Subduction Processes and Continental Growth

Initial Project Report

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Summary

The thermal structure of a subducting oceanic plate on a convergent plate boundary is reasonably well studied in the case of an old, cold oceanic plate. However, the temperature profile of a young, hot oceanic plate or an active-spreading ridge is relatively unknown. The goal of this project is to investigate the temperature structure of the subsurface in Chile where a ridge, and the warm plate produced by this ridge, has recently subducted. This will be done by using seismic imaging techniques to determine the seismic velocities, which can be used to estimate the temperature structure. Knowledge of the thermal structure of a young subducting plate is crucial to understand the processes underlying continental growth. It is thought that arc magmatism at subduction zones plays a major role in continental growth, but processes at subduction zones are poorly constrained. Thermal modelling suggests that subduction of a warm oceanic plate or a ridge could cause volcanism, producing large quantities of continental crust, but these processes are not well understood. This project could lead to improved constraints on the details of these processes, as a result of better understanding of the structure of these subduction zones.

1 Previous Work

The problem of a subducting oceanic plate is well understood – the colder, denser lithosphere sinks into the warmer, lighter astheosphere, pulled in by buoyancy forces. A chain of volcanoes is often associated with a subduction zone, and it is thought that these contribute to the production of continental crust. However, current understanding of the processes leading to this volcanism is incomplete. The cold descending slab is a heat sink, and so should not cause melting to occur. Volcanism could be explained as a result of water released when hydrated minerals in the subducted plate are heated, which lowers the temperature at which the crust melts. Despite this, it is thought that substantial melting only occurs when young, hot lithosphere is subducted [1]. Numerical modelling of the effects of ridge subduction suggests that slab melting can occur as a result of the elevated temperatures involved [2]. This could explain the production of granite batholiths, leading to continental crust formation. In order to better understand these processes, this project aims to develop a thermal image of the subsurface in Chile, where a spreading ridge has been subducted.

