Using seismic methods to determine the crustal structure of the Aleutian Island Arc

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Introduction
Subduction zones and their associated island arcs are sites of continental crust production. Weight percents of silica oxide differ between island arc magmas and the average continental crust. Removal of denser, more mafic material from the island arcs would push their composition closer to that of the continental crust. Differentiated magmas and delamination provide a mechanism for this removal (Rudnick, 1995; Behn and Kelemen, 2006). Studying island arcs is limited to geochronological studies of the erupted lavas and remote geophysical studies. The Aleutians in Alaska are well studied from both the geochemical and geophysical perspective. Most geophysical studies have utilized active source seismic data (i.e., Shillington et al., 2004). Fundamental questions still remain pertaining to the composition of the lower crust. This study uses passive source seismic data, which can help determine the validity of the structure from previous active source seismic studies, as well as put better constraints on the composition of the lower crust.

Methods
Fifteen seismic stations in the Aleutians collected data from earthquakes that were between 5.0 and 7.0 in magnitude and occurred from 25° to 90° away. Receiver functions were used to determine the crustal structure. Vertical, north, and east directions are recorded for each earthquake. North and east are rotated to the radial and transverse directions (parallel and perpendicular to the direction of P wave propagation respectively). The recorded seismic wave is a convolution of three components: the source, the structure, and the instrument response. A deconvolution in the time domain isolates the structure component. This isolated structure component is the receiver function. At abrupt boundaries seismic waves reflect, refract, and convert from P to S waves. Receiver functions record these interactions (Zhu and Stein, 1999). Receivers functions based on the results from the method to the structure component is the receiver function. S waves travel faster than P waves; therefore, the three reflections will arrive at different times, but will be indicative of the same boundary at the same depth. The difference in time between the initial P wave arrival and a reflection's arrival is dependent on the depth of the boundary, the ratio of the P to S wave velocities, and the ray parameter. In the Aleutian crust Vp = 6.5 km/s. This leaves the depth and Vp unknown. The three equations will be individually satisfied by various combinations of depth and Vp values. Taken together they determine the pair of values that best satisfies all three equations. Forward modeling was used to generate synthetic receiver functions based on the results from the method described above. These were compared to the actual receiver functions, and served to check our data.

Results and Interpretations

I. All Stations
A total of 378 receiver functions were used for analysis. Each station used between 8 and 45 receiver functions. Back azimuths from 170° to 70° were generally well represented in the data. There is very little data from 110° to 170° for all stations. Many of the receiver functions showed strong Ps multiples around 5 s, indicating a boundary around 35 km. This was interpreted as the Moho. The map below shows the depths of the Moho underneath all the stations. The Ps and PpS multiples were typically not obvious. This prevented us from getting reliable estimates of Vp/Vs, and in some cases made the depth of the interface unclear. This problem likely arose due to the complex geometries associated with island arcs - in particular the dipping slab. This method of receiver function analysis does not account for dipping layers. A shallow or steeply dipping slab could drastically alter the travel times of the later multiples relative to the Ps multiple. Ps multiples around 2.5 s were seen at ADK and NIKH, which indicated a boundary around 24 km. These are interpreted as a lower crustal discontinuity. Many of the stations' receiver functions exhibited a large dependence on back azimuth. In particular AKRB, AKGG, and AKUT showed high variation in the first 5 s of the receiver function dependent on back azimuth.

II. Akutan
Three of the four stations on the island of Akutan (AKRB, AKGG, and AKUT) showed large variation with back azimuth in shallow layers. This variation is dependent on the station's orientation towards the volcano on the middle of the island as shown in the figure to the left. A large Ps multiple appears around 1.2-2 s for back azimuths towards the volcano, but is absent for other directions (as illustrated in the figure below). The stacked receiver function data for these stations indicate a boundary around 10-13 km with a Vp/Vs range from 1.8-1.95. Due to the shallow boundary, high ratio, and the dependence on orientation with respect to the volcano, these receiver functions are likely showing evidence of a magma chamber. The receiver function stacking method has limited ability to show shallow layers (<10 km). For this reason, we used forward modeling extensively with these three stations. AKLV is not included in this set simply because of limited data - it had only 8 receiver functions. During the time period for which we have earthquake data, AKLV was turned on only for part of 2008.

III. Akutan Modeling
Above are two forward models generated for AKRB with the specified back azimuths. They both use a model that includes a magma chamber - it only fits for the 90°-105° range. Such models were generated for AKRB, AKGG, and AKUT focusing on the shallow structure. Models with a shallow, thin low velocity layer best fit the early receiver functions. The depths and ratio values for this layer at each station are as follows: AKRB: 6.1 km deep, Vp/Vs = 0.62, AKGKG: 6.9 km deep, Vp/Vs = 1.99, AKUT: 6.1 km deep, Vp/Vs = 2.03. These values were based on synthetic receiver functions generated for the back azimuths indicated in pink in the map. This layer is interpreted as the magma chamber.

Conclusions

1. We compared our data on the depths on the interfaces to the results from Shillington et al., 2004 for stations that were common to both, or for stations that were in the same general area. Overall the data is in agreement, which validates our methodology as well as supports the findings of previous active source seismic studies. We are not able to give conclusions about the composition of the lower crust in the Aleutians. Our Vp/Vs data were not well constrained due to the problems with the later multiples in the receiver functions. This was made very apparent in forward modeling - later multiples of the synthetic receiver functions far exceeded the multiples in the data they were trying to match. A more sophisticated receiver function methodology would be needed to cope with the complex geometries seen in the Aleutians.

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Citations