Chapter 1

Introduction

The Australian continent has relatively few permanent broadband seismic stations. The seismic structure of the continent has therefore been investigated through campaigns of portable instrument deployments. These began in 1992 and now provide coverage of most of the continent at a resolution that enables imaging of tectonic structures on a regional scale. Previous analysis has exploited event information: data segments extracted from each station corresponding to the arrival times of energy from teleseismic earthquakes. However, all the portable instrument deployments have been run with continuous recording (usually 25 samples/sec) making it possible to go back to the original data tapes and create a rich archive of continuous data.

The most recent campaign of portable instrument deployment, the TASMAL project, ran from 2003-2005 and provided improved instrument coverage across East Australia. In figure 1.1, the location of TASMAL stations is shown together with other portable and permanent broadband stations employed in this study.

The work described in this thesis uses both event data and continuous data. Receiver based techniques are developed and then applied to the new event data from the TASMAL project. Ambient noise based techniques are then explored and developed, and applied to the extensive new archive of continuous data that spans 1992 to 2006.

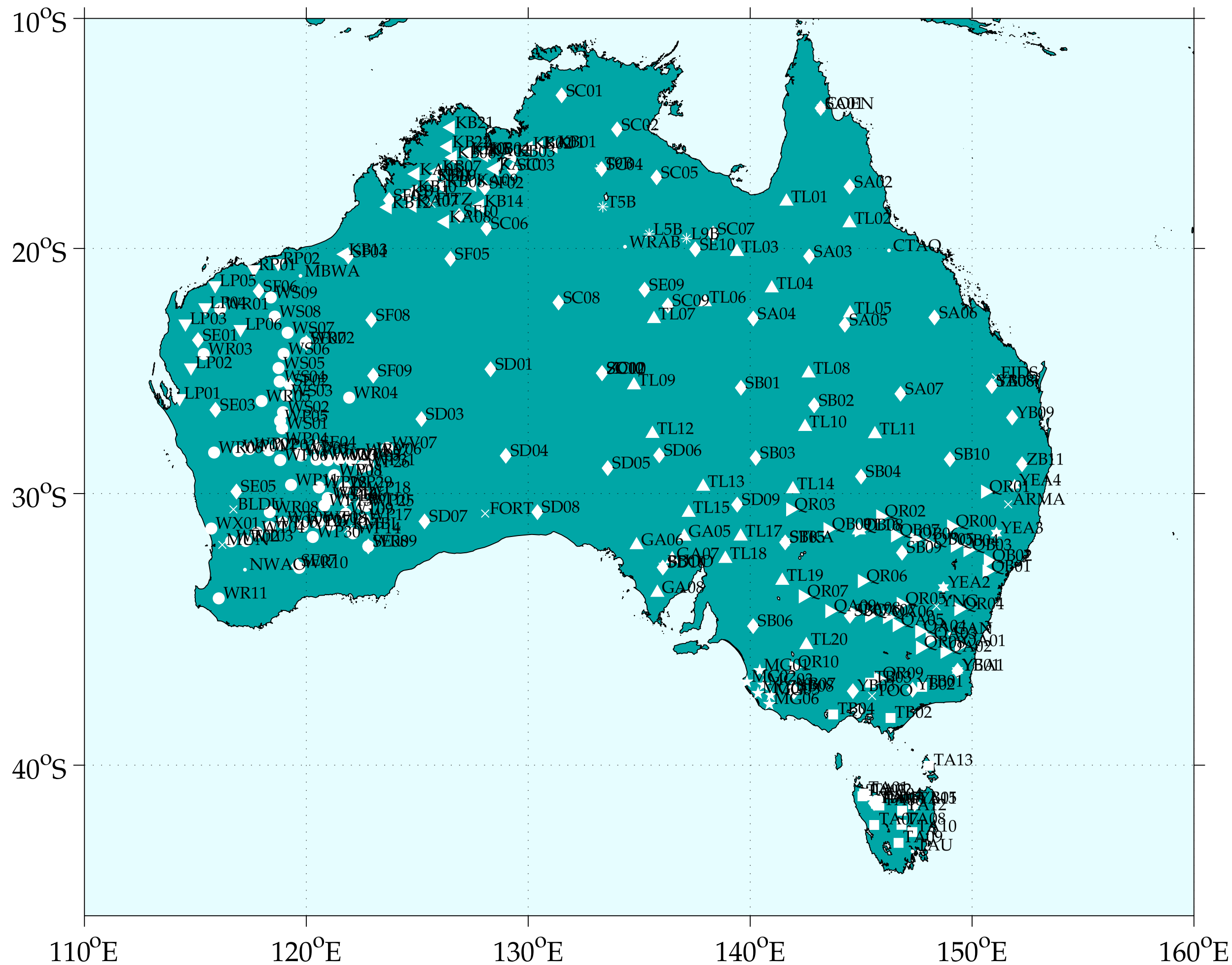

Figure 1.1: The location of the all broadband stations employed in this study. Stations of the TASMAL deployment are denoted by TL codes. Different symbols denote different portable instrument deployment campaigns. Permanent stations are denoted by their Global Seismic Network code: NWAO, MBWA, WRAB, CTAO, CAN and TAU

1.1 The TASMAL Project

Between July 2003 and May 2005, 20 portable, three component broadband stations were operated simultaneously across the Australian continent. The range of the interstation paths span from 200 km to over 2000 km. The experiment ran continuously with the sampling rate of 25 Hz which required planned services with an interval of 6 months.

