Imaging the Gutenberg Seismic Discontinuity beneath the North American Plate

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Problem

We are investigating a seismic discontinuity associated with the Lithosphere-Asthenosphere Boundary (LAB), called the Gutenberg Discontinuity (G). The discontinuity is only intermittently detected and there is considerable uncertainty in its origins. This project attempts to answer these questions by using seismic data to create a map of G beneath North America.

Hypotheses

1) Melt stalled at the LAB

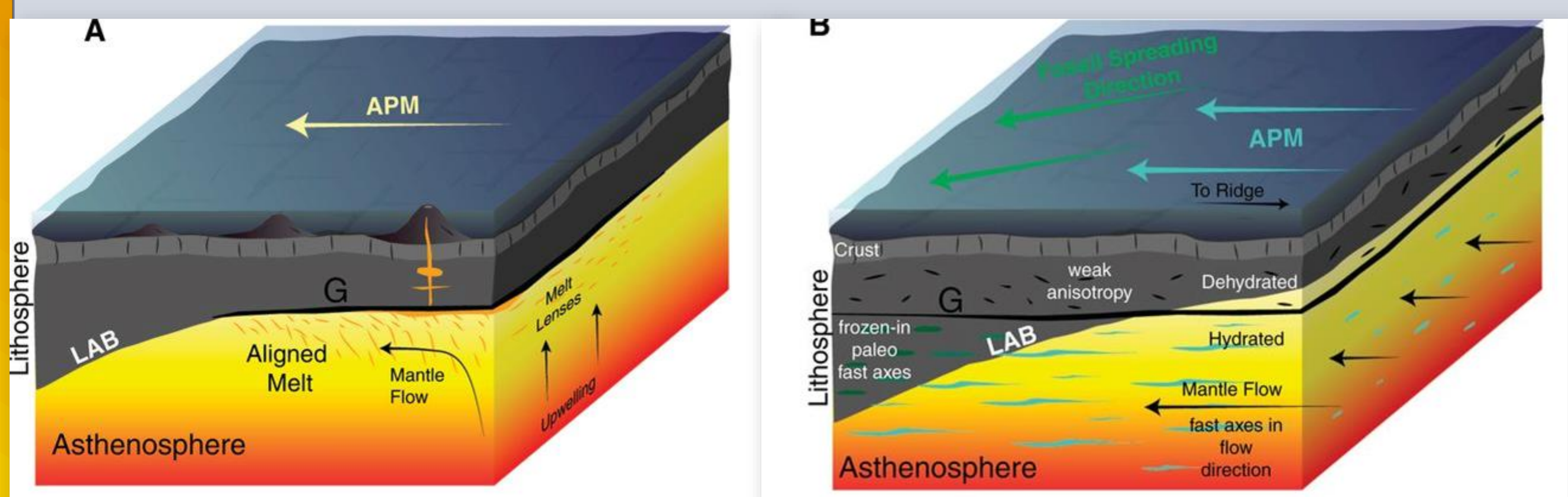
Partial melting would explain a reduce the seismic velocity, producing a seismic discontinuity at the base of the LAB.

2) Frozen-in anisotropy

Olivine crystals align with the direction of mantle flow, and this orientation can be preserved as the mantle cools. If this is happening at the LAB, the frozen alignment may differ from the current alignment in the asthenosphere. This change in velocity will be seen as the waves pass through one alignment into another.

3) **Dehydration front**

Waves travel faster through the dehydrated lithosphere then they do in the more fertile, hydrous asthenosphere. The change in hydration would cause velocities to change. Also, if there are frozen-in areas, these structures would have released water as they crystalize, causing a hydration difference, as seen in figure B.



