a list of corresponding earthquakes in the study region (Figure 15). A link to the individual earthquakes that correspond to a user’s search parameters can then be “clicked” to take one to a list of the observed and predicted arrival times at each seismic station as well as the phase of the readings, i.e. direct S-wave, direct P-wave, upper-mantle Pn-wave, upper-mantle Sn-wave, etc. The third database is the Natural Resources Canada earthquake database\(^3\). The Canadian search engine is very similar to the USGS search engine, but this earthquake database includes Canadian seismic stations (Figure 1, Appendix B). The result from a search of the Canadian earthquake database using the

---

1: Earthquake database search through Weston Observatory
   http://www.bc.edu/content/bc/research/westonobservatory/northeast/reports.html
search parameters mentioned above gives a list of earthquakes for a specific location, time, and magnitude. The user can “click” on each earthquake that resulted from the search on the website. This will then show the seismic station names along with the observed and predicted arrival times for the seismic phases that were used in locating the earthquake. This link also lists the type of seismic phase, breaking it down by direct P-waves, direct S-waves, upper-mantle Pn-waves and upper-mantle Sn-waves.

3.3 Subdivisions of the Study Area

The study region consists of a large area in NENA (Figure 1). To look for spatial variations in the uppermost mantle velocities, the region was divided into seven areas (Figure 16) based on previous uppermost mantle seismic velocity studies and also the location of seismic stations (Figures 1 and 4). The following is a description of each of the seven areas analyzed.

**Area 1:** consists of NE/SW trending tectonic belts through Maine and New Brunswick that are characterized by Silurian to Devonian marine to terrestrial sedimentary rocks and terrestrial bimodal volcanic rocks (Figure 2) (Williams, 1978; Hatcher, 2010). Seismic surveys in this area include the 1984 MSRP, studied by Luetgert et al. (1987), that showed an upper mantle velocity of 8.1 km/s throughout Maine at about a depth of 32 km in the southeast to 37 km in the northwest. Zhu and Ebel (1994) also determined seismic velocities for the uppermost mantle using tomography beneath seismic stations JKM and EMM in this area (Figure 1). Their results were 8.19 km/s and 8.00 km/s, respectively.
**Area 2**: constitutes the region from southeastern New England to northern New Jersey (Figure 16). Seismic studies for this area were conducted by Chiburis and Ahner (1980), Taylor and Toksoz (1979), and Zhu and Ebel (1994) (Figure 4). The results of these studies show an upper mantle velocity between 8.13 km/s (Taylor and Toksoz, 1979) in southern New Hampshire and 8.10 km/s in southern New England (Chiburis and Ahner, 1980) (Figure 4). Zhu and Ebel (1994) reported an uppermost mantle P-wave velocity of 8.14 km/s beneath seismic station WNH (Figure 4).

**Area 3**: consists of similar north-to-south trending tectonic features such as the Connecticut Valley, Bronson Hill Anticlinorium, and part of the Central Maine Synclinorium as well as the Adirondack Massif to the west (Figure 2). This area combines a portion of the Grenville Province and the northern Appalachians (Figure 2) to determine if a transitional boundary exists within Area 3. The area encompasses north and northeastern New York, middle to northern Vermont, and northern New Hampshire (Figure 16). Hughes and Luetgert (1991) found Pn velocities of 8.10 km/s for central New Hampshire and Eastern New York at depths of approximately 38 km and 40 km with an increase in seismic velocity to 8.20 km/s to 8.61 km/s from 55 km to 65 km, respectively. Zhu and Ebel (1994) showed a Pn velocity of 8.14 km/s beneath seismic station IVT at a depth of about 39 km.

**Area 4**: is at the westernmost edge of the study area and is contained in the southeastern Grenville Province. In western New York and eastern Ontario, Hughes and Luetgert (1991) show a P-wave velocity of 8.12 km/s at about 39 km below the western edge of
Figure 16: Areas 1 through 7 that were analyzed along with corresponding seismic stations as seen in Figure 1.
the Adirondacks Massif. This P velocity then increases to 8.61 km/s at 60 km depth. Beneath southeastern Canada (Figure 4) Hughes and Luetgert (1991) show P-wave velocities of 8.12 km/s, 8.32 km/s, and 8.74 km/s at depths of 40 km, 50 km, and 78 km, respectively.

**Area 5:** includes the southeastern edge of the Grenville Province along the US – Canadian border (Figures 2 and 16). This area was delineated to determine if the same step-wise upper mantle P velocity increases with respect to depth found to the south by Hughes and Luetgert (1991) could be recognized.

**Area 6:** covers the outer edge of the Grenville Province relative to the center of the Grenville craton (Figures 2 and 16) and yields step-wise increases in P-wave velocity also found by Zhu and Ebel (1994). Zhu and Ebel (1994) observed that P-wave apparent velocities of 8.22 km/s from epicentral distances of 190 km and beyond across the entire Quebec region. Zhu and Ebel (1994) also show for this area that the upper mantle seismic P-wave velocity further increases to approximately 8.32 km/s for epicentral distances of 300 km – 532 km, and to 8.74 km/s for epicentral distances greater than 532 km.

**Area 7:** is in the northwestern most part of this study and is the southwestern-most part of the Grenville Province and southeastern-most part of the superior province as defined on the basis of geochronological and metamorphic data (Rivers et al., 1989). This area was designed to compare with a seismic study by Zelt et al. (1994) and Winardhi and
Mereu (1997) who show an upper-mantle P-wave velocity of 8.30 km/s with the Moho at depths approximately 43 – 46 km (Figure 2).
4. RESULTS AND DISCUSSION

4.1 Results Based on the Least Squares Inversion Method

To illustrate the results from the inversions of the data for each region and distance range, the P-wave intercept time for each event was subtracted from each of the arrival times for that event, which makes the intercept of the line fit through the arrival time versus distance data set equal to zero. Once this was done, all of the data for that region and distance range were plotted to show the trend in the data from which the slowness value, and therefore the apparent P-wave velocity, was computed. For each of the seven regions (Figure 16) plots of observed arrival times (after the intercept times were subtracted from the observed arrival times at their respective events) versus epicentral distances for each distance range were created to illustrate the results of the least squares inversion for the apparent P-wave velocities.

4.2 Results for each Area

Area 1: The dataset for Area 1 consisted of 13 earthquakes for epicentral distance range of 200 – 400 km, 5 earthquakes for epicentral distance range of 400 – 600 km, and 1 earthquake for epicentral distance range of 600 – 900 km. Table 2 shows the final P-wave velocity results for Area 1. Table 2 column 1 shows the earthquake event omitted from the analysis (Appendix C). A velocity of 8.05 km/s with a standard deviation of 0.03 km/s for epicentral distance of 200 – 400 km (Figure 17). Similarly, for 400 – 600
km a P velocity of 8.07 km/s with a standard deviation of 0.04 km/s was calculated (Figure 18). For the 600 – 900 km range, only one event was retrieved from the databases, and therefore, there was not enough data for application of the jackknife analysis; thus, only a least squares line was fit to the data, for which a P-wave velocity of 8.21 km/s at epicentral distance 600 – 900 km was found (Figure 19). P velocities ranging from 8.05 – 8.07 km/s for the distance range from 200 – 400 km and an apparent increase in P-wave velocity of about 0.01 km/s for epicentral distances of 400 – 600 km (Figures 17 and 18). Unfortunately, the 8.21 km/s velocity P-wave velocity for epicentral distances of 600 – 900 km may not be an accurate representation of the P-wave velocity for that distance due to the small data set used for that velocity determination.

Table 2: Calculated P wave velocities for Area 1 using the least squares inversion and incorporating the jackknife methodology

<table>
<thead>
<tr>
<th>Earthquake event ID excluded using jackknife method (Appendix A)</th>
<th>Area 1 200-400 km Velocities (km/s)</th>
<th>Earthquake event ID excluded using jackknife method (Appendix A)</th>
<th>Area 1 400-600 km Velocities (km/s)</th>
<th>Earthquake event ID excluded using jackknife method (Appendix A)</th>
<th>Area 1 600-900 km Velocities (km/s)</th>
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Figure 17: Area 1 200 – 400 km least squares inversion velocity result after subtracting intercept times from arrival times.
Figure 18: Area 1 400 – 600 km least squares inversion velocity result after subtracting intercept times from arrival times.
Figure 19: Area 1 600 – 900 km least squares analysis observed travel times versus epicentral distance for each individual earthquake event.
**Area 2:** Area 2 consisted of 11 earthquakes analyzed for epicentral distances of 200 – 400 km, 13 earthquakes for epicentral distances of 400 – 600 km, and 4 earthquakes for epicentral distances of 600 – 900 km. Table 3 shows the P velocity results for Area 2 from the various epicentral distances analyzed. Table 3 column 1 shows the earthquake event omitted from the least squares analysis using the jackknife methodology (Appendix D). A velocity of 7.94 km/s with a standard deviation of 0.04 km/s for epicentral distances of 200 – 400 km (Figure 20). Using Equation 25 for epicentral distances at 400 – 600 km, a P velocity of 8.01 km/s with a standard deviation of 0.014 km/s was calculated (Figure 21). At epicentral distances of 600 – 900 km a P-wave velocity of 8.07 km/s with a standard deviation of 0.13 km/s was calculated (Figure 22).

Table 3: Calculated P wave velocities for Area 2 using the least squares inversion and incorporating the jackknife methodology

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<th>Area 2 400- 600 km Velocities (km/s)</th>
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<th>Area 2 600- 900 km Velocities (km/s)</th>
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Figure 20: Area 2 200 – 400 km least squares inversion velocity result after subtracting intercept times from arrival times.
Figure 21: Area 2 400 – 600 km least squares inversion velocity result after subtracting intercept times from arrival times.
Figure 22: Area 2 600 – 900 km least squares inversion velocity result after subtracting intercept times from arrival times.
**Area 3**: There were 36 earthquake events in total that were analyzed for Area 3. Epicentral distances of 200 – 400 km had 24 earthquakes, 400 – 600 km had 9 earthquakes, and 600 – 900 km had three earthquakes. The velocities given in Table 4 are very close to 8.0 km/s for all epicentral distance ranges for this area. The standard deviations of the velocities of 7.99 km/s and 8.02 km/s are 0.04 km/s and 0.01 km/s for distances of 200 – 400 km and 400 – 600 km, respectively. For epicentral distances of 600 km and greater only three earthquakes were acquired from the databases; therefore, there are few arrival time data for this epicentral distance range. Figures 23 to 25 show the results of the least squares inversion solving for the $M$ matrix in Equation 24 at epicentral distances of 200 – 400 km (Figure 23), 400 – 600 km (Figure 24), and 600 – 900 km (Figure 25). For epicentral distance range of 600 – 900 km there was a lower velocity of 7.78 km/s relative to the other epicentral distances in this area; however, within the uncertainties of the computed P velocities in this area there are no statistical differences between the velocities found for all three epicentral distance ranges.
Table 4: Calculated P wave velocities for Area 3 using the least squares inversion and incorporating the jackknife methodology

<table>
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<tr>
<th>Earthquake event ID excluded using jackknife method (Appendix A)</th>
<th>Area 3 200–400 km Velocities (km/s)</th>
<th>Earthquake event ID excluded using jackknife method (Appendix A)</th>
<th>Area 3 400–600 km Velocities (km/s)</th>
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Figure 23: Area 3 200 – 400 km least squares inversion velocity result after subtracting intercept times from arrival times.
Figure 24: Area 3 400 – 600 km least squares inversion velocity result after subtracting intercept times from arrival times.
Figure 25: Area 3 600 – 900 km least squares inversion velocity result after subtracting intercept times from arrival times.
Area 4: Area 4 had a total of 32 earthquakes analyzed. For epicentral distances of 200 – 400 km, 400 – 600 km and 600 – 900 km there were 13, 14 and 5 earthquakes, respectively, for which arrival-time readings were obtained. Arrival-time data from epicentral distances of 200 – 400 km had a calculated P velocity of 8.05 km/s with a standard deviation of 0.04 km/s. At epicentral distances of 400 – 600 km and 600 – 900 km, P velocities were within one standard deviation of one another with values of 8.22 km/s and 8.28 km/s, with standard deviations of 0.03 and 0.03, respectively. Figures 26 to 28 show the results of the least squares inversion for epicentral distances 200 – 400 km (Figure 28), 400 – 600 km (Figure 29), and 600 – 900 km (Figure 30).

Table 5: Calculated P wave velocities for Area 4 using the least squares inversion and incorporating the jackknife methodology

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<th>Earthquake event ID excluded using jackknife method (Appendix A)</th>
<th>Area 4 200–400 km Velocities (km/s)</th>
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<th>Area 4 400–600 km Velocities (km/s)</th>
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Figure 26: Area 4 200 – 400 km least squares inversion velocity result after subtracting intercept times from arrival times.
Figure 27: Area 4 400 – 600 km least squares inversion velocity result after subtracting intercept times from arrival times.
Figure 28: Area 4 600 – 900 km least squares inversion velocity result after subtracting intercept times from arrival times.
Area 5: Area 5 had a total of 122 earthquakes that were analyzed. Epicentral distances 200 – 400 km, 400 – 600 km and 600 – 900 km had 71, 35 and 16 earthquakes that were analyzed, respectively. For epicentral distances of 200 – 400 km, a velocity of 8.24 km/s was calculated with a standard deviation of 0.01 km/s (Figure 29). Likewise for epicentral distances of 400 – 600 km, a velocity of 8.29 km/s (Figure 30) was computed with a standard deviation of 0.028 km/s. Lastly the data from epicentral distances of 600 – 900 km yielded a velocity calculation of 8.52 km/s, with a standard deviation of 0.02 km/s (Figure 31). Table 6 shows the calculated P velocities for Area 5.

Table 6: Calculated P wave velocities for Area 5 using the least squares inversion and incorporating the jackknife methodology.

<table>
<thead>
<tr>
<th>Earthquake event ID excluded using jackknife method (Appendix A)</th>
<th>Area 5 200-400 km Velocities (km/s)</th>
<th>Earthquake event ID excluded using jackknife method (Appendix A)</th>
<th>Area 5 400-600 km Velocities (km/s)</th>
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Figure 29: Area 5 200 – 400 km least squares inversion velocity result after subtracting intercept times from arrival times.
Figure 30: Area 5 400 – 600 km least squares inversion velocity result after subtracting intercept times from arrival times.
Figure 31: Area 5 600 – 900 km least squares inversion velocity result after subtracting intercept times from arrival times.
Area 6: Area 6 had a total of 188 earthquakes that were analyzed for the three epicentral distance ranges. Epicentral distances 200 – 400 km, 400 – 600 km and 600 – 900 km had 96, 56 and 36 earthquakes that were analyzed, respectively. Like Area 5, seismic P velocities for Area 6 increase with an increase in epicentral distance. At epicentral distances from 200 – 400 km, the P velocity is 8.24 km/s with a standard deviation of 0.01 km/s (Figure 32). The P-wave velocity increases to a value of 8.46 km/s with a standard deviation of 0.01 km/s at epicentral distances of 400 – 600 km (Figure 33). At epicentral distances of 600 – 900 km the velocity further increases to 8.54 km/s with a standard deviation of 0.01 km/s. The velocity of 8.54 km/s at epicentral distances of 600 – 900 km in Area 6 is the highest seismic P-wave velocity calculated in this thesis (Table 7 and Figure 34).

Table 7: Calculated P wave velocities for Area 6 using the least squares inversion and incorporating the jackknife methodology

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Table 7 Cont.:

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<tr>
<td>DD</td>
<td>8.23</td>
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</table>
Figure 32: Area 6 200 – 400 km least squares inversion velocity result after subtracting intercept times from arrival times.
Figure 33: Area 6 400 – 600 km least squares inversion velocity result after subtracting intercept times from arrival times.
Figure 34: Area 6 600 – 900 km least squares inversion velocity result after subtracting intercept times from arrival times.
**Area 7**: Area 7 had a total of 22 earthquakes that were analyzed for the three epicentral distance ranges. Epicentral distances of 200 – 400 km, 400 – 600 km and 600 – 900 km had 11, 10 and 1 earthquakes that were analyzed, respectively. Like Areas 5 and 6, the velocity in Area 7 (Figure 16) increases with epicentral distance (Table 8). At epicentral distances of 200 – 400 km a P velocity of 8.15 km/s with a standard deviation of 0.04 km/s was calculated (Figure 35), and a P velocity of 8.31 km/s with a standard deviation of 0.04 km/s was calculated for epicentral distances of 400 – 600 km/s (Figure 36). For epicentral distances of 600 -- 900 km only two earthquake events were analyzed, and therefore, the jackknife analysis could not be utilized for this epicentral distance range. Using the least squares fit of the observed arrival times and corresponding epicentral distances (Figure 37), a velocity of 8.54 km/s was calculated.

Table 8: Calculated P wave velocities for Area 7 using the least squares inversion and incorporating the jackknife methodology.

<table>
<thead>
<tr>
<th>Earthquake event ID excluded using jackknife method (Appendix A)</th>
<th>Area 7 200- 400 km Velocities (km/s)</th>
<th>Earthquake event ID excluded using jackknife method (Appendix A)</th>
<th>Area 7 400- 600 km Velocities (km/s)</th>
<th>Earthquake event ID excluded using jackknife method (Appendix A)</th>
<th>Area 7 600- 900 km Velocities (km/s)</th>
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<tbody>
<tr>
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<td>None</td>
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<td>None</td>
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<td>C</td>
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<td>8.31</td>
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</table>
Figure 35: Area 7 200 – 400 km least squares inversion velocity result after subtracting intercept times from arrival times.
Figure 36: Area 7 400 – 600 km least squares inversion velocity result after subtracting intercept times from arrival times.
Figure 37: Area 7 600 – 900 km least squares analysis for each individual earthquake event.
4.2.1 Summary of Results

In Table 9 the velocities and standard deviations for Areas 1 – 7 for epicentral distances of 200 – 400 km, 400 – 600 km, and 600 – 900 km are listed. Apparent P velocities throughout, what is primarily, the New England Appalachians (Areas 1, 2 and 3) remain at approximately 8.0 km/s with increasing epicentral distances to at least 600 km. The apparent P velocity in the upper mantle for Areas 4, 5, 6, and 7 increases with increasing epicentral distances (Table 9).

Table 9: Velocity and standard deviation (SD) results from all areas.

<table>
<thead>
<tr>
<th></th>
<th>AREA 1</th>
<th>AREA 2</th>
<th>AREA 3</th>
<th>AREA 4</th>
<th>AREA 5</th>
<th>AREA 6</th>
<th>AREA 7</th>
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</thead>
<tbody>
<tr>
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<td>7.99</td>
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<td>8.24</td>
<td>8.15</td>
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<tr>
<td>SD (km/s)</td>
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<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
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<td>8.31</td>
</tr>
<tr>
<td>SD (km/s)</td>
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<td>SD (km/s)</td>
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<td>0.39</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
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</table>

* indicates insufficient data for determination of a standard deviation value

For Area 1 the higher velocity reported for epicenter distances of 600-900 km relative to the velocities at shorter distances may be an artifact of the small number of data used for that velocity determination. Area 4 is shown to have a similar P velocity of about 8.0 km/s as in Areas 1 through 3 for epicentral distances of 200 – 400 km, but at epicentral distances of 400 – 600 km and 600 – 900 km, a larger P velocity (approximately 8.0 km/s– 8.3 km/s) was calculated. In Areas 4, 5, 6 and 7 there is an increase in P velocity with increasing epicentral distances starting with a P velocity at epicentral distances of
200 – 400 km of about 8.15 km/s to 8.24 km/s and increasing to a P velocity of approximately 8.50 km/s at epicentral distances of 600 – 900 km (Table 9).

4.3 Depth of Refractor Estimate

The earthquake arrival time data in this study contains information about the P velocity structure of the upper mantle and not the crust; therefore, crustal P velocity information is utilized from previously published crustal P velocity models of Taylor and Toksoz (1979), Stewart et al. (1986), Luetgert et al. (1987), Kafka and Ebel (1988), Hughes and Luetgert (1991), and Luetgert et al. (1992). The depth to the interfaces is varied for the model to yield crossover distances of 200 km, 400 km, and beyond 600 km that are used for the velocity calculations. The maximum depth to an interface is calculated by taking the maximum observed epicentral distance taken from the earthquake databases for each area. In instances of Areas 1 – 3 the P velocity refractor interfaces are not recognized below the Moho so a minimum depth to the next deeper refracting layer within the mantle was used by assuming a velocity for that next deeper layer. This analysis was completed using velocities of 8.3 km/s, 8.5 km/s, and 8.7 km/s for the unobserved next upper mantle layer in order to cover the possible range of velocities for that layer. Where the resolvable velocity increases between 200 – 400 km, 400 – 600 km, and 600 – 900 km epicentral distances, the depths to the tops of the refracting layers are estimated based on an approximate crossover distance of 400 km, and 600+ km. This allows one to estimate the depths in the upper mantle from which the calculated P velocities are coming.
from. Figures 38, 39, 40 and 41 along with Table 10, show the P velocity versus refractor depth results.

Table 10: Crustal P velocities taken from previous studies with calculated depth to P velocity refractors using the independent crustal models and calculated upper mantle P velocities.

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<th>Area 1 Vel. (km/s)</th>
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<th>Area 2 Dep. (km)</th>
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<th>Area 5 Vel. (km/s)</th>
<th>Area 5 Dep. (km)</th>
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<th>Area 6 Dep. (km)</th>
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† Represents P velocities not observed but assumed for the next upper mantle refractor.
Figure 38: Velocity versus depth profile for Area 1. The Moho boundary is indicated by the red dashed line.
Figure 39: Velocity versus depth profile for Area 2. The Moho boundary is indicated by the red dashed line.
Figure 40: Velocity versus depth profile for Area 3. The Moho boundary is indicated by the red dashed line.
Figure 41: Velocity versus depth profile for Areas 4, 5, 6 and 7 from Table 10. The Moho boundary is indicated by the red dashed line.
For Area 1, crustal P velocity models from the MSRP study completed in Maine are taken to construct a velocity model of the crust in this area. Based on the Luetgert and Mann (1990) crustal models P velocities of 6.3 km/s at 10 km thickness and 6.7 km/s at 24 km thickness are used. Since there is no observable increase in P velocity with increasing epicentral distances in the upper mantle in Area 1, estimated P velocities of 8.3 km/s, 8.5 km/s and 8.7 km/s are used to constrain the maximum thickness of the 8.05 km/s velocity layer. Table 10 shows the P velocities used and their associated depths. The T-X analysis yielded crossover distances of approximately 194 km, 400 km, and 777 km. The minimum depth of the next deeper refractor using P velocities of 8.3 km/s, 8.5 km/s, or 8.7 km/s is 42 km, 58 km, or 68 km, respectively. Figure 38 shows the resulting velocity models if the next deeper mantle refractor has velocities of 8.3 km/s, 8.5 km/s, or 8.7 km/s.