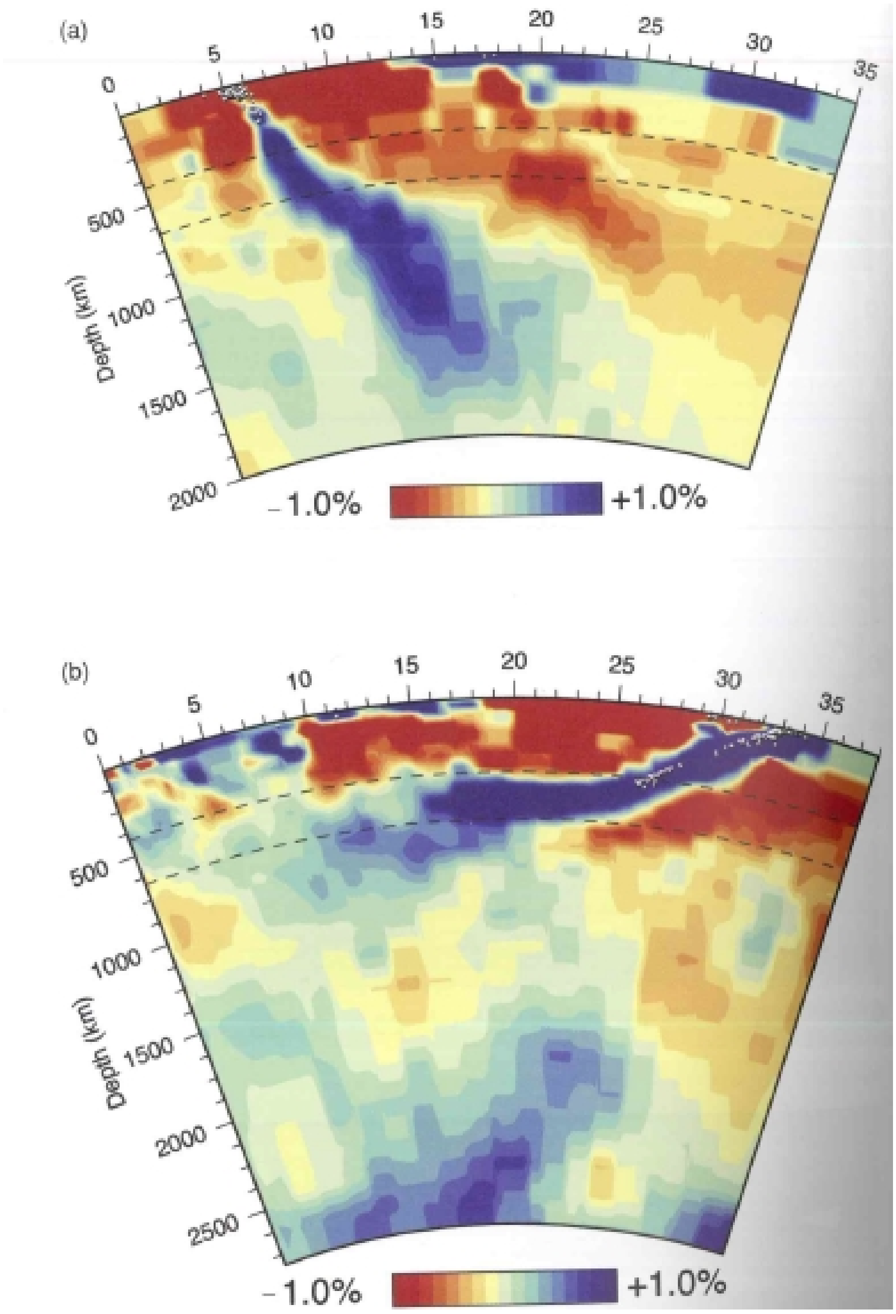

Figure 1: P-wave travel time anomalies in subduction zones, produced by Fowler (The Solid Earth, 2004). The blue areas show fast velocity structures, interpreted as cold subducting plates. Plot (a) depicts the Juan de Fuca plate, and plot (b) shows the subsurface of Japan. [7]

The temperature structures of many subduction zones have been well determined, as seen in Figure 1 on the previous page.
There has been some work on determining the velocity structure around the Chile Triple Junction, some of which can be seen below in Figure 2:

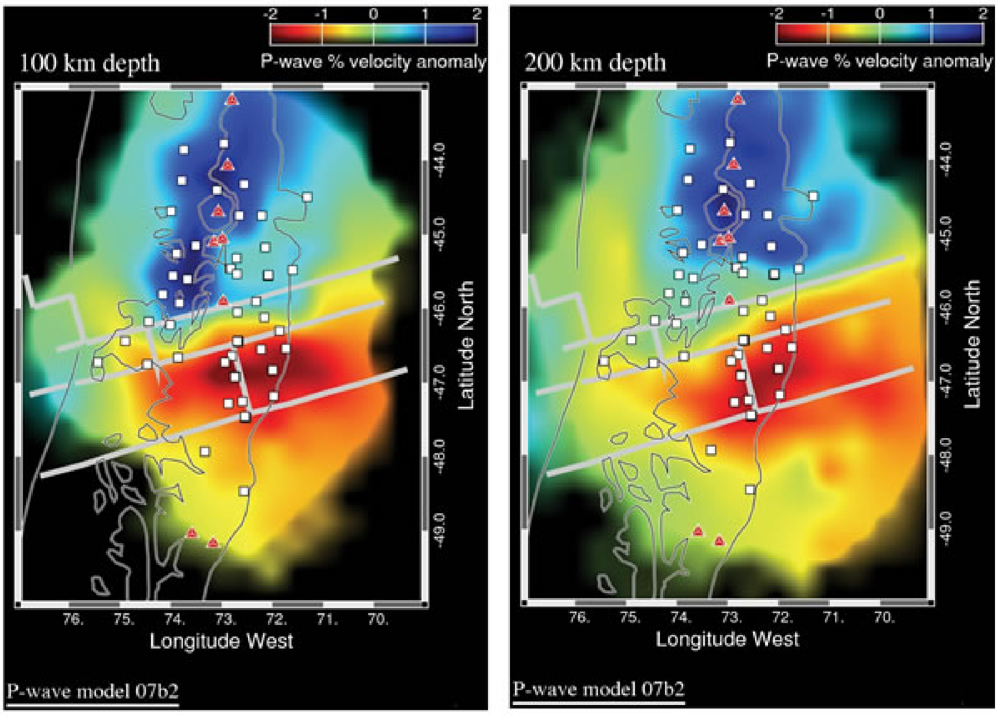

Figure 2: P-wave travel time anomalies at the Chile Triple Junction, produced by Russo et al. (2010), at depths of 100km and 200km. The cold plate in the north can be observed as a fast anomaly, while it is thought that the slow anomaly to the east is caused by the hot upwelling of the ridge. [4]

Russo et al. have used P-wave travel time inversion to image the velocity structure in this case. This image supports the slab window model of the subducted ridge, which assumes that the ridge continues to spread after subduction, but no new lithosphere is formed. This can be seen from the fast anomaly to the north-east, which is thought to be caused by the colder lithosphere, and the slow anomaly along the ridge, as a result of the thermal impact of the hot ridge. Relative-arrival teleseismic travel time tomography has been used to image the P and S-wave velocity structure [5], which is where slowness (inverse velocity) perturbations are calculated by comparing relative arrival times between rays to different locations. This gives results about the velocity structure to a depth of 300km which largely agree with Russo et al. A 3% fast P-wave velocity anomaly is observed to the north, and a 3% slow P-wave velocity anomaly is present in the south where the ridge lies.

