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Passive seismic multiscale subsurface imaging and characterization by utilizing natural quakes

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This thesis investigates the potential of passive seismic methods that make use of body waves, and especially the passive reflection method, as cost-effective applications for multiscale subsurface imaging and characterization. For this purpose, I develop several seismic techniques for different scales: basin, crustal, and lithospheric. For the basin scale, I developed horizontal- and vertical-components spectral ratio of global earthquake phases to estimate the basin depth. I also used the Sp-wave method and analysis of the frequency-dependent quality factor to characterize the basin's heterogeneities. The results show good agreement with active-seismic profiles. At the crustal scale, I investigated the application of seismic interferometry (SI). Comparison among different SI methodologies suggests that multidimensional deconvolution based on the truncated singular-value decomposition gives better structural imaging than do the conventional crosscorrelation or crosscoherence approaches, but also better than multidimensional deconvolution based on the damped least-squares scheme. This crustal-scale SI could be useful, for example, as a prescreening-exploration tool for deep geothermal reservoirs whose targets can be as deep as 10 km. At the lithospheric scale I studied not only the Earth, but also the Moon. For the Earth, I applied SI with global phases to obtain detailed images of aseismic parts of a subduction slab. Although the interpretation of the imaging results of the aseismic parts is not sufficiently decisive, the results suggest that the applied method is helpful for imaging aseismic parts of slabs. Furthermore, the radiation efficiency of intermediate-depth earthquakes is estimated to understand the source mechanism as a function of focal depth. The results indicate that there is a larger amount of nonradiated energy for intermediate-depth earthquakes. This implies one of the mechanisms for the slabs to be aseismic at certain depths. For the Moon, we applied SI to deep moonquakes to obtain reflection imaging of the lunar subsurface. With this application, the lunar Moho is interpreted to be approximately 50 km depth, indicating the potential usefulness of SI for other celestial bodies. Following the results obtained in this thesis, we conclude that the passive seismic methods with natural quakes have excellent potential usage in both the resource industry and academia.

Advisers: Deyan Draganov and Kees Wapenaar

Closed-loop surface related multiple estimation

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In seismic acquisition a source wavefield is fired at or close by the surface, and its response is then recorded by receivers usually located also at or close to the surface. The reflection response can be decomposed in three different types of wavefields, namely primaries, internal multiples, and surface multiples. Primaries are wavefields with only one bouncing point in the subsurface. Internal multiples are wavefields with at least one downward bouncing point in the subsurface and can be regarded as primaries in many processing schemes. Surface multiples are wavefields with at least one downward bouncing point at the surface and generally have strong amplitudes in the recordings. These strong amplitudes tend to hinder structurally important information; therefore, surface multiples are commonly regarded as noise and a large effort is then put in surface multiple prediction and subtraction.

In this thesis we present a new method for surface multiple estimation, which might be regarded as an inversion-oriented version of the well-known surface-related multiple elimination (SRME) method. The proposed algorithm (known as closed-loop SRME, or CL-SRME) presents practical advantages over its predecessor, the most important one being the ability to easily allow built-in extensions, making it possible to use multiples rather than to eliminate them.

In this research we will be especially interested in performing multiple separation (i.e., separating multiples from primaries) given incomplete data sets. This means that we will concentrate on extending the CL-SRME method to include data reconstruction. This is particularly useful as most of the acquisition techniques in the industry nowadays involve the recording of incomplete data sets due to coarse sampling. Coarse sampling is motivated by economic constraints.

Our interest in reconstruction will lead us to the implementation of the focal transform in the CL-SRME scheme. The focal transform is known to have reconstructive properties when applied to seismic data. This extension will allow CL-SRME to reconstruct over relatively large acquisition gaps. The information in the multiples will prove to be very useful when reconstructing the near-offset section of shallow reflection events.

The algorithm capabilities in terms of reconstruction and multiple separation is presented via synthetic and field data examples in both the 2D and 3D cases. Promising results are obtained in terms of near-offset reconstruction with an important application in shallow water scenarios. The current method is recommended for those cases. Other multiple prediction algorithms are recommended whenever the data is complete or the reconstruction effort is small.

Adviser: D. J. Verschuur