For Area 2, velocity crustal models from Taylor and Toksoz (1979), Chiburis and Ahner (1980), and Zhu and Ebel (1994) through the southern New England territory were taken to construct a crustal velocity profile for the area. Since the P velocity does not increase with epicentral distances in this area, P velocities of 8.3 km/s, 8.5 km/s, or 8.7 km/s are used to constrain the depth to the next P velocity refractor, yielding a minimum refractor depth of 47 km, 58 km, or 67 km, respectively. The T-X analysis results yielded crossover distances of approximately 202 km, 403 km, and 723 km. Figure 39 shows resulting velocity models if the next deeper mantle refractor has a velocity of 8.3 km/s, 8.5 km/s, or 8.7 km/s.
For Area 3, crustal P velocity model from Hughes and Luetgert (1991) through the central New England and New York territories was used as the crustal model for the T-X analysis. Table 10 shows the P velocities and their associated depth intervals. Since the upper mantle P velocity did not increase with increasing epicentral distance in this area P velocities of 8.3 km/s, 8.5 km/s, or 8.7 km/s were applied for a velocity of the next deeper refractor. The minimum depth to the next deeper P velocity refractor is estimated to be 48 km, 61 km, or 72 km based on the velocity of the next deeper refractor being 8.3 km/s, 8.5 km/s, or 8.7 km/s, respectively. These results yielded crossover distances of approximately 205 km, 403 km, and 797 km. Figure 40 shows resulting velocity models if the next deeper mantle refractor has a velocity of 8.3 km/s, 8.5 km/s, or 8.7 km/s.

In Area 4 a crustal model from Hughes and Luetgert (1991) was used. Calculated upper mantle P velocities from this study of 8.05 km/s, 8.22 km/s, and 8.28 km/s were used for the upper mantle depth calculations. Table 10 shows the P velocity crustal model from Hughes and Luetgert (1991) as well as calculated upper mantle velocities to estimate depths to these refractors. Crossover distances of approximately 208 km, 399 km, and 799 km (Figure 41) were calculated by varying the depths to the P wave refractor at each interface (Table 10). Figure 41 shows the model for Area 4 from Table 10.

For Area 5 the crustal model velocities and their respective depths from Hughes and Luetgert (1992) are used. Table 10 shows the Hughes and Luetgert (1992) crustal velocities and the calculated P velocities in this study, which are 8.24 km/s, 8.29 km/s and 8.52 km/s, with their corresponding depths. Varying the depths for the upper mantle refractors yielded crossover distances of approximately 205 km, 405 km, and 858 km.
The upper mantle P velocity layer of 8.29 km/s has a bottom depth of 86 km with P velocity of 8.52 km/s at depths greater than 86 km. Figure 41 shows the model for Area 5 from Table 10.

Area 6 crustal P velocities are based on a refraction study completed by Zhu and Ebel (1994). Based on the Zhu and Ebel (1994) crustal P velocity model, the crustal layer velocities with corresponding bottom depths are 6.3 km/s (~18 km) and 6.9 km/s (~42 km). The upper mantle P velocities calculated for Area 6 are 8.29 km/s, 8.46 km/s, and 8.54 km/s. This analysis yielded crossover distances of approximately 215 km, 392 km, and 885 km. The P velocity refractor of 8.46 km/s is calculated at a depth of 79 km and a P velocity 8.52 km/s should be recognized at depths greater than 79 km. Figure 41 shows the calculated depths for Area 6.

Area 7 crustal P velocities and depths are taken from the Zelt et al. (1994) and Winardhi and Mereu (1997) crustal models. They show crustal P velocities of approximately 6.0 km/s and 6.8 km/s with corresponding depths of the bottoms of these layers of 18 km and 42 km, respectively. For Area 7 upper mantle P velocity results of 8.15 km/s, 8.31 km/s, and 8.54 km/s were determined for epicentral distances of 200 – 400, 400 – 600 km, and 600 – 900 km, respectively. Depths to the interfaces of 18 km, 42 km, 64 km, and 95 km were calculated for the corresponding P velocities of 6.2 km/s, 7.1 km/s, 8.15 km/s, 8.31 km/s, and 8.54 km/s from the T-X model (Figure 41). Crossover distances used were approximately 210 km, 393 km, and 741 km.
4.4 Sub-regions

Areas 1 through 7 are grouped into two sub-regions based on the upper-mantle P-wave velocities calculated: (1) Areas 1, 2, and 3 located in the southeastern edge of the Grenville province and the New England Appalachians where the apparent P velocities are approximately 8.0 km/s with no recognizable increase with increasing epicentral distances; (2) the Precambrian Grenville basement in southeastern Canada and Quebec where the P-wave apparent velocities increases from approximately 8.2 km/s at epicentral distances of 200 – 400 km up to approximately 8.3 - 8.5 km/s with epicentral distances greater than 600 km, specifically in Areas 4, 5, 6, and 7 (Figures 30, 33, 36, and 39).

4.5 Upper Mantle Composition

Based on the seismic velocities in this study, the upper mantle composition are inferred using measured P velocities in the laboratory at upper mantle conditions (Christensen, 1974; Fountain and Christensen, 1989). For the New England Appalachians no increase in P velocities is recognized. Using the measured P velocities, it is proposed that a pyroxenite composition dominates the sub-Moho throughout New England. For the southeastern Grenville Province eclogite is the preferred mineral based on the measured seismic P velocities in this study.
4.5.1 Seismic Properties of Granulite & Pyroxenite

A candidate for the sub-Moho composition in the New England Appalachians is pyroxenite. Pyroxenite has been analyzed in the laboratory and has little seismic variation with increasing upper mantle pressures, as recognized throughout Areas 1 – 3 (Christensen, 1974; Fountain and Christensen, 1989; Anderson, 1990). The pyroxenite samples Christensen (1974) and Fountain and Christensen (1989) used were at pressures representing those of the upper mantle, 10 kbar, or approximately 40 – 60 km in depth. Christensen’s (1974) measured P velocities of pyroxenite were 7.94 km/s to 8.06 km/s ± 0.5%. The P velocities for Areas 1 – 3 are 7.86 ± 0.12 km/s as a minimum and 8.07 ± 0.04 as a maximum. With two standard deviations taken into account, all of the P velocities calculated for Areas 1 – 3 fall well within the range of the P velocities measured by Christensen (1974) for pyroxenite.

4.5.2 Seismic Properties of Eclogite

A proposed upper mantle composition for the southeastern Grenville province is eclogite based on the P velocities found in Areas 4 through 7. Christensen (1974) found that the P-wave velocities of eclogite were approximately 8.2 km/s to 8.5 km/s with an uncertainty of ± 0.5%. The eclogite P velocities measured by Christensen (1974) fall within the range of P velocities calculated for Areas 4 through 7 at depths of 45 – 90 km (Table 9).
Seismic images of the southeastern Grenville province from a 250 km Lithoprobe reflection profile studied (Eaton et al., 1995) show P velocity constraints on the crustal structure in this area of the Grenville orogen. Eaton et al. (1995) correlate crustal reflections with exposures of high-pressure metamorphic rocks in the eastern Grenville Province, Quebec, providing direct evidence for eclogite reflectivity in the Grenville province.

Upper mantle eclogites in the Bergen Arcs of Norway are also characterized by high seismic velocities comparable to those in the upper mantle in the southeastern Grenville province (Fountain et al., 1994). The increase in the upper mantle velocities in Areas 4 – 7, relative to Areas 1 – 3, from approximately 8.0 – 8.1 km/s to 8.2 – 8.5 km/s could represent a mid-Proterozoic magmatic underplating of the crust (Hughes and Luetgert, 1992).

4.6 Temperature Effects on the Seismic Velocities

It is well known that temperature and pressure affect the variation of seismic wave velocity as these effects have been measured in the laboratory on individual crustal and upper mantle minerals and on whole rock samples at approximate pressures from the surface values to 10 kbar and greater (Sobolev et al., 1996; Goes et al., 2000). If the mineral composition is known for the rocks in the upper mantle, then one can estimate the P velocities of those rocks; however, determinations of the petrology of upper mantle rocks comes with many uncertainties due to the lack of detailed knowledge of the exact
upper mantle petrology and of many other important variables that can affect the seismic velocities of rocks, such as temperature, mineral orientation, chemistry, porosity, water content, and thermal conductivity (Christensen, 1974).

4.6.1 Temperature Estimates

To estimate temperatures in the upper mantle values of heat production and thermal conductivity must be determined, although they are known only with large uncertainties (Mareschal et al. 2000). Using measured surface temperatures and temperature convection models Mareschal and Jaupart (2004) calculate how temperatures vary with respect to depth in 5° X 5° longitude-latitude grid elements covering the surface of the earth. The temperature vs. depth curves in the Grenville Province from Mareschal and Jaupart (2004) are used. The upper mantle temperatures they calculated were 350° C ± 25° C and 450 ± 25° C at approximately 40 km and 60 km depths, respectively.

Goes and van der Lee (2002) analyzed the thermal structure of the North American uppermost mantle based on P and S velocities determined from tomographic models. They found upper mantle temperatures in New England, corresponding to Areas 1 – 3, of approximately 500° C ± 50° C and 700° C ± 50° C at 40 km and 60 km depths, respectively.
4.6.2 Temperature Effects

Christensen (1979) used a least squares methodology to determine a constant (K) that represents the derivative of P velocity with respect to temperature at constant pressure (Equation 26).

\[ K = \frac{\partial V_p}{\partial T} = dV_p/dT \quad (26) \]

Christensen (1979) found a K value for eclogite of -0.84X10^{-3} km s^{-1} °C^{-1} ± 1.0% at temperatures between 300 – 400 °C. Unfortunately, the value of K for pyroxenite has not been measured in the laboratory for upper mantle conditions; therefore, there is no comparison that can be made of the K value of eclogite to that of pyroxenite. However, here it is assumed that the value of K is the same for eclogite and pyroxenite, approximately -8.4X10^{-4} km s^{-1} °C^{-1}.

If the value of K for eclogite can be used for all the locations analyzed using variations in P velocities between Areas 1 – 3 and Areas 4 – 7 (Table 9) one can determine if temperature difference between these locations can explain the observed vertical and lateral upper mantle P velocity variation between these two regions.

Solving for \( \Delta V_p \) in Equation 26 one can determine lateral change in P-wave velocities (\( \Delta V_p \)) that would be required to correlate with the reported differences in temperatures
\[ \Delta V_p = K \Delta T \] (27)

Based on geothermal models by Goes and van der Lee (2002) and Mareschal and Jaupart (2004) the difference in temperature between the Appalachians and Grenville Province are 150°C ± 25°C and 250°C ± 25°C at 40 km and 60 km depth when compared to the Grenville Province at the same depths.

The minimum and maximum ranges of seismic velocities at depths of 40 km and 60 km are calculated for Areas 1 – 3 and Areas 4 – 7. Using the data in Table 10 the minimum and maximum differences in the P velocity at 40 km depth between Areas 1-3 and Ares 4-7 are 0.20 km/s and 0.40 km/s, respectively. Likewise for 60 km depth the minimum and maximum P velocity differences are 0.39 km/s and 0.50 km/s. These minimum and maximum P velocity differences between Areas 1 – 3 and Areas 4 – 7 include the two standard deviation variations in the velocity estimates.

4.7 Temperature versus Velocity Results

Table 11 shows the P-wave velocity changes as a function of change in temperature based on the value of K for eclogite for rocks at depths of 40 km and 60 km. It is clear from Table 11 that the difference in P velocities (\( \Delta V_p \)) using Equation 27 are not within the 0.20 km/s to 0.40 km/s P velocity differences between Areas 1-3 and Areas 4-7 found at 40 km depth. At 60 km depth the calculated differences in P velocity (\( \Delta V_p \)) in Table 11 are also not within the minimum and maximum differences in P velocities of 0.39 km/s to 0.50 km/s between the two regions. This analysis suggests that temperature
differences at 40 km at 60 km in depth throughout this study region cannot explain the upper mantle velocity variations between Areas 1-3 and Areas 4-7.

Table 11: Changes in temperature and corresponding change in P-wave velocity at 40 km and 60 km depth in our study area based on a K value measured for eclogite.

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<tr>
<th>ΔVp (km/s)</th>
<th>K (km s⁻¹ °C⁻¹)</th>
<th>ΔT (°C) at 40 km</th>
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<th>ΔVp (km/s)</th>
<th>K (km s⁻¹ °C⁻¹)</th>
<th>ΔT (°C) at 60 km</th>
<th>Rock Assemblage</th>
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5. COMPARISON OF THE INVERSION RESULTS WITH PREVIOUS STUDIES

Upper mantle P-wave velocities and calculated layer thicknesses found across Areas 1 – 7 of New England and southeastern Canada are compared with results from previous crustal and upper mantle structure investigations in northeastern North America. Velocity-depth models of the upper mantle beneath individual sites in northeastern North America, determined from the previous studies, are shown in Figures 42 and 43.

5.1 Area 1

The upper mantle P velocity results found for Areas 1-7 are consistent with results from several previous studies (Figure 42). More specifically, the Area 1 velocity of 8.05 km/s at a depth of 34 km is within one standard deviation of the upper mantle velocity from the Maine Seismic Refraction Profile (MSRP) depth profile (Luetgert et al., 1987). A P velocity of 8.10 km/s throughout Maine at depths of approximately 33 to 37 km were calculated. Zhu and Ebel (1994) use tomography to determine P velocity variations; however, their method has a disadvantage in that inaccuracies in the velocities found for shallow layers can get mapped into the velocities calculated for the deeper layers, which leads to a systematic bias for all the blocks sampled by rays which traverse the inaccurate shallow layers. However, in their analysis Zhu and Ebel (1994) determined a P velocity of 8.03 km/s for the uppermost mantle throughout Area 1 (Figure 4) with no recognizable vertical increase in velocity.
Figure 42: Velocity (km/s)-depth (km) profile of different velocity structures of the lower crust and upper-most mantle beneath northeastern North America as determined by different researchers. The models are T&T – Taylor and Toksoz (1979); C&A – Chiburis and Ahner (1980); H&L – Hughes and Luetgert (1991); Luetgert et al. (1987); Z&E – Zhu and Ebel (1994); Zelt - Zelt (1994). The abbreviations are: NH – New Hampshire; CT – Connecticut; E. NY – Eastern New York; SGP – Southeastern Grenville Province; NW ME – Northwest Maine; SW ME – Southwest Maine; SE ME – Southeast Maine; HKM, EMM, WNH, JKM, and IVT are seismic stations; AT – Avalon Terrane. A1 to A3 are the areas studied (A1=Area 1; A2=Area 2; and A3=Area 3). The dashed line at the Moho boundary in the H&L model indicates that the depth to the boundary is not well constrained. The shaded areas are places in the depth profile that were undetermined in the published analyses or in this study. The Moho, where there are constraints on depth, is indicated by a solid line at the bottom of the interval.
5.2 Areas 2 & 3

Zhu and Ebel (1994) show P velocities of 8.00 km/s at 32 km depth under seismic station EMM (Figure 4), 8.10 km/s at 33 km depth under seismic station HKM, and 8.14 km/s and 8.04 km/s at depths of 36 km and 39 km under seismic stations WNH and IVT, respectively (Figure 42). They also reported a P velocity of 8.19 km/s at a depth of 38 km under seismic station JKM, which is a higher P velocity than the P velocity of 8.05 km/s at 34 km depth calculated herein. Area 2 P velocities are 7.94 km/s and 8.07 km/s, lower than those calculated by Taylor and Toksoz (1979), who found a P velocity of 8.13 km/s, and also lower than Chiburis and Ahner’s (1980) P velocity (8.10 km/s) (Figure 42). The Pn velocities of 7.94 km/s and 8.07 km/s for Area 2 are within 2 standard deviations of the Chiburis and Ahner (1980) and Taylor and Toksoz (1979) results.

5.3 Area 4

Hughes and Luetgert (1991) found higher upper mantle P velocities than the P velocity results in this study. They show a velocity increase up to 8.20 km/s at 50 km in depth, but they do not resolve deeper P velocity structures (Figure 42). The Area 4 upper mantle P velocity in this study is 8.05 km/s at a depth of 43 km, which closely matches the Hughes and Luetgert (1991) velocity of 8.05 km/s at a depth of 45 km. Hughes and Luetgert (1991) calculated P velocities versus depth using one-dimensional travel-time modeling, reflectivity synthetic amplitude modeling, and a two-dimensional linearized travel time inversion indicating that the depth to the boundary is not well constrained.
5.4 Area 5 & 6

In Area 5 the P velocities calculated by Hughes and Luetgert (1991) and Zelt (1994) vary from the P velocities and depths found herein by greater than two standard deviations (Figure 42). Zhu and Ebel (1994) calculate P velocities of 8.12 km/s from NW Quebec to the Canadian-US border, which are slower P velocities than found for Area 6 where a P velocity of 8.29 km/s at depths of 39 – 42 km (Figure 43). Zhu and Ebel (1994) report a P velocity refractor of 8.61 km/s at 60 km that was not observed in this analyses (Figure 43).

5.5 Area 7

Winardhi and Mereu (1997) conducted a tomographic inversion study based on a seismic refraction line through a portion of the southeastern Grenville Province encompassing Area 7. The mean P velocity calculated are 8.15 km/s at 42 km, while Winardhi and Mereu’s (1997) mean P velocity is 8.20 km/s at a depth of 42 km. There is high probability that these results are statistically the same based on the calculated standard deviations (Table 9; Figure 45).
Figure 43: Velocity (km/s)-depth (km) profile of different velocity structures of the lower crust and upper-most mantle beneath northeastern North America as determined by different researchers. The models are H&L – Hughes and Luetgert (1991); Z&E – Zhu and Ebel (1994); Zelt - Zelt (1994); W&M – Winardhi and Mereu (1997). The abbreviations are: SEG – Southeastern Grenville terrane; Q – Quebec; NA – Northern Appalachians; SGP – Southern Grenville Province; GF – Grenville Front. A4 to A7 are the areas studied in this thesis (A4=Area 4; A5=Area 5; A6=Area 6; and A7=Area 7). The dashed line at the Moho boundary in the H&L. The shaded areas are places in the depth profile that were undetermined in the published analyses or in the analyses in this study.
6. CONCLUSIONS

A number of conclusions were determined using the seismic refraction inversion technique:

1) P velocities throughout the uppermost mantle in Areas 1 – 3 in northeastern North America (largely underlain by the accreted Appalachian terranes) (~8.0 km/s) contain no resolvable change with respect to depth down to 70 km (Figure 42). For Areas 4 – 7 there is an increase in P velocity (8.2 km/s – 8.5 km/s) from the Moho down to depths greater than 70 km (Figure 43).

2) An upper mantle composition of pyroxenite is likely throughout New England (Areas 1 – 3), based on the calculated P velocities. Laboratory P velocity measurements made by Christensen (1979) at upper mantle conditions have P velocities in the same range as those measured in New England (7.94 km/s to 8.06 km/s) at pressures representative of upper mantle conditions of 10 kbar – 30 kbar, respectively.

Episodic fractionation and intrusion of felsic magmas from mantle-derived basaltic underplates may explain the increasing P velocities throughout the Grenville terrane in the upper mantle in Areas 4 – 7 as the basaltic rocks converted to eclogite. P velocities in Areas 4 – 7 (8.2 km/s – 8.5 km/s) at depths between 48 km to 87 km are consistent with the laboratory P velocities Christensen (1974) measured for eclogite.
3) The minimum and maximum $\Delta V_p$ between Areas 1 – 3 (New England Appalachians) and Areas 4 – 7 (underlain by Grenvillian basement) are 0.20 km/s and 0.40 km/s at 40 km depth and are 0.39 km/s and 0.50 km/s at 60 km depth. Upper mantle temperatures in the Grenville province and the New England Appalachians vary from 150$^\circ$C to 250$^\circ$C at 40 km and 60 km depths, respectively. Comparing the $V_p$ difference in this study to calculated $V_p$ differences in the laboratory, indicates that the effect that temperature has on upper mantle P velocities is not significant to explain vertical upper-mantle velocity variations between New England and southeastern Grenville Province.
REFERENCES


APPENDIX A
EARTHQUAKES AND CORRESPONDING STATIONS ANALYZED
*Numbers from 200-900 km distances represent station ID’s from Figure 1

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APPENDIX C
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event(1).distances=[211.4;364.2];
event(1).times=[30.71;49.78];
event(1).numobs=2;
event(2).name='2/6/2010 NB, 67.0KM WSW OF MONCTON';
event(2).stations=[{'EMMW'},{'PQI'},{'PKME'}];
event(2).distances=[200.5;200.6;297.0];
event(2).times=[29.81;29.88;41.40];
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event(3).name='3/30/2010 3 Mn ME, 14.0KM S OF BANGOR ';
event(3).stations=[{'LMN'},{'BATG'}];
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event(8).numobs=2;
event(9).name='03.09.1989 4.3MN CHARLEVOIX-KAMOURASKA';
event(9).stations=[{'MIM'},{'GGN'}];
event(9).distances=[282.18;371.60];
event(9).times=[40.635;51.855];
event(9).numobs=2;
event(10).name='03.11.1989 4.4MN CHARLEVOIX-KAMOURASKA';
event(10).stations=[{'MIM'},{'GGN'}];
event(10).distances=[282.70;372.63];
event(10).times=[40.592;50.972];
event(10).numobs=2;
event(11).name='07.05.1991 3.8MN NEAR HOWICK';
event(11).stations=[{'TRM'},{'HKM'},{'MIM'}];
event(11).distances=[304.0;338.0;378.0];
event(11).times=[43.42;47.54;51.94];
event(11).numobs=3;
event(12).name='10.05.1985 3.9MN FELT IN BATHURST';
event(12).stations=[{'JKM'},{'HKM'},{'HAL'}];
event(12).distances=[318.0;352.0;352.0];
event(12).times=[45.20;49.40;50.50];
event(12).numobs=3;
event(13).name='12.31.1990 4.5MN 25 km NE from LA TUQUE';
event(13).stations=[{'HKM'},{'TRM'},{'EMM'}];
event(13).distances=[400.0;415.0;507.0];
event(13).times=[55.08;56.86;67.98];
event(13).numobs=3;

numevents=length(event);
T=event(1).times;
for jj=2:numevents
    T=[T;event(jj).times];
end

G=[event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,numevents-1)];
for jj=2:numevents
    Gtemp=[event(jj).distances,zeros(event(jj).numobs,jj-1),ones(event(jj).numobs,1),zeros(event(jj).numobs,numevents-jj)];
    G=[G;Gtemp];
end

M=G\T;
M;
V1=1/M(1)

Vtot=[V1];

for jj=1:numevents
    G=[];
    T=[];

for ii=1:numevents
    if ii~=jj
        Gtemp=[event(ii).distances,zeros(event(ii).numobs,ii-1),ones(event(ii).numobs,1),zeros(event(ii).numobs,numevents-ii)];
        T=[T;event(ii).times];
        G=[G;Gtemp];
    end
end
    M=G\T;
    M;
    V=1/M(1)
    Vtot=[Vtot;V];
end
C=std(Vtot)
%Ep. Distance Analysis 400-600km from NE area sources

clear all

event(1).name='6/23/2010 PQ, OTTAWA, ON 4.9MN';
event(1).stations=[[WVL], [PKME]];
event(1).distances=[480.3;488.6];
event(1).times=[63.72;64.69];
event(1).numobs=2;
event(2).name='7/21/2009 4 Mn NB, 17.5 KM ESE OF STE ANNE-DE-MONTS';
event(2).stations=[[GGN], [EMMW]];
event(2).distances=[443.5;495.4];
event(2).times=[58.13;64.58];
event(2).numobs=2;
event(3).name='11/2/2008 3 Mn PQ, 45KM N OF QUEBEC';
event(3).stations=[[EMMW], [GGN], [LMN]];
event(3).distances=[412.1;419.6;519.4];
event(3).times=[54.32;55.85;67.80];
event(3).numobs=3;
event(4).name='11.09.1986 4.2MN FELT NORTH SHORE of THE ST.LAWRENCE';
event(4).stations=[[LMN], [GGN]];
event(4).distances=[424.0;460.0];
event(4).times=[56.82;61.63];
event(4).numobs=2;
event(5).name='11.14.1988 3.7MN JAY';
event(5).stations=[[KLN], [LMN]];
event(5).distances=[409.0;466.0];
event(5).times=[55.45;62.38];
event(5).numobs=2;

numevents=length(event);