The scale of the project and the seismic instrument inventory of RSES required the installation of various types of recorders and sensors. Recorder units are Refraction Technology, Earth Data, and Nanometrics Orion with an installed GPS clock correction system. Each of the unit was equipped with SCSI disks for fast data access rates. Sensors were chosen according to their instrument spectrum characteristics. Güralp CMG-3ESP, Streckeisen STS-2, and Nanometrics Trillium were employed. In order to decrease the thermal noise due to the heat differences between day and night time, sensors were buried in a trench with 1 m depth. The main power to the units was supplied via dual 12 V batteries charged with a solar panel during daytime. The locations of the stations were chosen not only according to geological formations but also logistical reasons. Each of the stations was built inside an agricultural property which helped to ensure the security of the equipment.

The primary objective of TASMAL experiment is to map the presence of the transition of Precambrian to Phanerozoic structure in central Australian continent. Previous experiments such as SKIPPY covered the east of Australia at considerably lower resolution with a lower number of instruments running simultaneously. The coverage and recorded simultaneous data of TASMAL enabled utilization of the collected data with various of seismological techniques. The earthquake generated surface waves were used to generate the crustal and upper mantle wavespeed images of Australia by Fishwick et al. (2005). Anisotropy across the continent was compiled by Heintz & Kennett (2005).

In the Earth, the majority of earthquakes occur along the plate boundaries. From Australia's perspective, the lack of significant active faults inside the Australian continent directs the seismologist to seek for the other earthquake sources from plate boundaries. However, the present seismicity surrounding the Australian plate has a nonuniform geographical coverage. The most significant portion of the teleseismic events recorded during TASMAL occurred along the boundary of Pacific and Australian plates. The remaining seismicity is present at Indian and Australian plates boundary. This created some limitations for imaging 3-D crustal structure with receiver function analysis which represents part of the work described in this thesis. Figure 1.2 shows a typical event distribution for the station of TL06 indicating the limitations of the azimuthal coverage.

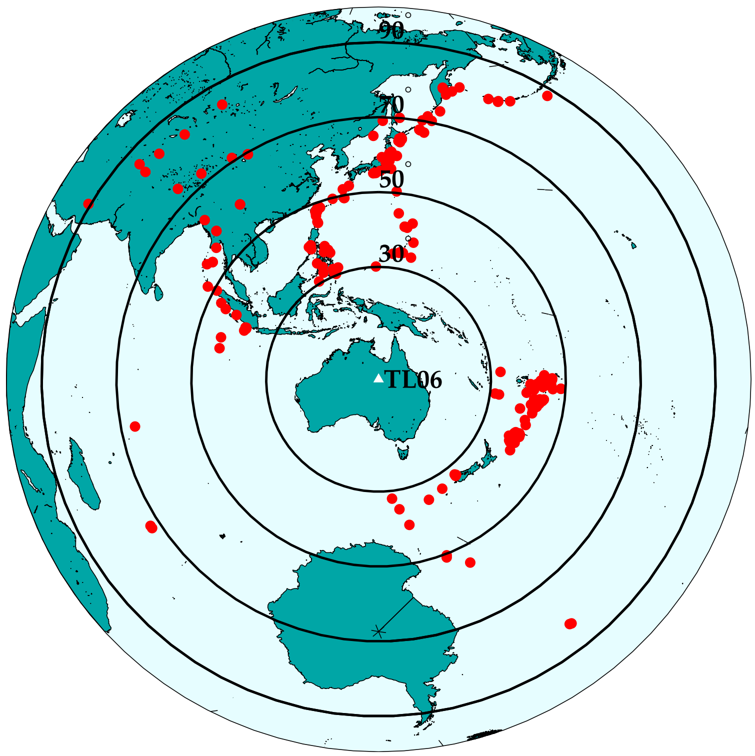

Figure 1.2: The teleseismic events are shown with red circles which were used in receiver function analysis of station TL06. The recorded events are concentrated to the north and east part from the Australia. As a result, the azimuthal coverage available is nonuniform.

The second part of the work described in this thesis consists of the exploitation of a recent advance in receiver based seismology. The Earth's noise field is used as the main source for imaging. This technique requires continuous and simultaneous recordings between any two stations. The geographical location and time span of the TASMAL experiment played a crucial role in the success of the results.

1.2 Organization of Thesis

Chapter 2 - Tectonic Setting of Australia

In this chapter, the tectonic framework of the Australian continent is outlined extensively in order to correlate the later geophysical findings with the structure. The Archaean Cratons which comprise an important part of the continent are given with the ages of each block and definitions of the pre plate tectonic type processes which led to their formation.