2 Goals

The primary goal of this project is to generate high-resolution seismic velocity and thermal images of the subsurface in Chile, at the Chile Triple Junction where a mid-oceanic ridge has recently subducted. In order to do this, I will use a variety of seismic imaging techniques, including ambient noise tomography, arrival time tomography, two-plane wave surface imaging and waveform tomography. As a result of this project, we should improve our understanding of the processes occurring when warm oceanic plates are subducted, and so build on our knowledge of continental growth.

3 Plan

Data has been taken from over 60 seismometers around the Chile Triple Junction for several years, as part of the Seismic Experiment in Aysen Region of Chile (SEARCH) project. Figure 3 on the next page shows a map of the instrument locations. An example of the seismogram data can be seen on page 6, in Figure 4.
I plan to use Seismic Analysis Code (SAC) to visualise and filter the seismograms according to the type of tomography used. Ambient noise tomography will be used to build up a wavespeed model between the stations. This technique involves removing any earthquake signals from a day's data from seismographs, then cross-correlating the data between all station pairs. These cross-correlations are stacked, to build up many days of data, and the resulting waveform gives a estimate of the Green function [3]. This can be used to measure group and phase velocities. Long-period seismograms can also be used to analyse surface wave dispersion, giving more information about the velocity structure. A receiver function technique can be used to develop a vertical profile of wavespeed with depth. The receiver function is the waveform resulting from the deconvolution of the vertical and longitudinal components of a seismogram [6]. A variety of techniques will, therefore, be used to build up a wavespeed model.

The resulting wavespeed model will be imaged using the Generic Mapping Tools (GMT), a collection of tools used for mapping datasets. These images can then be interpreted in terms of the temperature of the subducted ridge, to develop our understanding of continental growth.