T=event(1).times;
for jj=2:numevents
    T=[T;event(jj).times];
end

G=[event(1).distances, ones(event(1).numobs, 1), zeros(event(1).numobs, numevents-1)];
for jj=2:numevents
    Gtemp=[event(jj).distances, zeros(event(jj).numobs, jj-1), ones(event(jj).numobs, 1), zeros(event(jj).numobs, numevents-jj)];
    G=[G;Gtemp];
end

M=G\T;

M;

V1=1/M(1)
Vtot=[V1];

for jj=1:numevents
    G=[];
    T=[];
    for ii=1:numevents
        if ii~=jj
            Gtemp=[event(ii).distances,zeros(event(ii).numobs,ii-1),ones(event(ii).numobs,1),zeros(event(ii).numobs,numevents-ii)];
            T=[T;event(ii).times];
            G=[G;Gtemp];
        end
    end
    if jj==3
        G(:,4)=[];
    end
    M=G\T;
    M;
    V=1/M(1)
    Vtot=[Vtot;V];
end

C=std(Vtot)
clear all
event(1).name='6/23/2010 PQ, OTTAWA, ON 4.9MN';
event(1).stations = [{'EMMW'}, {'GGN'}, {'BATG'}];
event(1).distances=[643.7;683.4;740.2];
event(1).times=[82.68;87.65;94.41];
event(1).numobs=3;
event(2).name='09.26.1987  3.8MN FELT WIDELY IN N.Y.';
event(2).stations = [{'GGN'}, {'KLN'}, {'LMN'}];
event(2).distances=[613.0;687.0;779.0];
event(2).times=[82.59;90.29;101.38];
event(2).numobs=3;

tumevents=length(event);
T=event(1).times;
for jj=2:tumevents
    T=[T;event(jj).times];
end

G=event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,tumevents-1)];
for jj=2:tumevents
    Gtemp=event(jj).distances,zeros(event(jj).numobs,jj-1),ones(event(jj).numobs,1),zeros(event(jj).numobs,tumevents-jj));
    G=[G;Gtemp];
end

M=G\T;
M;
V1=1/M(1)

Vtot=[V1];

for jj=1:tumevents
    G=[];
    T=[];
    for ii=1:tumevents
        if ii~=jj
            Gtemp=event(ii).distances,zeros(event(ii).numobs,ii-1),ones(event(ii).numobs,1),zeros(event(ii).numobs,tumevents-ii));
            T=[T;event(ii).times];
            G=[G;Gtemp];
        end
    end
    M=G\T;

\[
\begin{align*}
M; \\
V &= 1/M(1) \\
\text{Vtot} &= [\text{Vtot}; V]; \\
\text{end} \\
C &= \text{std}('Vtot')
\end{align*}
\]
APPENDIX D
MATLAB CODE FOR REGIONALIZED AREA 2
%Ep. Distance Analysis 200-400km from NE area sources Area 2
clear all
event(1).name='10/3 bar harbor data';
event(1).stations=[{'FFD'},{'WES'}];
event(1).distances=[298.2;337.1];
event(1).times=[43.3;47.64];
event(1).numobs=2;
event(2).name='Bar Harbor 12/29';
event(2).stations=[{'FFD'},{'BRYW'}];
event(2).distances=[296.7;384.9];
event(2).times=[42.77;53.67];
event(2).numobs=2;
event(3).name='1/9/06 St. Antoine Abbe 3.9 Mn';
event(3).stations=[{'FFD'},{'QUA2'}];
event(3).distances=[253;334.5];
event(3).times=[36.75;46.2];
event(3).numobs=2;
event(4).name='8/26/03 Milford 3.6Mn';
event(4).stations=[{'QUA2'},{'WES'}];
event(4).distances=[294.1;370.8];
event(4).times=[42.64;52.22];
event(4).numobs=2;
event(5).name='06.16.1995 3.8MN NEAR LISBON';
event(5).stations=[{'HRV'},{'LSCT'}];
event(5).distances=[206.12;309.67];
event(5).times=[28.934;43.614];
event(5).numobs=2;
event(6).name='08.22.1992 4.9MB OFFSHORE NEW JERSEY';
event(6).stations=[{'NSC'},{'FLR'},{'MD3'},{'MD4'},{'CRNY'},{'BCT'},{'WES'},{'PRIN','HRV'}];
event(6).distances=[297.0;304.0;325.0;326.0;366.0;371.0;380.0;395.0;398.0];
event(6).times=[43.02;43.46;46.1;46.68;51.65;52;53.12;54.77;55.49];
event(6).numobs=9;
event(7).name='10.06.1992 3.0Mn 200 km S from COATICOOK';
event(7).stations=[{'NSC'},{'MD2'},{'MD3'},{'BCT'}];
event(7).distances=[208.0;213.0;217.0;254.0];
event(7).times=[31.86;32.42;32.96;38.28];
event(7).numobs=4;
event(8).name='10.12.1997 3.1MN ADIRONDACKS';
event(8).stations=[{'BINY'},{'LSCT'}];
event(8).distances=[322.63;374.57];
event(8).times=[46.597;53.627];
event(8).numobs=2;
event(9).name='11.12.1995 3.1MN Maine';
event(9).stations=[{'ONH'},{'WFM'},{'WES'}];
event(9).distances=[305.89;343.01;347.90];
event(9).times=[42.431;47.531;47.771];
event(9).numobs=3;
event(10).name='12/23/2007 3.6 Mc PQ, 12.8KM N OF CHICHESTER';
event(10).stations=[{'LONY'},{'NCB'}];
event(10).distances=[254.7;325.2];
event(10).times=[37.01;45.72];
event(10).numobs=2;
event(11).name='12/27/2008 3.5 Mn PA, 25.6KM NNE OF CARLISLE';
event(11).stations=[{'BINY'},{'TRY'}];
event(11).distances=[217.3;383.8];
event(11).times=[32.92;53.44];
event(11).numobs=2;
numevents=length(event);
T=event(1).times;
for jj=2:numevents
    T=[T;event(jj).times];
end

G=[event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,numevents-1)];
for jj=2:numevents
    Gtemp=[event(jj).distances,zeros(event(jj).numobs,jj-1),ones(event(jj).numobs,1),zeros(event(jj).numobs,numevents-jj)];
    G=[G;Gtemp];
end

M=G\T;
M;
V1=1/M(1)

Vtot=[V1];
for jj=1:numevents
    G=[];
    T=[];
    for ii=1:numevents
        if ii~=jj
            Gtemp=[event(ii).distances,zeros(event(ii).numobs,ii-1),ones(event(ii).numobs,1),zeros(event(ii).numobs,numevents-ii)];
            T=[T;event(ii).times];
            G=[G;Gtemp];
        end
    end
    M=G\T;
    M;
V=1/M(1)
Vtot=[Vtot;V];
end

C=std(Vtot)
Ep. Distance Analysis 400-600km from NE area sources, Area 2

clear all

event(1).name='Presque Isle 7/14';
event(1).stations=[{'WES'},{'QUA2'}];
event(1).distances=[546.2;592.9];
event(1).times=[72.06;77.06];
event(1).numobs=2;
event(2).name='5/25/97 Southern ON 3.9 MC';
event(2).stations=[{'WES'},{'LSCT'},{'YLE'}];
event(2).distances=[456;477.8;522.6];
event(2).times=[71.61;74.25;79.96];
event(2).numobs=3;
event(3).name='05.24.1997 4.2MN WESTERN QUEBEC SEISMIC ZONE';
event(3).stations=[{'WES'},{'BCX'},{'YLE'}];
event(3).distances=[456.26;467.33;521.61];
event(3).times=[62.193;63.983;70.533];
event(3).numobs=3;
event(4).name='6/23/2010 PQ, OTTAWA, ON 4.9MN';
event(4).stations=[{'HRV'},{'WES'},{'BRYW'}];
event(4).distances=[488.6;511.4;542.2];
event(4).times=[64.59;67.09;71.47];
event(4).numobs=3;
event(5).name='08.22.1992 4.9MB OFFSHORE NEW JERSEY';
event(5).stations=[{'LVNJ'},{'LNX'}];
event(5).distances=[418;439.0];
event(5).times=[57.8;59.82];
event(5).numobs=2;
event(6).name='09.16.1994 3.6MN NEAR SPRINGFIELD';
event(6).stations=[{'WFM'},{'PNH'},{'WES'}];
event(6).distances=[401;401;413];
event(6).times=[55.16;55.68;56.8];
event(6).numobs=3;
event(7).name='10/1/2007 3.6 Mn PQ, 82.3KM NW OF MANIWAKI';
event(7).stations=[{'BINY'},{'FFD'}];
event(7).distances=[541.3;567.8];
event(7).times=[71.64;75.47];
event(7).numobs=2;
event(8).name='10.16.1993 3.7Mn MAG 3.4 USGS';
event(8).stations=[{'BINY'},{'GPD'}];
event(8).distances=[421.0;553.0];
event(8).times=[59.75;76.29];
event(8).numobs=2;
event(9).name='11.06.1997 5.1MN Quebec City Region. Felt';
event(9).stations=[{'DNH'},{'WFM'},{'TRY'},{'WES'},{'BCX'}];
event(9).distances=[411.16;465.96;486.11;491.10;496.96];
event(9).times=[55.876;62.116;66.046;65.006;66.206];
event(9).numobs=5;
event(10).name='1992/11/17 4.4Mn (NEIC) 2 OBS. Felt';
event(10).stations=[{'LNX'},{'HRV'},{'WES'},{'BCT'},{'MD2'},{'MD4'},{'MD3'},{'TB R'},{'PNJ'}];
event(10).distances=[404.0;452.0;475.0;492.0;513.0;513.0;514.0;545.0];
event(10).times=[56.86;62.50;64.40;67.72;69.28;70.56;69.46;75.10];
event(10).numobs=8;
event(11).name='1992/11/17 4.4Mn (NEIC) 2 OBS. Felt';
event(11).stations=[{'BINY'},{'TRY'},{'FFD'},{'QUA2'}];
event(11).distances=[440.8;461.3;518.9;567.3];
event(11).times=[59.99;62.53;69.64;75.61];
event(11).numobs=4;
event(12).name='12/31/2008 3.2 Mn ON, 19.7KM NNE OF VAL-DES-BOIS';
event(12).stations=[{'TRY'},{'FFD'},{'BINY'}];
event(12).distances=[405.3;422.9;441.3];
event(12).times=[60.22;64.36;65.81];
event(12).numobs=3;
event(13).name='10.05.1985 3.9MN FELT IN BATHURST';
event(13).stations=[{'WNH'},{'DNH'},{'ONH'}];
event(13).distances=[512.0;548.0;566.0];
event(13).times=[69.38;73.82;76.10];
event(13).numobs=3;
event(14).name='5/25/97 Southern ON 3.9 MC';
event(14).stations=[{'WES'},{'LSCT'},{'YLE'}];
event(14).distances=[456;477.8;522.6];
event(14).times=[71.61;74.25;79.96];
event(14).numobs=3;

tumevents=length(event);
T=event(1).times;
for jj=2:tumevents
    T=[T;event(jj).times];
end

G=[event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,numevents-1)];
for jj=2:tumevents
    Gtemp=[event(jj).distances, zeros(event(jj).numobs,jj-1),ones(event(jj).numobs,1),zeros(event(jj).numobs,numevents-jj)];
    G=[G;Gtemp];
end

M=G\T;
M;
V1=1/M(1)
Vtot=[V1];

for jj=1:numevents
    G=[];
    T=[];
    for ii=1:numevents
        if ii~=jj
            Gtemp=[event(ii).distances,zeros(event(ii).numobs,ii-1),ones(event(ii).numobs,1),zeros(event(ii).numobs,numevents-ii)];
            T=[T;event(ii).times];
            G=[G;Gtemp];
        end
    end
    M=G\T;
    M;
    V=1/M(1)
    Vtot=[Vtot;V];
end

C=std(Vtot)
clear all

event(1).name='Miramichi 7/15';
event(1).stations=[{'BCX'},{'WES'},{'HRV'}];
event(1).distances=[630.4;632.8;632.8];
event(1).times=[84.2;84.22;84.56];
event(1).numobs=3;
event(2).name='3/8/2009 3.2 Mn NB, 90.0KM NNE OF FREDERICTON';
event(2).stations=[{'WES'},{'BRYW'},{'QUA2'},{'UCCT'}];
event(2).distances=[620.9;672.9;685.8;719.3];
event(2).times=[80.77;87.06;89.44;93.27];
event(2).numobs=4;
event(3).name='10/28/2007 3.5 Mn ON, 53KM NNE OF PETAWAWA';
event(3).stations=[{'QUA2'},{'WES'}];
event(3).distances=[606.5;652.7];
event(3).times=[81.50;87.21];
event(3).numobs=2;
event(4).name='11.09.1986 4.2MN FELT NORTH SHORE of THE ST.LAWRENCE';
event(4).stations=[{'WNH'},{'WES'},{'DNH'},{'ONH'},{'PNH'},{'WFM'}];
event(4).distances=[671.0;731.0;734.0;774.0;802.0];
event(4).times=[87.32;93.97;95.09;100.55;102.79];
event(4).numobs=5;

numevents=length(event);
T=event(1).times;
for jj=2:numevents
    T=[T;event(jj).times];
end

G=[event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,numevents-1)];
for jj=2:numevents
    Gtemp=[event(jj).distances,zeros(event(jj).numobs,jj-1),ones(event(jj).numobs,1),zeros(event(jj).numobs,numevents-jj)];
    G=[G;Gtemp];
end

M=G\T;
M;
V1=1/M(1)

Vtot=[V1];

for jj=1:numevents
    G=[];
    T=[];
    for ii=1:numevents
if ii~=jj
    Gtemp=[event(ii).distances,zeros(event(ii).numobs,ii-1),ones(event(ii).numobs,1),zeros(event(ii).numobs,numevents-ii)];
    T=[T;event(ii).times];
    G=[G;Gtemp];
end
end
M=G\T;
M;
V=1/M(1)
Vtot=[Vtot;V];
end

C=std(Vtot)
APPENDIX E
MATLAB CODE FOR REGIONALIZED AREA 3
%Ep. Distance Analysis 200-400km from NE area sources, Area 3
clear all;
event(1).name='02.15.1995 3.5MN WESTERN QUEBEC ZONE. Felt';
event(1).stations=[{"FLET"},{"HBVT"},{"MIV"},{"MDV"}];
event(1).distances=[210.0;232.0;236.0;258.0];
event(1).times=[33.18;35.74;36.05;38.26];
event(1).numobs=4;
event(2).name='2/28/2010 3.6 Mn PQ, 71.0KM WNW OF MONTREAL';
event(2).stations=[{"MDV"},{"LBNH"},{"HNH"}];
event(2).distances=[221.0;263.4;287.2];
event(2).times=[32.81;38.65;41.15];
event(2).numobs=3;
event(3).name='03.14.1996 4.4MN Western Quebec';
event(3).stations=[{"HBVT"},{"MIV"},{"MDV"}];
event(3).distances=[202.88;216.80;258.36];
event(3).times=[30.712;32.892;34.702];
event(3).numobs=3;
event(4).name='04.03.1997 3.6MN Felt. Southern Quebec';
event(4).stations=[{"BGR"},{"MSNY"},{"MDV"},{"MIV"},{"LOZ"}];
event(4).distances=[204.20;225.52;229.05;230.99;231.63];
event(4).times=[31.148;34.358;34.468;34.808;34.888];
event(4).numobs=5;
event(5).name='06.16.1995 3.8MN NEAR LISBON';
event(5).stations=[{"LOZ"},{"PTN"},{"MSNY"}];
event(5).distances=[204.5;235.65;235.73];
event(5).times=[31.424;35.414;35.784];
event(5).numobs=3;
event(6).name='06.20.1997 3.4MN Felt';
event(6).stations=[{"BGR"},{"LOZ"},{"PTN"}];
event(6).distances=[205.74;225.24;227.77];
event(6).times=[31.763;34.653;35.933];
event(6).numobs=3;
event(7).name='6/23/2010 PQ, OTTAWA, ON 4.9MN';
event(7).stations=[{"NCB"},{"MDV"}];
event(7).distances=[233.6;276.6];
event(7).times=[33.37;38.57];
event(7).numobs=2;
event(8).name='09.16.1994 3.6MN NEAR SPRINGFIELD';
event(8).stations=[{"LBNH"},{"DNH"},{"ONH"}];
event(8).distances=[319.0;327.0;349.0];
event(8).times=[45.29;46.74;49.54];
event(8).numobs=3;
event(9).name='09.16.1994 3.3MN NEAR SPRINGFIELD(3)';
event(9).stations=[{"PTN"},{"LONY"},{"FRNY"},{"WCNY"},{"NCB"}];
event(9).distances=[284.6;294.1;322.3;331.0;370.9];
event(9).times=[40.86;41.70;45.71;46.62;51.38];
event(9).numobs=5;
event(10).name='10/1/2007 3.6 Mn PQ, 82.3KM NW OF MANIWAKI';
event(10).stations=[{'LONY'},{'NCB'}];
event(10).distances=[320.0;396.3];
event(10).times=[44.32;53.64];
event(10).numobs=2;
event(11).name='10.02.1994 3.1MN U.S.A.';
event(11).stations=[{'LOZ'},{'PTN'},{'MSNY'}];
event(11).distances=[314.0;330.0;361.0];
event(11).times=[47.10;48.10;54.10];
event(11).numobs=3;
event(12).name='10.02.1994 3.5MN U.S.A.';
event(12).stations=[{'LBNH'},{'PTN'}];
event(12).distances=[208.0;325.0];
event(12).times=[32.04;47.40];
event(12).numobs=2;
event(13).name='10.12.1997 3.1MN ADIRONDACKS';
event(13).stations=[{'LBNH'},{'BINY'}];
event(13).distances=[221.15;322.63];
event(13).times=[34.657;46.597];
event(13).numobs=2;
event(14).name='11/2/2008 3 Mn PQ, 45KM N OF QUEBEC';
event(14).stations=[{'LBNH'},{'LONY'},{'MDV'}];
event(14).distances=[346.8;397.1;399.3];
event(14).times=[46.83;50.90;53.57];
event(14).numobs=3;
event(15).name='11.06.1997 5.1MN Quebec City Region. Felt';
event(15).stations=[{'MIM'},{'HNH'}];
event(15).distances=[253.19;350.84];
event(15).times=[36.296;48.776];
event(15).numobs=2;
event(16).name='11.06.1997 5.1MN Quebec City Region. Felt';
event(16).stations=[{'PNY'},{'FLET'},{'HBVT'},{'MDV'}];
event(16).distances=[227.0;266.0;293.0;322.0];
event(16).times=[34.99;40.85;43.51;46.87];
event(16).numobs=4;
event(17).name='11.12.1995 3.1MN Maine';
event(17).stations=[{'ONH'},{'HNH'}];
event(17).distances=[305.89;349.74];
event(17).times=[42.431;52.051];
event(17).numobs=2;
event(18).name='1992/11/17 4.4Mn (NEIC) 2 OBS. Felt';
event(18).stations=[{'HBVT'},{'MDV'}];
event(18).distances=[215.0;241.0];
event(18).times=[32.52;35.37];
event(18).numobs=2;
event(19).name='11.20.1994 3.2MN SOME 40 km NW of LEWISTON';
event(19).stations=[{'LOZ'},{'PTN'}];
event(19).distances=[324.0;355.0];
event(19).times=[50.00;54.00];
event(19).numobs=2;
event(20).name='12/23/2007 3.6 Mc PQ, 12.8KM N OF CHICHESTER';
event(20).stations=[{'LONY'},{'NCB'}];
event(20).distances=[254.7;325.2];
event(20).times=[37.01;45.72];
event(20).numobs=2;
event(21).name='12/31/2008 3.2 Mn ON, 19.7KM NNE OF VAL-DES-BOIS';
event(21).stations=[{'FRNY'},{'WCNY'},{'MDV'},{'LBNH'}];
event(21).distances=[206.1;241.1;298.2;348.9];
event(21).times=[31.08;35.73;42.75;49.74];
event(21).numobs=4;
event(22).name='10.19.1990 5.0MN 11 km SW from MONT-LAURIER';
event(22).stations=[{'GNF'},{'HBVT'},{'NWC'},{'PGY'}];
event(22).distances=[304.0;307.0;314.0;331.0];
event(22).times=[43.26;43.07;44.60;46.58];
event(22).numobs=4;
event(23).name='11.14.1988 3.7MN JAY';
event(23).stations=[{'FLET'},{'HBVT'},{'MDV'}];
event(23).distances=[202.0;211.0;227.0];
event(23).times=[29.35;30.53;33.08];
event(23).numobs=3;
event(24).name='11.16.1989 4.0MN WESTERN QUEBEC. Felt';
event(24).stations=[{'MSNY'},{'PNY'},{'HBVT'}];
event(24).distances=[222.0;306.0;370.0];
event(24).times=[33.29;42.94;51.04];
event(24).numobs=3;

numevents=length(event);
T=event(1).times;
for jj=2:numevents
    T=[T;event(jj).times];
end

G=[event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,numevents-1)];
for jj=2:numevents
    Gtemp=[event(jj).distances,zeros(event(jj).numobs,jj-1),ones(event(jj).numobs,1),zeros(event(jj).numobs,numevents-jj)];
    G=[G;Gtemp];
end

