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# Abstract

In this thesis I present an extensive study of the potential to use microseism noise for reservoir-scale passive seismic interferometry. Microseism noise is excited by interfering ocean swells exerting pressure variations on the sea floor. In marine recordings, this noise is composed primarily of interface waves travelling along the sea floor. Previously, the belief was that the low-frequency noise in marine seismic recordings carried no useful information for imaging the subsurface. The theory of passive seismic interferometry predicts that crosscorrelating recordings made at two stations retrieves the seismic response measured at one station as if the other station were a seismic source. This theory retrieves an estimate for the Green's function but holds only under certain constraints on the character of the seismic noise. Most important is the constraint of energy equipartition and illumination by uncorrelated noise sources surrounding the station pair. I test whether these conditions are fulfilled for microseism noise recorded by ocean-bottom cables at two locations in the North Sea: Valhall and Ekofisk. Then, I study which properties of the near-surface lithology below the sea floor can be imaged using virtual seismic sources retrieved from crosscorrelating microseism noise.

Both recordings contain strong microseism noise below 2 Hz. The microseism noise grows stronger when weather conditions deteriorate. The waves composing the noise appear chaotic, and beam steering show that waves generally travel in all azimuths with equal strength. These characteristics match the constraints necessary for passive seismic interferometry to turn recording stations into virtual seismic sources. Bandpassing removes energy that does not fulfill the constraints, and isolates the

microseism energy. Crosscorrelations of all combinations of recordings of particle velocity at Valhall retrieves an estimate for the Green's matrix for Scholte and Love waves between frequencies 0.175 and 1.75 Hz. Crosscorrelation of pressure recordings at Ekofisk retrieves an estimate for the Green's function for Scholte waves between frequencies 0.4 and 1.2 Hz. These Scholte and Love waves are dispersive, i.e. their velocity is frequency dependent. The frequency-variable wavelength of interface waves implies a frequency-variable sensitivity to medium parameters away from the interface of propagation. The medium parameters vary strongly as a function of depth in the near surface immediately below the sea-floor, causing dispersion of the interface waves traveling along the sea-floor. Two properties commonly extracted from surface waves are their frequency-dependent group and phase velocities. These properties vary as a function of space and maps of the group and phase velocities image the subsurface lithology.

Measurements of group travel-time are inverted by straight-ray tomography into maps of group velocities. Scholte-waves at Valhall image buried paleochannels and other geology known (from controlled-source data) to be in the top 300 m below the sea floor. These images can be retrieved with high-repeatability from short recordings (six hours to a day), making continuous subsurface monitoring an achievable application. By comparing Scholte-wave velocities obtained from ambient-seismic recordings made in 2004 with Scholte-wave velocities from ambient-seismic recordings made in 2010, I find a time-lapse velocity change. The overall shape of the velocity change from ambient-seismic data compares very well with the overall shape of a velocity change obtained from controlled source data. The overall shape is interpreted to represent near-surface geomechanical effects of production-induced reservoir compaction. The Love-wave group-velocity images at Valhall are dominated by smoother shapes that may relate to the production-altered stress-state of the reservoir's overburden. Scholte-wave group-velocity maps at Ekofisk image a high-velocity anomaly in the center of the array surrounded by a lower-velocity region. The high-velocity anomaly coincides with the center of a production-induced sea-floor subsidence bowl. The ring of lower velocities corresponds with high magnitudes of the bathymetry gradient. I find higher velocities again under the southern end of the array.

Phase velocity maps are found through a novel version of eikonal tomography. An eikonal equation is derived for an elliptically anisotropic wave-mode at a single frequency propagating in two dimensions. This eikonal equation relates the spatial derivatives of phase travel-time surfaces to the local elliptically anisotropic slowness. Measurements of the spatial derivatives of phase travel-time surfaces for virtual sources retrieved at all stations can be inverted into elliptical-anisotropic phase-velocity maps. The method is applied to Scholte and Love waves at Valhall and Scholte waves at Ekofisk. The isotropic component of phase velocities generally images the same features as the group velocities from straight-ray tomography. The fast direction of anisotropy of Scholte-wave phase velocities form a large circular pattern over the Valhall and Ekofisk fields. They are likely related to the production-induced sea floor subsidence bowl.