Background

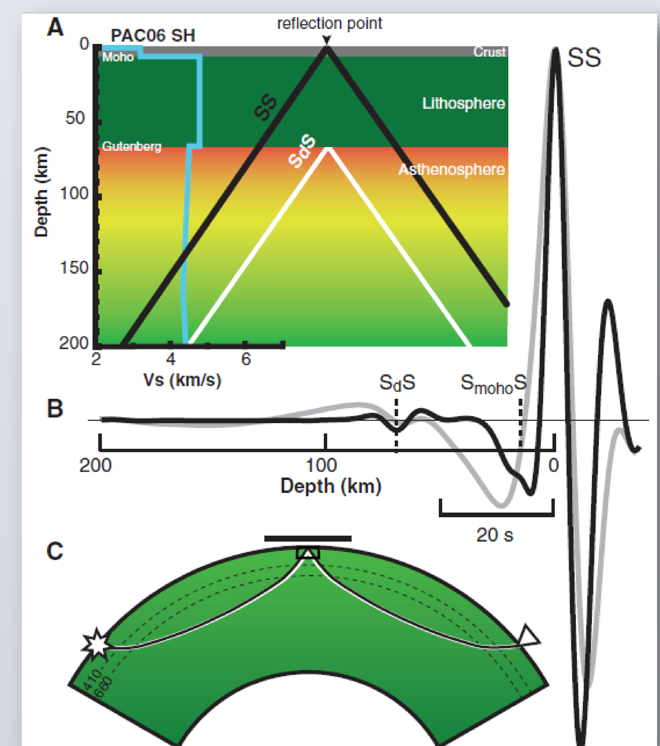
Seismology is a branch of geology that studies earthquakes and seismic waves that move throughout the earth. Seismic waves are waves of energy that are created when rocks within the earth break apart. These wave energies can be recorded all over the earth's surface using seismographs. There are two types of waves that we can study; P waves, or compressional waves, which vibrate parallel to the direction the wave is traveling, and S waves, which vibrate perpendicular to the wave's direction of propagation.

For this study, I will be focusing on SS waves and more specifically, SS precursors. The SS waves are S waves that have traveled from their source, reflected once off of the earth's surface, and then were received by a seismic station. The SS precursors are similar, however, they reflect once off of a discontinuity boundary before reaching the seismograph station. Due to the difference in travel distances and velocities, these two waves will arrive several tenths of a second apart from each other. This difference can be seen and studied to obtain information on properties such as the discontinuities depth and impedance. The use of SS precursors has an overall advantage over other methods as it enables us to sample relatively large areas where no stations are deployed.

Procedures

The first step to this study is gathering seismograms which I can then interpret. To construct the dataset of usable seismograms, I must first get the seismic data from the Incorporated Research Institutions for Seismology (IRIS), a publically accessible database for seismic data. To do this, I selected earthquake and seismograph pairs that sampled beneath North America within the past 25 years, from 1990 to present. In order to receive the most useful information, I restricted the event depths below 35km to limit the interface of depth phases of earlier arriving phases with the precursor wave-field. I also restricted the source magnitudes greater than 5.8 to ensure a good signal to noise ratio for the SS phase. Approximately 1800 earthquake events meet the criteria for source magnitude and depth.