M=G\T;
M;
\[ V_1 = 1/M(1) \]

\[ V_{tot} = [V_1]; \]

\[
\text{for } jj = 1:\text{numevents}
\]
\[
\quad G = []; \\
\quad T = []; \\
\quad \text{for } ii = 1:\text{numevents}
\]
\[
\quad \quad \text{if } ii \neq jj
\]
\[
\quad \quad \quad G_{\text{temp}} = [\text{event}(ii).\text{distances}, \text{zeros}(\text{event}(ii).\text{numobs}, ii-1), \text{ones}(\text{event}(ii).\text{numobs}, 1), \text{zeros}(\text{event}(ii).\text{numobs}, \text{numevents} - ii)]; \\
\quad \quad \quad T = [T; \text{event}(ii).\text{times}]; \\
\quad \quad \quad G = [G; G_{\text{temp}}]; \\
\quad \quad \quad \text{end}
\]
\[
\quad M = G \backslash T; \\
\quad M; \\
\quad V = 1/M(1) \\
\quad V_{tot} = [V_{tot}; V]; \\
\quad \text{end}
\]

\[ C = \text{std}(V_{tot}) \]
clear all

event(1).name='Miramichi 7/15';
event(1).stations=[{'LBNH'},{'HNH'}];
event(1).distances=[513.6;573.6];
event(1).times=[69.86;77.05];
event(1).numobs=2;
event(2).name='3/8/2009 3.2 Mn NB, 90.0KM NNE OF FREDERICTON';
event(2).stations=[{'LBNH'},{'HNH'}];
event(2).distances=[521.5;579.2];
event(2).times=[69.18;76.73];
event(2).numobs=2;
event(3).name='09.25.1994 4.3MN 19 km NE of LA MALBAIE';
event(3).stations=[{'MSNY'},{'LOZ'},{'CHIP'},{'PTN'}];
event(3).distances=[486.71;499.68;521.16;525.94];
event(3).times=[66.25;66.75;70.25;71.25];
event(3).numobs=4;
event(4).name='09.25.1994 4.3MN 19 km NE of LA MALBAIE';
event(4).stations=[{'ACCN'},{'LBNH'},{'BINY'}];
event(4).distances=[449.8;463.8;524.5];
event(4).times=[61.52;64.74;71.34];
event(4).numobs=3;
event(5).name='10/1/2007 3.6 Mn PQ, 82.3KM NW OF MANIWAKI';
event(5).stations=[{'MDV'},{'LBNH'},{'BINY'}];
event(5).distances=[441.7;493.0;541.3];
event(5).times=[58.94;65.29;71.64];
event(5).numobs=3;
event(6).name='10/28/2007 3.5 Mn ON, 53KM NNE OF PETAWAWA';
event(6).stations=[{'LBNH'},{'BINY'},{'HNH'}];
event(6).distances=[480.7;489.8;493.8];
event(6).times=[65.99;67.10;67.60];
event(6).numobs=3;
event(7).name='11.09.1994 3.0MN LOWER ST. LAWRENCE';
event(7).stations=[{'LBNH'},{'HNH'},{'MDV'},{'LONY'}];
event(7).distances=[413.3;479.4;484.5;502.7];
event(7).times=[57.58;65.04;67.50;67.82];
event(7).numobs=4;
event(8).name='1992/11/17 4.4Mn (NEIC) 2 OBS. Felt';
event(8).stations=[{'BINY'},{'LBNH'},{'HNH'}];
event(8).distances=[440.8;454.6;462.1];
event(8).times=[59.99;61.69;62.62];
event(8).numobs=3;
event(9).name='06.16.1991 4.2MN 95 km NW from MANIWAKI';
event(9).stations=[{'DVT'},{'IVT'},{'BNH'},{'HNH'}];
event(9).distances=[424.0;488.0;508.0;510.0];
event(9).times=[58.42;65.52;68.28;67.74];
event(9).numobs=4;

numevents=length(event);
T=event(1).times;
for jj=2:numevents
    T=[T;event(jj).times];
end

G=[event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,numevents-1)];
for jj=2:numevents
    Gtemp=[event(jj).distances,zeros(event(jj).numobs,jj-1),ones(event(jj).numobs,1),zeros(event(jj).numobs,numevents-jj)];
    G=[G;Gtemp];
end

M=G\T;
M;
V1=1/M(1)

Vtot=[V1];

for jj=1:numevents
    G=[];
    T=[];
    for ii=1:numevents
        if ii~=jj
            Gtemp=[event(ii).distances,zeros(event(ii).numobs,ii-1),ones(event(ii).numobs,1),zeros(event(ii).numobs,numevents-ii)];
            T=[T;event(ii).times];
            G=[G;Gtemp];
        end
    end
    M=G\T;
    M;
    V=1/M(1)
    Vtot=[Vtot;V];
end

C=std(Vtot)
clear all

event(1).name='St. Anne Des Monts 3.1 Mn 5/28/06';
event(1).stations=[{'LBNH'},{'HNH'}];
event(1).distances=[727.3;793.1];
event(1).times=[93.53;101.63];
event(1).numobs=2;
event(2).name='08.22.1992 4.9MB OFFSHORE NEW JERSEY';
event(2).stations=[{'BNH'},{'DVT'}];
event(2).distances=[622.0;675.0];
event(2).times=[82.54;89.54];
event(2).numobs=2;
event(3).name='10.05.1985 3.9MN FELT IN BATHURST';
event(3).stations=[{'PNH'},{'WFM'}];
event(3).distances=[615.0;623.0];
event(3).times=[81.31;84.01];
event(3).numobs=2;

numevents=length(event);
T=event(1).times;
for jj=2:numevents
    T=[T;event(jj).times];
end

G=[event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,numevents-1)];
for jj=2:numevents
    Gtemp=[event(jj).distances,zeros(event(jj).numobs,jj-1),ones(event(jj).numobs,1),zeros(event(jj).numobs,numevents-jj)];
    G=[G;Gtemp];
end

M=G\T;
M;
V1=1/M(1)

Vtot=[V1];

for jj=1:numevents
    G=[];
    T=[];
    for ii=1:numevents
        if ii~=jj
            Gtemp=[event(ii).distances,zeros(event(ii).numobs,ii-1),ones(event(ii).numobs,1),zeros(event(ii).numobs,numevents-ii)];
            T=[T;event(ii).times];
        end
    end
    G=[G;Gtemp];
end
G=[G;Gtemp];
end
end
M=G\T;
M;
V=1/M(1)
Vtot=[Vtot;V];
end
C=std(Vtot)
APPENDIX F
MATLAB CODE FOR REGIONALIZED AREA 4
%Ep. Distance Analysis 200-400km from sources, Area 4

clear all;
event(1).name='2010/03/10 3.3 Mn PQ, 69.0KM WNW OF MONTREAL';
event(1).stations=['DELO', 'WLVO'];
event(1).distances=[282.3;370.2];
event(1).times=[41.78;52.62];
event(1).numobs=2;
event(2).name='03.14.1996 4.4MN Western Quebec';
event(2).stations=['EFO', 'ACTO', 'STCO'];
event(2).distances=[212.0;221.00;229.0];
event(2).times=[33.8;34.84;35.7];
event(2).numobs=3;
event(3).name='03.28.1992 3.1Mn SOUTH SHORE LAKE ERIE';
event(3).stations=['WLVO', 'WEO'];
event(3).distances=[297.0;307.0];
event(3).times=[46.64;48.36];
event(3).numobs=2;
event(4).name='06.03.1992 3.3Mn 51 km SE from MONT-LAURIER';
event(4).stations=['WEO', 'WLVO'];
event(4).distances=[363.0;372.0];
event(4).times=[50.70;51.74];
event(4).numobs=2;
event(5).name='07.28.1995 3.3MN WESTERN QUEBEC SEISMIC ZONE';
event(5).stations=['SADO', 'WLVO'];
event(5).distances=[362.98;368.81];
event(5).times=[49.561;55.536];
event(5).numobs=2;
event(6).name='09.12.1995 3.7MN WESTERN QUEBEC SEISMIC ZONE';
event(6).stations=['WLVO', 'SADO'];
event(6).distances=[364.31;380.70];
event(6).times=[50.834;52.108];
event(6).numobs=2;
event(7).name='9/30/2007 3.2 Mn PQ, 58.5KM NW OF MANIWAKI';
event(7).stations=['SADO', 'PECO'];
event(7).distances=[313.0;331.7];
event(7).times=[44.30;46.52];
event(7).numobs=2;
event(8).name='10.10.1995 3.5MN WESTERN QUEBEC SEISMIC ZONE';
event(8).stations=['WLVO', 'ACTO', 'STCO', 'TYNO'];
event(8).distances=[281.92;331.30;361.21;382.45];
event(8).times=[40.768;46.719;50.621;53.51];
event(8).numobs=4;
event(9).name='10.12.1997 3.1MN ADIRONDACKS';
event(9).stations=['SADO', 'PKRO'];
event(9).distances=[363.71;375.19];
event(9).times=[51.022;51.247];
event(9).numobs=2;

event(10).name='10.13.1997 3.0MN New York State';

event(10).stations=[{'WLVO'},{'PKRO'}];

event(10).distances=[278.75;331.22];

event(10).times=[42.453;48.73];

(event(10).numobs=2;

event(11).name='10/28/2007 3.5 Mn ON, 53KM NNE OF PETAWAWA';

event(11).stations=[{'DELO'},{'SADO'}];

event(11).distances=[226.0;249.8];

(event(11).times=[34.53;37.47];

event(11).numobs=2;

(event(12).name='1992/11/17 4.4Mn (NEIC) 2 OBS. Felt';

(event(12).stations=[{'WEO'},{'WLVO'}];

(event(12).distances=[335.0;343.0];

(event(12).times=[47.16;48.2];

(event(12).numobs=2;

(event(13).name='12.31.1996 3.5MN WESTERN QUEBEC SEISMIC ZONE';

(event(13).stations=[{'WLVO'},{'PKRO'}];

(event(13).distances=[355.06;385.54];

(event(13).times=[51.64;55.34];

(event(13).numobs=2;

numevents=length(event);

T=event(1).times;
for jj=1:numevents
    T=[T;event(jj).times];
end

G=[event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,numevents-1)];

for jj=1:numevents
    Gtemp=[event(jj).distances,zeros(event(jj).numobs,jj-1),ones(event(jj).numobs,1),zeros(event(jj).numobs,numevents-jj)];
    G=[G;Gtemp];
end

M=G\T;
M;
V1=1/M(1)
Vtot=[V1];

for jj=1:numevents
    G=[];
    T=[];
    for ii=1:numevents
        if ii~=jj

Gtemp = [event(ii).distances, zeros(event(ii).numobs, ii-1), ones(event(ii).numobs, 1), zeros(event(ii).numobs, numevents-ii)];
    T = [T; event(ii).times];
    G = [G; Gtemp];
    end
end
    M = G \ T;
    M;
    V = 1 / M(1)
    Vtot = [Vtot; V];
end

C = std(Vtot)
clear all;
event(1).name='01.16.1994 3.8MN FORESHOCK of MAG 4.6 NEIC EQ';
event(1).stations={{'WLVO'},{'ACTO'}};
event(1).distances=[446.0;496.0];
event(1).times=[63.95;70.04];
event(1).numobs=2;
event(2).name='01.16.1994 4.6MB 373 km SE from FORT ERIE';
event(2).stations={{'STCO'},{'WLVO'},{'ACTO'},{'LDN'}};
event(2).distances=[412.0;444.0;493.0;523.0];
event(2).times=[60.69;63.44;70.89;73.10];
event(2).numobs=4;
event(3).name='03.14.1996 4.4MN Western Quebec';
event(3).stations={{'PKRO'},{'STCO'},{'ACTO'},{'TYNO'},{'BRCO'}};
event(3).distances=[428.66;484.88;517.31;537.11;585.47];
event(3).times=[58.773;65.811;69.204;70.705;78.702];
event(3).numobs=5;
event(4).name='05.06.1993 3.5Mn 7 km E of NOTRE-DAME-DE-PONTMAIN';
event(4).stations={{'STCO'},{'ACTO'}};
event(4).distances=[448.0;466.0];
event(4).times=[61.21;63.74];
event(4).numobs=2;
event(5).name='05.24.1997 4.2MN WESTERN QUEBEC SEISMIC ZONE';
event(5).stations={{'SADO'},{'PKRO'},{'STCO'}};
event(5).distances=[404.76;438.57;493.74];
event(5).times=[54.598;59.558;65.762];
event(5).numobs=3;
event(6).name='06.03.1992 3.3Mn 51 km SE from MONT-LAURIER';
event(6).stations={{'ACTO'},{'TYNO'}};
event(6).distances=[496.0;521.0];
event(6).times=[66.74;69.77];
event(6).numobs=2;
event(7).name='06.03.1995 3.9MN Western Quebec';
event(7).stations={{'STCO'},{'ACTO'},{'TYNO'}};
event(7).distances=[480.42;480.92;519.44];
event(7).times=[64.678;65.088;69.298];
event(7).numobs=3;
event(8).name='08.16.1996 3.7MN 43 km SW from KAPUSKASING';
event(8).stations={{'BRCO'},{'SADO'}};
event(8).distances=[566.28;574.36];
event(8).times=[74.824;74.798];
event(8).numobs=2;
event(9).name='09.12.1995 3.7MN WESTERN QUEBEC SEISMIC ZONE';
event(9).stations={{'ACTO'},{'TYNO'}};
event(9).distances=[497.96;514.50];
event(9).times=[66.42;69.927];
event(9).numobs=2;
event(10).name='10.10.1995 3.5MN WESTERN QUEBEC SEISMIC ZONE';
event(10).stations=[{'ELF'},{'LDN'},{'DLA'}];
event(10).distances=[413.64;423.92;449.58];
event(10).times=[57.145;58.245;61.145];
event(10).numobs=3;
event(11).name='11.16.1993 4.3MN NAPIERVILLE';
event(11).stations=[{'WEO'},{'STCO'},{'ACTO'}];
event(11).distances=[411.0;507.0;555.0];
event(11).times=[55.95;67.98;73.67];
event(11).numobs=3;
event(12).name='1992/11/17 4.4Mn (NEIC) 2 OBS. Felt';
event(12).stations=[{'STCO'},{'ACTO'},{'TYNO'},{'ELF'}];
event(12).distances=[442.0;473.0;494.0;584.0];
event(12).times=[60.09;63.68;66.54;76.80];
event(12).numobs=4;
event(13).name='12.31.1996 3.5MN WESTERN QUEBEC SEISMIC ZONE';
event(13).stations=[{'STCO'},{'TYNO'}];
event(13).distances=[456.08;500.91];
event(13).times=[66.53;72.92];
event(13).numobs=2;
event(14).name='10.19.1985 4.1MN 394 km SE from KINGSTON';
event(14).stations=[{'WEO'},{'EFO'}];
event(14).distances=[477.0;488.0];
event(14).times=[64.66;65.50];
event(14).numobs=2;

dumevents=length(event);
T=event(1).times;
for jj=2:dumevents
    T=[T;event(jj).times];
end

G=[event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,dumevents-1)];
for jj=2:dumevents
    Gtemp=[event(jj).distances,zeros(event(jj).numobs,jj-1),ones(event(jj).numobs,1),zeros(event(jj).numobs,dumevents-jj)];
    G=[G;Gtemp];
end

M=G\T;
M;
V1=1/M(1)
Vtot=[V1];

for jj=1:nuenevents
    G=[];
    T=[];
    for ii=1:nuenevents
        if ii~=jj
            Gtemp=[event(ii).distances,zeros(event(ii).numobs,ii-1),ones(event(ii).numobs,1),zeros(event(ii).numobs,numevents-ii)];
            T=[T;event(ii).times];
            G=[G;Gtemp];
        end
    end
    M=G\T;
    M;
    V=1/M(1)
    Vtot=[Vtot;V];
end

C=std(Vtot)
clear all;

event(1).name='05.19.1992 3.7Mn 42 km SE from MONT-LAURIER';
event(1).stations=[{'ELF'},{'LDN'}];
event(1).distances=[608.0;610.0];
event(1).times=[82.0;83.1];
event(1).numobs=2;
event(2).name='06.16.1995 3.8MN NEAR LISBON';
event(2).stations=[{'TYNO'},{'ACTO'}];
event(2).distances=[645.48;648.47];
event(2).times=[86.944;89.914];
event(2).numobs=2;
event(3).name='08.16.1996 3.7MN 43 km SW from KAPUSKASING';
event(3).stations=[{'PKRO'},{'ACTO'},{'WLVO'}];
event(3).distances=[656.6;663.21;685.41];
event(3).times=[84.313;85.454;90.777];
event(3).numobs=3;
event(4).name='10.28.1997 4.7MN CHARLEVOIX SEISMIC ZONE';
event(4).stations=[{'WLVO'},{'SADO'}];
event(4).distances=[780.48;782.10];
event(4).times=[101.121;100.022];
event(4).numobs=2;
event(5).name='12.06.1995 3.5MN Felt';
event(5).stations=[{'SADO'},{'WLVO'}];
event(5).distances=[633.94;678.85];
event(5).times=[81.493;91.96];
event(5).numobs=2;

numevents=length(event);
T=event(1).times;
for jj=1:numevents
    T=[T;event(jj).times];
end

G=[event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,numevents-1)];

for jj=1:numevents
    Gtemp=[event(jj).distances,zeros(event(jj).numobs,jj-1),ones(event(jj).numobs,1),zeros(event(jj).numobs,numevents-jj)];
    G=[G;Gtemp];
end

M=G\T;
M;
V1=1/M(1)
Vtot=[V1];

for jj=1:nevents
    G=[];
    T=[];
    for ii=1:nevents
        if ii~=jj
            Gtemp=[event(ii).distances,zeros(event(ii).numobs,ii-1),ones(event(ii).numobs,1),zeros(event(ii).numobs,nevents-ii)];
            T=[T;event(ii).times];
            G=[G;Gtemp];
        end
    end
    M=G\T;
end

V=1/M(1)
Vtot=[Vtot;V];
end

C=std(Vtot)
APPENDIX G
MATLAB CODE FOR REGIONALIZED AREA 5
%Ep. Distance Analysis 200-400km from sources, Area 5
clear all;
event(1).name='Ferme-Nueve 3.1 Mn';
event(1).stations=['WBO','MPPO','MOQ'];
event(1).distances=[233.4;246.9;359.5];
event(1).times=[33.36;34.73;48.74];
event(1).numobs=3;
event(2).name='Raymond 3.0Mn 1/27/00 WVL, MOQ, MNT, WBO';
event(2).stations=['MOQ','WBO'];
event(2).distances=[270.8;396.5];
event(2).times=[40.51;55.99];
event(2).numobs=2;
event(3).name='Sarnac Lake 3.8 Mn 4/20/00 MOQ, DPQ';
event(3).stations=['MOQ','DPQ'];
event(3).distances=[219;324.1];
event(3).times=[33.07;45.50];
event(3).numobs=2;
event(4).name='01.10.1997 3.2MN Felt';
event(4).stations=['DPQ','MOQ'];
event(4).distances=[216.67;291.18];
event(4).times=[32.66;44.48];
event(4).numobs=2;
event(5).name='01.11.1994 3.4Mn SOUTH of LOW';
event(5).stations=['EEO','SADO','DPQ','MOQ'];
event(5).distances=[252.0;265.0;274.0];
event(5).times=[39.29;38.37;41.96];
event(5).numobs=3;
event(6).name='01.14.1997 3.1MN CHARLEVOIX SEISMIC ZONE';
event(6).stations=['DPQ','MOQ','TRQ'];
event(6).distances=[245.39;318.37;390.50];
event(6).times=[36.445;45.685;53.805];
event(6).numobs=3;
event(7).name='02.20.1996 3.1MN WESTERN QUEBEC';
event(7).stations=['CRLO','MOQ'];
event(7).distances=[201.48;210.11];
event(7).times=[30.539;31.419];
event(7).numobs=2;
event(8).name='02.23.1997 3.3MN 58 km SW from VAL-DOR';
event(8).stations=['GRQ','GAC','TRQ','WBO'];
event(8).distances=[237.75;326.88;344.87;397.35];
event(8).times=[36.768;49.858;49.378;57.338];
event(8).numobs=4;
event(9).name='03.02.1995 3.0MN ADIRONDACKS';
event(9).stations=['MOQ','TRQ','GRQ','DPQ','CRLO'];
event(9).distances=[210.0;220.0;285.0;300.0;306.0];
event(9).times=[32.03;33.31;41.63;43.56;43.11];
event(9).numobs=5;

event(10).name='03.04.1993  3.1Mn LA MALBAIE';
 event(10).stations=[{'DPQ'},{'MOQ'},{'MNT'},{'TRQ'}];
 event(10).distances=[205.63;284.96;335.84;350.72];
 event(10).times=[31.174;43.554;46.004;48.024];
 event(10).numobs=4;

event(11).name='03.10.1992  3.3Mn 23 km E  from LA MALBAIE';
 event(11).stations=[{'DPQ'},{'MNQ'},{'MOQ'},{'MNT'},{'TRQ'}];
 event(11).distances=[249.60;323.30;324.64;379.38;394.42];
 event(11).times=[38.187;;45.317;47.237;57.207;53.767];
 event(11).numobs=5;

event(12).name='03.17.1993  3.2MN 54 km S  from MONT-LAURIER';
 event(12).stations=[{'DPQ'},{'MOQ'}];
 event(12).distances=[208.0;254.0];
 event(12).times=[31.57;37.64];
 event(12).numobs=2;

event(13).name='03.24.1996  3.1MN The Laurentians';
 event(13).stations=[{'GAC'},{'DAQ'},{'OTT'},{'WBO'},{'CRLO'}];
 event(13).distances=[200.88;208.99;237.06;246.06;318.26];
 event(13).times=[31.788;30.678;35.118;36.808;43.358];
 event(13).numobs=5;

event(14).name='04.03.1997  3.6MN Felt. Southern Quebec';
 event(14).stations=[{'GAC'},{'OTT'}];
 event(14).distances=[246.45;271.55];
 event(14).times=[38.508;41.458];
 event(14).numobs=2;

event(15).name='1992/05/01  3.2Mn 7 km E  from BAIE-SAINT-PAUL';
 event(15).stations=[{'MOQ'},{'MNT'},{'TRQ'}];
 event(15).distances=[276.71;328.33;344.69];
 event(15).times=[40.098;49.938;47.708];
 event(15).numobs=3;

event(16).name='05.06.1993  3.5Mn 7 km E of NOTRE-DAME-DE-PONTMAIN';
 event(16).stations=[{'DPQ'},{'MOQ'}];
 event(16).distances=[216.0;278.0];
 event(16).times=[32.5;40.16];
 event(16).numobs=2;

event(17).name='05.12.1996  3.1MN Felt';
 event(17).stations=[{'DPQ'},{'MOQ'},{'TRQ'}];
 event(17).distances=[228.60;299.02;374.13];
 event(17).times=[33.888;42.755;52.088];
 event(17).numobs=3;