# Preface

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# Acknowledgments

First and foremost I want to thank my Mom and dad. Thank you for your support and encouragement to follow my dreams.

My adviser Biondo Biondi, for giving me so much freedom and support. This combination was the biggest challenge of my PhD but yielded the most reward. Thanks to Bob Clapp, a member of my oral examination committee. Without his advice and insights I would have never been able to complete my research. Thanks to Joe Dellinger, who rescued my research plans with a perfect data set and invaluable insights. Thanks to Jon Claerbout, who taught me that the most basic observations carry most importance and are key to all deeper insights. And I would like to thank the remaining members of my reading committee: Jesse Lawrence, who was always able to get me going when I was stuck, and George Papanicolaou, whose endless questions during my reviews, quals and defense were a great yearly source for research questions. Thanks to Phil Scherrer for chairing my oral examination committee.

Thanks to Diane Lau, who always made attending conferences and fitting my complicated travel schedules a walk in the park. My former advisers and mentors; Evert Slob, Kees Wapenaar and Roel Snieder, for their continued advice and support. The research skills Evert taught me for my masters have been some of my sharpest tools at Stanford. I would like to thank Greg Beroza and Mark Zoback, their doors were always open for advice. Professors Xiaohong Chen and Jianguo Zhao from CUPB, and Jie Zhang from USTC for hosting me to China. Thanks to Joe Dellinger (again), Joe Stefanie and Olav Barkved for advising me during internships.



I would like to thank my fellow students in SEP, who have left before or stayed after me, for their company, advice and mentorship. I will be forever grateful that you guys gave me so much space and resources on our shared computational environment (sorry I crashed it so often): Adam Halpert, Xukai Shen, Mandy Wong, Yunyue Li, Yang Zhang, Ohad Barak, Chris Leader, Ali Almomin, Yi Shen, Musa Maharramov, Jason Chang, Taylor Dahlke, Huy Le, Eileen Martin, Daniel Blatter, Guillaume Barnier, Gustavo Alves, Qiang Fu, Gboyega Ayeni, Yaxun Tang, Kittinat Taweessintananon, Claudio Cardoso, Mohammad Maysami, Nader Moussa, Abdullah Al Theyab, Jeff Shragge, Bill Curry, Alejandro Valenciano, Guojian Shan, Roland Gunther, Brad Artman and Marie Clapp.

There are so many more people to thank. My friends and colleague geophysicists at Utrecht and Delft: Joost van der Neut, Elmer Ruigrok, Niels Grobbe and Wouter Kimman. Thanks for keeping me part of the Dutch geophysics scene. My former apartment mate Yi Gu; I was so lucky to meet you. And my former apartment mate Nishank Saxena for leaving so many delicious curries as left overs for me to snack on when I got home late in the evening. My friends Marine Denolle, Justin Brown and Dan Sinnet, I hope our friendship will last forever and we will see each other often. And my Dutch friends: Jelle van der Hoeven, Gody van den Bogaard, Koen and Mara Kooper, Menne Schakel, Jelmer Oosthoek and Gerson van Luijk, thanks for your support and good times that helped keep me going. My long time friends in China: Zhijian Wang and Sha Ma, Fang Gang and Sun Wei, I hope to meet you again soon. There is a long list of friends, family and colleagues whose names I could not include here, but I will never forget their support.

Lastly, I would like to thank Erin Stoesz and Dawn Burgess for their patience and writing advice. Without their help I would have never been able to get this thesis written.

*To my grandfather,  
thank you for inspiring me to seek scholarship.*

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