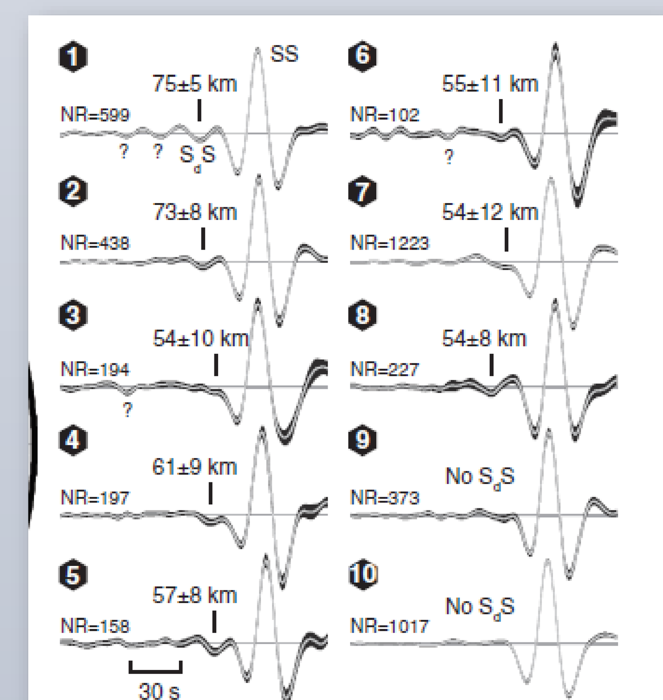
I then process the data. I first remove the instrumental response from the data. This is followed by rotating the seismic station into the back-azimuth of the station-earthquake pair. to obtain the transverse component of the incoming waves. I eliminate any seismograms with gaps. Next, I will visually inspect each seismogram to reject those with poor quality arrivals, and to pick the first major SS pulse. This step will significantly reduce the number of data I have to analyze. An example seismogram from Schmerr et. al. (2006) shows arrival times of SS and SS precursors.



This figure shows seismic ray path and theoretical waveforms of underside reflections from the G.
A. Reference velocity model of oceanic lithosphere (blue) and reflection point geometry of the SS precursory seismic phase (SdS).
B. Synthetic acceleration (black) and displacement (gray) seismograms at an epicentral distance of 125° and low-pass filtered to a corner of 10s.
C. Global seismic ray path of SS (black) and SdS (white). The small box outlines the location of (A), found halfway between the earthquake (star) and seismometer (inverted triangle).

Stacking the Data

The next step will be to stack the data. This technique is used to reduce background "noise" that has nothing to do with the targeted event. In order to accomplish this, individual data will be aligned together on their SS arrivals, and their amplitudes will be summed. Once stacked, we can look at the SS precursor and measure its amplitude and difference in arrival times.



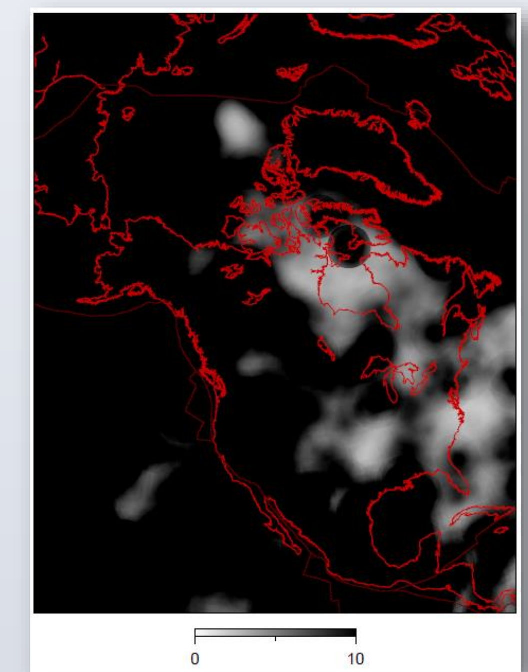
The figure to the left shows example stacks from detecting G in the Pacific. The maximum amplitude of each stack is normalized to unity. Amplitudes are displayed relative to the zero line. Shading shows statistical variation in combined stacks, anything that falls within the gray is 2 sigma with 95% confidence, and if it does not, it will be considered background noise .