event(18).name='06.03.1995  3.9MN Western Quebec';
 event(18).stations=[{'MNT'},{'DPQ'},{'MOQ'}];
 event(18).distances=[265.49;270.25;365.54];
 event(18).times=[37.758;38.731;50.415];
 event(18).numobs=3;
event(19).name='06.07.1996 3.1MN Felt';
event(19).stations=[{'DPQ'},{'MOQ'},{'TRQ'}];
event(19).distances=[235.2;304.11;380.76];
event(19).times=[34.293;43.843;51.277];
event(19).numobs=3;
event(20).name='06.16.1995 3.8MN NEAR LISBON';
event(20).stations=[{'WBO'},{'DPQ'},{'TRQ'},{'GAC'}];
event(20).distances=[267.08;267.95;288.61;311.09];
event(20).times=[37.894;38.677;41.777;47.594];
event(20).numobs=4;
event(21).name='6/23/2010 PQ, OTTAWA, ON 4.9MN';
event(21).stations=[{'DPQ'},{'MOQ'}];
event(21).distances=[227.2;259.8];
event(21).times=[32.83;37.21];
event(21).numobs=2;
event(22).name='06.28.1992 3.3Mn 22 km W from QUEBEC';
event(22).stations=[{'MNT'},{'TRQ'},{'GRQ'},{'WBO'},{'OTT'}];
event(22).distances=[220.0;243.0;333.0;356.0;362.0];
event(22).times=[33.98;35.87;46.06;49.83;54.63];
event(22).numobs=5;
event(23).name='07.10.1997 3.0MN Felt';
event(23).stations=[{'CRLO'},{'DPQ'}];
event(23).distances=[233.42;243.04];
event(23).times=[43.597;44.717];
event(23).numobs=2;
event(24).name='07.14.1996 3.4MN CHARLEVOIX SEISMIC ZONE';
event(24).stations=[{'DPQ'},{'MOQ'}];
event(24).distances=[239.38;243.04];
event(24).times=[35.28;45.28];
event(24).numobs=2;
event(25).name='07.30.1993 3.8Mn 1 km NE of SALABERRY-DE-VALLEYFIELD';
event(25).stations=[{'OTT'},{'CRLO'},{'MNT'},{'TRQ'},{'GAC'},{'GRQ'}];
event(25).distances=[223.61;255.70;267.42;318.03;336.61;358.65];
event(25).times=[36.204;43.104;43.034;48.574;49.454;51.974];
event(25).numobs=6;
event(26).name='07.30.1993 3.8Mn 1 km NE of SALABERRY-DE-VALLEYFIELD';
event(26).stations=[{'DPQ'},{'MOQ'},{'TRQ'}];
event(26).distances=[245.23;318.82;390.28];
event(26).times=[37.051;88.692;52.991];
event(26).numobs=3;
event(27).name='08.20.1995 3.3MN Felt; Richelieu River Region';
event(27).stations=[{'GRQ'},{'CRLO'}];
event(27).distances=[240.47;327.06];
event(27).times=[36.344;46.297];
event(27).numobs=2;
event(28).name='08.20.1997 3.7MN Felt';
event(28).stations=[{'DPQ'}, {'MNT'}, {'TRQ'}];
event(28).distances=[211.42;341.41;356.50];
event(28).times=[31.975;50.985;48.805];
event(28).numobs=3;
event(29).name='08.21.1996 3.6MN NORTHERN APPALACHIANS SEISMIC ZONE';
event(29).stations=[{'MNT'}, {'DPQ'}, {'WBO'}, {'TRQ'}, {'GAC'}, {'OTT'}];
event(29).distances=[223.10;289.67;317.95;329.79;359.11;363.56];
event(29).times=[33.412;39.969;45.162;45.392;51.622;50.985];
event(29).numobs=6;
event(30).name='1992/08/28 3.6Mn 15 km SE from QUEBEC';
event(30).stations=[{'TRQ'}, {'GRQ'}];
event(30).distances=[269.0;363.0];
event(30).times=[39.32;50.07];
event(30).numobs=2;
event(31).name='08.28.1994 3.6Mn WESTERN QUEBEC';
event(31).stations=[{'WBO'}, {'MNT'}, {'DPQ'}, {'MOQ'}];
event(31).distances=[204.0;285.0;334.0;393.0];
event(31).times=[31.06;41.90;46.18;52.16];
event(31).numobs=4;
event(32).name='09.16.1994 3.3MN NEAR SPRINGFIELD';
event(32).stations=[{'MOQ'}, {'DPQ'}];
event(32).distances=[318.0;385.0];
event(32).times=[45.76;54.08];
event(32).numobs=2;
event(33).name='09.16.1994 3.6MN NEAR SPRINGFIELD';
event(33).stations=[{'MOQ'}, {'DPQ'}];
event(33).distances=[318.0;385.0];
event(33).times=[45.26;53.08];
event(33).numobs=2;
event(34).name='09.20.1995 3.0MN WESTERN QUEBEC SEISMIC ZONE';
event(34).stations=[{'DPQ'}, {'MOQ'}];
event(34).distances=[268.94;342.37];
event(34).times=[40.645;49.162];
event(34).numobs=2;
event(35).name='09.21.1995 3.1MN Felt';
event(35).stations=[{'DPQ'}, {'GRQ'}];
event(35).distances=[208.88;212.16];
event(35).times=[31.715;33.282];
event(35).numobs=2;
event(36).name='09.23.1993 3.8MN 26 km W from STE-AGATHE-DES-MONTS';
event(36).stations=[{'MOQ'}, {'CKO'}];
event(36).distances=[202.0;220.0];
event(36).times=[31.11;33.04];
event(36).numobs=2;
event(37).name='09.24.1996 3.1MN Felt';
event(37).stations=[{'MOQ'}, {'ICQ'}, {'TRQ'}];
event(46).distances=[224.40;264.46;268.05;316.30;325.88];
event(46).times=[33.528;37.395;39.735;44.745;45.662];
event(46).numobs=5;
event(47).name='10.12.1997 3.1MN ADIRONDACKS';
event(47).stations=[{'DPQ'},{'CRLO'}];
event(47).distances=[240.54;254.77];
event(47).times=[37.187;39.367];
event(47).numobs=2;
event(48).name='10.13.1997 3.0MN New York State';
event(48).stations=[{'MOQ'},{'GRQ'},{'CRLO'},{'DPQ'}];
event(48).distances=[239.39;259.39;265.96;309.68];
event(48).times=[36.434;39.154;39.034;44.794];
event(48).numobs=4;
event(49).name='10.28.1997 4.7MN CHARLEVOIX SEISMIC ZONE';
event(49).stations=[{'MOQ'},{'MNT'},{'TRQ'}];
event(49).distances=[318.50;373.45;389.17];
event(49).times=[45.707;51.907;53.357];
event(49).numobs=3;
event(50).name='10/28/2007 3.5 Mn ON, 53KM NNE OF PETAWAWA';
event(50).stations=[{'ALFO'},{'TRQ'},{'MPPO'},{'WBO'},{'DPQ'}];
event(50).distances=[200.6;201.4;206.3;222.7;334.6];
event(50).times=[31.28;31.50;32.11;34.13;47.94];
event(50).numobs=5;
event(51).name='11/2/2008 3 Mn PQ, 45KM N OF QUEBEC';
event(51).stations=[{'MOQ'},{'MNT'}];
event(51).distances=[236.9;273.3];
event(51).times=[33.17;37.91];
event(51).numobs=2;
event(52).name='11.06.1993 5.1MN Quebec City Region. Felt';
event(52).stations=[{'MNT'},{'TRQ'},{'GAC'},{'GRQ'},{'WBO'},{'OTT'}];
event(52).distances=[223.06;248.95;335.77;340.11;359.84;367.10];
event(52).times=[32.846;49.416;47.086;50.396;51.576];
event(52).numobs=6;
event(53).name='11/15/2008 4.2 Mn PQ, 24KM SE OF RIVIERE-DU-LOUP';
event(53).stations=[{'MOQ'},{'MNT'}];
event(53).distances=[322.3;380.8];
event(53).times=[47.87;52.72];
event(53).numobs=2;
event(54).name='11.16.1993 4.3MN NAPIERVILLE';
event(54).stations=[{'GRQ'},{'CKO'},{'LPQ'}];
event(54).distances=[244.0;324.0;358.0];
event(54).times=[36.71;45.40;50.61];
event(54).numobs=3;
event(55).name='11.20.1994 3.2MN SOME 40 km NW of LEWISTON';
event(55).stations=[{'DPQ'},{'TRQ'}];
event(55).distances=[318.0;382.0];
event(55).times=[47.65;54.38];
event(55).numobs=2;
event(56).name='12.01.1993 3.5Mn 20 km S from LA MALBAIE';
event(56).stations=[{'DPQ'},{'TRQ'}];
event(56).distances=[217.42;363.0];
event(56).times=[32.867;50.667];
event(56).numobs=2;
event(57).name='12/23/2007 3.6 Mc PQ, 12.8KM N OF CHICHESTER';
event(57).stations=[{'MRHQ'},{'MNT'},{'MOQ'}];
event(57).distances=[223.7;276.9;386.1];
event(57).times=[33.19;39.76;53.24];
event(57).numobs=3;
event(58).name='12.31.1996 3.5MN WESTERN QUEBEC SEISMIC ZONE';
event(58).stations=[{'DPQ'},{'MOQ'}];
event(58).distances=[225.71;298.36];
event(58).times=[33.95;43.77];
event(58).numobs=2;
event(59).name='01.28.1992 3.0Mn 111 km N from PETAWAWA';
event(59).stations=[{'OTT'},{'TRQ'},{'WBO'},{'DPQ'}];
event(59).distances=[231.0;233.0;269.0;356];
event(59).times=[34.39;37.9;42.51;51.73];
event(59).numobs=4;
event(60).name='12.08.1991 4.3MN 26 km W from RIVIERE-DU-LOUP';
event(60).stations=[{'DPQ'},{'MOQ'},{'MNT'},{'TRQ'}];
event(60).distances=[252.36;330.09;383.45;396.78];
event(60).times=[35.286;45.246;52.446;52.786];
event(60).numobs=4;
event(61).name='06.17.1991 4.3MN NORTHERN NEW YORK STATE';
event(61).stations=[{'WBO'},{'OTT'},{'MNT'},{'MOQ'}];
event(61).distances=[273.0;324.0;335.0;359.0];
event(61).times=[38.67;44.23;46.42;49.47];
event(61).numobs=4;
event(62).name='07.05.1991 3.8MN NEAR HOWICK';
event(62).stations=[{'GRQ'},{'CKO'}];
event(62).distances=[221.0;294.0];
event(62).times=[33.53;43.25];
event(62).numobs=2;
event(63).name='09.19.1986 4.2MN LARGEST CHARLEVOIX';
event(63).stations=[{'KLN'},{'TRQ'}];
event(63).distances=[304.33;345.18];
event(63).times=[42.172;47.162];
event(63).numobs=2;
event(64).name='09.26.1987 3.8MN FELT WIDELY IN N.Y.';
event(64).stations=[{'GRQ'},{'GNT'}];
event(64).distances=[258.0;268.0];
event(64).times=[39.01;39.87];
event(64).numobs=2;
event(65).name='10.20.1988 3.9MN NORTHERN NEW HAMPSHIRE';
event(65).stations=[{'MNT'},{'DPQ'},{'LPQ'},{'TRQ'},{'WBO'}];
event(65).distances=[219.90;267.0;322.24;323.22;328.59];
event(65).times=[34.308;39.388;46.765;46.128;47.428];
event(65).numobs=5;
event(66).stations=[{'MNT'},{'DPQ'},{'TRQ'},{'WBO'}];
event(66).distances=[275.0;302.0;375.0;387.0];
event(66).times=[39.78;42.62;51.40;53.28];
event(66).numobs=4;
event(67).name='11.16.1989 4.0MN WESTERN QUEBEC. Felt';
event(67).stations=[{'MNT'},{'DPQ'}];
event(67).distances=[260.0;293.0];
event(67).times=[37.39;40.83];
event(67).numobs=2;
event(68).name='11.25.1988 5.9Mw 34 km SW from LA BAIE';
event(68).stations=[{'TRQ'},{'MNT'},{'GRQ'}];
event(68).distances=[331.0;345.0;391.0];
event(68).times=[45.70;47.53;52.56];
event(68).numobs=3;
event(69).name='12.08.1991 4.3MN RIVIERE-DU-LOUP';
event(69).stations=[{'MOQ'},{'MNT'},{'TRQ'}];
event(69).distances=[330.09;383.45;396.78];
event(69).times=[45.246;52.446;52.786];
event(69).numobs=3;
event(70).name='12.31.1990 4.5MN LA TUQUE';
event(70).stations=[{'TRQ'},{'MNT'}];
event(70).distances=[216.0;248.0];
event(70).times=[32.39;36.48];
event(70).numobs=2;

numevents=length(event);
T=event(1).times;
for jj=1:numevents
    T=[T;event(jj).times];
end

G=[event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,numevents-1)];
for jj=1:numevents
    Gtemp=[event(jj).distances,zeros(event(jj).numobs,jj-1),ones(event(jj).numobs,1),zeros(event(jj).numobs,numevents-jj)];
    G=[G;Gtemp];
end
M = G \div T;
M;
V1 = 1 / M(1)
Vtot = [V1];

for jj = 1 : numevents
    G = [];
    T = [];
    for ii = 1 : numevents
        if ii ~= jj
            Gtemp = [event(ii).distances, zeros(event(ii).numobs, ii-1), ones(event(ii).numobs, 1), zeros(event(ii).numobs, numevents-ii)];
            T = [T; event(ii).times];
            G = [G; Gtemp];
        end
    end
    M = G \div T;
    M;
    V = 1 / M(1)
    Vtot = [Vtot; V];
end

C = std(Vtot)
%Analysis of eastern Canada/Grenville terrane seismic stations from
%epicentral distances from 400-600 km, Area 5

clear all;
event(1).name='Grand Falls 3.3Mn 10/18/03';
event(1).stations=[{'DPQ'},{'MOQ'},{'MNT'},{'TRQ'}];
event(1).distances=[426.1;430.1;520.2;568.6];
event(1).times=[57.68;58.34;69.04;75.02];
event(1).numobs=4;
event(2).name='Bar Harbor 4.2Mn 10/3/06';
event(2).stations=[{'MNT'},{'TRQ'}];
event(2).distances=[451.4;544.3];
event(2).times=[61.35;72.3];
event(2).numobs=2

event(3).name='Bar Harbor 3.1Mn 12/29/06';
event(3).stations=[{'MNT'},{'TRQ'},{'WBO'},{'GAC'}];
event(3).distances=[449.3;542.2;567.8;595.5];
event(3).times=[62.4;73.53;76.86;80.04];
event(3).numobs=4;
event(4).name='Raymond 3.0Mn 1/27/00';
event(4).stations=[{'DPQ'},{'TRQ'}];
event(4).distances=[428;447.2];
event(4).times=[59.91;62.12];
event(4).numobs=2;
event(5).name='1992/01/09  3.0Mn KINGSTON';
event(5).stations=[{'WBO'},{'MOQ'}];
event(5).distances=[521.0;576.0];
event(5).times=[70.68;78.57];
event(5).numobs=2;
event(6).name='01.16.1994 4.6MB 373 km SE from FORT ERIE';
event(6).stations=[{'OTT'},{'GAC'}];
event(6).distances=[563.0;599.0];
event(6).times=[77.46;81.28];
event(6).numobs=2;
event(7).name='04.20.1996 3.3MN Cochrane';
event(7).stations=[{'CRLO'},{'GRQ'},{'GAC'}];
event(7).distances=[441.11;476.97;566.09];
event(7).times=[60.603;64.316;77.503];
event(7).numobs=3;
event(8).name='05.06.1995 3.9MN Miramichi Region';
event(8).stations=[{'DPQ'},{'MOQ'}];
event(8).distances=[472.76;475.50];
event(8).times=[64.292;65.592];
event(8).numobs=2;
event(9).name='12.30.1993 3.8MN 10 km E from BAIE-SAINT-PAUL';
event(9).stations=[{'GAC'},{'WBO'}];
event(9).distances=[437.90;467.02];
event(9).name='06.04.1992 3.4Mn 16 km W from MONT-JOLI';
event(9).stations=[{'MOQ'},{'TRQ'}];
event(9).numobs=2;

event(10).name='06.07.1996 3.1MN Felt';
event(10).stations=[{'GRQ'},{'GAC'}];
event(10).numobs=2;

event(11).name='07.14.1994 4.1Mn MIRAMICHI';
event(11).stations=[{'DPQ'},{'MNT'}];
event(11).numobs=2;

event(12).name='08.07.1993 3.1Mn CHARLEVOIX SEISMIC ZONE';
event(12).stations=[{'GRQ'},{'WBO'}];
event(12).numobs=2;

event(13).name='08.20.1997 3.7MN Felt';
event(13).stations=[{'GRQ'},{'GAC'},{'WBO'},{'CRLO'}];
event(13).numobs=4;

event(14).name='08.21.1996 3.6MN NORTHERN APPALACHIANS SEISMIC ZONE';
event(14).stations=[{'GRQ'},{'CRLO'}];
event(14).numobs=2;

event(15).name='09.02.1996 3.1MN FELT';
event(15).stations=[{'MOQ'},{'DPQ'}];
event(15).numobs=2;

event(16).name='1992/01/09  3.0Mn 465 km SE from KINGSTON';
event(16).stations=[{'WBO'},{'MOQ'}];
event(16).numobs=2;

event(17).name='09.16.1994 3.6MN NEAR SPRINGFIELD';
event(17).stations=[{'MNT'},{'TRQ'},{'WBO'},{'GAC'}];
event(17).numobs=2;
event(18).numobs=4;
event(19).name='10.02.1994 3.1MN U.S.A.';
event(19).stations=[{'GAC'},{'TRQ'},{'DPQ'}];
event(19).distances=[452.0;467.0;482.0];
event(19).times=[63.16;63.76;72.26];
event(19).numobs=3;
event(20).name='10.02.1994 3.5MN U.S.A.';
event(20).stations=[{'GAC'},{'TRQ'},{'DPQ'}];
event(20).distances=[448.0;463.0;479.0];
event(20).times=[64.35;64.95;66.26];
event(20).numobs=3;
event(21).name='10.10.1995 3.5MN WESTERN QUEBEC SEISMIC ZONE';
event(21).stations=[{'DPQ'},{'MOQ'}];
event(21).distances=[460.69;521.70];
event(21).times=[61.595;70.128];
event(21).numobs=2;
event(22).name='10.16.1993 3.7Mn MAG 3.4 USGS';
event(22).stations=[{'CKO'},{'WBO'}];
event(22).distances=[557.0;592.0];
event(22).times=[74.91;78.25];
event(22).numobs=2;
event(23).name='10.28.1997 4.7MN CHARLEVOIX SEISMIC ZONE';
event(23).stations=[{'GRQ'},{'WBO'},{'CRLO'}];
event(23).distances=[367.18;509.17;598.42];
event(23).times=[62.327;68.997;77.667];
event(23).numobs=3;
event(24).name='12.01.1993 3.5Mn 20 km S from LA MALBAIE';
event(24).stations=[{'GRQ'},{'CKO'}];
event(24).distances=[443.96;581.02];
event(24).times=[59.547;75.387];
event(24).numobs=2;
event(25).name='12.01.1994 3.0MN CHARLEVOIX';
event(25).stations=[{'GRQ'},{'GAC'}];
event(25).distances=[431.84;440.53];
event(25).times=[59.334;56.884];
event(25).numobs=2;
event(26).name='12.06.1995 3.5MN Felt';
event(26).stations=[{'CRLO'},{'GRQ'}];
event(26).distances=[513.84;552.42];
event(26).times=[68.36;72.493];
event(26).numobs=2;
event(27).name='12.08.1991 4.3MN 26 km W from RIVIERE-DU-LOUP';
event(27).stations=[{'GRQ'},{'WBO'}];
event(27).distances=[472.91;518.45];
event(27).times=[60.306;67.336];
event(27).numobs=2;
event(28).name='03.11.1989 4.4MN CHARLEVOIX-KAMOURASKA';
event(28).stations=[{'DPQ'},{'MNT'},{'TRQ'}];
event(28).distances=[248.58;378.56;393.35];
event(28).times=[36.352;52.272;53.612];
event(28).numobs=3;
event(29).name='06.16.1991 4.2MN 95 km NW from MANIWAKI';
event(29).stations=[{'MNT'},{'DPQ'},{'MOQ'}];
event(29).distances=[297.0;307.0;398.0];
event(29).times=[42.63;42.83;54.65];
event(29).numobs=3;
event(30).name='01.31.1986 5.0MB PAINESVILLE';
event(30).stations=[{'TRQ'},{'CKO'},{'GRQ'},{'DPQ'},{'EEO'}];
event(30).distances=[405.0;440.0;458.0;479.0;572.0];
event(30).times=[54.78;58.27;61.15;64.79;74.14];
event(30).numobs=5;
event(31).name='07.13.1987 4.1MN NEAR ASHTABULA';
event(31).stations=[{'CKO'},{'WBO'},{'GAC'}];
event(31).distances=[522.0;557.0;594.0];
event(31).times=[71.05;75.33;79.57];
event(31).numobs=3;
event(32).name='10.19.1985 4.1MN 394 km SE from KINGSTON';
event(32).stations=[{'WBO'},{'OTT'}];
event(32).distances=[435.0;486.0];
event(32).times=[59.54;66.01];
event(32).numobs=2;
event(33).name='11.14.1988 3.7MN JAY';
event(33).stations=[{'GRQ'},{'CKO'}];
event(33).distances=[483.0;575.0];
event(33).times=[64.97;76.02];
event(33).numobs=2;
event(34).name='11.25.1988 5.9Mw 34 km SW from LA BAIE';
event(34).stations=[{'GAC'},{'WBO'},{'CKO'}];
event(34).distances=[423.0;468.0;532.0];
event(34).times=[57.20;62.46;68.88];
event(34).numobs=3;
event(35).name='12.08.1991 4.3MN RIVIERE-DU-LOUP';
event(35).stations=[{'GRQ'},{'WBO'}];
event(35).distances=[472.91;518.45];
event(35).times=[60.306;67.336];
event(35).numobs=2;

numevents=length(event);
T=event(1).times;
for jj=2:numevents
    T=[T;event(jj).times];
end
G=[event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,numevents-1)];
for jj=2:numevents
    Gtemp=[event(jj).distances, zeros(event(jj).numobs,jj-1), ones(event(jj).numobs,1), zeros(event(jj).numobs,numevents-jj)];
    G=[G;Gtemp];
end
M=G\T;
M;
V1=1/M(1)

Vtot=[V1];
for jj=1:numevents
    G=[];
    T=[];
    for ii=1:numevents
        if ii~=jj
            Gtemp=[event(ii).distances, zeros(event(ii).numobs,ii-1), ones(event(ii).numobs,1), zeros(event(ii).numobs,numevents-ii)];
            T=[T,event(ii).times];
            G=[G;Gtemp];
        end
    end
    M=G\T;
    M;
    V=1/M(1)
    Vtot=[Vtot;V];
end
C=std(Vtot)
% Analysis of eastern Canada/Grenville terrane seismic stations from
% epicentral distances from 600 - 900 km, Area 5

clear all;
event(1).name='Grand Falls 3.3 Mn 10.18.03';
event(1).stations=[{'GAC'},{'WBO'}];
event(1).distances=[651.8;661];
event(1).times=[85.26;86.49];
event(1).numobs=2;
event(2).name='12.29.06 Bar Harbor 3.1 Mn';
event(2).stations=[{'GRQ'},{'CRLO'}];
event(2).distances=[651.1;747.5];
event(2).times=[86.94;98.73];
event(2).numobs=2;
event(3).name='01.26.1991 3.7MN 100 km SE of CHATHAM';
event(3).stations=[{'GRQ'},{'TRQ'}];
event(3).distances=[720.0;763.0];
event(3).times=[95.81;100.93];
event(3).numobs=2;
event(4).name='03.15.1992 3.7Mn 102 km SE of CHATHAM';
event(4).stations=[{'MOQ'},{'DPQ'}];
event(4).distances=[822.0;864.0];
event(4).times=[108.13;111.29];
event(4).numobs=2;
event(5).name='01.01.1989 4.0MN LOWER ST.LAWRENCE';
event(5).stations=[{'MNT'},{'TRQ'}];
event(5).distances=[634.0;639.0];
event(5).times=[82.58;83.48];
event(5).numobs=2;
event(6).name='10.05.1985 3.9MN FELT IN BATHURST';
event(6).stations=[{'GAC'},{'WBO'}];
event(6).distances=[615.68;698.44;707.78;708.27;833.98];
event(6).times=[81.508;92.835;93.875;92.292;107.175];
event(6).numobs=5;
event(7).name='05.06.1995 3.9MN Miramichi Region';
event(7).stations=[{'TRQ'},{'GAC'},{'WBO'},{'GRQ'},{'CRLO'}];
event(7).distances=[615.68;698.44;707.78;708.27;833.98];
event(7).times=[81.508;92.835;93.875;92.292;107.175];
event(7).numobs=5;
event(8).name='03.21.1991 3.9MN 55 km S from SEPT-ILES';
event(8).stations=[{'TRQ'},{'GRQ'}];
event(8).distances=[720.0;782.0];
event(8).times=[92.68;100.76];
event(8).numobs=2;
event(9).name='06.04.1992 3.4Mn 16 km W from MONT-JOLI';
event(9).stations=[{'WBO'},'{CKO'}];
event(9).distances=[662.0;745.0];
numevents=length(event);
T=event(1).times;
for jj=2:numevents
  T=[T;event(jj).times];
end

