GLOMAR

Ph.D. Defence

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Beyond Seismic Imaging - Seismic Inversion as a Tool for Quantitative Interpretation, Data Integration and Comprehensive Data Presentation

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Beyond Seismic Imaging - Seismic Inversion as a Tool for Quantitative Interpretation, Data Integration and Comprehensive Data Presentation

Active reflection seismic data offer unprecedented possibilities to image structures in the Earth's interior. Employing inversion techniques, those images can be complemented by quantitative information making seismic interpretation less ambiguous and enabling the deduction of subsurface properties of relevance for applied research or engineering purposes. Mostly deep targets in lithified sediments or rocks have been targeted with seismic inversion studies and employed low resolution seismic sources. Constraints and methods established for this purpose are not applicable to the marine near surface, which is mainly comprised of unconsolidated sediments, and for which high resolution seismic signals are required. The comparatively few high resolution studies focussing on the marine near surface proofed the general feasibility of marine near surface seismic inversion, which sparked industry interest, e.g., for offshore wind farm investigations. However, the methods often require additional ground truthing data, or are not only based on the reflected wavefield, or methodological limitations impede a general application.

To invert marine near surface seismic data, this study focused on the optimization of data acquisition, and the development of inversion methods based exclusively on P-Wave reflection seismic data aided by empirical relations fitted to unconsolidated sediments. For the data acquisition optimization, the different types of unconsolidated sediments are characterized and detailed analyses of two types of near surface seismic sources are conducted. On this basis, numerical models and inversion trials are developed to test acquisition set-ups and to investigate the potential of the different inversion approaches for, among others, shear property estimation. These tests are then used to develop a catalogue of requirements for data acquisition and possible limitations are indicated. As a proof of concept for impedance inversion, seismic data from the North Sea and the Baltic Sea in offshore wind park areas have been inverted. For this purpose, algorithms have been improved and implemented for attenuation estimation and correction, low frequency trend generation by interval velocity estimation and conversion to density, band limited impedance inversion, merging of low frequency trends with band limited impedance as well as depth conversion. The resulting impedance profiles resemble a significant improvement for quantitative interpretation of geologically complex areas reducing interpretation biases and capture intra-unit lithologic variations and property boundaries which are not evident on seismic amplitude images. It is demonstrated that the impedance correlates well to Cone Penetration Test measurements and that the Soil Behaviour Type can be classified based on the impedance. Thus, these seismic inversion results improve the extraction of important sediment properties, e.g., for engineering purposes. For the estimation of shear properties, a pre-stack inversion algorithm with a steepest descent optimization scheme and a convolutional forward model based on unconstrained Zoeppritz P-Wave reflection coefficients is developed and tested. The initial model for the pre-stack inversion is based on impedance inversion results and fitted empiric relations. In the feasibility study conducted with data from the North Sea, the inversion scheme successfully predicted S-Wave velocities compared to available Cone Penetration Test ground truthing data, although the sensitivity for low S-Wave velocities is limited. A sensitivity analysis with synthetic test data indicates that this lack of sensitivity is a general limitation of P-Wave reflection data inversion.

In summary, in this thesis it is disclosed how marine near surface P-Wave reflection seismic data have to be acquired and inverted to deduce quantitative information reaching beyond and complementing qualitative standard interpretation results.