Obtaining Discontinuity Depth

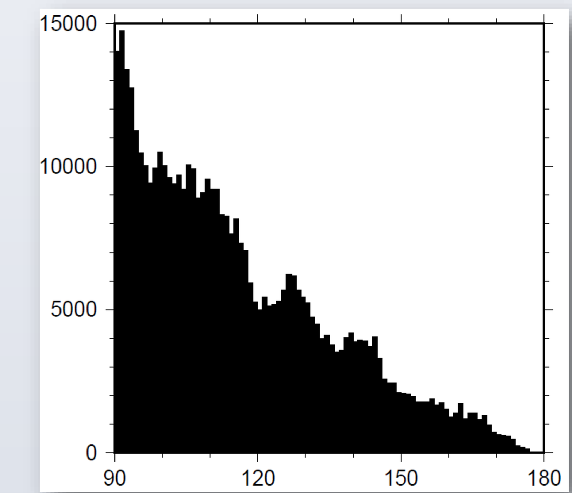
After stacking, the timing of the precursor of interest is converted to discontinuity depth. This requires a systematic pick of precursor arrival times. I will find the precursor arrival times by picking the peak amplitude of the precursor pulse that arrives closest in time to the predicted peak for that depth. By measuring the amplitudes and the delay times between the SS and SS precursors, I will be able to distinguish discontinuity depths and map the discontinuities' topography.

Preliminary Data

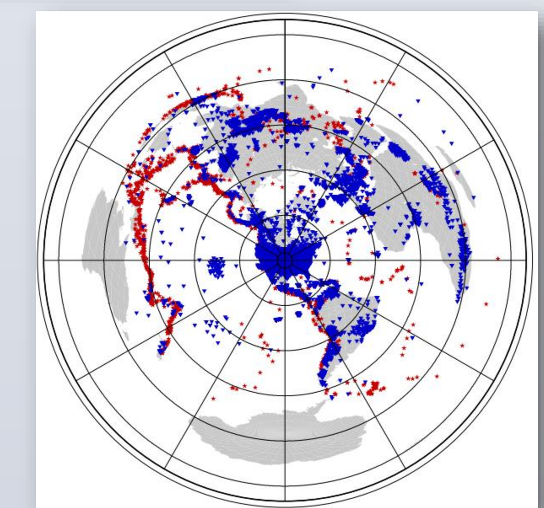
The map below shows the distribution of underside reflections beneath the North American plate. White would mean that area has little to no records available and black means there will be plenty of data there to create a useable stack.



Below shows a histogram of the number of records sampled for North America. The Y-axis shows the number of records that were recorded and the X-axis shows epicentral distance.



The map on the right shows a global distribution of all station and earthquake pairs that have sampling beneath the North American plate. Stations are represented as blue triangles and earthquakes are shown as red stars.



Summary

No systematic study using SS precursors has been used to observe the seismic discontinuity associated with the lithosphere-asthenosphere boundary, called the Gutenberg Discontinuity (G). This study proposes to map G beneath North America in order to find an explanation or better understanding on what mechanisms drive the G, and why it is present. In doing this, I will be testing multiple hypotheses. One hypothesis states there is melt that is pooling and collecting at the LAB. This could be tested by observing any correlation between G and active volcanism. We would expect to see melt in those areas and this would back up the hypothesis. Another hypothesis is that frozen-in anisotropy is responsible for G. I could test this by observing the azimuthal distribution of G. If the precursors depend on azimuthal distance, it would make sense that anisotropy is responsible. The last hypothesis calls for a difference in hydration. This will depend on the other mechanisms and whether hydration distribution is consistent in the areas where G is detected. Each of these will be systematically tested against the final map in order to better classify G and its location beneath North America. To get to results, I will have to follow specific procedures. First, I must collect the seismic data from IRIS from earthquake and station pairs that sample beneath North America. Then, I will have to examine the data and visually determine the quality of each seismogram to remove events that do not have a well-developed SS arrival. After that, programs will be used to stack the data set to quantify the data and to identify the arrival times. This will give me a better understanding of the depth, sharpness and topography of G and allow me to map what it looks like beneath North America. Finally, the data can be used to make assumptions of the seismic impedance, and help give me a better understanding of what mechanics are responsible for the Gutenberg discontinuity.

References

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Schmerr, N., Garnero, E. Investigation of upper mantle discontinuity structure beneath the central Pacific using SS precursors. Journal of Geophysical Research, 111, B08305. (2006).

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