G=[event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,numevents-1)];
for jj=2:numevents
    Gtemp=[event(jj).distances,zeros(event(jj).numobs,jj-1),ones(event(jj).numobs,1),zeros(event(jj).numobs,numevents-jj)];
    G=[G;Gtemp];
end

M=G\T;
M;
V1=1/M(1)

Vtot=[V1];

for jj=1:numevents
    G=[];
    T=[];
    for ii=1:numevents
        if ii~=jj
            Gtemp=[event(ii).distances,zeros(event(ii).numobs,ii-1),ones(event(ii).numobs,1),zeros(event(ii).numobs,numevents-ii)];
            T=[T;event(ii).times];
            G=[G;Gtemp];
        end
    end
    M=G\T;
    M;
    V=1/M(1)
    Vtot=[Vtot;V];
end

C=std(Vtot)
APPENDIX H
MATLAB CODE FOR REGIONALIZED AREA 6
%Ep. Distance Analysis 200-400km from sources, Area 6
clear all;
event(1).name='lower st. lawrence Mn 3.5 1/20/02';
event(1).stations=['A21','A61','A16','LMQ','A54','A11'];
event(1).distances=[277.6;300.1;313.1;324.2;335.6;341.3];
event(1).times=[38.6;40.8;43.08;43.81;45.44;46.45];
event(1).numobs=6;
event(2).name='Livermore falls 3.4 Mn 1/3/00 PQI, DPQ, A54, A16, LMQ, A21';
event(2).stations=['A54','A16','LMQ','A21'];
event(2).distances=[349.8;350.7;359.6;378.6];
event(2).times=[48.95;49.36;50.15;52.66];
event(2).numobs=4;
event(3).name='St. Antoine Abbe 3.9 Mn 1/9/06 QCQ, A11, A54, DAQ, LMQ';
event(3).stations=['QCQ','A11','A54','DAQ','LMQ'];
event(3).distances=[278.9;374.7;378.1;381.4;390.0];
event(3).times=[39.86;51.02;51.36;51.32;53.1];
event(3).numobs=5
event(4).name='Baie St. Paul 3.5 Mn 7/12/00 CNQ, ICQ, MNQ';
event(4).stations=['CNQ','ICQ','MNQ'];
event(4).distances=[294;355.2;367.8];
event(4).times=[42.03;49.11;51.14];
event(4).numobs=3;
event(5).name='Jolliette 3.4 Mn 2/11/02 A54, LMQ, A61, A64, A21';
event(5).stations=['A54','LMQ','A61','A64','A21'];
event(5).distances=[272.7;283.4;307.2;327.8;333.7];
event(5).times=[40.36;41.87;44.59;47.25;48.07];
event(5).numobs=5;
event(6).name='Mont Laurier 3.0Mn 2/9/03 A54, LMQ, A11';
event(6).stations=['A54','LMQ','A11'];
event(6).distances=[376.7;385.6;389.3];
event(6).times=[51.32;52.23;52.66];
event(6).numobs=3;
event(7).name='St Agathe Des Monts 4.5 Mn 3.14.96 A54, A61';
event(7).stations=['A54','A61'];
event(7).distances=[349.9;383.3];
event(7).times=[49.87;53.84];
event(7).numobs=2;
event(8).name='Miramichi EQ 2.7 Mn 4.26.96 A21, A16, A61, DAQ';
event(8).stations=['A21','A16','A61','DAQ'];
event(8).distances=[242.6;260.2;271.3;362.5];
event(8).times=[39.09;41.35;42.63;53.87];
event(8).numobs=4;
event(9).name='St. Gabriel 3.0Mn 4/8/05 A54, LMQ, A61, A64';
event(9).stations=['A54','LMQ','A61','A64'];
event(9).distances=[263.2;273.2;296.1;316.6];
event(9).times=[37.9;38.96;41.87;44.17];
event(9).name='St. Anne Des Monts 2.7Mn 5/28/06 A21, A64, A61, A16, LMQ, A11';
event(9).numobs=4;
event(10).name='St. Anne Des Monts 2.7Mn 5/28/06 A21, A64, A61, A16, LMQ, A11';
event(10).stations=[{'A21'},{'A64'},{'A61'},{'A16'},{'LMQ'},{'A11'}];
event(10).distances=[318.8;322.1;343;353.7;367;381.4];
event(10).times=[43.46;43.71;45.91;47.51;49.19;50.48];
event(10).numobs=6;
event(11).name='St. Anne Des Monts 2.7Mn 5/28/06 A21, A64, A61, A16, LMQ, A11';
event(11).stations=[{'A21'},{'A64'},{'A61'},{'A16'},{'LMQ'},{'A11'}];
event(11).distances=[318.8;322.1;343;353.7;367;381.4];
event(11).times=[43.46;43.71;45.91;47.51;49.19;50.48];
event(11).numobs=6;
event(12).name='St. Anne Des Monts 2.7Mn 5/28/06 A21, A64, A61, A16, LMQ, A11';
event(12).stations=[{'A21'},{'A64'},{'A61'},{'A16'},{'LMQ'},{'A11'}];
event(12).distances=[318.8;322.1;343;353.7;367;381.4];
event(12).times=[43.46;43.71;45.91;47.51;49.19;50.48];
event(12).numobs=6;
event(13).name='St. Anne Des Monts 2.7Mn 5/28/06 A21, A64, A61, A16, LMQ, A11';
event(13).stations=[{'A21'},{'A64'},{'A61'},{'A16'},{'LMQ'},{'A11'}];
event(13).distances=[318.8;322.1;343;353.7;367;381.4];
event(13).times=[43.46;43.71;45.91;47.51;49.19;50.48];
event(13).numobs=6;
event(14).name='St. Anne Des Monts 2.7Mn 5/28/06 A21, A64, A61, A16, LMQ, A11';
event(14).stations=[{'A21'},{'A64'},{'A61'},{'A16'},{'LMQ'},{'A11'}];
event(14).distances=[318.8;322.1;343;353.7;367;381.4];
event(14).times=[43.46;43.71;45.91;47.51;49.19;50.48];
event(14).numobs=6;
event(15).name='St. Anne Des Monts 2.7Mn 5/28/06 A21, A64, A61, A16, LMQ, A11';
event(15).stations=[{'A21'},{'A64'},{'A61'},{'A16'},{'LMQ'},{'A11'}];
event(15).distances=[318.8;322.1;343;353.7;367;381.4];
event(15).times=[43.46;43.71;45.91;47.51;49.19;50.48];
event(15).numobs=6;
event(16).name='St. Anne Des Monts 2.7Mn 5/28/06 A21, A64, A61, A16, LMQ, A11';
event(16).stations=[{'A21'},{'A64'},{'A61'},{'A16'},{'LMQ'},{'A11'}];
event(16).distances=[318.8;322.1;343;353.7;367;381.4];
event(16).times=[43.46;43.71;45.91;47.51;49.19;50.48];
event(16).numobs=6;
event(17).name='St. Anne Des Monts 2.7Mn 5/28/06 A21, A64, A61, A16, LMQ, A11';
event(17).stations=[{'A21'},{'A64'},{'A61'},{'A16'},{'LMQ'},{'A11'}];
event(17).distances=[318.8;322.1;343;353.7;367;381.4];
event(17).times=[43.46;43.71;45.91;47.51;49.19;50.48];
event(17).numobs=6;
event(18).name='St. Anne Des Monts 2.7Mn 5/28/06 A21, A64, A61, A16, LMQ, A11';
event(18).stations=[{'A21'},{'A64'},{'A61'},{'A16'},{'LMQ'},{'A11'}];
event(18).distances=[318.8;322.1;343;353.7;367;381.4];
event(18).times=[43.46;43.71;45.91;47.51;49.19;50.48];
event(18).numobs=6;
event(18).distances=[359.0;389.0];
event(18).times=[50.75;53.6];
event(18).numobs=2;
event(19).name='02.15.1995 3.5MN WESTERN QUEBEC ZONE. Felt';
event(19).stations=['DAQ','A54'];
event(19).distances=[369.0;394.0];
event(19).times=[49.83;57.93];
event(19).numobs=2;
event(20).name='28/2010 3.6 Mn PQ, 71.0KM WNW OF MONTREAL';
event(20).stations=['QCQ','LMQ'];
event(20).distances=[273.1;376.4];
event(20).times=[41.15;52.63];
event(20).numobs=2;
event(21).name='03.04.1993 3.1Mn LA MALBAIE';
event(21).stations=['CNQ','GSQ','ICQ','MNQ'];
event(21).distances=[261.31;287.57;319.44;355.48];
event(21).times=[39.134;41.634;45.704;48.904];
event(21).numobs=4;
event(22).name='3/8/2009 3.2 Mn NB, 90.0KM NNE OF FREDERICTON';
event(22).stations=['LMQ','QCQ'];
event(22).distances=[328.2;387.8];
event(22).times=[45.11;52.75];
event(22).numobs=2;
event(23).name='3/8/2009 3.6 Mn NB, 86.2KM NNE OF FREDERICTON';
event(23).stations=['A11','LMQ'];
event(23).distances=[309.7;327.4];
event(23).times=[43.64;45.15];
event(23).numobs=2;
event(24).name='03.10.1992 3.3Mn 23 km E from LA MALBAIE';
event(24).stations=['GSQ','ICQ','MNQ','SMQ'];
event(24).distances=[243.55;277.0;323.30;362.17];
event(24).times=[36.417;39.917;45.317;50.477];
event(24).numobs=4;
event(25).name='03.14.1996 4.4MN Western Quebec';
event(25).stations=['QCQ','A54','A11','SHQ','LMQ','A16','A61'];
event(25).distances=[258.36;349.21;353.68;357.85;359.72;377.30;383.10];
event(25).times=[38.902;47.842;48.942;48.702;51.052;51.412;51.812];
event(25).numobs=7;
event(26).name='03.17.1993 3.2MN 54 km S from MONT-LAURIER';
event(26).stations=['MOQ','DAQ'];
event(26).distances=[254.0;375.0];
event(26).times=[37.64;54.34];
event(26).numobs=2;
event(27).name='03.18.1995 3.1MN Lower St. Lawrence';
event(27).stations=['MNQ','A21','A64','A61','A16','LMQ','A54','A11','DAQ'];
event(27).distances=[202.44;286.65;290.17;310.93;321.61;334.85;346.21;349.34;369.24];
event(27).times=[30.586;41.166;41.346;43.666;46.516;47.411;48.506;48.906;51.169];
event(27).numobs=9;
event(28).name='03.24.1996 3.1MN The Laurentians';
event(28).stations=['DAQ','A54','LMQ','A11','A61','A64'];
event(28).distances=[208.99;237.98;247.33;247.88;269.59;288.89];
event(28).times=[30.678;34.618;37.943;37.898;38.468;42.768];
event(28).numobs=6;
event(29).name='03.28.1994 3.6Mn SOME 20 km W of MURDOCHVILLE';
event(29).stations=['MNQ','A21','A64','A61','LMQ','A11','A54'];
event(29).distances=[278.0;326.0;334.0;353.0;359.0;376.0;385.0;387.0];
event(29).times=[40.4;46.51;46.82;49.15;50.42;52.07;53.73;53.81];
event(29).numobs=8;
event(30).name='04.03.1997 3.6MN Felt. Southern Quebec';
event(30).stations=['A11','A54','LMQ','DAQ','A16','A64'];
event(30).distances=[216.34;221.20;233.10;236.96;243.96;256.98;277.96];
event(30).times=[32.798;33.518;36.983;36.528;36.598;37.728;42.498];
event(30).numobs=7;
event(31).name='04.04.1993 3.0MN 4 km S of DORION';
event(31).stations=['DAQ','A11','A54','LMQ','A16'];
event(31).distances=[362.0;364.0;365.0;376.0;390.0];
event(31).times=[47.31;52.88;51.41;54.00;54.26];
event(31).numobs=5;
event(32).name='04.20.1995 3.3MN Felt';
event(32).stations=['A64','A61','A16','LMQ','A54','DAQ'];
event(32).distances=[217.35;238.33;251.82;262.33;274.06;291.12];
event(32).times=[32.796;35.116;37.276;39.306;39.816;40.256];
event(32).numobs=6;
event(33).name='1992/05/01 3.2Mn 7 km E from BAIE-SAINT-PAUL';
event(33).stations=['CNQ','GSQ','ICQ','MNQ'];
event(33).distances=[269.33;294.67;327.25;363.75];
event(33).times=[39.208;42.318;45.858;50.608];
event(33).numobs=4;
event(34).name='05.06.1995 3.9MN Miramichi Region';
event(34).stations=['GSQ','A21','A16','A64','A11','CNQ','ICQ','A54','SMQ','DAQ'];
event(34).distances=[216.38;246.35;263.35;265.06;274.51;274.90;285.01;293.33;358.70;366.15];
event(34).times=[34.092;37.255;39.545;39.725;41.025;40.555;40.892;42.308;43.265;50.958;51.375];
event(34).numobs=11;
event(35).name='05.12.1996 3.1MN Felt';
event(35).stations=['DPQ','CNQ','GSQ','ICQ','MNQ','SMQ'];
event(35).distances=[228.60;245.86;266.95;302.17;348.10;387.65];
event(35).times=[33.888;35.458;39.138;43.108;47.908;53.238];
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event(35).numobs=6;
event(36).name='05.19.1992 3.0MN 42 km E from MONT-LAURIER';
event(36).stations=[{'DAQ'},{'A54'},{'A11'},{'A16'},{'A61'}];
event(36).distances=[331.0;366.0;376.0;396.0;397.0];
event(36).times=[46.25;50.76;51.71;54.03;54.36];
event(36).numobs=5;
event(37).name='05.24.1997 4.2MN WESTERN QUEBEC SEISMIC ZONE';
event(37).stations=[{'DAQ'},{'A11'},{'LMQ'},{'A16'},{'A61'},{'A64'}];
event(37).distances=[322.95;343.54;350.29;367.48;373.78;394.13];
event(37).times=[45.193;48.283;50.698;51.013;51.573;54.253];
event(37).numobs=6;
event(38).name='05.30.1993 3.7Mn 239 km E of SEPT-ILES';
event(38).stations=[{'SMQ'},{'ICQ'},{'GSQ'}];
event(38).distances=[263.0;318.0;334.0];
event(38).times=[38.95;45.42;47.04];
event(38).numobs=3;
event(39).name='06.03.1992 3.3Mn 51 km SE from MONT-LAURIER';
event(39).stations=[{'DAQ'},{'A54'},{'A11'}];
event(39).distances=[343.0;375.0;383.0];
event(39).times=[47.78;51.56;52.67];
event(39).numobs=3;
event(40).name='06.04.1992 3.4Mn 16 km W from MONT-JOLI';
event(40).stations=[{'A11'},{'MNQ'},{'SMQ'},{'DAQ'}];
event(40).distances=[205.0;215.0;216.0;224.0];
event(40).times=[30.83;32.58;32.30;33.58];
event(40).numobs=4;
event(41).name='06.07.1996 3.1MN Felt';
event(41).stations=[{'CNQ'},{'GSQ'},{'ICQ'},{'MNQ'},{'SMQ'}];
event(41).distances=[240.88;260.83;296.74;345.00;382.47];
event(41).times=[35.21;38.10;42.09;47.66;52.62];
event(41).numobs=5;
event(42).name='06.16.1995 3.8MN NEAR LISBON';
event(42).stations=[{'A11'},{'A16'},{'GRQ'}];
event(42).distances=[354.64;383.75;391.64];
event(42).times=[53.854;52.264;55.277];
event(42).numobs=3;
event(43).name='06.20.1997 3.4MN Felt';
event(43).stations=[{'DAQ'},{'LMQ'}];
event(43).distances=[323.49;372.16];
event(43).times=[45.033;52.633];
event(43).numobs=2;
event(44).name='6/23/2010 PQ, OTTAWA, ON 4.9MN';
event(44).stations=[{'QCQ'},{'DAQ'}];
event(44).distances=[339.5;398.1];
event(44).times=[46.71;52.81];
event(44).numobs=2;
event(45).name='07.14.1994 4.1Mn MIRAMICHI';
event(45).stations=[
    {'GSQ'},
    {'A21'},
    {'A16'},
    {'A64'},
    {'A11'},
    {'A61'},
    {'CNQ'},
    {'ICQ'},
    {'LMQ'},
    {'A54'},
    {'SMQ'},
    {'DAQ'}
];
event(45).distances=[216.0;246.0;263.0;265.0;275.0;275.0;279.0;285.0;289.0;293.0;359.0;366.0];
event(45).times=[34.38;37.37;39.55;38.98;40.86;40.15;41.56;42.76;43.10;42.77;51.63;52.05];
event(45).numobs=12;

event(46).name='07.14.1996 3.4MN CHARLEVOIX SEISMIC ZONE';
event(46).stations=[
    {'GSQ'},
    {'ICQ'},
    {'MNQ'}
];
event(46).distances=[253.40;285.80;328.32];
event(46).times=[37.86;40.81;45.54];
event(46).numobs=3;

event(47).name='07.28.1995 3.3MN WESTERN QUEBEC SEISMIC ZONE';
event(47).stations=[
    {'LMQ'},
    {'A11'}
];
event(47).distances=[349.3;359.3];
event(47).times=[46.33;48.26];
event(47).numobs=2;

event(48).name='07.30.1993 3.8Mn 1 km NE of SALABERRY-DE-VALLEYFIELD';
event(48).stations=[
    {'LMQ'},
    {'A11'}
];
event(48).distances=[373.0;387.0];
event(48).times=[52.93;56.37];
event(48).numobs=2;

event(49).name='08.08.1994 3.2Mn LOWER ST.LAWRENCE';
event(49).stations=[
    {'A21'},
    {'A64'},
    {'A61'},
    {'A16'},
    {'LMQ'},
    {'A54'},
    {'A11'},
    {'DAQ'}
];
event(49).distances=[284.0;285.0;306.0;319.0;330.0;341.0;348.0;356.0];
event(49).times=[41.27;41.32;43.61;46.02;47.15;48.31;49.56;49.78];
event(49).numobs=8;

event(50).name='08.20.1992 06:19:33 3.5MN 78 km W from NEWCASTLE';
event(50).stations=[
    {'GSQ'},
    {'CNQ'},
    {'SMQ'},
    {'DAQ'}
];
event(50).distances=[216.0;279.0;359.0;366.0];
event(50).times=[34.17;41.23;51.05;52.45];
event(50).numobs=4;

event(51).name='08.20.1995 3.3MN Felt; Richelieu River Region';
event(51).stations=[
    {'GRQ,'},
    {'A11,'},
    {'A54,'},
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    {'A16'},
    {'A61,'},
    {'A21'}
];
event(53).distances=[240.47;313.09;317.10;324.38;328.89;340.56;352.86;375.58];
event(53).times=[36.344;46.907;45.407;46.194;50.227;48.397;49.797;57.817];
event(53).numobs=8;
event(54).name='08.20.1997 3.7MN Felt';
event(54).stations=[{'CNQ,'},{'GSQ,'},{'ICQ,'},{'MNQ,'},{'SMQ'}];
event(54).distances=[256.09;281.86;314.03;351.52;398.39];
event(54).times=[37.635;41.145;44.325;49.115;56.075];
event(54).numobs=5;
event(55).name='08.21.1996 3.6MN NORTHERN APPALACHIANS SEISMIC ZONE';
event(55).stations=[{'A54'},{'A16'},{'LMQ'},{'A61'},{}];
event(55).distances=[363.72;373.17;375.10;395.12];
event(55).times=[49.672;49.532;53.077;54.172];
event(55).numobs=4;
event(56).name='08.27.1992 3.4Mn 15 km N  from RIMOUSKI';
event(56).stations=[{'DAQ'},{'MNQ'},{'SMQ'}];
event(56).distances=[207.0;220.0;231.0];
event(56).times=[32.54;33.71;34.61];
event(56).numobs=3;
event(57).name='1992/08/28 3.6Mn 15 km SE from QUEBEC';
event(57).stations=[{'CNQ'},{'GSQ'}];
event(57).distances=[368.0;388.0];
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event(58).name='08.28.1996 3.2MN EASTERN BACKGROUND SEISMIC ZONE';
event(58).stations=[{'CNQ'},{'MNQ'}];
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event(58).times=[33.105;41.075];
event(58).numobs=2;
event(59).name='08.30.1993 3.7Mn 35 km E  from MONT-LAURIER';
event(59).stations=[{'DAQ'},{'LMQ'}];
event(59).distances=[334.0;380.0];
event(59).times=[46.90;52.32];
event(59).numobs=2;
event(60).name='09.02.1996 3.1MN FELT';
event(60).stations=[{'A21'},{'GSQ'},{'A11'},{'A64'},{'A61'},{'LMQ'},{'A54'},{'CNQ'},{'ICQ'}];
event(60).distances=[326.20;330.15;333.39;346.44;350.98;358.81;360.17;392.29;398.72];
event(60).times=[45.212;46.802;41.782;47.322;48.322;51.107;49.292;53.372;55.312];
event(60).numobs=9;
event(61).name='09.12.1995 3.7MN WESTERN QUEBEC SEISMIC ZONE';
event(61).stations=[{'DAQ'},{'A54'},{'LMQ'}];
event(61).distances=[359.26;372.10;383.04];
event(61).times=[51.048;52.327;54.508];
event(61).numobs=3;
event(62).name='09.16.1994 3.3MN NEAR SPRINGFIELD';
event(62).stations=[{'A11'},{'A16'},{'A21'},{'A54'},{'LMQ'},{'A61'},{'A64'},{'DAQ'}];
event(62).distances=[263.0;276.0;288.0;292.0;296.0;301.0;307.0;375.0];
event(62).times=[41.15;40.31;41.95;42.17;43.57;43.07;43.92;53.05];
event(62).numobs=8;
event(63).name='09.16.1994 3.6MN NEAR SPRINGFIELD';
event(63).stations=[{'A11'},{'A16'},{'A21'},{'A54'},{'LMQ'},{'A61'},{'A64'},{'DAQ'}];
event(63).distances=[263.0;276.0;288.0;292.0;296.0;301.0;307.0;375.0];
event(63).times=[38.13;39.47;41.63;41.37;42.8;42.4;43.0;52.23];
event(63).numobs=8;
event(64).name='09.21.1995 3.1MN Felt';
event(64).stations=[{'DAQ'},{'A54'}];
event(64).distances=[392.43;393.56];
event(64).times=[55.015;54.325];
event(64).numobs=2;
event(65).name='09.23.1993 3.8MN 26 km W from STE-AGATHE-DES-MONTs';
event(65).stations=[{'DAQ'},{'LMQ'},{'LPQ'}];
event(65).distances=[332.0;366.0;379.0];
event(65).times=[46.53;50.42;53.82];
event(65).numobs=3;
event(66).name='09.23.1996 3.0MN Felt in Rawdon near Joliette';
event(66).stations=[{'DAQ'},{'A54'},{'LMQ'},{'A61'},{'A21'}];
event(66).distances=[277.67;288.73;299.62;323.31;349.53];
event(66).times=[38.748;42.558;46.013;47.658;53.378];
event(66).numobs=5;
event(67).name='09.24.1996 3.1MN Felt';
event(67).stations=[{'CNQ'},{'GSQ'},{'ICQ'},{'MNQ'},{'SMQ'}];
event(67).distances=[252.71;277.98;310.46;349.17;394.97];
event(67).times=[36.813;40.513;43.433;48.513;53.943];
event(67).numobs=5;
event(68).name='09.25.1994 4.3MN 19 km NE of LA MALBAIE';
event(68).stations=[{'CNQ'},{'GSQ'},{'ICQ'},{'MNQ'},{'SMQ'}];
event(68).distances=[220.63;247.14;278.42;319.91;362.87];
event(68).times=[32.52;35.35;39.00;43.49;48.64];
event(68).numobs=5;
event(69).name='10.07.1997 3.3MN Felt';
event(69).stations=[{'ICQ'},{'GSQ'},{'CNQ'},{'MNQ'}];
event(69).distances=[235.61;260.39;298.80;323.31];
event(69).times=[34.639;40.959;45.039;44.649];
event(69).numobs=4;
event(70).name='10.09.1995 3.2MN Felt';
event(70).stations=[{'DAQ'},{'A54'}];
event(70).distances=[366.19;397.69];
event(70).times=[50.804;55.124];
event(70).numobs=2;
event(71).name='10.28.1997 4.7MN CHARLEVOIX SEISMIC ZONE';
event(71).stations=[{'CNQ'},{'GSQ'},{'ICQ'},{'MNQ'},{'SMQ'}];
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**Event Data:**