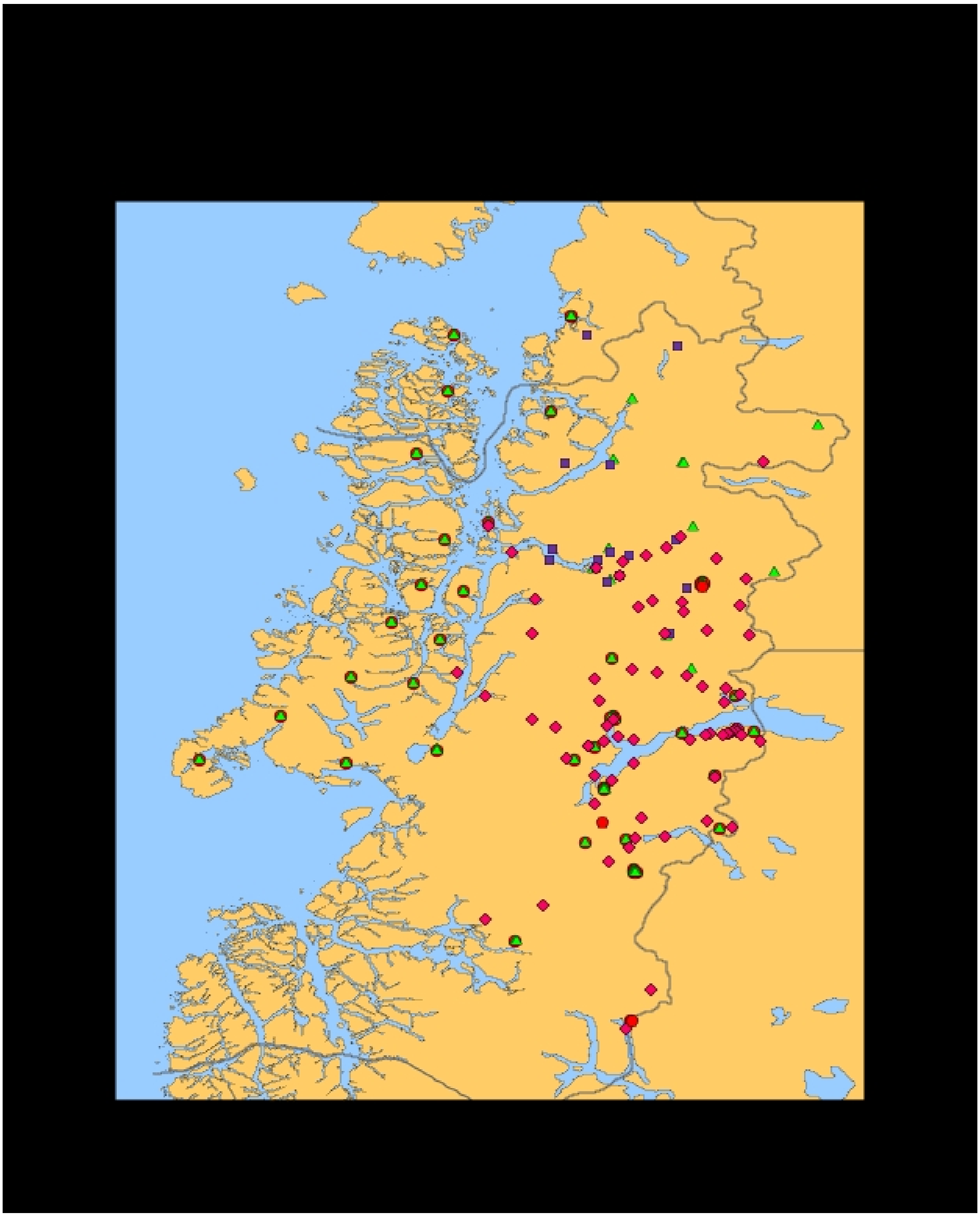

Figure 3: A map of the seismic station locations in the Aysen region of Chile. The instruments are located in the south of the country, around the Chile Triple Junction. Produced by K. Priestley (2015).

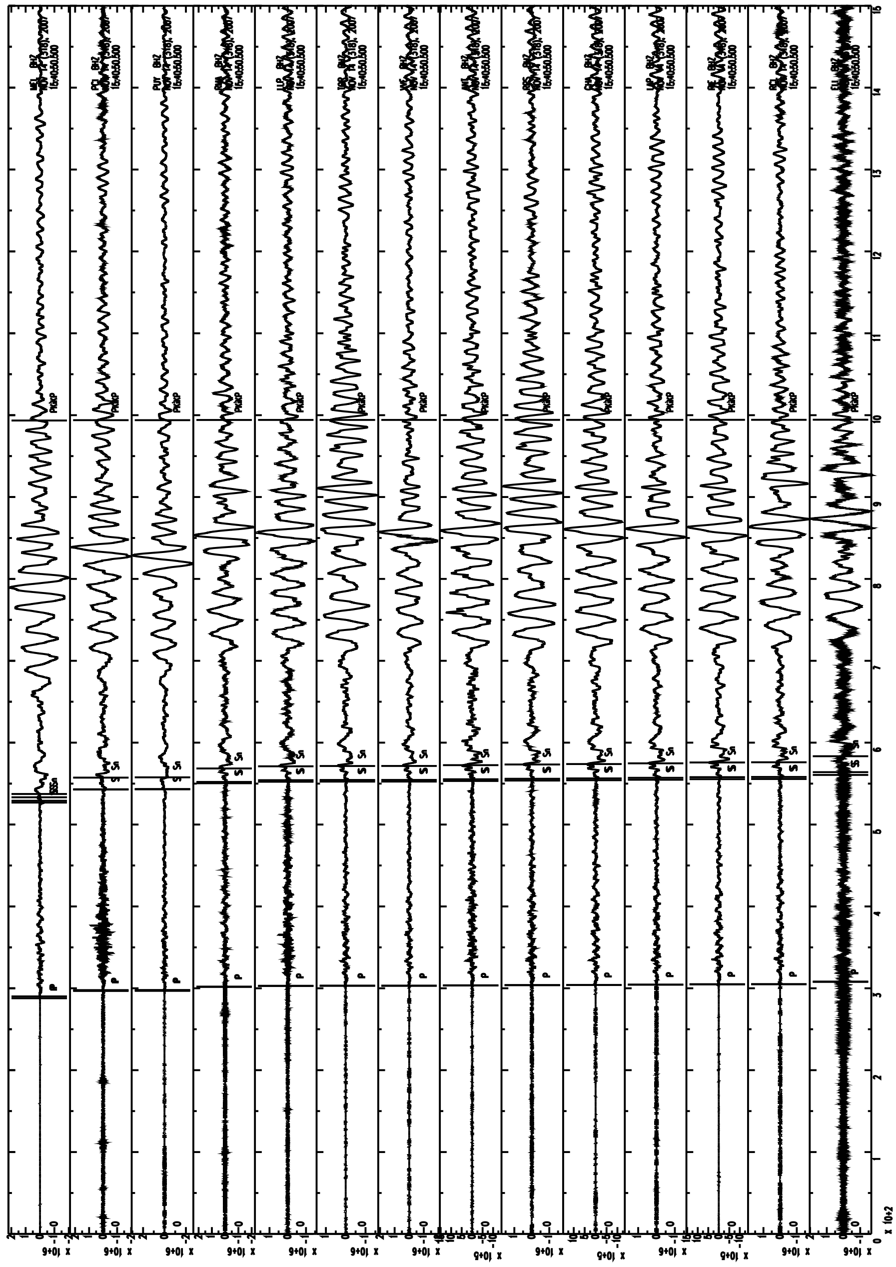

Figure 4: An example of seismogram data.

References

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