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# 学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称 博士（理 学） 氏 名 垂水 洸太郎

## 学 位 論 文 題 名

Seismological Structure and Source Studies with Teleseismic Body-wave Analysis  
(遠地実体波解析による地震学的構造および波源の研究)

We propose new approaches using teleseismic P-wave analyses to investigate seismic structures and source processes. The first half (Part I) of this thesis focuses on structural studies, with an emphasis on mapping the spatial distribution of seismic discontinuities in the upper mantle. The second half (Part II) aims to resolve the complex seismic wave sources using a source imaging method, P-wave back-projection. These broad topics are essential for advancing our understanding of Earth's internal structure and dynamics, including earthquake ruptures and volcanic eruptions.

A joint analysis method combining teleseismic receiver functions (RFs) and surface waves has recently been developed and applied to estimate seismic discontinuities in the upper mantle.

This approach traditionally assumes a one-dimensional stratified structure beneath a seismic station, leading to the use of azimuthally averaged RF data, which represent wave-type conversions (from P to S, or vice versa) at seismic interfaces. However, lateral structural variations in the upper mantle generate significant azimuthal dependence in RFs, depending on the incoming directions of body waves. In this study, we utilize azimuth-dependent RFs to extend the conventional RF inversion method, enabling the detection of localized variations in seismic interfaces and their properties.

The new approach utilizing azimuth-dependent RFs is applied to the Australian continent. First, we construct a catalog of the orientations of horizontal sensors in seismometers installed across Australia, and compute P-wave RFs (P-RFs) with corrections for station orientations. The resultant datasets, even in the stable cratonic areas, exhibit significant dependence on the directions of seismic events. We incorporate the azimuth-dependent P-RFs into a joint inversion method with multimode surface wave dispersions (SWDs). This novel usage of P-RFs in joint inversions with multimode SWDs reveals localized variations in upper mantle discontinuities and associated elastic properties. By extensively applying the joint inversion method to a large number of permanent and temporary stations, we map the Australian upper mantle discontinuities, including the Lithosphere-Asthenosphere Boundary (LAB), the Mid-Lithospheric Discontinuity (MLD), and X-discontinuity (X-D) beneath LAB.

The LAB is shallow (70–100 km) in Phanerozoic eastern Australia and deepens toward western cratonic regions (120–200 km). A thick lithosphere (170–200 km) with significant radial anisotropy but minimal S-velocity reductions is observed beneath central Australia. MLDs in cratonic regions are identified at three distinct depths (from 60 to 130 km), with either negative or positive S-velocity changes depending on the tectonic setting. X-Ds, characterized by velocity increases beneath the LAB, are detected at multiple depths (~170 km, 220–280 km, and ~310 km), often associated with a weakening of radial anisotropy below the X-Ds. The shallowest X-D (~170 km) is predominantly found beneath eastern Australia and is likely influenced by thermal effects in the asthenosphere, while deeper X-Ds may correspond to the Lehmann discontinuity or phase transitions in pyroxene. These results demonstrate that our approach is effective for reconstructing upper

mantle discontinuities and their elastic properties on both large and localized scales.

In the second half of this thesis, we explore the new applicability of back-projection (BP), a seismic source imaging method. The first application of the BP analysis is to teleseismic P-waves from a massive eruption at Hunga Tonga-Hunga Ha'apai in 2022. The BP results successfully detected the locations and timing of multiple explosions, even when P-waves from each eruption overlapped and were masked by other seismic signals and noises. The second application of the BP analysis involves multi-frequency teleseismic P-wave records generated by the 2024 Mw 7.5 Noto Peninsula Earthquake, which could be a doublet earthquake. The resultant BP images successfully depict the complex frequency-dependent seismic radiation process, suggesting contributions from crustal fluids and a complex fault system. These two applications demonstrate the potential of the BP method to track intermittent and continuous multiple sources and to resolve frequency-dependent radiation processes linked to complex source phenomena.

Observed teleseismic body waveforms contain abundant information about seismic structure and wave sources, making them invaluable for investigating seismic phenomena. Teleseismic data-oriented explorations through new approaches deepen our understanding of Earth's dynamics processes.