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<td>11.20.1994</td>
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<td>SOME 40 km NW of LEWISTON</td>
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**Event Data (continued):**

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<td>12.01.1994</td>
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<td>[265.73, 289.50, 323.13, 362.51]</td>
<td>[39.54, 41.38, 43.21, 47.65, 51.09]</td>
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</table>
event(80).times=[39.734;43.234;46.214;50.434];
event(80).numobs=4;
event(81).name='12.12.1992 3.0Mn 78 km W from NEWCASTLE';
event(81).stations=['GSQ','A21','A16','A64','A61','A11','CNQ','ICQ','A54','SMQ','DAQ'];
event(81).distances=[216.0;246.0;263.0;265.0;275.0;275.0;279.0;285.0;293.0;359.0;366.0];
event(81).times=[33.7;37.77;40.07;40.34;41.62;43.60;41.49;42.42;43.86;50.58;53.38];
event(81).numobs=11;
event(82).name='12.18.1993 3.0Mn LOWER ST.LAWRENCE';
event(82).stations=['LMQ','LPQ','DAQ'];
event(82).distances=[264.0;264.0;295.0];
event(82).times=[38.2;40.01;42.63];
event(82).numobs=3;
event(83).name='12.30.1993 3.8MN 10 km E from BAIE-SAINT-PAUL';
event(83).stations=['CNQ','GSQ'];
event(83).distances=[266.63;291.48];
event(83).times=[38.756;41.846];
event(83).numobs=2;
event(84).name='12.08.1991 4.3MN 26 km W from RIVIERE-DU-LOUP';
event(84).stations=['CNQ','GSQ','ICQ','MNQ','SMQ'];
event(84).distances=[214.93;240.10;272.22;316.63;357.03];
event(84).times=[30.046;33.676;42.376;47.226];
event(84).numobs=5;
event(85).name='01.28.1988 3.8MN BAY of CHALEUR';
event(85).stations=['HTQ','A21','A64','A16','A61','LMQ','MNQ','A54'];
event(85).distances=[241.0;303.0;317.0;331.0;333.0;351.0;353.0;362.0];
event(85).times=[35.64;43.31;43.51;46.51;49.21;48.80;49.82];
event(85).numobs=8;
event(86).name='02.10.1989 4.3MN LOWER ST.LAWRENCE-NORTH SHORE';
event(86).stations=['GSQ','HTQ','MNQ'];
event(86).distances=[220.0;288;298.0];
event(86).times=[32.93;40.75;42.28];
event(86).numobs=3;
event(87).name='03.09.1989 4.3MN CHARLEVOIX-KAMOURASKA';
event(87).stations=['GSQ','MNQ'];
event(87).distances=[243.48;323.25];
event(87).times=[36.675;45.525];
event(87).numobs=2;
event(88).name='03.20.1991 3.7MN 55 km S from SEPT-ILES';
event(88).stations=['A21','A64'];
event(88).distances=[326.0;328.0];
event(88).times=[45.87;46.13];
event(88).numobs=2;
event(89).name='07.05.1991 3.8MN NEAR HOWICK';
event(89).stations=[{'A11'},{'DAQ'}];
event(89).distances=[362.0;367.0];
event(89).times=[50.85;50.79];
event(89).numobs=2;
event(90).name='08.26.1988 3.8MN MIRAMICHI';
event(90).stations=[{'GSQ'},{'A21'},{'LPQ'},{'A16'},{'A64'},{'A11'},{'A61'},{'HTQ'},{'A54'}];
event(90).distances=[216.0;246.0;261.0;264.0;265.0;274.0;275.0;278.0;293.0];
event(90).times=[33.81;36.24;38.20;38.42;37.74;39.65;39.38;40.03;41.51];
event(90).numobs=9;
event(91).name='08.26.1988 3.8MN MIRAMICHI';
event(91).stations=[{'GSQ'}];
event(91).distances=[216.0;261.0;357.0];
event(91).times=[33.28;38.31;49.90];
event(91).numobs=3;
event(92).name='10.07.1990 3.9MN 35 km SE from MONT-LAURIER';
event(92).stations=[{'DAQ'},{'A54'}];
event(92).distances=[352.0;386.0];
event(92).times=[48.60;53.04];
event(92).numobs=2;
event(93).name='10.17.1986 4.1MN FELT IN BATHURST';
event(93).stations=[{'GSQ'},{'LPQ'},{'HTQ'}];
event(93).distances=[216.0;261.0;278.0];
event(93).times=[34.57;39.36;41.22];
event(93).numobs=3;
event(94).name='10.26.1988 4.1MN SAGUENAY REGION';
event(94).stations=[{'TRQ'},{'GRQ'}];
event(94).distances=[326.0;385.0];
event(94).times=[45.85;52.55];
event(94).numobs=2;
event(95).name='12.08.1991 4.3MN RIVIERE-DU-LOUP';
event(95).stations=[{'CNQ'},{'GSQ'},{'DPQ'},{'ICQ'},{'MNQ'},{'SMQ'}];
event(95).distances=[214.93;240.10;252.36;272.22;316.63;357.03];
event(95).times=[30.046;33.676;35.286;36.986;42.376;47.226];
event(95).numobs=6;
event(96).name='12.31.1990 4.5MN LA TUQUE';
event(96).stations=[{'A64'},{'A21'}];
event(96).distances=[204.0;218.0];
event(96).times=[31.14;32.86];
event(96).numobs=2;
event(97).name='06.27.1992 3.3Mn 93 km E from SEPT-ILES';
event(97).stations=[{'CNQ'},{'MNQ'}];
event(97).distances=[219.0;266.0];
event(97).times=[34.24;38.61];
event(97).numobs=2;
numevents = length(event);
T = event(1).times;
for jj = 1:numevents
    T = [T; event(jj).times];
end

G = [event(1).distances, ones(event(1).numobs, 1), zeros(event(1).numobs, numevents-1)];
for jj = 1:numevents
    Gtemp = [event(jj).distances, zeros(event(jj).numobs, jj-1), ones(event(jj).numobs, 1), zeros(event(jj).numobs, numevents-jj)];
    G = [G; Gtemp];
end
M = G \ T;
M;
V1 = 1 / M(1)
Vtot = [V1];
for jj = 1:numevents
    G = [];
    T = [];
    for ii = 1:numevents
        if ii ~= jj
            Gtemp = [event(ii).distances, zeros(event(ii).numobs, ii-1), ones(event(ii).numobs, 1), zeros(event(ii).numobs, numevents-ii)];
            T = [T; event(ii).times];
            G = [G; Gtemp];
        end
    end
    M = G \ T;
    M;
    V = 1 / M(1)
    Vtot = [Vtot; V];
end
C = std(Vtot)
%Analysis of eastern Canada/Grenville terrane seismic stations from
%epicentral distances from 400-600 km, Area 6

clear all;

event(1).name='St. Antoine Abbe 3.9Mn 1/9/06';
event(1).stations=[{'A16'},{'A61'},{'A64'},{'A21'}];
event(1).distances=[401.6;413.8;435.2;437];
event(1).times=[54.58;55.79;58.72;58.79];
event(1).numobs=4;

event(2).name='Joliette 3.4Mn 2/11/02';
event(2).stations=[{'CNQ'},{'GSQ'},{'ICQ'},{'MNQ'}];
event(2).distances=[533.5;567.1;594.7;597];
event(2).times=[72.52;76.30;79.76;79.94];
event(2).numobs=4;

event(3).name='St. Agathe Des Monts 4.5Mn 3/14/96';
event(3).stations=[{'A64'},{'A21'}];
event(3).distances=[403.8;411];
event(3).times=[20.57;21.6];
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event(4).name='Sarnac Lake 3.8 Mn 4/20/00';
event(4).stations=[{'QCQ'},{'A11'},{'A54'},{'LMQ'},{'A16'},{'A61'},{'A21'}];
event(4).distances=[483.4;490.9;502.7;511.6;526.7;547.3;547.6];
event(4).times=[65.46;66.11;67.38;68.83;70.42;73.32;73.1];
event(4).numobs=7;

event(5).name='St. Agathe Des Monts 4.5Mn';
event(5).stations=[{'A64'},{'A21'}];
event(5).distances=[408.6;416.8];
event(5).times=[53.98;55.19];
event(5).numobs=2;

event(6).name='Mont Laurier 2.9Mn 9/6/05';
event(6).stations=[{'A11'},{'LMQ'},{'A16'},{'A61'},{'A64'},{'A21'}];
event(6).distances=[402.7;403;422.9;424.8;443.7;453.7];
event(6).times=[53.76;53.99;56.6;56.85;59.06;60.40];
event(6).numobs=6;

event(7).name='01.10.1997 3.2MN Felt';
event(7).stations=[{'ICQ'},{'MNQ'}];
event(7).distances=[311.24;352.26];
event(7).times=[43.4;48.66];
event(7).numobs=2;

event(8).name='02.15.1995 3.5MN WESTERN QUEBEC ZONE. Felt';
event(8).stations=[{'A11'},{'LMQ'},{'A61'},{'A64'},{'A21'}];
event(8).distances=[400;404;427;447;455];
event(8).times=[55.51;57.17;59.31;61.6;62.83];
event(8).numobs=5;

event(9).name='03.02.1995 3.0MN ADIRONDACKS';
event(9).stations=[{'A54'},{'DAQ'},{'A61'}'];
event(9).distances=[475.0;482.0;510.0;532.0];

190
event(9).times=[64.95;66.16;70.59;73.31];
event(9).numobs=4;
event(10).name='3/8/2009 3.6 Mn NB, 86.2KM NNE OF FREDERICTON';
event(10).stations=['A64', 'A21'];
event(10).distances=[403.34;410.16];
event(10).times=[54.292;55.312];
event(10).numobs=2;
event(11).name='04.03.1997 3.6MN Felt. Southern Quebec';
event(11).stations=['CNQ', 'GSQ'];
event(11).distances=[489.74;512.27];
event(11).times=[64.818;70.408];
event(11).numobs=2;
event(12).name='04.04.1993 3.0MN 4 km S of DORION';
event(12).stations=['A61', 'A64', 'A21'];
event(12).distances=[400.0;421.0;425.0];
event(12).times=[54.93;59.32;59.77];
event(12).numobs=3;
event(13).name='04.16.1994 3.0Mn WESTERN QUEBEC. Felt';
event(13).stations=['DAQ', 'LMQ'];
event(13).distances=[321.0;360.0];
event(13).times=[47.83;53.57];
event(13).numobs=2;
event(14).name='05.19.1992 3.0MN 42 km E from MONT-LAURIER';
event(14).stations=['A64', 'A21'];
event(14).distances=[416.0;426.0];
event(14).times=[56.55;57.88];
event(14).numobs=2;
event(15).name='06.03.1992 3.3Mn 51 km SE from MONT-LAURIER';
event(15).stations=['A16', 'A61', 'A64', 'A21'];
event(15).distances=[405.0;407.0;426.0;435.0];
event(15).times=[55.10;55.41;57.78;59.31];
event(15).numobs=4;
event(16).name='06.03.1995 3.9MN Western Quebec';
event(16).stations=['A54', 'LMQ'];
event(16).distances=[447.54;454.82];
event(16).times=[52.408;61.523];
event(16).numobs=2;
event(17).name='06.16.1995 3.8MN NEAR LISBON';
event(17).stations=['A61', 'DAQ', 'A64'];
event(17).distances=[403.82;409.30;423.33];
event(17).times=[55.834;56.011;58.224];
event(17).numobs=3;
event(18).name='6/23/2010 PQ, OTTAWA, ON 4.9MN';
event(18).stations=['A54', 'A11', 'LMQ', 'A64'];
event(18).distances=[426.4;433.3;436.3;478.8];
event(18).times=[56.16;57.71;57.51;62.66];
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<th>Event ID</th>
<th>Date</th>
<th>Magnitude</th>
<th>Distance</th>
<th>Stations</th>
<th>Times</th>
<th>NumObs</th>
</tr>
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<td>18</td>
<td>06.27.1992</td>
<td>3.3Mn</td>
<td>93 km</td>
<td>SEPT-ILES</td>
<td>[59.18;56.99;59.93;61.42;64.69;63.75]</td>
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<td>06.28.1992</td>
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<td>22 km</td>
<td>QUEBEC</td>
<td>[56.24;59.36;62.26]</td>
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<td>07.14.1994</td>
<td>4.1Mn</td>
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<td>MIRAMICHI</td>
<td>[58.85;69.01]</td>
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<td>07.21.1997</td>
<td>3.0Mn</td>
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<td>[57.403;60.773;60.493;60.783]</td>
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<td>3.4Mn</td>
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<td>[82.874;82.724]</td>
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<td>23</td>
<td>08.20.1995</td>
<td>3.3Mn</td>
<td></td>
<td>Richelieu River Region</td>
<td>[78.177;80.527;85.36;86.86]</td>
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<td>WESTERN QUEBEC</td>
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<td>QUEBEC</td>
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event(28).name='08.28.1996 3.2MN EASTERN BACKGROUND SEISMIC ZONE';
event(28).stations=[{'A61'}, {'A16'}, {'LMQ'}, {'A54'}, {'DAQ'}];
event(28).distances=[419.89; 427.90; 443.47; 454.36; 483.12];
event(28).times=[57.885; 59.705; 63.36; 62.855; 66.255];
event(28).numobs=5;
event(29).name='09.02.1996 3.1MN FELT';
event(29).stations=[{'DAQ'}, {'DPQ'}, {'MNQ'}];
event(29).distances=[441.11; 512.14; 538.22];
event(29).times=[59.502; 66.915; 70.922];
event(29).numobs=3;
event(30).name='09.05.1994 3.1Mn MAINE';
event(30).stations=[{'LMQ'}, {'DAQ'}, {'GSQ'}];
event(30).distances=[418.0; 480.0; 592.0];
event(30).times=[59.75; 65.33; 78.96];
event(30).numobs=3;
event(31).name='09.16.1994 3.3MN NEAR SPRINGFIELD';
event(31).stations=[{'GSQ'}, {'CNQ'}, {'ICQ'}, {'SMQ'}, {'MNQ'}];
event(31).distances=[407.0; 442.0; 472.0; 556.0; 581.0];
event(31).times=[57.40; 60.83; 64.68; 74.73; 77.30];
event(31).numobs=5;
event(32).name='09.16.1994 3.6MN NEAR SPRINGFIELD';
event(32).stations=[{'GSQ'}, {'MNT'}, {'CNQ'}, {'ICQ'}, {'SMQ'}];
event(32).distances=[407.0; 442.0; 472.0; 556.0; 581.0];
event(32).times=[56.68; 60.33; 63.90; 74.01; 76.83];
event(32).numobs=5;
event(33).name='09.16.1994 3.6MN NEAR SPRINGFIELD';
event(33).stations=[{'GSQ'}, {'CNQ'}, {'ICQ'}, {'SMQ'}, {'MNQ'}];
event(33).distances=[407.0; 442.0; 472.0; 556.0; 581.0];
event(33).times=[57.53; 61.20; 64.31; 74.55; 77.96];
event(33).numobs=5;
event(34).name='09.20.1995 3.0MN WESTERN QUEBEC SEISMIC ZONE';
event(34).stations=[{'DAQ'}, {'A54'}];
event(34).distances=[412.03; 457.39];
event(34).times=[55.245; 59.802];
event(34).numobs=2;
event(35).name='10/1/2007 3.6 Mn PQ, 82.3KM NW OF MANIWAKI';
event(35).stations=[{'QCQ'}, {'DAQ'}, {'A54'}, {'LMQ'}];
event(35).distances=[425.4; 435.41; 489.7; 496.8];
event(35).times=[56.89; 56.66; 63.56; 64.09];
event(35).numobs=4;
event(36).name='10.02.1994 3.5MN U.S.A.';
event(36).stations=[{'LMQ'}, {'DAQ'}];
event(36).distances=[478.0; 515.0];
event(36).times=[68.2; 72.1];
event(36).numobs=2;
event(37).name='10.09.1993 3.4Mn 17 km E of LE DOMAINE';
event(37).stations=[{'LMQ'},{'LPQ'}];
event(37).distances=[458.0;480.0];
event(37).times=[59.75;64.47];
event(37).numobs=2;
event(38).name='10.09.1995 3.2MN Felt';
event(38).stations=[{'LMQ'},{'A61'},{'A64'}];
event(38).distances=[407.29;429.72;449.07];
event(38).times=[57.345;59.034;61.304];
event(38).numobs=3;
event(39).name='10.13.1997 3.0MN New York State';
event(39).stations=[{'DAQ'},{'A54'}];
event(39).distances=[493.45;493.52];
event(39).times=[67.044;67.084];
event(39).numobs=2;
event(40).name='11.06.1997 5.1MN Quebec City Region. Felt';
event(40).stations=[{'ICQ'},{'MNQ'},{'SMQ'},{'MTQ'}];
event(40).distances=[432.53;458.89;516.35;565.54];
event(40).times=[58.436;61.676;68.626;73.43];
event(40).numobs=4;
event(41).name='11.11.1992 3.3Mn 24 km E from MONT-LAURIER';
event(41).stations=[{'A61'},{'A64'},{'A21'}];
event(41).distances=[408.0;426.0;437.0];
event(41).times=[55.09;54.32;59.16];
event(41).numobs=3;
event(42).name='11.12.1995 3.1MN Maine';
event(42).stations=[{'CNQ'},{'ICQ'}];
event(42).distances=[546.22;573.53];
event(42).times=[70.264;74.331];
event(42).numobs=2;
event(43).name='1992/11/17  4.4Mn (NEIC) 2 OBS. Felt';
event(43).stations=[{'LMQ'},{'A16'},{'A61'},{'A64'},{'A21'}];
event(43).distances=[404.0;422.0;427.0;447.0;454.0];
event(43).times=[56.82;58.46;58.53;60.96;61.90];
event(43).numobs=5;
event(44).name='1992/11/18 3.3Mn NEAR CAP-PELE N.B. Felt';
event(44).stations=[{'ICQ'},{'CNQ'},{'SMQ'},{'DAQ'},{'MNQ'}];
event(44).distances=[417.0;432.0;467.0;552.0;571.0];
event(44).times=[58.24;60.19;64.11;74.77;76.42];
event(44).numobs=5;
event(45).name='1992/11/18 3.3Mn NEAR CAP-PELE N.B. Felt';
event(45).stations=[{'DAQ'},{'GSQ'},{'CNQ'}];
event(45).distances=[412.0;577.0;588.0];
event(45).times=[59.70;81.86;81.55];
event(45).numobs=3;
event(46).name='12.12.1992 3.0Mn 78 km W from NEWCASTLE';
event(46).stations=[{'MNQ'},{'MOQ'}];
event(46).distances=[424.0;476.0];
event(46).times=[59.44;65.00];
event(46).numobs=2;
event(47).name='12/23/2007 3.6 Mc PQ, 12.8KM N OF CHICHESTER';
event(47).stations=[{'LMQ'},{'A11'}];
event(47).distances=[541.5;543.2];
event(47).times=[72.42;72.64];
event(47).numobs=2;
event(48).name='12.25.1993 4.1Mn 12 km SW from MONT-LAURIER';
event(48).stations=[{'LMQ'},{'LPQ'}];
event(48).distances=[420.0;438.0];
event(48).times=[56.5;59.56];
event(48).numobs=2;
event(49).name='03.06.1991 3.9MN LAC DUVAL';
event(49).stations=[{'DAQ'},{'A54'},{'A11'},{'A61'},{'A16'},{'A64'}];
event(49).distances=[429.0;484.0;526.0];
event(49).times=[58.04;64.01;68.72];
event(49).numobs=3;
event(50).name='03.06.1991 3.9MN LAC DUVAL';
event(50).stations=[{'DAQ'},{'A54'},{'A64'}];
event(50).distances=[429.0;484.0;526.0];
event(50).times=[58.04;64.01;68.72];
event(50).numobs=3;
event(51).name='06.16.1991 4.2MN 95 km NW from MANIWAKI';
event(51).stations=[{'DAQ'},{'A54'},{'A64'}];
event(51).distances=[429.0;484.0;526.0];
event(51).times=[58.14;64.02;68.70];
event(51).numobs=3;
event(52).name='10.19.1990 5.0MN 11 km SW from MONT-LAURIER';
event(52).stations=[{'A54'},{'LMQ'},{'A11'},{'A61'},{'A16'},{'A64'}];
event(52).distances=[409.0;418.0;420.0;439.0;439.0;458.0];
event(52).times=[56.20;56.82;59.36;59.1;61.21;62.63];
event(52).numobs=6;
event(53).name='10.23.1987 3.7MN NEAR KILMAR';
event(53).stations=[{'A61'},{'A64'}];
event(53).distances=[401.0;421.0];
event(53).times=[55.92;58.37];
event(53).numobs=2;
event(54).name='11.15.1990 4.1MN 83 km NW from MONT-LAURIER';
event(54).stations=[{'LMQ'},{'A61'},{'LPQ'}];
event(54).distances=[432.0;458.0;475.0];
event(55).times=[58.46;61.63;63.57];
event(55).numobs=3;
event(56).name='11.16.1989 4.0MN WESTERN QUEBEC. Felt';
event(56).stations=[{'DAQ'},{'CIQ'},{'LPQ'},{'A64'},{'A21'}];
event(56).distances=[434.0;477.0;509.0;527.0;539.0];
event(56).times=[57.18;62.90;66.43;68.31;69.66];
event(56).numobs=5;

numevents=length(event);
T=event(1).times;
for jj=2:numevents
    T=[T;event(jj).times];
end

