The University of Oxford Department of Earth Sciences

EARTHSCIENCES

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Robustly imaging mantle upwellings under isolated oceanic islands

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Overview

Mantle upwellings link the deep mantle to the surface and regulate Earth's outgassing and internal temperature, which is a fundamental control on the atmosphere and our planet's habitability. Such upwellings often manifest themselves on the surface as oceanic islands, such as Hawaii, the Azores, Galapagos, etc. While the mineralogy of erupted basalts at these oceanic islands provides some insights into the source of the lavas, seismic imaging is typically employed to characterise the underlying mantle structure and to delineate the responsible mantle upwellings.

Oceanic islands are often found away from plate boundaries in the middle of wide oceanic basins. Such isolated settings, far from land and seismic instruments, typically lead to poor and heterogeneous seismic data coverage in tomographic models of underlying mantle structure. This introduces artefacts in the resulting images, such as smearing along ray paths and increased amplitudes, leading to inaccurate interpretations of temperature anomalies (Fig.1).

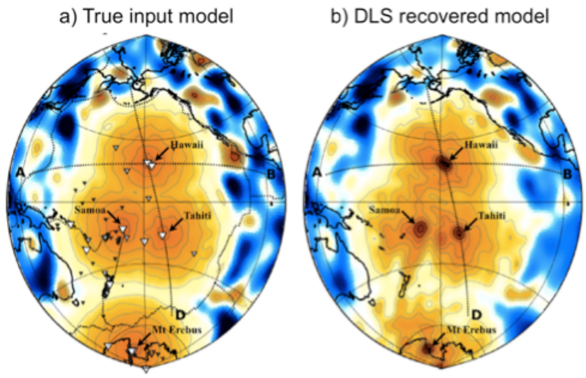

Figure 1: Traditional inversions (damped least squares - DLS) lead to model misinterpretations in case of sparse and heterogeneous data coverage, as artificially large amplitude anomalies are observed below isolated island stations. Figure taken from Zaroli et al. (2017).

Of special interest are the ocean islands in the South Atlantic, where at some hotspots (Tristan, St Helena) upwellings are identified in global tomography models (French & Romanowicz, 2015), while at other hotspots (Bouvet) no upwellings or link to the deep mantle is identified (O'Connell et al., 2012). It also remains unclear whether the Tristan and Gough hotspots originate from one upwelling or whether these are separate upwellings, while the link to the Parana-Etendeka Large Igneous Province is also still debated (Gassmoller et al., 2016).

In this project, we aim to utilise a novel seismological imaging technique that can handle sparse and heterogeneous seismic data coverage without leading to artificially large amplitudes (Zaroli, 2016; Zaroli et al., 2017). Based on a Backus-Gilbert approach, this method focuses on the resolution of the imaged structures, while providing model uncertainties at the same time. Models developed using this inverse method represent real averages of true Earth structure, rather than a smeared and damped image. By applying this method to image mantle structure under oceanic islands, we will be able to answer some of the questions above and robustly interpret the seismic structures in terms of mantle temperatures and composition.

Methodology

Throughout this project, we will use the SOLA method (Zaroli, 2016; Zaroli et al., 2017), which ensures that recovered amplitudes are truly representative of Earth structure and can thus be physically interpreted, while also providing uncertainties on the model parameters. To set up the inverse problem, a few ingredients are required; most importantly the seismic data set and uncertainties, the expected target resolution (based on data coverage), the underlying physics and the acceptable model uncertainties. The student will have to spend time to understand these different ingredients. As the data uncertainties drive the inversion, particular attention needs to be paid to characterising these.

Initially, the student will collate a data set of regional seismic data for the chosen region of interest and compute sensitivity kernels to relate these to model parameters. The student will then run the SOLA inversions using a Python implementation. An important step in the inverse process will be to decide on the target kernels for the resolution and test the upper limits of resolution that can be achieved.

Resulting models will be analysed by comparisons to available geochemical constraints on mantle temperatures and geodynamic simulations of mantle upwellings.

Timeline

Year 1: Doctoral training courses, literature review, start of seismic data collection and analysis

Years 2 and 3: Seismic data analyses, setting up inverse problem and development of workflow, experimenting with kernel size and resolution-uncertainty trade-offs, development of seismic velocity models.

Year 4: Interpretation of results and integration of seismic data with geochemical constraints, thesis completion, writing of papers for international journals and presentation of results at international conferences.

Training & Skills

The successful candidate will join the vibrant seismology group at the University of Oxford, and benefit from interactions with existing PhD students, postdocs and faculty who work on similar topics.

The PhD student will receive training in computational methods and the processing of seismic data sets, as well as inverse methodologies and interpretations. In addition, they will be mentored on how to prepare scientific results at (inter)national conferences, how to write manuscripts for publication in international journals and how to communicate their science to a general audience.

In addition to the training in these transferable skills and research skills, the student will be provided with advice on funding applications and career support.

References & Further Reading

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Further Information

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