The previous geophysical studies conducted on the Australian continent with body waves (Clitheroe et al., 2000) and surface waves (Debayle & Kennett, 2003; Fishwick et al., 2005; Simons et al., 1999; Zielhuis & van der Hilst, 1996) are discussed.

Chapter 3 - Receiver Function Analysis

The theory of receiver function imaging is explained by incorporating all of the contributions from source to receiver. Different estimators such as plain water-level deconvolution, homomorphic deconvolution, multitaper estimation, and wavevector approach are explained with an associated example from station TL06. The advantages, differences and the weaknesses of the each technique are discussed.

The fundamentals of geophysical inversion are briefly given in the context of the receiver function method. The details of Neighbourhood Algorithm (NA) which is used for inverting the radial receiver function, is explained with its operating procedure.

The details of the dataset from TASMAL experiment, data selection criteria for the receiver function generation, and the parameters of the employed deconvolution technique are described.

The estimated Moho depth beneath each station is discussed in the context of corresponding geological block. The estimation of depths are compared with the previous receiver function of Clitheroe et al. (2000) of the same region for assessing the consistency. Each of the crustal thickness estimates are classified according to its signature on the inverted velocity profile e.g., broad, sharp etc. This gives an extra information about the nature of the anomaly derived for the particular geological block. At the end, the implications of the results are discussed in the context of the presence of

Precambrian-Phanerozoic boundary of the continent.

Chapter 4 - Ambient Noise Cross-Correlations

In this chapter, the new imaging technique of ambient noise correlations is widely discussed. In the beginning, the origin of the microseisms and the first studies which utilized the ambient noise wavefield are given.

In the following section, the fundamentals of imaging with the noise field is described with the major concepts such as elastodynamic motion equation, representation theorem and seismic reciprocity. After the theoretical development of the fundamental concepts, two different cases are given for the describing the mechanism of imaging with noise field. In the first case, the Green's function retrieval is described for excitation near the stations. This approach aims to give the overview of the technique in a simplified way. In the second case, the noise sources are spatially distributed and does not necessarily have temporal dependence. This approach describes the success of the observations for very long distance cross-correlations by combining two different explanations of deterministic (Wapenaar, 2004; Wapenaar & Fokkema, 2006) and diffuse (Shapiro & Campillo, 2004) wavefields.

The practical aspect of the ambient noise cross-correlations is given with a flow chart which was followed during the extraction of Rayleigh wave type Green's function. The group velocity extraction from the dispersed surface waves via narrow band filtering (Dziewonski et al., 1969) is described. For posing an imaging problem, theory of seismic tomography, the forward problem solver; *Fast Marching Method* (Rawlinson & Sambridge, 2004a), and subspace inversion technique (Kennett et al., 1988) are illustrated.

In the section describing the results of the analysis, the sensitivity of the surface waves for a given velocity model is shown for two different expected structural orientation. The initial results of the ambient noise correlations of TASMAL experiment are plotted with associated group velocities. This part shows that it is possible to extract coherent information from the ambient noise correlations with portable deployments up to distances of 2000 km. Following this, the application of the technique to the whole Australian continent is given with the observed waveforms. The raypath distribution and raypath density are plotted to show the feasibility of posing a tomographic problem with the extracted data. The resolution tests conducted for two different cell sizes of $1° \times 1°$ and $2° \times 2°$. After conducting the resolution tests, the effect of the smoothing and parameters on the estimated models is experimented with the different range of values. With the optimal parameters of smoothing and damping, the estimated models are presented for four different period ranges; 5 sec, 6.6 sec, 8.3 sec and 12.5 sec.

The estimated group velocity model for the Australian continent is interpreted with the information of surface geology, surface sediment thickness and crustal heat distribution.

Chapter 5 - Coda Waveform Correlations

Following the work of Campillo & Paul (2003), the application of cross-correlation of the coda waves from teleseismic earthquakes is carried on the stations of the regional broadband array of Warramunga.

After removing the moveout of the arriving earthquake signal, cross-correlations are calculated between the array elements for each of the earthquakes. The results of the cross-correlation for the same time frame, are then averaged for that particular station pairs. The evolution of the coherent wavefield is observed for different time time frames of the arriving earthquake signals. The differences on the estimated signals; Green's functions are discussed.

Chapter 6 - Method Development

In this chapter, two different approaches which exploit the ambient noise wavefield are presented.

In the first half, the spectral broadening of the ambient noise cross-correlations is introduced. Instead of cross-correlation, a transfer function approach with water-level type correction is applied on the records in order to broaden the spectrum therefore getting better estimates. An application is made for the data of TASMAL experiment and compared with conventional cross-correlation results of the same dataset.

In the second section, instead two station approaches of exploiting the recorded ambient noise wavefield, records from a single station are used to recover coherent signals related with the structure. In the first case, cepstral averaging is used to suppress the effect of non-stationary excitations to recover the structural information. In the second case, instead of cepstral domain, the log spectrum domain is chosen for averaging the records of single station. The obtained results for different stations are discussed with their frequency and spatial dependencies.

Chapter 7 - Conclusions and Further Work

The results of the each chapter are listed briefly. The correlation with the tectonic elements of the Australian continent is discussed.

Further research goals related with this work is given and discussed.