G=[event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,numevents-1)];
for jj=2:numevents
    Gtemp=[event(jj).distances,zeros(event(jj).numobs,jj-1),ones(event(jj).numobs,1),zeros(event(jj).numobs,numevents-jj)];
    G=[G;Gtemp];
end

M=G\T;
M;
V1=1/M(1)

Vtot=[V1];

for jj=1:numevents
    G=[];
    T=[];
    for ii=1:numevents
        if ii~=jj
            Gtemp=[event(ii).distances,zeros(event(ii).numobs,ii-1),ones(event(ii).numobs,1),zeros(event(ii).numobs,numevents-ii)];
            T=[T;event(ii).times];
            G=[G;Gtemp];
        end
    end
    M=G\T;
    M;
    V=1/M(1)
    Vtot=[Vtot;V];
end

C=std(Vtot)
%Analysis of eastern Canada/Grenville terrane seismic stations from
% epicentral distances from 600 km

clear all;
event(1).name='1/9/06 St. Antoine Abbe 3.9 Mn';
event(1).stations=[ {'CNQ'}, {'GSQ'}, {'ICQ'}, {'MNQ'}, {'SMQ'} ];
event(1).distances=[645.6;670.8;704.9;718.9;788.7];
event(1).times=[84.09;87.77;91.35;92.90;101.19];
event(1).numobs=5;
event(2).name='9.6.05 2.9Mn Mont Laurier';
event(2).stations=[ {'CNQ'}, {'MNQ'}, {'GSQ'}, {'ICQ'} ];
event(2).distances=[635.5;674.2;680.5;698.5];
event(2).times=[81.39;87.6;87.6;87.91];
event(2).numobs=4;
event(3).name='01.28.1992 3.0Mn 111 km N from PETAWAWA';
event(3).stations=[ {'MNQ'}, {'ICQ'} ];
event(3).distances=[754.0;809.0];
event(3).times=[98.23;104.74];
event(3).numobs=2;
event(4).name='02.15.1995 3.5MN WESTERN QUEBEC ZONE. Felt';
event(4).stations=[ {'CNQ'}, {'GSQ'}, {'MNQ'}, {'ICQ'} ];
event(4).distances=[646;686;694;708];
event(4).times=[85.3;90.83;92.3;92.61];
event(4).numobs=4;
event(5).name='02.20.1996 3.1MN WESTERN QUEBEC';
event(5).stations=[ {'MNQ'}, {'ICQ'} ];
event(5).distances=[676.40;688.38];
event(5).times=[89.449;89.749];
event(5).numobs=2;
event(6).name='02.23.1997 3.3MN 58 km SW from VAL-DOR';
event(6).stations=[ {'MNQ'}, {'ICQ'} ];
event(6).distances=[609.75];
event(6).times=[86.99];
event(6).numobs=1;
event(7).name='03.02.1995 3.0MN ADIRONDACKS';
event(7).stations=[ {'CNQ'}, {'GSQ'}, {'ICQ'}, {'MNQ'} ];
event(7).distances=[743.0;764.0;801.0;819.0];
event(7).times=[97.70;100.41;104.70;105.91];
event(7).numobs=4;
event(8).name='04.20.1996 3.3MN Cochrane';
event(8).stations=[ {'DAQ'}, {'MNQ'} ];
event(8).distances=[730.09;889.27];
event(8).times=[93.993;113.723];
event(8).numobs=2;
event(9).name='05.06.1993 3.5Mn 7 km E of NOTRE-DAME-DE-PONTMAIN';
event(9).stations=[ {'CNQ'}, {'MNQ'}, {'GSQ'}, {'ICQ'}, {'SMQ'} ];
event(9).distances=[651.0;687.0;697.0;714.0;787.0];
event(9).times=[86.31;89.86;91.16;93.86;101.48];
event(9).numobs=5;
event(10).name='06.03.1992 3.3Mn 51 km SE from MONT-LAURIER';
event(10).stations=[{'CNQ'},{'MNQ'},{'GSQ'},{'ICQ'},{'SMQ'}];
event(10).distances=[620.0;632.0;663.0;683.0;758.0];
event(10).times=[80.83;87.00;87.53;88.39;98.06];
event(10).numobs=5;
event(11).name='06.03.1995 3.9MN Western Quebec';
event(11).stations=[{'CNQ'},{'MNQ'},{'ICQ'}];
event(11).distances=[661.65;676.55;724.74];
event(11).times=[86.198;88.131;92.931];
event(11).numobs=3;
event(12).name='06.16.1995 3.8MN NEAR LISBON';
event(12).stations=[{'CNQ'},{'GSQ'},{'MNQ'}];
event(12).distances=[630.84;634.81;682.50;733.12];
event(12).times=[82.811;82.961;88.444;94.927];
event(12).numobs=4;
event(13).name='06.20.1997 3.4MN Felt';
event(13).stations=[{'MNQ'},{'SMQ'}];
event(13).distances=[634.60;735.17];
event(13).times=[83.453;95.413];
event(13).numobs=2;
event(14).name='6/23/2010 PQ, OTTAWA, ON 4.9MN';
event(14).stations=[{'CNQ'},{'ICQ'},{'SMQ'}];
event(14).distances=[675.6;738.4;814.4];
event(14).times=[85.71;92.89;102.67];
event(14).numobs=3;
event(15).name='07.21.1997 3.0MN WESTERN QUEBEC SEISMIC ZONE';
event(15).stations=[{'CNQ'},{'MNQ'},{'GSQ'},{'ICQ'}];
event(15).distances=[659.45;701.18;702.40;722.16];
event(15).times=[89.733;92.593;93.793;94.023];
event(15).numobs=4;
event(16).name='07.28.1995 3.3MN WESTERN QUEBEC SEISMIC ZONE';
event(16).stations=[{'CNQ'},{'GSQ'},{'MNQ'},{'ICQ'}];
event(16).distances=[622.53;664.51;667.39;685.10];
event(16).times=[79.586;86.403;86.553;87.853];
event(16).numobs=4;
event(17).name='07.28.1995 3.3MN WESTERN QUEBEC SEISMIC ZONE';
event(17).stations=[{'CNQ'},{'GSQ'},{'ICQ'},{'MNQ'},{'SMQ'}];
event(17).distances=[642.0;670.0;702.0;710.0;784.0];
event(17).times=[86.03;86.06;93.31;93.45;102.01];
event(17).numobs=5;
event(18).name='07.31.1997 3.4MN NORTHERN NEW YORK STATE';
event(18).stations=[{'LMQ'},{'A61'},{'A21'},{'CNQ'},{'GSQ'},{'ICQ'},{'MNQ'}];
event(18).distances=[601.27;625.15;646.64;857.87;878.37;915.93;933.68];
event(18).times=[86.324;88.544;92.144;117.204;119.264;122.654;124.206];
event(18).numobs=7;
event(19).name='08.21.1996 3.6MN NORTHERN APPALACHIANS SEISMIC ZONE';
event(19).stations=[{'CNQ'},{'MNQ'}];
event(19).distances=[615.74;725.49];
event(19).times=[80.852;94.802];
event(19).numobs=2;
event(20).name='08.28.1994 3.6Mn WESTERN QUEBEC';
event(20).stations=[{'MNQ'},{'GSQ'},{'ICQ'},{'SMQ'}];
event(20).distances=[773.0;804.0;816.0;885.0];
event(20).times=[99.68;103.90;103.25;112.70];
event(20).numobs=4;
event(21).name='08.30.1993 3.7Mn 35 km E from MONT-LAURIER';
event(21).stations=[{'CNQ'},{'MNQ'},{'GSQ'},{'ICQ'},{'SMQ'}];
event(21).distances=[610.0;649.0;656.0;673.0;747.0];
event(21).times=[79.91;85.51;86.08;87.06;97.18];
event(21).numobs=5;
event(22).name='09.12.1995 3.7MN WESTERN QUEBEC SEISMIC ZONE';
event(22).stations=[{'CNQ'},{'MNQ'},{'ICQ'}];
event(22).distances=[632.74;692.62;693.93];
event(22).times=[84.065;91.298;91.565];
event(22).numobs=3;
event(23).name='09.21.1995 3.1MN Felt';
event(23).stations=[{'CNQ'},{'ICQ'}];
event(23).distances=[659.79;719.54];
event(23).times=[86.765;93.848];
event(23).numobs=2;
event(24).name='09.23.1993 3.8MN 26 km W from STE-AGATHE-DES-MONTs';
event(24).stations=[{'CNQ'},{'GSQ'},{'MNQ'},{'ICQ'},{'SMQ'}];
event(24).distances=[609.0;648.0;659.0;671.0;748.0];
event(24).times=[79.56;86.1;85.96;87.5;96.26];
event(24).numobs=5;
event(25).name='10.02.1994 3.5MN U.S.A.,'

event(25).stations=[{'CNQ'},{'ICQ'}];
event(25).distances=[836.0;884.0];
event(25).times=[109.3;116.00];
event(25).numobs=2;
event(26).name='10.09.1993 3.4Mn 17 km E of LE DOMAINE';
event(26).stations=[{'CNQ'},{'MNQ'},{'GSQ'},{'ICQ'},{'SMQ'}];
event(26).distances=[666.0;682.0;721.0;729.0;796.0];
event(26).times=[86.75;89.10;94.96;93.01;102.15];
event(26).numobs=5;
event(27).name='10.10.1995 3.5MN WESTERN QUEBEC SEISMIC ZONE';
event(27).stations=[{'A54'},{'A61'},{'A21'}];
event(27).distances=[646.46;674.10;704.02];
event(27).times=[83.155;86.845;89.705];
event(27).numobs=3;
event(28).name='11.16.1993 4.3MN NAPIERVILLE';
event(28).stations=['CNQ','GSQ','ICQ','MNQ','SMQ'];
event(28).distances=[627.0;636.0;680.0;690.0;755.0];
event(28).times=[84.37;84.20;89.70;89.90;98.33];
event(28).numobs=5;
event(29).name='1992/11/17 4.4Mn (NEIC) 2 OBS. Felt';
event(29).stations=['CNQ','GSQ','MNQ','ICQ','SMQ'];
event(29).distances=[648.0;686.0;700.0;710.0;788.0];
event(29).times=[84.76;90.42;91.33;92.18;101.52];
event(29).numobs=5;
event(30).name='11.20.1994 3.2MN SOME 40 km NW of LEWISTON';
event(30).stations=['ICQ','MNQ','SMQ'];
event(30).distances=[633.0;707.0;721.0];
event(30).times=[85.91;94.68;97.45];
event(30).numobs=3;
event(31).name='12.25.1993 4.1Mn 12 km SW from MONT-LAURIER';
event(31).stations=['CNQ','MNQ','GSQ','ICQ'];
event(31).distances=[645.0;677.0;693.0;709.0];
event(31).times=[83.48;88.75;89.96;90.78];
event(31).numobs=4;
event(32).name='12.25.1993 4.1Mn 12 km SW from MONT-LAURIER';
event(32).stations=['CNQ','MNQ','GSQ','ICQ'];
event(32).distances=[645.0;677.0;693.0;709.0];
event(32).times=[83.48;88.75;89.96;90.78];
event(32).numobs=4;
event(33).name='03.06.1991 3.9MN LAC DUVAL';
event(33).stations=['CNQ','MNQ','ICQ'];
event(33).distances=[740.0;763.0;803.0];
event(33).times=[94.87;98.28;101.95];
event(33).numobs=3;
event(34).name='03.10.1988 3.7MN WESTERN QUEBEC. Felt';
event(34).stations=['MNQ','GSQ'];
event(34).distances=[691.0;704.0];
event(34).times=[90.38;91.93];
event(34).numobs=2;
event(35).name='06.16.1991 4.2MN 95 km NW from MANIWAKI';
event(35).stations=['CNQ','MNQ'];
event(35).distances=[694.0;704.0];
event(35).times=[89.07;90.67];
event(35).numobs=2;
event(36).name='07.05.1991 3.8MN NEAR HOWICK';
event(36).stations=['CNQ','ICQ','MNQ','SMQ'];
event(36).distances=[632.0;691.0;704.0;774.0];
event(36).times=[83.88;90.54;91.60;100.69];
event(36).numobs=4;

denevents=length(event);
T = event(1).times;
for jj = 2:numevents
    T = [T; event(jj).times];
end

G = [event(1).distances, ones(event(1).numobs, 1), zeros(event(1).numobs, numevents-1)];
for jj = 2:numevents
    Gtemp = [event(jj).distances, zeros(event(jj).numobs, jj-1), ones(event(jj).numobs, 1), zeros(event(jj).numobs, numevents-jj)];
    G = [G; Gtemp];
end

M = G \ T;
M;
V1 = 1 / M(1)
Vtot = [V1];

for jj = 1:numevents
    G = [];
    T = [];
    for ii = 1:numevents
        if ii ~= jj
            Gtemp = [event(ii).distances, zeros(event(ii).numobs, ii-1), ones(event(ii).numobs, 1), zeros(event(ii).numobs, numevents-ii)];
            T = [T; event(ii).times];
            G = [G; Gtemp];
        end
    end
    M = G \ T;
    M;
    V = 1 / M(1)
    Vtot = [Vtot; V];
end

C = std(Vtot)
APPENDIX I
MATLAB CODE FOR REGIONALIZED AREA 7
%Ep. Distance Analysis 200-400km from sources, Area 7

clear all;
event(1).name='02.23.1997 3.3MN 58 km SW from VAL-DOR';
event(1).stations=[{'SWXO'},{'ELLO'}];
event(1).distances=[255.14;358.97];
event(1).times=[37.569;50.201];
event(1).numobs=2;
event(2).name='2010/03/10 3.3 Mn PQ, 69.0KM WNW OF MONTREAL';
event(2).stations=[{'VLDQ'},{'EEO'},{'BUKO'}];
event(2).distances=[349.2;370.2;386.0];
event(2).times=[48.04;52.62;51.82];
event(2).numobs=3;
event(3).name='04.20.1996 3.3MN Cochrane';
event(3).stations=[{'SWO'},{'SWXO'},{'SZO'},{'EEO'}];
event(3).distances=[271.82;287.85;307.19;315.51];
event(3).times=[38.885;40.902;42.632;44.833];
event(3).numobs=4;
event(4).name='05.24.1997 4.2MN WESTERN QUEBEC SEISMIC ZONE';
event(4).stations=[{'VALQ'},{'EEO'}];
event(4).distances=[353.08;381.45];
event(4).times=[49.228;52.683];
event(4).numobs=2;
event(5).name='06.03.1995 3.9MN Western Quebec';
event(5).stations=[{'EEO'},{'KLO'},{'SUO'},{'SWXO'}];
event(5).distances=[216.94;308.96;367.65;384.15];
event(5).times=[32.608;43.58;51.379;52.419];
event(5).numobs=4;
event(6).name='08.30.1993 3.7Mn 35 km E from MONT-LAURIER';
event(6).stations=[{'VDQ'},{'EEO'}];
event(6).distances=[295.0;309.0];
event(6).times=[45.49;45.91];
event(6).numobs=2;
event(7).name='10/1/2007 3.6 Mn PQ, 82.3KM NW OF MANIWAKI';
event(7).stations=[{'RSPO'},{'BUKO'}];
event(7).distances=[247.4;264.2];
event(7).times=[35.89;37.58];
event(7).numobs=2;
event(8).name='10.09.1993 3.4Mn 17 km E of LE DOMAINE';
event(8).stations=[{'EEO'},{'SWO'},{'SUO'},{'SWXO'}];
event(8).distances=[214.0;359.0;365.0;382.0];
event(8).times=[32.53;50.99;51.76;53.09];
event(8).numobs=4;
event(9).name='10/28/2007 3.5 Mn ON, 53KM NNE OF PETAUWAWA';
event(9).stations=[{'RSPO'},{'BUKO'}];
event(9).distances=[208.2;212.5];
event(9).times=[32.34;32.87];
event(9).numobs=2;
event(10).name='12.06.1995 3.5MN Felt';
event(10).stations=[{'SWO'},{'SWXO'},{'SZO'},{'SUO'},{'ELLO'},{'EEO'}];
event(10).distances=[319.93;331.58;347.62;355.97;358.35;383.58];
event(10).times=[45.045;46.15;48.061;49.998;51.269;52.52];
event(10).numobs=6;
event(11).name='12.31.1996 3.5MN WESTERN QUEBEC SEISMIC ZONE';
event(11).stations=[{'VALQ'},{'EEO'},{'KLO'}];
event(11).distances=[230.12;258.77;385.54];
event(11).times=[35.244;39.18;55.34];
event(11).numobs=3;

numevents=length(event);
T=event(1).times;
for jj=1:numevents
    T=[T;event(jj).times];
end

G=[event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,numevents-1)];

for jj=1:numevents
    Gtemp=[event(jj).distances,zeros(event(jj).numobs,jj-1),ones(event(jj).numobs,1),zeros(event(jj).numobs,numevents-jj)];
    G=[G;Gtemp];
end

M=G\T;
M;
V1=1/M(1)
Vtot=[V1];

for jj=1:numevents
    G=[];
    T=[];
    for ii=1:numevents
        if ii~=jj
            Gtemp=[event(ii).distances,zeros(event(ii).numobs,ii-1),ones(event(ii).numobs,1),zeros(event(ii).numobs,numevents-ii)];
            T=[T;event(ii).times];
            G=[G;Gtemp];
        end
    end
    M=G\T;
    M;
    V=1/M(1)
Vtot=[Vtot;V];
end

C=std(Vtot)
%Analysis of eastern Canada/Grenville terrane seismic stations from
%epicentral distances from 400-600 km, Area 7

clear all;
event(1).name='03.14.1996 4.4MN Western Quebec';
event(1).stations=[{'SUO'},{'SWO'},{'SWXO'},{'SZO'}];
event(1).distances=[513.54;516.55;536.01;551.35];
event(1).times=[68.37;68.852;70.934;73.094];
event(1).numobs=4;
event(2).name='06.03.1995 3.9MN Western Quebec';
event(2).stations=[{'SZO'},{'TYNO'}];
event(2).distances=[403.71;519.44];
event(2).times=[55.482;69.298];
event(2).numobs=2;
event(3).name='6/23/2010 PQ, OTTAWA, ON 4.9MN';
event(3).stations=[{'KILO'},{'TOBO'},{'BRCO'}];
event(3).distances=[433.9;477.3;503.3];
event(3).times=[57.47;62.80;65.90];
event(3).numobs=3;
event(4).name='08.16.1996 3.7MN 43 km SW from KAPUSKASING';
event(4).stations=[{'EEO'},{'VALQ'},{'BRCO'}];
event(4).distances=[408.51;415.61;566.28];
event(4).times=[55.033;56.689;74.824];
event(4).numobs=3;
event(5).name='10.09.1993 3.4Mn 17 km E of LE DOMAINE';
event(5).stations=[{'SZO'},{'KAO'}];
event(5).distances=[401.0;536.0];
event(5).times=[55.85;72.70];
event(5).numobs=2;
event(6).name='10.13.1997 3.0MN New York State';
event(6).stations=[{'EEO'},{'KLO'}];
event(6).distances=[409.06;577.05];
event(6).times=[57.154;77.368];
event(6).numobs=2;
event(7).name='10.16.1993 3.7Mn MAG 3.4 USGS';
event(7).stations=[{'SUO'},{'SZO'},{'SWO'},{'EEO'}];
event(7).distances=[523.0;528.0;560.0;571.0];
event(7).times=[72.53;73.33;76.43;77.49];
event(7).numobs=4;
event(8).name='10.27.1992 3.1Mn 341 km W of RUPERT HOUSE';
event(8).stations=[{'SWO'},{'SZO'},{'SUO'}];
event(8).distances=[544.0;564.0;579.0];
event(8).times=[74.19;76.52;74.74];
event(8).numobs=3;
event(9).name='1992/11/17 4.4Mn (NEIC) 2 OBS. Felt';
event(9).stations=[{'SUO'},{'SWO'},{'TYNO'},{'SZO'}];
event(9).distances=[476.0;480.0;494.0;513.0];
event(9).times = [64.54; 64.71; 66.54; 68.85];
event(9).numobs = 4;
event(10).name = '01.31.1986 5.0MB PAINESVILLE';
event(10).stations = [{'SUO'}, {'EEO'}];
event(10).distances = [523.0; 575.0];
event(10).times = [71.50; 78.25];
event(10).numobs = 2;

tumevents = length(event);
T = event(1).times;
for jj = 2:tumevents
    T = [T; event(jj).times];
end

G = [event(1).distances, ones(event(1).numobs, 1), zeros(event(1).numobs, tumevents - 1)];
for jj = 2:tumevents
    Gtemp = [event(jj).distances, zeros(event(jj).numobs, jj - 1), ones(event(jj).numobs, 1), zeros(event(jj).numobs, tumevents - jj)];
    G = [G; Gtemp];
end

M = G \ T;
M;
V1 = 1 / M(1)

Vtot = [V1];
for jj = 1:tumevents
    G = [];
    T = [];
    for ii = 1:tumevents
        if ii ~= jj
            Gtemp = [event(ii).distances, zeros(event(ii).numobs, ii - 1), ones(event(ii).numobs, 1), zeros(event(ii).numobs, tumevents - ii)];
            T = [T; event(ii).times];
            G = [G; Gtemp];
        end
    end
    M = G \ T;
    M;
    V = 1 / M(1)
    Vtot = [Vtot; V];
end

C = std(Vtot)
clear all;

event(1).name='06.16.1995 3.8MN NEAR LISBON';
event(1).stations=[ {'EEO'}, {'TYNO'} ];
event(1).distances=[606.83;645.48];
event(1).times=[81.174;86.944];
event(1).numobs=2;
event(2).name='10.28.1997 4.7MN CHARLEVOIX SEISMIC ZONE';
event(2).stations=[ {'EEO'}, {'KLO'} ];
event(2).distances=[704.69;756.23];
event(2).times=[90.617;96.046];
event(2).numobs=2;

numevents=length(event);
T=event(1).times;
for jj=2:numevents
    T=[T;event(jj).times];
end

G=[event(1).distances,ones(event(1).numobs,1),zeros(event(1).numobs,numevents-1)];
for jj=2:numevents
    Gtemp=[event(jj).distances,zeros(event(jj).numobs,jj-1),ones(event(jj).numobs,1),zeros(event(jj).numobs,numevents-jj)];
    G=[G;Gtemp];
end

M=G\T;
M;
V1=1/M(1)

Vtot=[V1];

for jj=1:numevents
    G=[];
    T=[];
    for ii=1:numevents
        if ii~=jj
            Gtemp=[event(ii).distances,zeros(event(ii).numobs,ii-1),ones(event(ii).numobs,1),zeros(event(ii).numobs,numevents-ii)];
            T=[T;event(ii).times];
            G=[G;Gtemp];
        end
    end
end

%Analysis of eastern Canada/Grenville terrane seismic stations from
%epicentral distances from 600 - 900 km, Area 7
M = G \backslash T;
M;
V = 1 / M(1)
Vtot = [Vtot; V];
end

C = std(Vtot)